Long Swiss Meteorological Series

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Final report

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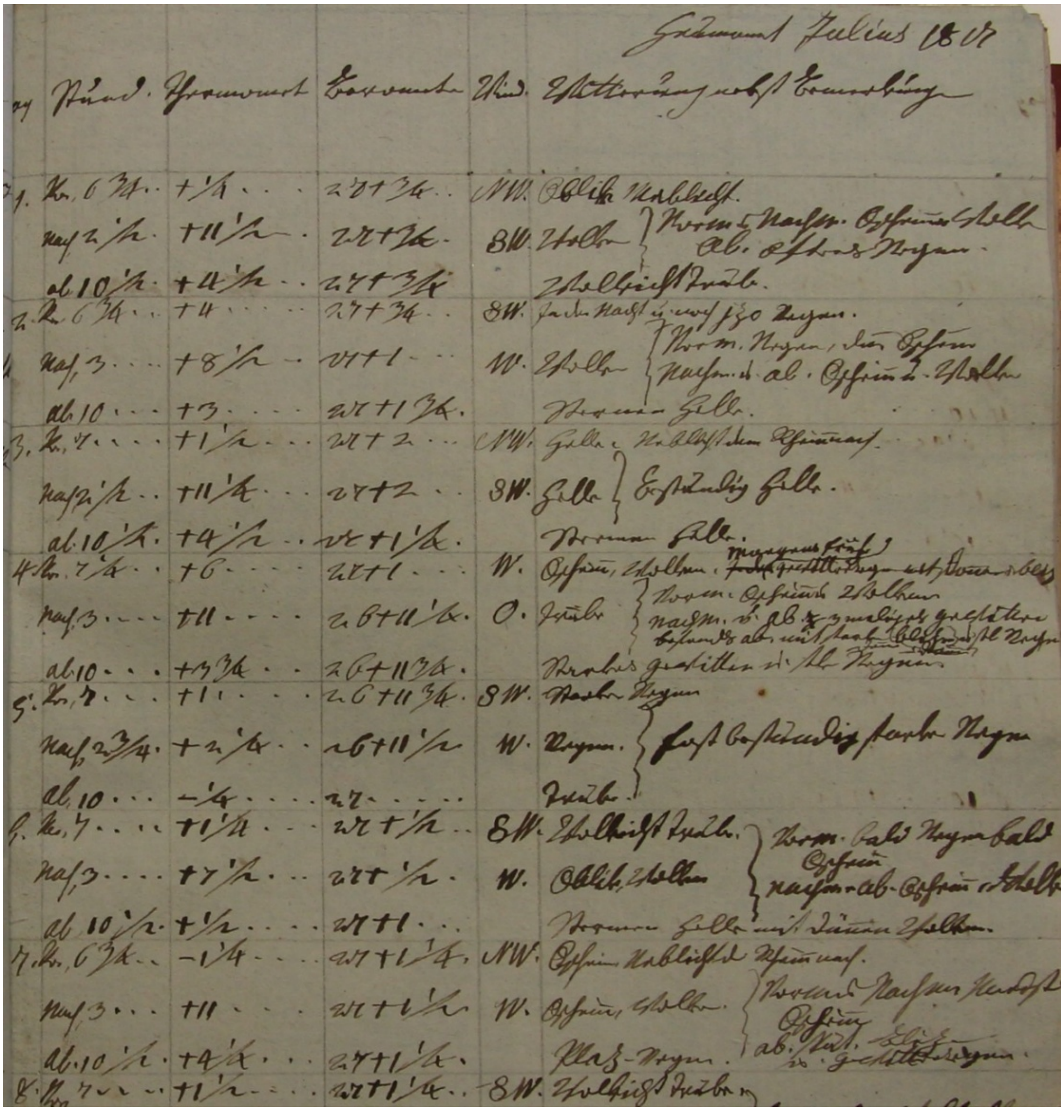

Summary

The goal of the project "Long Swiss Meteorological Series" was to provide, through digitisation and homogenisation efforts, revised as well as new long Swiss meteorological time series that reach back beyond the start of the official Swiss network in 1863. "Revised" means that the two only currently available series, Geneva and Basel, that reach back to 1753 and 1755, respectively, were complemented by digitising additional past segments. In the current version of both series, long gaps were filled with data from stations that are relatively far away (Basel with data from Mulhouse and Delémont, Geneva with data from Neuchâtel). While this may be appropriate when working with monthly or seasonal mean values, current scientific questions more and more target day-to-day variability and extremes, for which it might be more useful to unmerge the series and fill the gaps in the Basel and Geneva with more proximate series. Moreover, both series rely largely on long segments by relatively few observers, whereas there are many further segments in both cases. These overlap with the existing record and help to improve or confirm the quality of the records. In addition to Geneva and Basel, the existing record from the Gr. St. Bernard was back-extended by two years.

The project also provides new, long series. The two most important ones are those from Zurich and Bern, providing temperature records back to 1756 and 1760, respectively. Both are composed of a larger number (17 and 19, respectively) of segments. The Zurich series reaches even back to 1708 for pressure and precipitation, though with long gaps. Finally, the project also contributed to the digitisation and documentation of long meteorological series from Marschlins (1782-1863), Schaffhausen (1794-1845), Aarau (1807-1865), Delémont (1801-1832), Vevey (1805-1840), and St. Gallen (1812-1853) as well as many shorter records. The project was affected by the COVID-19 situation as archives were inaccessible for several months.

The project provides digitized data in quality-controlled form for all of the segments digitized. These data have been submitted to the in-situ database of the Copernicus Climate Change Service, MeteoSwiss, and EURO-CLIMHIST. Homogenisation was undertaken for the temperature records from Zurich, Bern, Basel, and Geneva, yielding new and revised, long Swiss records. Scientific papers on the records have been written. The other records and segments are described in a volume of *Geographica Bernensia*, comprising 23 papers that describe locations, observers, instrument, and the quality control of the series.

3. Scientific Report

3.1. Introduction

The work in the project encompassed all phases of data rescue from archive research to imaging data sheets, digitizing the data into electronic format, performing quality control and eventually homogenization. Additionally, we collected metadata in instruments, observers, and locations. In the following, we first list some general remarks that concern all series and then describe the work performed for individual series.

The project was linked to the Copernicus Climate Change Service (C3S). It became a test user for the Data Rescue Service within C3S. For instance, the “Best Practice Guidelines for Climate Data and Metadata Formatting, Quality Control and Submission” (Brunet et al., 2021) features work from the project. In turn, we used the “Station Exchange Format” (SEF) developed in C3S Data Rescue Service to facilitate data exchange with C3S and we used the quality control tool developed in the C3S Data Rescue Service. All data produced in this project were submitted to the C3S in situ database (Noone et al., 2021). Furthermore, the project was linked to ACRE (Atmospheric Circulation Reconstructions over the Earth) Initiative and the UK project “GLOSAT” and was presented at numerous occasions.

3.2. Methods and activities

3.2.1. Archive work

The archive work was based on the inventory described by Pfister et al. (2019). However, much more archive work was necessary for obtaining metadata for the individual stations. Conversely, not all records listed in Pfister et al. (2019) could eventually be found, or they turned out to be less ore more voluminous than anticipated, or contained other observation years, or were copies of a series from a different location.

3.2.2. Imaging

Fortunately, a considerable fraction of the images was already available as they were taken by our group in the context of previous projects (but not digitized) or because they were available online. COVID-19 made archive visits impossible for some time, and therefore many images were provided by the archives, mainly the University library Basel. These sources were put online by the University library Basel:

https://www.e-manuscripta.ch/bau/content/titleinfo/3213478
https://www.e-manuscripta.ch/nidn/117571660
https://www.e-manuscripta.ch/bau/content/titleinfo/3216947
https://www.e-manuscripta.ch/bau/content/titleinfo/3219862
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https://doi.org/10.7891/e-manuscripta-102051
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https://doi.org/10.7891/e-manuscripta-102046
https://doi.org/10.7891/e-manuscripta-102048
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https://swisscollections.ch/Record/991170526119105501
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https://swisscollections.ch/Record/991170458730805501
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3.2.3 Digitising and processing

Digitising the imaged data was performed by student assistants. Some of the sources turned out to be very difficult and therefore quite time demanding. Excerpts of a particularly chaotic record are shown in Fig. 1. These are measurements made in Basel by Daniel Huber. The record was far more voluminous than anticipated. Huber measured up to 13 times per day, at very irregular times, using several different barometers and thermometers. We have digitized far over 100,000 instrumental measurements (in addition to thousands of wind observations), from very chaotic sources. Some of the observations were noted even on playing cards.

For each digitising job, a template was generated, and jobs were assigned to the student assistants working in the project. The data were typed into Excel and returned. Then all files were checked and formatted into the Station Exchange Format (SEF, see above). In the same step, units and observation times were converted, metadata was collected and included in the file header or in the data records. For details, see Brugnara et al. (2020a,b).

Figure 1. Excerpts from rather chaotic data sheets from the Huber series (University Library, Basel).

3.2.4. Quality control

Quality control was performed using the R package dataresqc developed within C3S. Flags were added to the SEF files. For the publication in *Geographica Bernensia* (see below), additional QC (Brugnara et al., 2020b) was performed for plotting. The QC sometimes revealed specific problems *(e.g.,* when identical data were copied by another observer, or when instruments were changed etc.), such that this process was iterative.

3.2.5. Data publication

The digitized and quality checked data were submitted to several repositories. The main repository for all data series is the GLAMOD repository of C3S (Noone et al. 2021), to which all data were submitted. All data will also be available from MeteoSwiss, and they have been sent to EURO-CLIMHIST.

3.2.6. Metadata publication

Some metadata is included in the SEF files for the individual stations. Metadata can be added to the file header as well as to each individual record. Metadata in the file header concerns the entire record (e.g., geographical coordinates, observer name, indication on whether pressure data were reduced to 0 °C, etc.). Metadata at the level of the data records contain the originally digitized value (in original units), the time of day in local time or the time label given by the observer, and any quality flags that were added during QC.

However, there is a lot more metadata than fits into the file and that is relevant for processing and eventually using the data. Background information on the observers, exact locations, context of the measurements and data publication is summarised in short articles that are published in *Geographica Bernensia*. In total, this volume comprises 23 papers.

3.2.7. Homogenisation

Homogenizing of the four long series (Basel, Geneva, Zurich, and Bern) has been performed following a semi-automatic procedure that makes use of most of the newly digitised records from Switzerland (as well as from neighbouring regions) as reference series, after they have been carefully checked for inhomogeneities. The paper on Bern and Zurich is in review (Brugnara et al. 2022), the paper on Geneva and Basel in draft form.

3.3. Results

3.3.1. Grand St Bernard

Within the GCOS Switzerland project we digitised the first two years (1817/1818) of data from the Grand Saint Bernard, the earliest permanent high-altitude observatory (Fig. 2). Although short, these first two years are particularly important as very close to the station, a climate-related disaster occurred during this time. A dam of ice from the Gietro glacier blocked the Dranse river in spring 1818, leading to a lake that threatened the valley. An effort to artificially lower the lake level was partly successful, but when the dam burst on 16 June 1818, two thirds of the water volume were still in the lake and devastated the valley down to Martigny, causing 36 fatalities. Abrupt warming in early June 1818 might have played a role (Figure 3 shows all Swiss temperature observations for this period).

Figure 2. Left: The station around 1935 (photo: Max Kettel, Médiathèque Valais). Right: Location of the weather station in 2010 (Photo: Renate Auchmann).

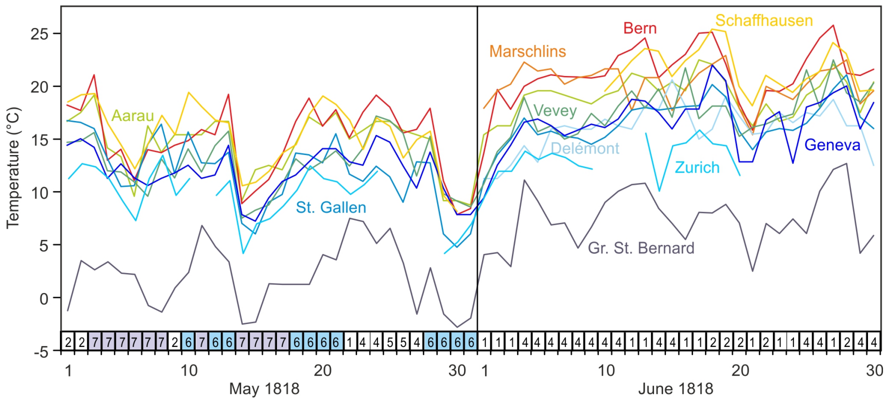

Figure 3. Daily temperature series from several sites in Switzerland (note that the different series refer to different times of the day). The bottom part (numbers) indicate the daily weather types of the CAP7 classification according to Schwander et al. (2017). For the period May and June 1818. During this period, ice from the Gietro glacier blocked the Dranse, which formed a lake in the upper Val de Bagne. During May, which was relatively cool, a tunnel was dug through the ice under the lead of Ignatz Venetz and the lake level could be lowered The collapse of the ice dam on 16 June and the subsequent flooding killed 36 persons (from Brönnimann 2019).

3.3.2. Geneva

The archive of the astronomical observatory in Geneva (Versoix) could not be accessed during COVID and was not accessible well beyond the re-opening due various reasons, but eventually, most of the data could be digitized and re-evaluated. As an example, Figure 4 shows one of the standard analysis performed for all segments, namely the comparison of the diurnal cycle with that from the present (reduced by 1 °C), for the records by Lubières (1760-1789), Deluc (1768-1800), Mallet (at Avully 1778-1786), and Maurice (at Geneva-Genthod, 1789-1798) in Geneva. This shows rather reliable seasonal cycle of all series.

A new homogenized temperature series for Geneva was produced based on the sub-daily measurements (Fig. 5). This includes a thorough revision of the data digitized in a previous project (1798-1863). Measurements prior to 1768 were of insufficient quality and are not included in the homogenised version. Unlike previous attempts, we did not use the Neuchatel series to back-extend the series.

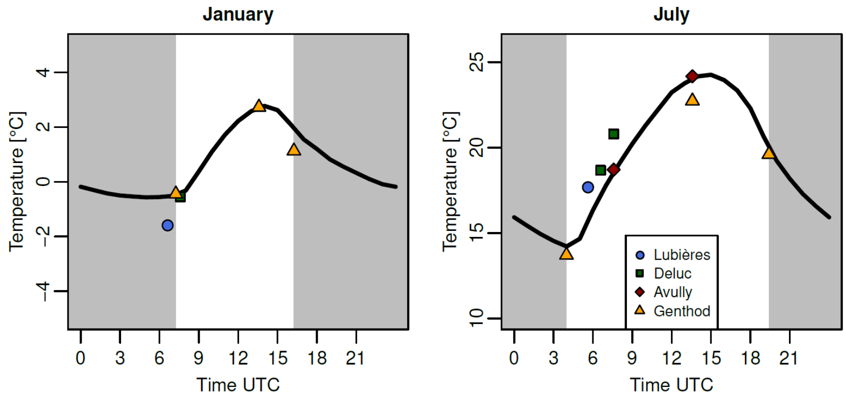

Figure 4. Diurnal cycle of temperature in January (left) and July (right) in present-day MeteoSwiss data (thick black line, shifted by 1 °C to account for warming) and in four segments of the Geneva series (grey = nighttime).

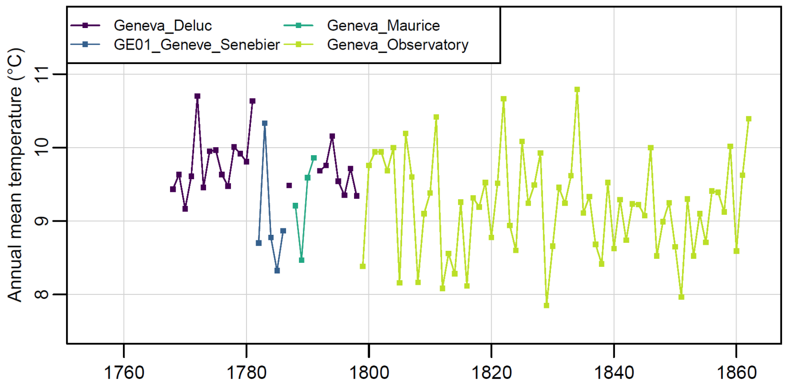

Figure 5. Annual mean temperature in Geneva, 1768-1863, after homogenisation. The colour indicates the series that contributes the most days to the corresponding year (the different series were merged at the daily scale).

3.3.3. Zurich

A new series generated in the GCOS Switzerland project was that of Zurich. Measurements go back as far as 1708, these are the first meteorological measurements in Switzerland. The observer in this early period was J. J. Scheuchzer. Unfortunately, not all data could be found. Pressure is available for every day in 1708, but then only maxima and minima per year are recorded. From 1718 onward, pressure is available from two sources. Precipitation is partly only available as monthly means (Fig. 6). We also digitised all temperature data, we did not further process the data because the scale remains unknown and because very large variations within a day or from day-to-day raise doubts about the usefulness of the data.

The pressure and temperature series then continue in 1756. With some shorter gaps, the meteorological records continue to 1852. The gap to the start of the MeteoSwiss network in December 1863 was filled with data from Küsnacht and Winterthur. Another option would be

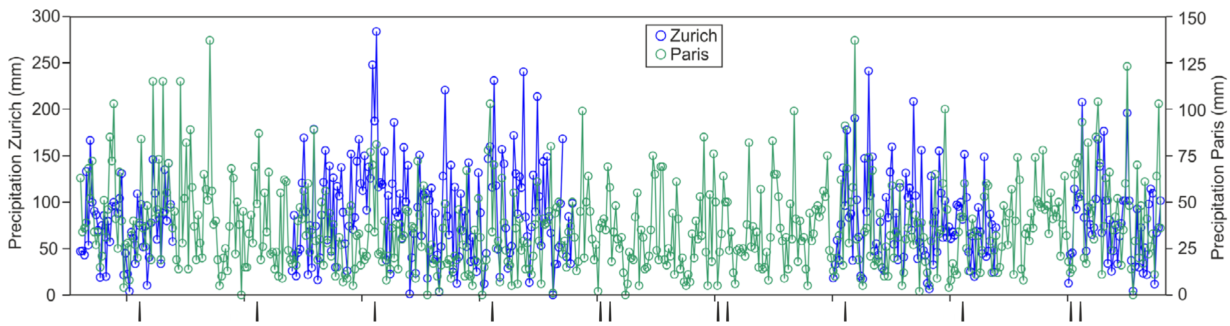

Figure 6. Monthly precipitation in Zurich (blue) from Scheuchzer (1708-1729) and Gessner (1740-1754). The green curve shows precipitation in Paris (Slonosky et al., 2002). Note the different scales.

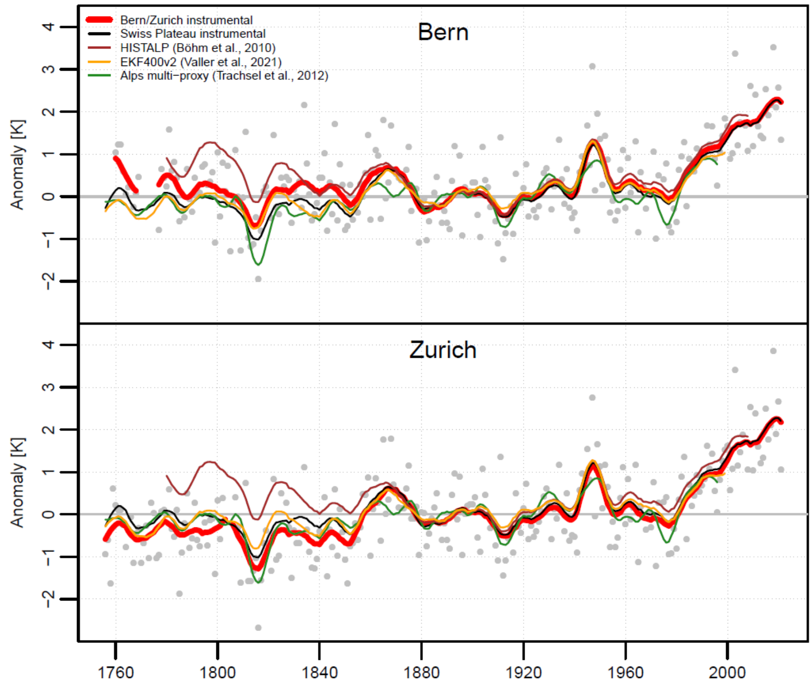

Figure 7. Smoothed time series of the warm season (April–September) mean temperature anomalies (with respect to the 1871–1900 average) for Bern and Zurich (red thick lines), and their average (black line). Dots represent the unsmoothed seasonal anomalies. The brown and orange lines show the annual mean temperature from the nearest grid point in HISTALP and EKF400, respectively. The green line represents the summer temperature "mean" reconstruction from multiple proxies for the Greater Alpine Region by Trachsel et al. (2012). All data series were smoothed using a Gaussian filter with sigma = 3 years (from: Brugnara et al. 2022).

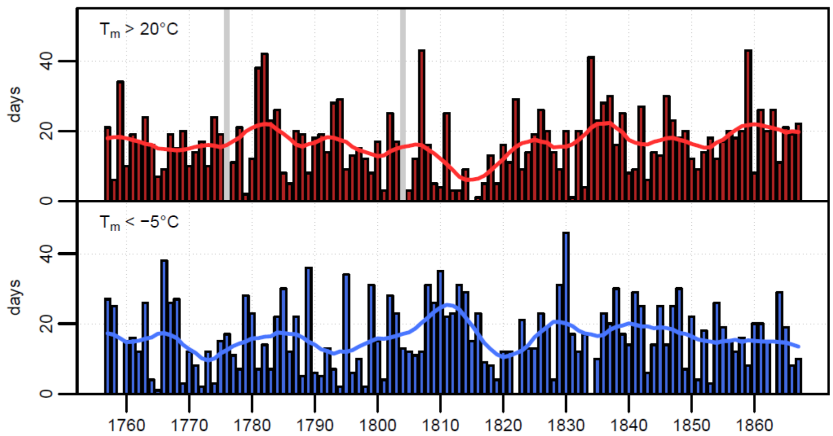

Figure 8. Number of days with mean temperature above 20 °C in May–September (red) and below -5 °C in November–March (blue) in the Swiss Plateau series. The indices are not calculated in years when more than 10% of days are missing (indicated by grey bars). The smoothed lines are produced using a Gaussian filter with sigma = 3 years (from Brugnara et al., 2022).

to use data from Uetliberg, which is very close to the city but 460 m higher. In total, 17 segments were used. The resulting series is a new long Swiss series – the same length as the Geneva and Basel records, and when including precipitation and temperature, the longest Swiss meteorological record.

The Zurich temperature record from 1756 onward has been homogenized (Brugnara et al. 2022). Results show significant differences to other available records such as the HISTALP data (Böhm et al. 2010). It shows lower temperatures prior to ca. 1860, suggesting that the HISTALP data (and other data sets) could be biased. In addition to changes in the mean, which are illustrated in Fig. 7 (together with other reconstructions), the new records (since these are daily data) also allow to address changes in daily statistics when combining Bern (see next Section) and Zurich to a “Swiss Plateau series”. This is shown in Fig. 8. Together, these figures show substantial climatic changes. Since the 18th century, temperature has increased by 2 °C (summer) or even 3 °C (winter).

3.3.4. Bern

Another new long series generated in the project is that from Bern, reaching back to 1760. The temperature series consists of 19 segments by different observers. This includes segments from Sutz, Büren, and Burgdorf. All segments were digitized, processed, and quality-controlled, an example sheet is shown in Fig. 9. The 19 segments were concatenated, and the resulting series was homogenized in the same way as Zurich (see Brugnara et al., 2022). The resulting curve is included in Fig. 7. It shows a very similar pattern as the data from Zurich. Combining both series, a daily Swiss Plateau record can be generated (Fig. 8). This figure shows individual extreme seasons such as the “heat summer” of 1807 or the “Year without a Summer” of 1816, but also the cold winter 1829/30.

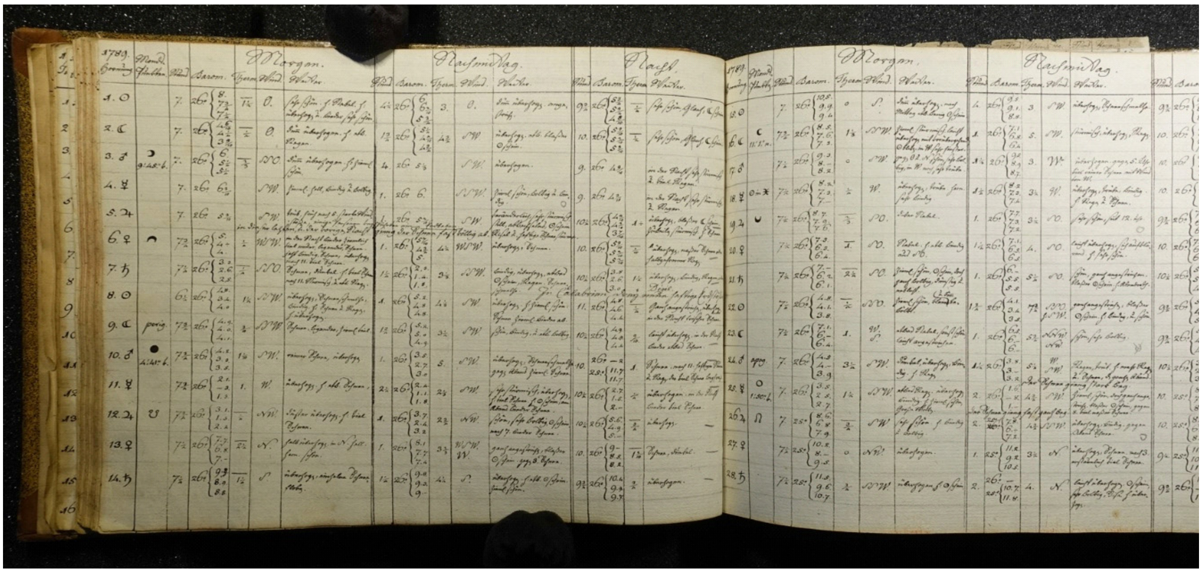

Figure 9. Data sheet from Samuel Studer, Bern, 1787 (Burgerbibliothek Bern).

3.3.5. Basel

The Basel series is a very prominent Swiss climate series. The currently available series is based mainly on the data from two observers, each of which observed for an extended time period: Johann Jakob D’Annone (1755-1804) and Peter Merian (1826-1863). The gap was filled with data from Mulhouse and Delémont. However, many other observers made meteorological measurements in Basel during the period, including during the long gap (Fig. 10), although some gaps remain. We have digitised the D’Annone and Merian data and have also digitised the data from many other observers. Most importantly, we have digitised the extensive material by Daniel Huber (Fig. 1).

Arguably, the series by D’Annone and Merian are those of the highest quality, but the other records help to confirm the quality and to fill gaps. In this context the extensive Huber series is of interest as it covers a 20 year long gap. However, it turns out that the measurements were irregular such that despite the fact that we have digitised 100’000 measurements, typically only 40-50% of the days per year have observations. At the same time, because of its chaotic nature and irregular observations, and constantly changing observation time, the data set has never been used in the literature. Our analysis suggests that the data are of high quality. Comparisons with other records in the overlapping portions show a good agreement. Moreover, the Huber series include many interesting parallel measurements between different instruments and different exposures. Unfortunately, the high fragmentation of the series meant that a large part of it could not be homogenized. In the new Basel homogenized record (Fig. 11) we still make use of data from Mulhouse and Delémont to fill gaps in the period 1805-1817, while we use mainly the Huber series in the period 1818-1827.

Figure 10. Measurement locations in Basel, 1755-1863 (map by Samuel Ryhiner, 1784, UB Basel Maps, Wikimedia Commons).

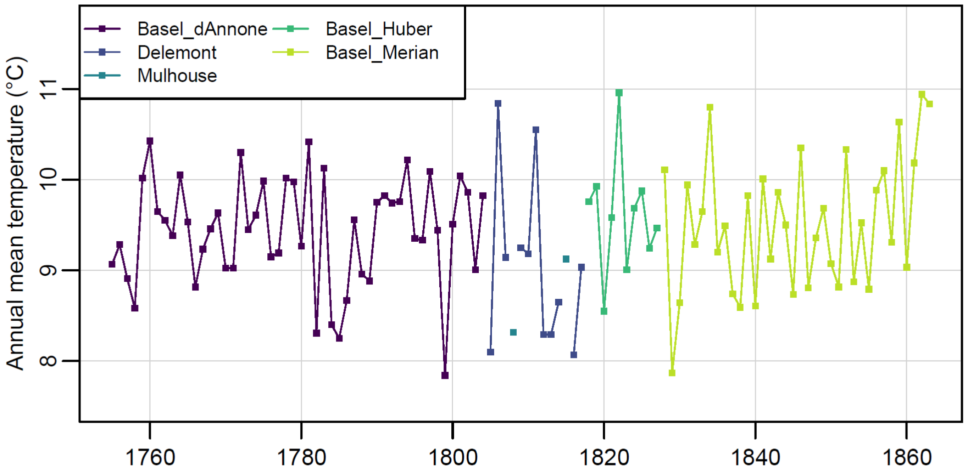

Figure 11. Annual mean temperature in Basel, 1755-1863, after homogenisation. The colour indicates the series that contributes the most days to the corresponding year (the different series were merged at the daily scale).

3.4. Outreach and publications

The project was presented in detail at various occasions, such as:

Symposium of Meteorological Libraries/Archives in Europe (Vienna, 24 Oct 2019)
Atmospheric Circulation Reconstructions over the Earth virtual Meeting (27 Aug 2020),
GCOS/GAW Symposium (Bern, 14 Sep 2021),
13th EUMETNET Data Management Workshop (Patras, Greece, 25-27 Oct 2021).

Numerous further presentations acknowledged material from project. Furthermore, the GCOS project was part of an "mLab residency project" at the University of Bern, in which a film essay was produced that will be shown in the Zentralbibliothek Zürich in the exhibit «Wind und Wetter - Das Klima in Zürich seit der Steinzeit» in fall 2022.

The main new homogenized series from Bern and Zurich will be published in a scientific paper, which is in review in "Climate of the Past" (Brugnara et al. 2022). A second paper on the series of Basel and Geneva is in preparation. In addition, each series or group of series is described in a non-peer-reviewed article, which together form volume G96 of *Geographica Bernensia* (jointly with Swiss National Science Foundation project CHIMES):

Swiss Early Instrumental Meteorological Series (Ed. S. Brönnimann). Geographica Bernensia G96

Brönnimann, S. (2020) Preface. p. 5.

Brönnimann, S., C. Rohr, Y. Brugnara, and F. A. Isotta, (2020) A Collection of Early Swiss Meteorological Series. p. 7–15, doi: 10.4480/GB2020.G96.01.

Brugnara, Y., J. Flückiger, and S. Brönnimann (2020) Instruments, Procedures, Processing, and Analyses. p. 17–32, doi: 10.4480/GB2020.G96.02.

Häderli, S., S. Pfister, L. Villiger, Y. Brugnara, and S. Brönnimann (2020) Two Meteorological Series from Geneva, 1782–1791. p. 33–46, doi: 10.4480/GB2020.G96.03.

Brönnimann, S., M. Bühler, and Y. Brugnara (2020) The Series from Geneva, 1798–1863, p. 47–59, doi: 10.4480/GB2020.G96.04.

Faden, M., L. Villiger, Y. Brugnara, and S. Brönnimann (2020) The Meteorological Series from Aarau, 1807–1865, p. 61–72, doi: 10.4480/GB2020.G96.05.

Weber, J., Y. Brugnara, and S. Brönnimann (2020) Two Meteorological Series from Herisau, 1821–1844, p. 73–85, doi: 10.4480/GB2020.G96.06.

Hürzeler A., Y. Brugnara, and S. Brönnimann (2020) The Meteorological Record from St. Gall, 1812–1853, p. 87–95, doi: 10.4480/GB2020.G96.07.

Flückiger, J., A.-M. Burgdorf, Y. Brugnara, and S. Brönnimann (2020) Two Meteorological Series from Bern from Trechsel, 1826–1849, and Benoit, 1837–1853, p. 97–108, doi: 10.4480/GB2020.G96.09.

Brönnimann, S., and Y. Brugnara (2020) The meteorological series from the Great St. Bernard, 1817-1863, p. 109-117, doi: 10.4480/GB2020.G96.10.

Brönnimann, S., and Y. Brugnara (2020) D'Annone's Meteorological Series from Basel, 1755–1804, p. 119-126, doi: 10.4480/GB2020.G96.11.

Brönnimann, S. and Y. Brugnara (2021) Meteorological Series from Basel, 1825-1863, p. 127–138, DOI: 10.4480/GB2020.G96.12.

Fritze, R., Y. Brugnara, and S. Brönnimann (2021) Four Meteorological Series from Zurich Covering 1756–1802, p. 139–155. DOI: 10.4480/GB2020.G96.13

Brugnara, Y., S. Brönnimann, and L. Pfister (2021) The First Swiss Meteorological Record: Scheuchzer's Series from Zurich 1708–1733, p. 157-167, DOI: 10.4480/GB2020.G96.15.

Wyer, V., Y. Brugnara, and S. Brönnimann (2021) Meteorological Series from Neuchâtel, Bern and Gurzelen, p. 169-182, DOI: 10.4480/GB2020.G96.16.

Brugnara, Y., L. Pfister, and S. Brönnimann (2021) Zurich's Many 19th Century Meteorological Records, p. 183-197, DOI: 10.4480/GB2020.G96.14.

Hari, C., Y. Brugnara, C. Rohr, and S. Brönnimann (2022) Meteorological Observations in Bern and Vicinity, 1777-1834, p. 199-211, DOI: 10.4480/GB2020.G96.19.

Brönnimann, S., Y. Brugnara, and L. Pfister (2022) Several little-known meteorological series from Basel, 1766-1802, p. 213–224, DOI: 10.4480/GB2020.G96.17.

Brugnara, Y. and S. Brönnimann (2022) Daniel Huber's Meteorological Record from Basel, 1789-1829, p. 225–235, DOI: 10.4480/GB2020.G96.18.

Brönnimann, S., Y. Brugnara, S. Eggenberger, L. Pfister, and C. Rohr (2022) A long meteorological series from Schaffhausen, 1794–1845, p. 237-244, DOI: 10.4480/GB2020.G96.21.

Brönnimann, S., and Y. Brugnara (2022) Nineteenth century meteorological records from Vevey, Einsiedeln, Bellinzona, Lucerne, Fribourg, and Zug, p. 245-259, DOI: 10.4480/GB2020.G96.22.

Brugnara Y., S. Brönnimann, M. Grenon, J. Baumann, and P. Wyss (2022) Early meteorological series from Geneva, 1760-1795, p. 261-274, DOI: 10.4480/GB2020.G96.20.

Brönnimann, S., Y. Brugnara, L. Pfister, and C. Rohr (2022) A new collection of Swiss early instrumental meteorological data and some applications, p. 275-287, DOI: 10.4480/GB2020.G96.23.

3.5. Conclusions

The GCOS Switzerland project generated additional meteorological data to better assess, support, and extend the existing long Swiss meteorological series. It also led to two new long Swiss series, namely those from Zurich and Bern, both of which reach to the mid-18th century (the Zurich series even further back). The series of Basel and Geneva were revised, the one from Gr. St. Bernard extended. Several shorter (but still more than 200 years long) series could be produced.

The data have been submitted to the C3S global in situ-data repository (Noone et al., 2021), to MeteoSwiss, and to EURO-CLIMHIST. Detailed descriptions of the individual series are given in a series of 23 articles in *Geographica Bernensia*.

3.6. Outlook

Only the four longest series were homogenized. Based on the data digitised in the project, and using the same tools and methods, several further long series could be produced. This includes long series for Marschlins/Chur, Schaffhausen, Aarau, and St. Gallen and somewhat shorter series for Delémont and Vevey.

3.7. Acknowledgements

The project closely collaborated with the C3S Data Rescue Service in which it served as a trail blazer project. We used the quality control tools developed in that project and formatted all data to the standard format of the C3S Data Rescue Service, which ensures easy ingestion into the C3S in-situ database. We further acknowledge the ERC project PALAEO-RA, within which we digitized many series from neighbouring countries that we could use as comparison series or reference series.

3.8. References

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