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Climate Evolution in Switzerland – Pre-industrial Reference Period and Change since 1864 on the Basis of Temperature Monitoring

Michael Begert, Reto Stöckli, Mischa Croci-Maspoli

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Abstract

There are different methods for calculating temperature change over decades or centuries from long-term data series. The most popular are linear trend fitting and the comparison of mean values from periods at the beginning and at the end of the series. These methods lead to differing results and they may have a significant impact on the communication of climate change.

The present study investigates several methods for calculating temperature change in Switzerland since 1864 and discusses the differences as well as the advantages and disadvantages of their use. Furthermore, a pre-industrial reference period is evaluated in order to put temperature change in Switzerland into the context of the global 1.5/2°C target. Finally, the five most widely used global temperature data sets are compared with respect to differences in their long-term evolution and their data coverage. The most suitable data set used to compare Swiss and global temperature evolution is assessed.

The study concludes that the comparison of mean values from an early and a recent reference period is suitable for calculating and communicating climate change in Switzerland in the context of the global 1.5/2°C target. The period 1871 to 1900 is chosen to represent conditions not influenced by anthropogenic greenhouse gas emissions. Following the wording of the Intergovernmental Panel on Climate Change (IPCC) the period is called "the pre-industrial reference period". Depending on the context, today's conditions can be characterized either by using the current WMO standard period (e.g. comparison with CH2018 climate scenarios) or the most recent 30 years (e.g. including latest evolution). Linear trend fitting is still possible and is essential for comparison with external data analysis and studies. The exact declaration of the method used is essential in either case. The HadCRUT4 global temperature data set of the UK Met Office and the Climatic Research Unit of the University of East Anglia is chosen as a basis for comparing Swiss temperature evolution in the global context. HadCRUT4 is the most suitable compromise between data availability und comparability with other data sets. HadCRUT4 covers the whole measurement period of Switzerland, is routinely produced by the UK Met Office and is in agreement with most of the other data sets with respect to temperature increase since pre-industrial levels.

Zusammenfassung

Zur Berechnung der Temperaturveränderung über Jahrzehnte bis Jahrhunderte aus langjährigen Messreihen stehen verschiedene Möglichkeiten zur Verfügung. Weit verbreitet ist die Verwendung eines linearen Trends oder der Vergleich von Mittelwerten aus Perioden zu Beginn und am Ende des untersuchten Zeitraumes. Die Methoden führen zu unterschiedlichen Resultaten und haben einen bedeutenden Einfluss auf die Kommunikation des Klimawandels.

Der vorliegende Bericht stellt verschiedene Methoden zur Berechnung der Temperaturveränderung in der Schweiz seit Messbeginn um 1864 vor und diskutiert Unterschiede sowie Vor- und Nachteile ihrer Anwendung. Zudem wird untersucht, welche frühe Referenzperiode aus dem 19. Jahrhundert geeignet ist, um die Temperaturzunahme in der Schweiz in den Kontext des globalen 1.5/2°C-Ziels zu stellen. Schliesslich wird evaluiert, welcher der verfügbaren globalen Datensätze an der MeteoSchweiz verwendet werden soll, um die Temperaturentwicklung in der Schweiz in den Kontext der globalen Entwicklung zu stellen.

Die Auswertungen kommen zum Schluss, dass sich der Vergleich von Mittelwerten einer frühen mit einer aktuellen Referenzperiode eignet, um die Temperaturzunahme in der Schweiz im Kontext des globalen 1.5/2°C-Ziels zu berechnen und zu kommunizieren. Zur Beschreibung der Bedingungen ohne Einfluss anthropogen verursachter Treibhausgasemissionen wird die Periode 1871-1900 gewählt. Analog zur Vorgehensweise des Weltklimarats (IPCC) wird der Zeitraum als vorindustrielle Referenzperiode bezeichnet. Je nach Anwendung empfiehlt es sich, für die aktuelle Zeit eher die gültige WMO-Standardperiode (z.B. Vergleich mit Klimaszenarien CH2018) oder die letzten 30 Jahre (z.B. Einbezug der jüngsten Entwicklung) zu verwenden. Der lineare Fit bleibt ebenfalls möglich und ist insbesondere für den Vergleich mit externen Datensätzen und Arbeiten unerlässlich. Wichtig ist in jedem Falle die klare Deklaration der Methode, die zur Berechnung der kommunizierten Werte verwendet wurde. Für den Vergleich mit der globalen Entwicklung wird an der MeteoSchweiz der HadCRUT4-Datensatz verwendet, welcher vom UK Met Office und der Climatic Research Unit der University of East Anglia entwickelt und zur Verfügung gestellt wird. Er stellt den besten Kompromiss aus Datenverfügbarkeit und Vergleichbarkeit mit anderen Datensätzen dar. HadCRUT4 deckt den gesamten, in der Schweiz verfügbaren Messzeitraum ab, wird routinemässig vom UK Met Office bereit gestellt und vergleicht sich gut mit den meisten anderen globalen Datensätzen in Bezug auf die Temperaturzunahme seit der vorindustriellen Zeit.

Contents

Abstract		**V**
Zusammenfassung		**VI**
1	**Introduction**	**1**
2	**Pre-industrial reference period**	**2**
2.1	Comparison of various pre-industrial reference periods	3
2.2	Discussion and choice of period	5
2.2.1	Choice of 1871-1900 as pre-industrial reference period	6
2.2.2	External comments	7
3	**Calculation of temperature change since 1864**	**8**
3.1	Comparison of different methods	8
3.2	Discussion and choice of method	13
4	**Comparison: temperature increase in Switzerland and on a global scale**	**14**
4.1	Global data sets for temperature	14
4.2	Comparison of global temperature data sets	15
4.2.1	Comparison of temperature evolution	15
4.2.2	Comparison of different normal periods in global data sets	17
4.3	Discussion and choice of the global data set	18
Literature		**20**

1 Introduction

In climatology, reference periods are used to describe a normal, expected state and serve as a basis for classifying recent observations and future conditions. In a stable (stationary) climate the selection of a suitable period depends largely on its duration since the entire natural variability of a parameter should, to the greatest possible extent, be covered. For that purpose, the World Meteorological Organization (WMO) has defined 30-year periods (WMO, 1959, 2011, 2017). In a changing (non-stationary) climate such as can be observed today both on a global scale and in Switzerland, especially as regards temperature, not only the duration but also the temporal situation of the reference period are essential. Depending on the question under investigation, it can make sense to choose either a very early, a middle or a rather recent period.

Today MeteoSwiss uses and communicates temperature deviations for a year, a season or a month in terms of the reference periods 1961 – 1990 or 1981 – 2010, in accordance with WMO recommendations. Those two reference periods, however, are not ideal when it comes to communicating and classifying warming in Switzerland with regard to the global target of 1.5/2°C (UNFCCC, 2012; IPCC, 2018), which aims at reducing global warming due to greenhouse gas emissions caused by human activities (anthropogenic) to a maximum of 2°C, and even to 1.5°C in order to avoid major consequences and risks. In the global context (e.g. IPCC, 2013) a reference period mostly called “pre-industrial” is chosen, from which it can be assumed that it reflects conditions mostly unaffected by anthropogenic factors. By defining such an additional early reference period for Switzerland, MeteoSwiss aims to provide a factual basis for the political discussion. Since natural variability can lead to substantial regional climate fluctuations, the choice of this period for Switzerland will have to be examined in depth to determine its applicability.

The introduction of an early reference period situated at the beginning of instrumental measurements raises the question of how the rise in temperature since observations started should be communicated. At present MeteoSwiss calculates and uses the temperature increase from a linear regression which runs across the measurement series. The gradient of the line yields an increase per 100 years or over the entire period since observations started. The introduction of an early reference period opens up the option of calculating warming as the difference between the early and a recent reference series, a practice also used by IPCC (2013, 2018). This question is equally relevant in the political discussion and MeteoSwiss is striving to find a uniform and scientifically well-founded solution.

Finally, the question arises – in the context of temperature evolution in Switzerland and its communication – how the increase in temperature compares with global warming. Since there are several global data sets which can provide this information it should be decided which data set to use at MeteoSwiss for the purpose of comparison.

2 Pre-industrial reference period

Both world-wide and in Switzerland climate is characterized by substantial temperature fluctuations. Until the beginning of the 20th century these fluctuations were caused primarily by natural causes. The more or less continuous warming since this point in time is connected to the worldwide rise of greenhouse gas emissions (IPCC, 2013; Medhaug et al., 2017) and has been termed as the anthropogenic impact on temperature evolution. The long temperature measurement series of Basel / Binningen, with observations dating back to 1755, clearly illustrates the interplay of natural fluctuations and rise since the beginning of the 20th century (see figure 1).

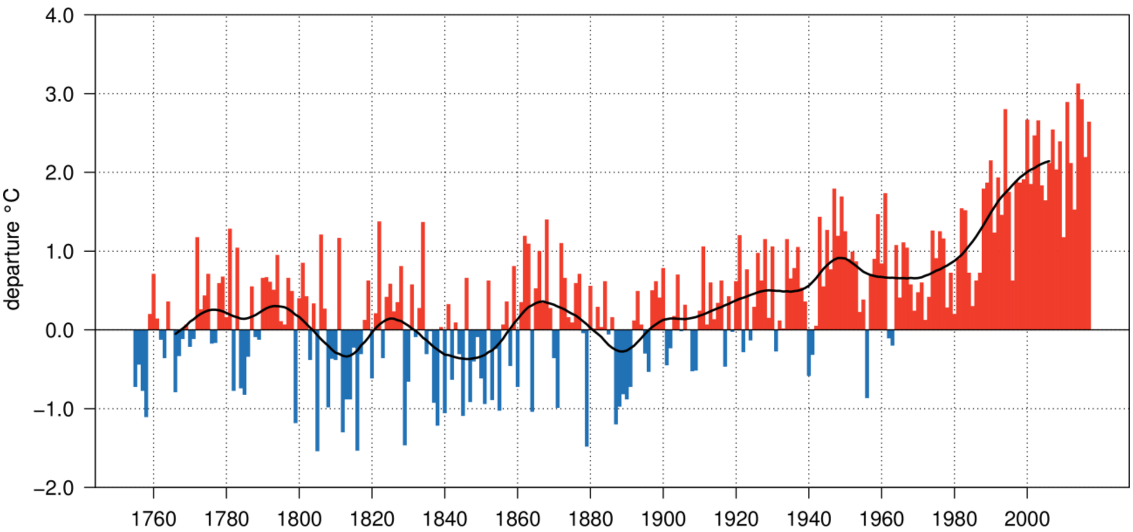

Figure 1: Annual mean temperature in Basel / Binningen between 1755 and 2017 as deviation in °C from the period 1871-1900. Smoothed curve displayed in black (Gaussian lowpass filter over 30 years).

The reference period 1961 – 1990 defined by WMO is less than ideal for the communication and classification of recent temperature measurements compared with the global 1.5/2°C target aimed at limiting global warming to 1.5/2°C compared with pre-industrial levels. With an additional reference period situated farther in the past and as little influenced by the industrial revolution as possible, MeteoSwiss aims at providing a further basis for the political discussion.

The anthropogenic impact on greenhouse gas concentrations in the atmosphere began – in theory – with the invention of the steam engine by Thomas Newcomen in 1712. However, only the increased efficiency made possible by the work of James Watt led to the breakthrough of the new technology in the 1770s, and the pronounced anthropogenic impact on global greenhouse gas concentration only began to make itself felt from the 1860s with the widespread use of steam engines in England.

In theory, the boundary between the pre-industrial and industrial period is dated to the middle of the 19th century. Scientific studies, however, in their attempt to determine the beginning of anthropogenic influence on temperature have come to different conclusions, ranging from the 1830s (Abram et al., 2016) to the 1930s (King et al., 2016). As there are hardly any meteorological data available from the time before 1750, the period from 1850 to 1900 is mostly used to characterize temperature conditions free of anthropogenic influence in the context of global climate change (e.g. IPCC, 2013, 2018, Henley et al., 2017). This period starts with the end of the Little Ice Age and compares well with the globally best choice from 1720 – 1800, according to Hawkins et al. (2017). It makes sense scientifically (Knutti et al., 2016) since – on a global scale - there are enough instrumental observation data available in order to make assured statements on temperature conditions and since developments from that moment onwards can be assessed globally. For Switzerland, too, a period from the second half of the 19th century makes a strong case for itself as reference period due to the lack of earlier measurement data.

With the use of a pre-industrial reference period on a regional scale MeteoSwiss is breaking new ground in Europe, as a survey among the meteorological services of neighbouring countries has revealed. WMO has also confirmed upon request that there are no recommendations on their behalf. As natural climate fluctuations can lead to important regional differences, the choice of a uniform and meaningful reference period for different countries might not even be possible. With this in mind, the evaluation conducted in the following study is therefore only valid for Switzerland.

2.1 Comparison of various pre-industrial reference periods

In Switzerland systematic meteorological observations started in 1864 with the initial operation of a nation-wide observation network under the aegis of the then-called “Schweizerische Naturforschende Gesellschaft” (today: Swiss Academy of Sciences). A pre-industrial reference period which makes sense for Switzerland therefore has to be within a time frame from 1864 to 1900. MeteoSwiss has three homogenous temperature measurement series (Basel / Binningen, Genève / Cointrin and Grand-St-Bernard) which go back longer than 1864 and can be used to analyse differences between various possible reference periods. Below, the annual and seasonal differences of various reference periods are shown, in comparison with temperature evolution since the mid-18th century in general and, in particular, the period 1850 – 1900, using these available measurement series:

- 1864-1900 corresponds to the longest possible period within the frame 1850–1900 for most of the measurement series of the Swiss Climatological Network (Swiss NBCN; Begert, 2007)
- 1861-1880 corresponds to a reference period used by IPCC in their fifth Assessment Report on Climate Change for the purpose of illustrating global warming (IPCC, 2013)
- 1871-1900 takes up the WMO conception of standard periods

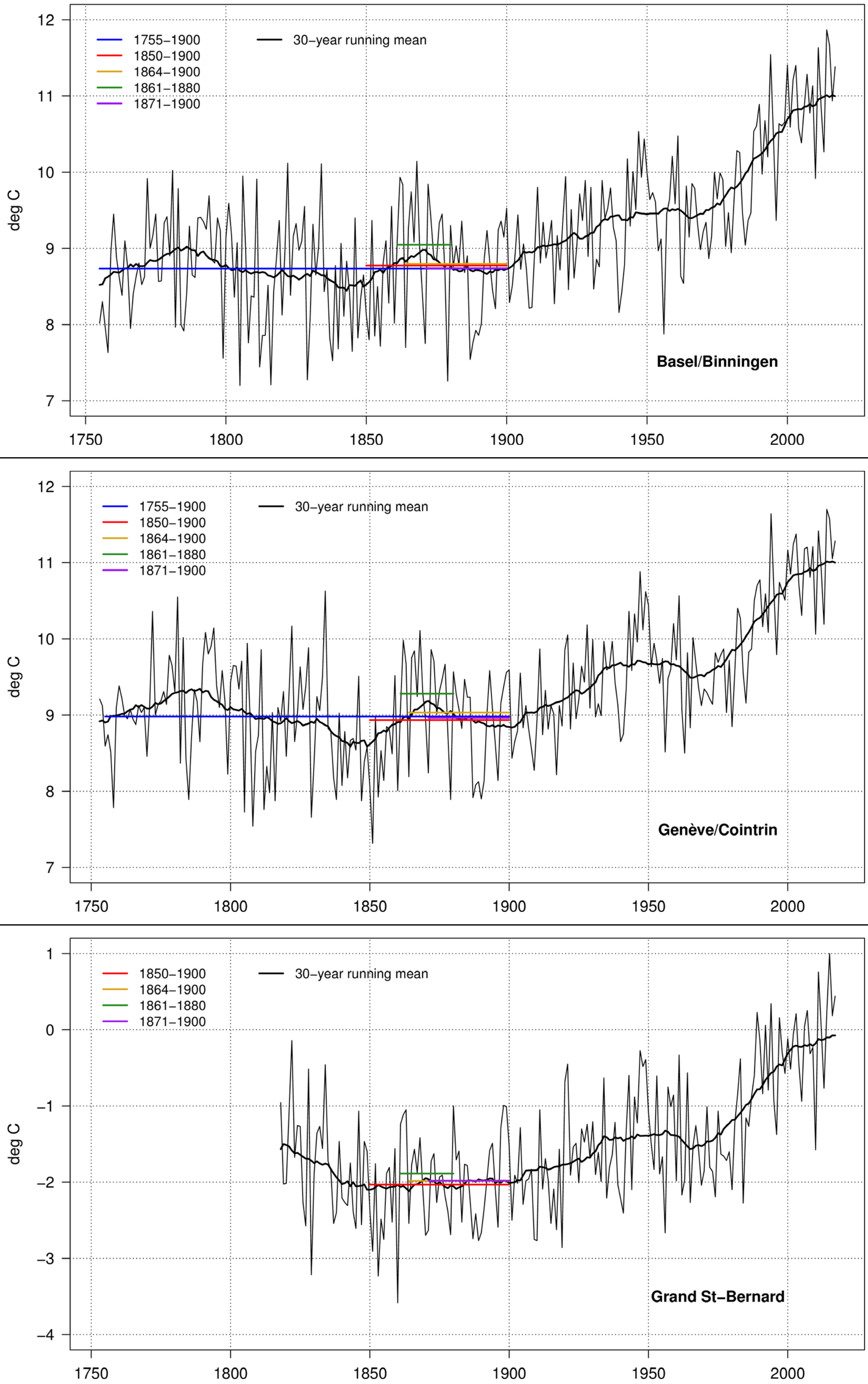

Figure 2: Annual mean temperatures in Basel, Genève and on Grand St-Bernard between 1755 and 2017 including various pre-industrial reference periods (in colour) and a 30-year running average (black).

Table 1: Differences of mean values (°C) from various pre-industrial reference periods to the period 1850-1900 for the four seasons and the entire year in Basel (BAS), Genève (GVE) and on Grand St-Bernard (GSB).

Difference to 1850-1900	DJF			MAM			JJA			SON			Year		
	BAS	GVE	GSB	BAS	GVE	GSB	BAS	GVE	GSB	BAS	GVE	GSB	BAS	GVE	GSB
1755-1900	-0.09	-0.13	-	0.08	0.29	-	-0.07	0.10	-	-0.04	-0.06	-	-0.04	0.05	-
1864-1900	0.04	0.09	0.14	0.09	0.14	0.00	-0.07	0.08	0.01	0.05	0.10	0.06	0.02	0.10	0.05
1861-1880	0.20	0.25	0.07	0.45	0.44	0.26	0.18	0.35	0.20	0.19	0.29	0.00	0.27	0.35	0.15
1871-1900	-0.10	-0.06	0.09	-0.05	0.04	-0.08	-0.08	0.01	0.03	0.05	0.09	0.13	-0.04	0.03	0.05

2.2 Discussion and choice of period

In the pre-industrial phase from 1755 to 1900 temperature evolution in Switzerland is characterized in all seasons by decadal fluctuations without any overlying trend. 30-year mean values from this time fluctuate at around ±0.5°C, depending on the time frame and period chosen (see running average in figure 2). The beginning of instrumental measurements in the mid-18th century, which coincides with the theoretical start of the anthropogenic influence, corresponds with an average of the period 1755 to 1900 (at least on the Swiss Plateau). The investigated mean values from the period 1850 to 1900 are all, with the exception of 1861-1880, relatively close to the average from 1755 to 1900.

From the many instrumental data series available in Switzerland for the period 1864-1900, the periods 1864-1900 and 1871-1900 compare very well with the pre-industrial reference period 1850-1900 which is often used in the context of climate change. The differences amount to ±0.1 °C or less for most seasons. The period 1861-1880, however, does not provide a useful choice for Switzerland: for most seasons a surplus of 0.2-0.4°C is recorded in comparison with the period 1850-1900.

The period 1864-1900 can be considered to be an informed compromise for a pre-industrial period in Switzerland on the basis of data availability and their representative nature. A useful, if on average slightly colder choice would be the period 1871-1900 which at the same time conforms to the WMO conception of 30-year standard periods. Table 2 contains the difference of mean values in the Swiss temperature average (Begert et al., 2018) from 1864-1900 to 1871-1900 for the individual seasons and table 3 shows the differences between the mean values of both reference periods and the current reference period 1981-2010 for the same data.

Table 2: Differences of mean values in the Swiss temperature average (°C) from 1864-1900 to period 1871-1900 for the four seasons and the entire year.

Diff to 1871-1900	DJF	MAM	JJA	SON	Year
1864-1900	0.15	0.10	-0.01	-0.02	0.04

Table 3: Differences of mean values in the Swiss temperature average (°C) from 1864-1900 and 1871-1900 to the current normal period 1981-2010 for the four seasons and the entire year.

Difference to 1981-2010	DJF	MAM	JJA	SON	Year
1864-1900	1.47	1.47	1.54	1.40	1.47
1871-1900	1.62	1.57	1.53	1.38	1.51

A pre-industrial reference period is useful not only for the purpose of communicating deviations, it also enables the graphic display of temperature evolution in Switzerland and shows effectively the overlay of a general rise in temperature and decadal, natural fluctuations (see figure 1, the example 1871-1900).

2.2.1 Choice of 1871-1900 as pre-industrial reference period

Both 1871-1900 and 1864-1900 would be suitable as pre-industrial reference periods for Switzerland. Differences are slight and statements on climate change / warming since the pre-industrial period are much the same. This is the reason why other arguments for or against one or the other period have to be considered:

Pro 1864-1900

- Choice of the reference period as close as possible to 1850-1900.
- Although "closer" to the Little Ice Age, the period 1864-1900 is, especially in winter and spring, around 0.1°C warmer than 1871-1900. Thus, the choice of 1864-1900 is a more conservative choice as the basis for evaluating change since pre-industrial times.
- The duration of the WMO 30-year period is a compromise of available data, covering natural variability and the requirements of various observation parameters. Scientifically speaking, a longer period is not a disadvantage in the pre-industrial phase.

Pro 1871-1900

- More clearly positioned after the Little Ice Age, which can be an advantage for communication. With regard to actual temperatures, especially in winter and spring, however, around 0.1°C colder than 1864-1900.
- This period reflects the WMO 30-year standard period: a fact that can be advantageous in terms of communication.
- The choice of 1871-1900 could facilitate conformity with other countries / institutions. 1864-1900 is unlikely to be chosen by any other (neighbouring) country as it contains the Swiss-specific starting date 1864 of its observation network.
- As regards communication, the choice of a 30-year period has its advantages since its duration is comparable with the current normal period 1981-2010 and with the periods used for the 30-year climate scenarios in CH2018 (NCCS, 2018).

Undecided

- As far as statements about warming since the pre-industrial era are concerned, the choice is practically irrelevant.
- There are no additional observation parameters which would be better served in Switzerland by a reference period with a later starting date. Interesting parameters such as sunshine duration or long data series of a denser precipitation-measurement network begin mostly after 1880.

Conclusion:

The period 1871-1900 will be used as the pre-industrial reference period in order to calculate and document climate evolution in Switzerland in the context of the global 1.5/2°C target. MeteoSwiss gives greater weight to arguments in favour of the period 1871-1900 than the other arguments (conception of WMO standard periods and potentially better comparability with neighbouring countries).

2.2.2 External comments

In order to create broad support for the choice of a pre-industrial reference period for Switzerland eleven experts from the Swiss scientific community were asked – via ProClim – to give their comments. Essentially the idea of introducing a pre-industrial reference period met with approval and many valuable suggestions, for example, as regards terminology or communication were gathered. In short, the main points are the following:

- The initiative to introduce a reference period with the aim of defining the pre-industrial temperature level in Switzerland is appreciated und supported. Both options, 1864-1900 and 1871-1900, are seen as possible solutions.
- The clear definition and description of the period used are seen as important, as is the discussion of their sensitivity with respect to statements about temperature evolution. Since the term "pre-industrial" can be defined in different ways it was suggested that another name for the period might be chosen.
- The following aspect is seen as problematic in the context of the introduction of a pre-industrial reference period for Switzerland: national and global scales could be confounded. An example: the global 1.5/2 target has not yet been exceeded when the rising temperature in Switzerland has already reached that level. In the relevant communication this relation has to be explicitly mentioned and discussed.

When establishing and introducing an early reference period, MeteoSwiss will try to incorporate as many suggestions by experts as possible. For practical reasons, however, and due to contradictory requests, it is not possible to integrate all suggestions in a final compromise. Particularly the wish for the use of the period 1850-1900 cannot be granted because of the absence of data. However, it can be shown that the use of the chosen period 1871-1900 does not lead to relevant differences compared with most other proposals. The idea of introducing another term instead of "pre-industrial" is dismissed in order to avoid any confusion in comparison with the wording used by IPCC. In fact, 1871-1900 is chosen to allow comparability with the IPCC pre-industrial reference. Using another term would therefore not make sense.

3 Calculation of temperature change since 1864

3.1 Comparison of different methods

In order to calculate temperature increase in the instrumental measuring period MeteoSwiss currently uses only the value from a linear regression which is determined by the measured values since the beginning of observations to the present date. Based on this, the communicated increase of the annual mean temperature in Switzerland since 1864 amounted to 1.30 °C per 100 years and 2.01 °C over the entire period of 154 years by the end of 2017 (see figure 3). The method is based on the premise that the observed evolution in temperature is caused by both a linear increase due to a continually changing external forcing and an overlaid decadal variability.

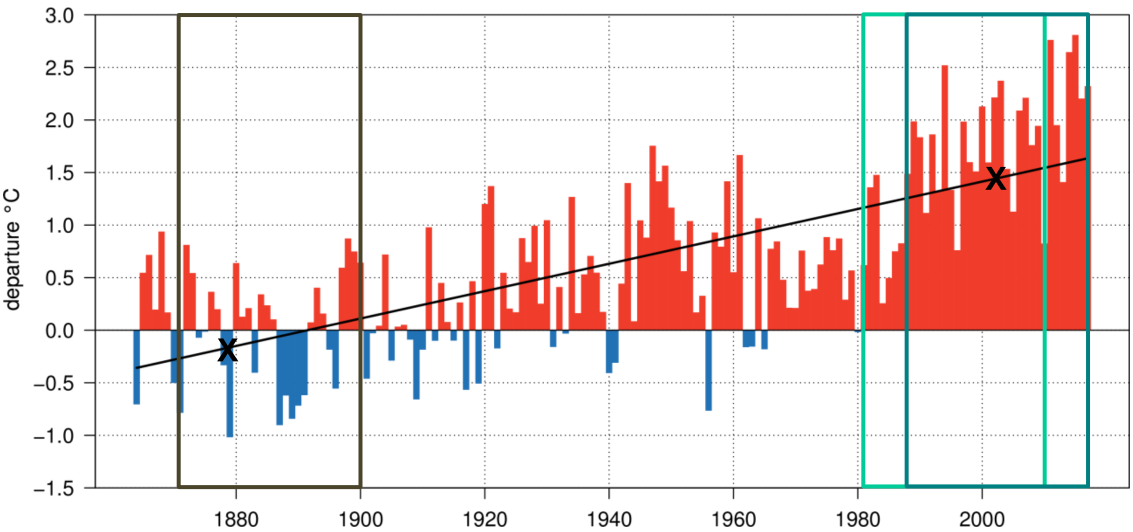

Figure 3: Annual mean temperature in Switzerland 1864-2017 as digression from the pre-industrial reference period 1871-1900 with linear trend (black) and various reference periods (black: 1871-1900; light green: 1981-2010; dark green: 1988-2017). The black crosses mark the centres of a 30-year period at the beginning (1864-1893) and at the end (1988-2017) of the entire period.

In the context of the introduction of a pre-industrial reference period, the method of the linear trend as a measure for temperature increase in the instrumental measuring period is subject to question for various reasons. Firstly, on the basis of the linear model, the calculated temperature increase in the Swiss annual mean temperature begins at around 0.4 °C below the pre-industrial reference period (see figure 3). Secondly, the expected current temperature rises year by year in this model although in such short a time it would hardly be appropriate to talk about climate change. Thirdly, the starting point for calculations has an impact on the calculated temperature increase and the year 1864 is coincidental and Switzerland-specific.

According to the World Meteorological Organization, WMO mean values from 30-year measurement periods (normal periods) are used to describe climate (WMO, 2017). At the end of each decade these periods are moved forward 10 years in order to have the most recent climate change represented in the current period. According to the WMO definition, the period 1981-2010 therefore describes the current climate up to the year 2020. Analogous to IPCC (2013, 2018), it would be possible to use the difference between the pre-industrial reference period and a current period (e.g. 1981-2010) instead of the linear trend to document temperature change. With this approach future changes contained in climate scenarios existing for Switzerland (NCCS, 2018) could be compared more easily and consistently with developments in the past as these scenarios describe the expected changes in terms of a difference to the mean value of a current period.

On the basis of the linear trend and the differences of mean values from reference periods, several possibilities can be established of how to determine temperature change. The following approaches will be analysed further as follows (see also figure 3):

- Linear trend (least squares fit) whereby the change is defined as the difference between the first and the last value of the linear trend line (**LinTrend1**).
- Linear trend (least squares fit) whereby the change is defined as the difference of two points on the linear trend line, which are both set at a distance of 15 years from the beginning and the end of the entire measuring period. (**LinTrend2**).
- Difference of the mean values from the pre-industrial reference period and the current WMO standard period (**DiffPer1**).
- Difference of mean values from the pre-industrial reference period and the last 30 years (**DiffPer2**).

For both the linear trend and the difference of mean values from various periods additional alternative options are possible. The following methods have been considered but not be followed up for the reasons given here:

- Non-parametrical, robust, linear trend (Ex. Theil-Senn / Mann-Kendall): Approach that reacts less strongly to outliers at the beginning or end of a period. When tested, however, only very few substantial differences were found in comparison with results from LinTrend1.
- Difference from weighted mean values at the beginning and at the end of the examined period (Ex. 30-year Gauss low-pass filter): Here, too, tests revealed only minor differences in comparison with DiffPer1. Furthermore, one would forgo the possibility of evaluating the significance of differences by a statistical hypothesis test. In addition, it would be difficult to argue why the climatological average of a 30-year period should be a weighted mean value.
- Difference of the pre-industrial period to a current mean value of a period, combining measured data and decadal forecasts (e.g. 15 years each): one advantage would be to get a more realistic expected value for the present period. However, this approach currently lacks the necessary foundation and would be even further removed from WMO specifications.

In table 4 the following four methods which have been examined in depth are presented and compared, together with their advantages and disadvantages as well as with the calculated change including uncertainty. In the linear trend the uncertainties correspond to the 95% confidence interval for the coefficient of the linear regression, in the difference of mean values to the 95% confidence interval from the two-sample t-test. Below the table, the advantages and disadvantages are deduced and described in more detail.

Table 4: Approaches to calculating temperature change in Switzerland since the start of systematic instrumental monitoring in 1864, including advantages and disadvantages of individual methods and the calculated change in the Swiss annual mean temperature.

Method	Advantages	Disadvantages	Δ from period 1864-2017
LinTrend1 Difference from the first to the last of the linear fit (1864-2017)	• Current, tried-and-tested approach by MeteoSwiss • Approach is widely used and established • Most recent recorded change is included in the calculation	• Assumption of a linear increase • Expected value at the beginning / end of the series rather high / low if assumption is violated • Climate changes from year to year	+2.01 ± 0.34 °C
LinTrend2 Difference from the middle of a 30-year period at the beginning and the end of a linear fit (1879-2002)	• Expected values at the beginning and end centred in a 30-year period • More similar to the comparison of two periods at the beginning and the end, but taking into account the change within the normal period • Most recent recorded change is included in the calculation	• Assumption of a linear increase • Climate changes from year to year • New, hardly-used approach • Communication made more difficult	+1.62 ± 0.27 °C
DiffPer1 Comparison of mean values of two fixed periods over a lengthy duration at the beginning and the end (e.g. 1871-1900 to 1981-2010)	• Use of WMO standard periods • Period corresponds to the one used to classify individual years (e.g. climate bulletin) • Can be used in comparison with results from scenarios (e.g. CH2018) • Communication made easier	• Change since the end of the period (e.g. 2010) is not taken into account • Communicated warming remains the same for 10 years	+1.51 ± 0.30 °C
DiffPer2 Comparison of mean values of two periods at the beginning and the end whereby the end period is moved forward each year (e.g. 1871-1900 to 1988-2017)	• Most recent recorded change is included in the calculation	• Climate changes every year (partly even more pronounced than in the linear trend) • Duration of the period unclear (IPCC sometimes uses only 20 years at the end) • Difficult to communicate as an additional period is added to two WMO periods and a pre-industrial period	+1.85 ± 0.28 °C

From table 4 it becomes evident that there is no easy answer to the question of how temperature in Switzerland has changed within the last 150 years. Depending on the method, different statements emerge which, in addition, can differ to a greater or lesser extent depending on the initial situation (mainly the date within a WMO standard period). In figure 4 and figure 5 a comparison is shown of the evolution of the Swiss mean temperature (annual, seasonal) and change since the start of observation / pre-industrial, calculated with four different methods. The comparison demonstrates the general differences of the statements and how they develop in time.

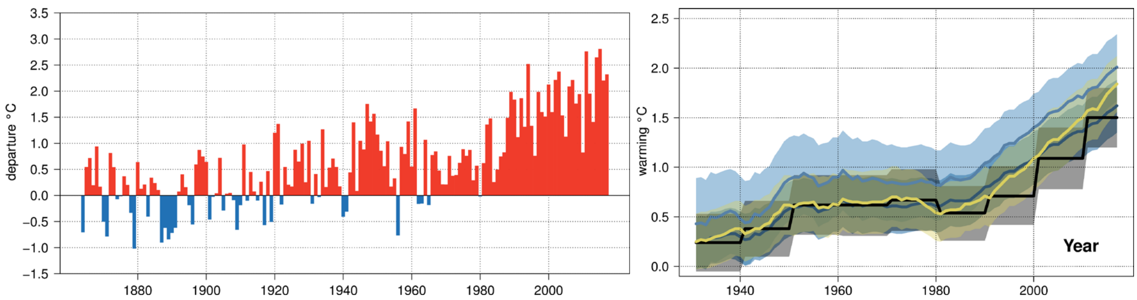

Figure 4: Annual mean temperature in Switzerland from 1864 to 2017 as deviation from the pre-industrial reference period 1871-1900 (left) and evolution of the temperature change – calculated with different methods - since the beginning of observations in the period 1931 - 2017 (right). The calculated differences are shown together with their 95% confidence intervals (light blue: LinTrend1; dark blue: LinTrend2; black: DiffPer1; yellow: DiffPer2).

Overall it is apparent that LinTrend1 often leads to the highest value over the entire duration with regard to temperature increase since 1864. This is especially true for periods when temperature rose more of less continually since observations started (e.g. year, autumn) or when a temporary, more pronounced increase in temperature occurred (e.g. spring, summer). In extreme cases LinTrend1 presents – over short or longer periods - values which are 0.5°C above the others and are frequently outside the confidence intervals of other methods. The reason being that, on the one hand, LinTrend1 takes into account the difference between the first and the last value of the data set – contrary to the other approaches – and that, on the other hand, it reacts more strongly to changes at the end of the period. Examples for this are the 1940s (spring, summer) or the year 2003 (summer) after which the value shoots up 0.2°C. The impact of individual outliers could be limited by the use of a more robust linear trend estimate. In all other instances, however, this would not influence the fact that LinTrend1 leads to the highest values.

LinTrend2 and DiffPer2 usually show relatively similar values whereby DiffPer2 reacts more strongly to the decadal variability of the annual and seasonal temperature means. DiffPer2 therefore manifests somehow stronger fluctuations and also decreases more significantly with falling temperature. It is also noticeable that DiffPer2 has been getting closer to LinTrend1 since 2000 – as far as the year, spring and summer are concerned. This is caused by the pronounced leap in temperature at the end of the 1980s in these seasons, to which the individual methods react differently.

DiffPer1 leads to the smallest values in most cases and can thus be considered, especially since 1980, to be the most conservative approach. This method continuously lags behind the other approaches, a fact that, depending on the season, leads to a difference of up to 0.8°C in comparison with LinTrend1 at the end of a WMO standard period. But also in comparison with DiffPer2 there are differences of up to 0.5 °C. In relation to the entire rise in temperature since observations started/pre-industrial period, this amounts to a difference in the general order of up to 50%.

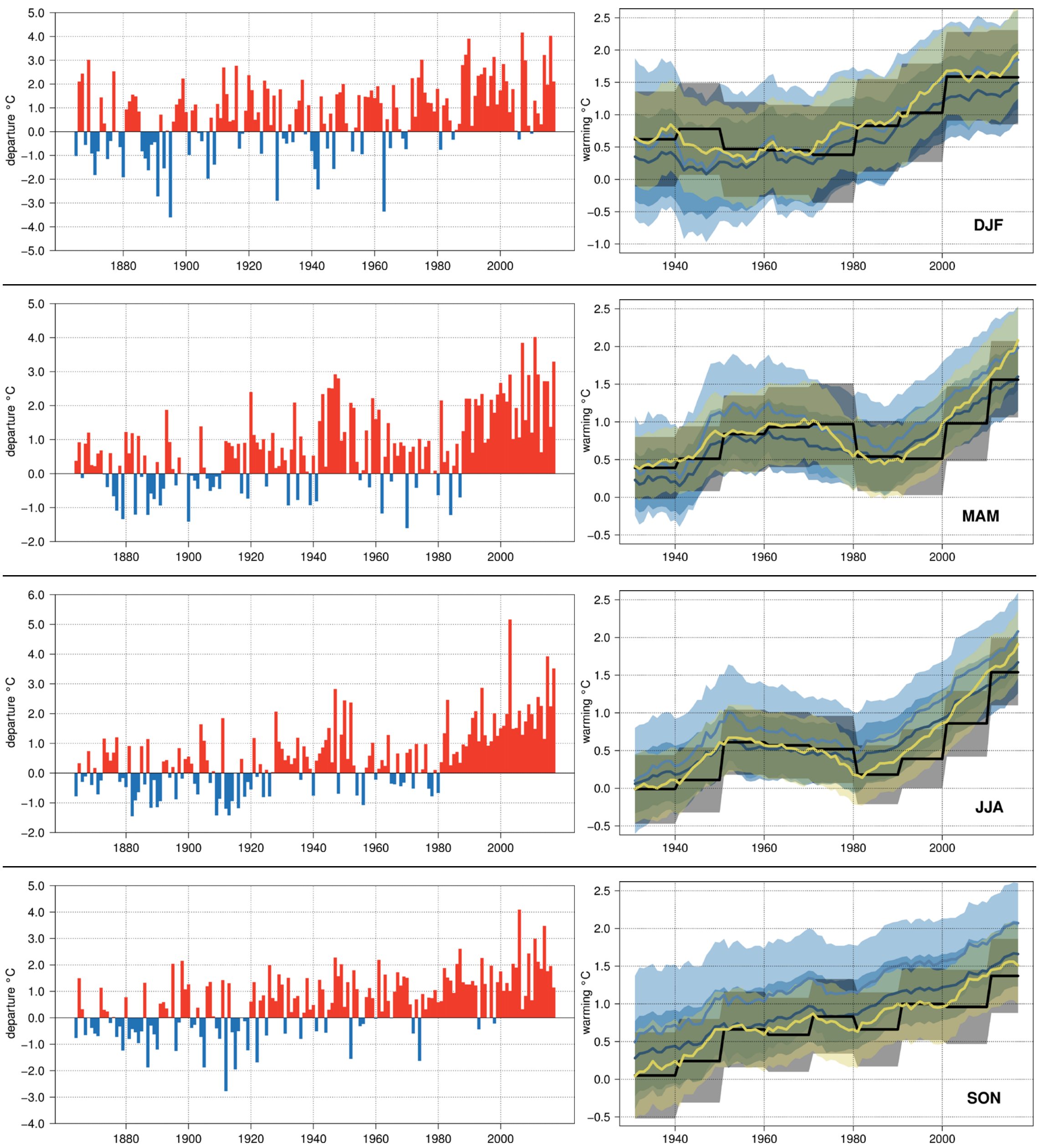

Figure 5: Seasonal mean temperature in Switzerland from 1864 to 2017 as deviation from the pre-industrial reference period 1871-1900 (left) and evolution of the temperature change – calculated with different methods - since the beginning of observations in the period 1931 - 2017 (right). The calculated differences are shown together with their 95% confidence intervals (light blue: LinTrend1; dark blue: LinTrend2; black: DiffPer1; yellow: DiffPer2).

3.2 Discussion and choice of method

All methods presented here have advantages and disadvantages and there is no approach which commends itself more strongly than others. The following considerations led to the priorisation of the methods presented:

1. Climate can be defined as the statistical description of the relevant climate elements which characterize the conditions and variations of the terrestrial atmosphere for a time scale which is not too small (Hantel, 1987). Individual years or seasons can diverge significantly from these conditions and are the expression of natural variability – also in a changing climate. In that sense they should not lead to the modification of the reference value (climate) in order to determine temperature change.

2. The assumption of a linear temperature evolution since 1864 overlaid by decadal variability is problematic. An obvious general warming has only occurred since the mid-20th century and cannot be statistically proven in Switzerland before that time. The linear fit has the effect of producing an estimation of the expected value at the beginning and the end of the time series which is too low and too high, respectively (see Figure 3), a fact which leads to the calculation of a relatively high change in temperature. The applicability of a linear model since 1864 is difficult to defend.

3. MeteoSwiss uses the official 30-year WMO standard period as a basis for classifying the current atmospheric condition (e.g. climate bulletin, climate report). The mean values of this period correspond to the expected values and in that sense describe the current climate. In the interest of consistent argumentation, it would be appropriate to use the same definition (employed for the current climate) also with respect to the change in climate compared with the past. At the end of a standard period, however, this can result in statements on warming since pre-industrial times which already show clear differences in comparison with the most recent 30 years.

Conclusion:

In order to calculate temperature increase in the context of the global 1.5/2°C target, MeteoSwiss now prefers the comparison of the pre-industrial reference period 1871-1900 with a current 30 year period (DiffPer1 or DiffPer2). Depending on the application, the official WMO standard period commends itself (e.g. comparison with climate scenarios CH2018) or the last 30 years (e.g. inclusion of most recent developments). Der linear fit (LinTrend1) remains a possibility and is indispensable especially for the comparison with external data sets and studies. At any rate, the exact declaration of the method is vital for revealing how the communicated values have been calculated.

4 Comparison: temperature increase in Switzerland and on a global scale

In the context of long-term temperature evolution in Switzerland and its communication the question arises how this change compares with global warming. With the same approach, using the difference between the fixed pre-industrial reference period and the most recent WMO standard period, the increase in temperature on a global level can be determined and – to serve the above-mentioned purpose - compared with Swiss values. Since various global data sets are available for this comparison it should be clarified which global data set to use as standard and what the consequences of the pertaining choice are for the comparison with Switzerland. In the following chapter the five most important data sets are briefly presented and differences as regards the pre-industrial reference period, the linear trend since 1864 and statements in comparison with Switzerland are shown.

4.1 Global data sets for temperature

Global gridded temperature data sets are the basis of climate monitoring on a global and continental level. Today many different data sets exist which have been supplied by various working groups on the basis of long-term series of data collected over both land and sea surfaces. The most important and most widely used data sets are the following:

- **HadCRUT4:** UK Met Office and Climatic Research Unit of the University of East Anglia (Morice et al., 2012), data from 1850; http://www.metoffice.gov.uk/hadobs/hadcrut4/
- **Cowtan-Way:** University of York (Cowtan and Way, 2014), data from 1850; http://www-users.york.ac.uk/~kdc3/papers/coverage2013/
- **NOAAGlobalTemp:** National Center for Environmental Information of NOAA (Vose et al., 2012), data from 1880; https://www.ncdc.noaa.gov/data-access/marineocean-data/noaa-global-surface-temperature-noaaglobaltemp
- **GISTEMP:** Goddard Institute for Space Studies of NASA (Hansen et al., 2010), data from 1880; https://data.giss.nasa.gov/gistemp/
- **BEST:** University of Berkeley (Rohde et al., 2013), data from 1850; http://berkeleyearth.org/data/

There are differences in the data sets concerning many aspects (e.g. data basis, homogenisation of measurement series, dealing with missing values in space and time, methodology of gridding/interpolation, inclusion of Arctic/Antarctic zones, etc.). The main differences can be summarised as follows: HadCRUT4 and Cowtan-Way as well as NOAAGlobalTemp and GISTEMP are all based on the same data basis; however, they differ with respect to the inclusion of regions with scant or missing coverage by observation stations. While HadCRUT4 and NOAAGlobalTemp restrict themselves to grid cells with sufficient station information when establishing a global mean, Cowtan-Way and GISTEMP perform interpolation on all grid cells at all times. Nevertheless, numerous comparisons of global mean temperature, calculated with the various data sets, have shown ample consistency with respect to variability and long-term trends (e.g. Wen et al., 2011; Jones, 2016). Differences are mostly within uncertainties. In the following chapter these differences between the data sets are shown and their consequences for a comparison with Switzerland are discussed.

4.2 Comparison of global temperature data sets

The five available data sets cover different periods: while HadCRUT4, Cowtan-Way and BEST start at 1850, NOAAGlobalTemp and GISTEMP only provide data from 1880. This fact already restricts the choice of a data set for the comparison with Switzerland because the pre-industrial reference period is only applicable for three data sets. In the following, however, all five data sets will initially be included in the comparison in order to establish a better basis for the decision between HadCRUT4, Cowtan-Way and BEST.

4.2.1 Comparison of temperature evolution

In general, variability and trends for the global mean temperature are similar for all seasons in all data sets under investigation. Within the period covered by all data sets differences from 0.1 to 0.2 °C appear in the smoothed evolution. HadCRUT4, GISTEMP, NOAAGlobalTemp and Cowtan-Way start at a similar level and begin drifting apart slightly in the first half of the 20th century. At this stage HadCRUT4 and Cowtan-Way show a stronger increase than the other time series and on average register at up to 0.1°C higher than the other data sets. In the second half of the 20th century all curves converge again. BEST shows the most notable deviation: on the one hand, the smoothed curve registers at 0.1 to 0.2 °C below the other four data series for all seasons in the 19th century. On the other hand, BEST presents the strongest increase in the first half of the 20th century, “overtakes” GISTEMP and NOAAGlobalTemp and comes close to HadCRUT4 and Cowtan-Way. HadCRUT4 shows the smallest increase over the entire available period. The above-described progression is also reflected in the linear trends (see table 5). HadCRUT4 shows the lowest values in all seasons, BEST the highest. With the exception of BEST, the differences in the trends amount to ≤ 0.1 °C and the ranking of the 4 warmest years is identical.

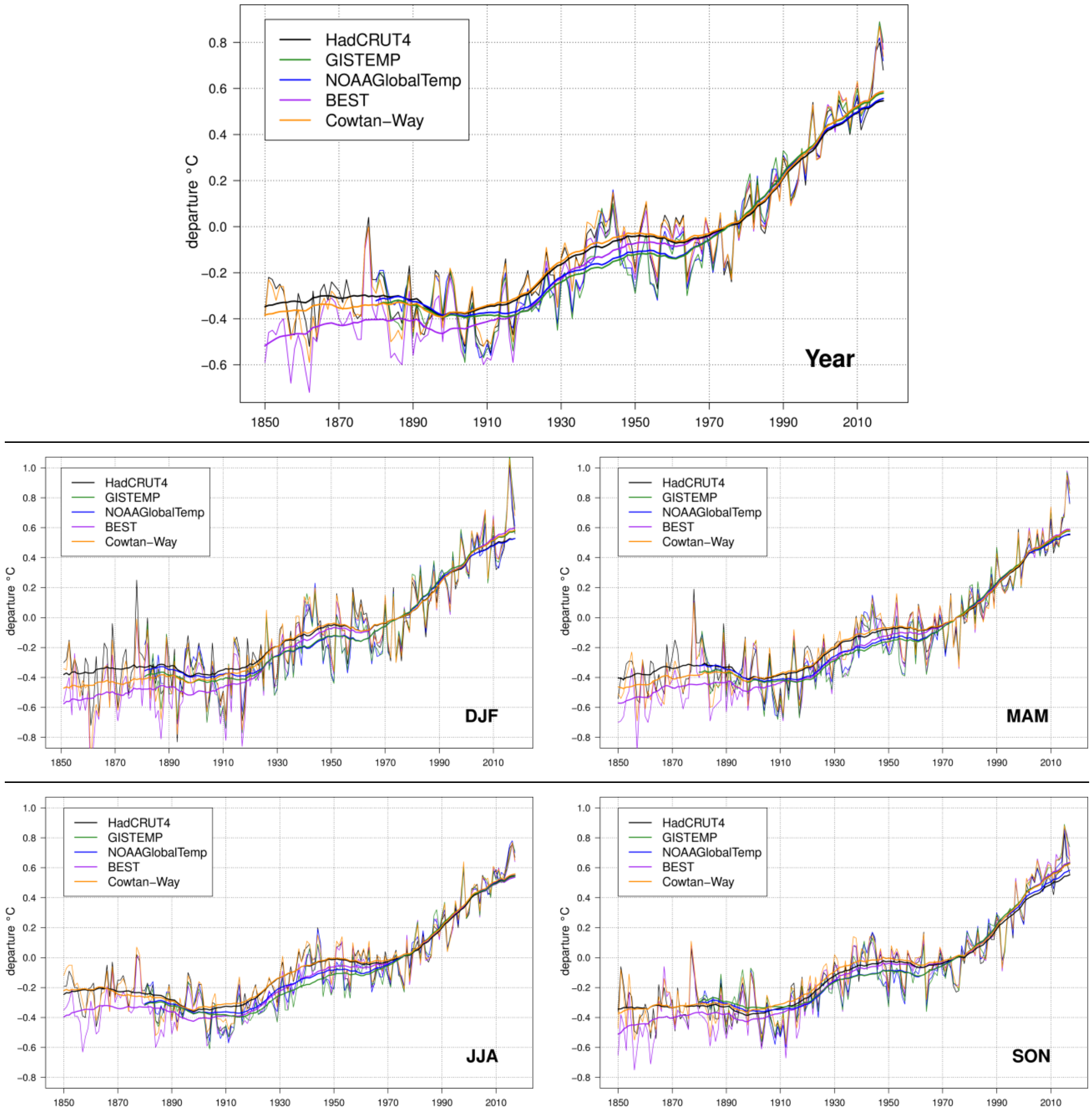

Figure 6: Global mean temperature (year, season) in the period 1850-2017 as deviation from the period 1961-1990, calculated from five different data sets. In addition to the individual values a 30-year running mean is displayed.

Table 5: Seasonal and annual global temperature increase in °C per 100 years in the period 1880 to 2017, calculated with linear regression from five different global data sets.

	DJF	MAM	JJA	SON	Year
HadCRUT4	0.69	0.70	0.65	0.66	0.67
Cowtan-Way	0.76	0.73	0.66	0.68	0.71
GISTEMP	0.77	0.75	0.69	0.67	0.72
NOAAGlobalTemp	0.71	0.72	0.68	0.66	0.69
BEST	0.85	0.82	0.73	0.76	0.79

The reasons for differences between the data sets consist of a combination of differences in the data basis (e.g. number of stations used), in data processing (e.g. homogenisation) and in the spatial interpolation (mainly in regions without observation data) – on the whole difficult to pinpoint. However, the differences in dealing with the uneven distribution of observation stations may have an important role to play and – in this context – the individual ways of interpolating temperature in non-represented regions, above all in polar regions (Arctic / Antarctic zones) (UK MetOffice, 2018). While BEST, Cowtan-Way and GISTEMP perform region-specific interpolations, NOAAGlobalTemp and HadCRUT4 use the mean of the rest of the world for non-represented regions. In years with above-average warm temperatures in polar regions (e.g. 2016 and 2017) this leads to marked differences in the global mean temperature, and differing long-term evolutions in individual regions can lead to differing trends. But the different handling of inhomogeneities in the measurement series also contributes to the divergence. While HadCRUT4 and Cowtan-Way use mainly measurement series which are already homogenised, the other data sets perform this process centrally, whereby meta information is rarely entered.

4.2.2 Comparison of different normal periods in global data sets

Due to the period available, only HadCRUT4, Cowtan-Way and BEST can be used for the comparison of different pre-industrial reference periods. Table 6 shows the relevant annual and seasonal values calculated as anomalies to 1961-1990.

Table 6: Mean values (as anomalies to 1961-1990 in °C) of various pre-industrial reference periods for the four seasons and the entire year in the global mean temperature by HadCRUT4, Cowtan-Way and BEST.

Period	DJF			MAM			JJA			SON			Year		
	CRU	COW	BES	CRU	COW	BES	CRU	COW	BES	CRU	COW	BES	CRU	COW	BES
1850-1900	-0.34	-0.42	-0.50	-0.35	-0.40	-0.48	-0.24	-0.24	-0.35	-0.32	-0.32	-0.40	-0.31	-0.35	-0.43
1861-1880	-0.35	-0.45	-0.52	-0.32	-0.39	-0.45	-0.19	-0.20	-0.28	-0.32	-0.30	-0.35	-0.29	-0.33	-0.40
1864-1900	-0.33	-0.41	-0.47	-0.33	-0.38	-0.44	-0.24	-0.25	-0.32	-0.32	-0.30	-0.36	-0.30	-0.33	-0.40
1871-1900	-0.33	-0.40	-0.48	-0.32	-0.37	-0.44	-0.25	-0.27	-0.34	-0.32	-0.30	-0.37	-0.30	-0.33	-0.40

The differences between the mean values of various pre-industrial reference periods are very small within the individual data set and amount to less than 0.1 °C in all seasons. Major deviations can be discerned in summer (JJA) for the period 1861-1880. The choice of a pre-industrial reference period does not play a vital role in the communication of temperature increase on a global scale. The period 1871-1900 can confidently be used as the pre-industrial reference period. The differences to 1850-1900 are between 0.00 und 0.03 °C for HadCRUT4, between 0.02 und 0.03°C for Cowtan-Way and between 0.01 und 0.04 °C for BEST.

4.3 Discussion and choice of the global data set

Were the pre-industrial reference period 1871–1900 evaluated in this report also to be used as a reference for calculating temperature increase in the case of global temperature means, only HadCRUT4, Cowtan-Way and BEST would be suitable on the basis of their available data. The data series of GISTEMP and NOAAGlobalTemp only begin in 1880 and are therefore too short for this application. GISTEMP and NOAAGlobalTemp, however, provide useful indications as to the choice of a global data set. Both start in 1880, and in contrast to BEST, on a similar level with HadCRUT4 and Cowtan-Way. Comparisons of early reference periods with a recent period yield therefore very similar values with HadCRUT4, Cowtan-Way, GISTEMP and NOAAGlobalTemp, while BEST calculates a slightly stronger increase for all seasons. The data sets of HadCRUT4 and Cowtan-Way differ primarily in winter and spring, where the reference period 1871-1900 shows a variance of 0.05 to 0.07°C. The reason for these differences is the variety of methodologies when it comes to taking into account regions on the planet which are not represented in the monitoring. This problem is more pronounced in an earlier period with a less dense station network than in more recent times.

Since an ultimate decision on which data set is closest to the truth cannot be reached, IPCC (2018) uses an average of several data sets for the calculation of global temperature increase since pre-industrial times. The same approach is proposed by Cowtan-Way (University of York), as, due to limited resources, it can only maintain its data set according to the principle of best effort. Considering the very small differences between HadCRUT4 and Cowtan-Way it is hardly worth the effort for MeteoSwiss to continuously evaluate several global data sets for their own application.

Conclusion:

In order to compare temperature increase in Switzerland with global temperature evolution the HadCRUT4 data set is standardly used. It covers the required period, compares better than BEST with the other data sets and is maintained and up-dated with a high degree of reliability by the Met Office Hadley Centre.

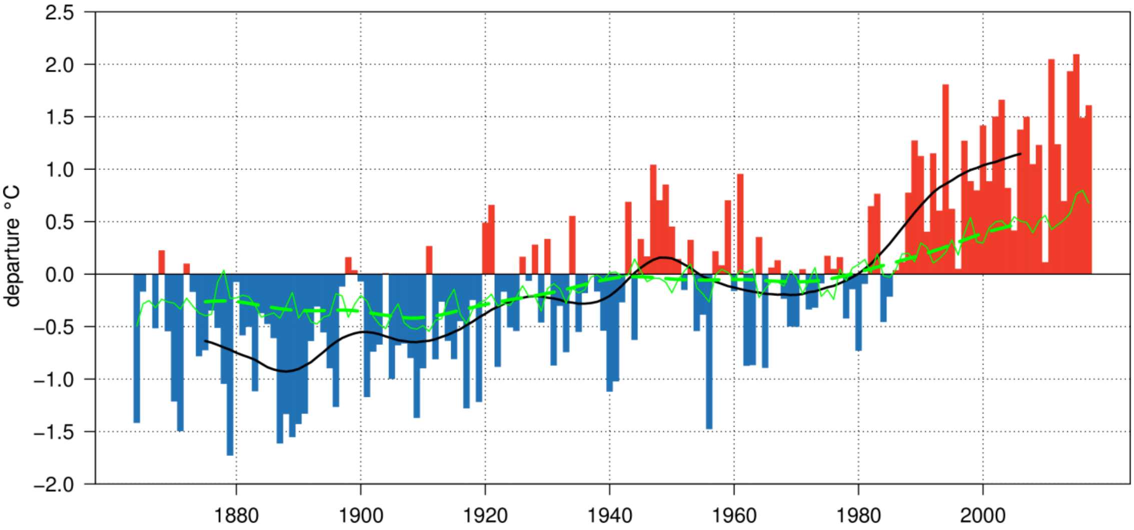

Figure 7: Annual mean temperature in Switzerland 1864-2017 in comparison with global temperature evolution calculated from the HadCRUT4 data set. The deviations from the reference period 1961-1990 are shown (Switzerland: red-blue columns; HadCRUT4: green line) together with a 30-year Gauss low-pass filter (Switzerland: black line; HadCRUT4: green dashed line).

Table 7: Changes in the Swiss mean temperature (°C) in the period 1864 to 2017 in comparison with the global mean temperature from HadCRUT4, calculated with three different methods discussed.

Method	**DJF**		**MAM**		**JJA**		**SON**		**Year**	
	CH	global	CH	global	CH	global	CH	global	CH	global
DiffPer1 1871-1900 to 1981-2010	1.65	0.63	1.57	0.62	1.53	0.54	1.38	0.59	1.51	0.60
DiffPer2 1871-1900 to 1988-2017	1.91	0.74	2.08	0.75	1.90	0.67	1.52	0.72	1.85	0.72
LinTrend1 1864-2017	1.88	0.90	1.98	0.92	2.05	0.76	2.08	0.85	2.01	0.86

Literature

Abram NJ, McGregor HV, Tierney JE, Evans MN, McKay NP, Kaufman DS & the PAGES 2k Consortium, 2016: Early onset of industrial-era warming across the oceans and continents. Nature 536, 411-418. doi:10.1038/nature19082

Begert M, 2007: Die Überführung der klimatologischen Referenzstationen der Schweiz in das Swiss National Climatological Network (Swiss NBCN), Arbeitsbericht der MeteoSchweiz, 215, 43p.

Begert M, Frei C, 2018: Long-term area-mean temperature series for Switzerland – Combining homogenized station data and high resolution grid data. Int. J. Climatol. 1-16. doi:10.1002/joc.5460

Cowtan K, Way RG, 2014: Coverage bias in the HadCRUT4 temperature series and its impact on recent temperature trends. Quarterly Journal of the Royal Meteorol. Soc. 140: 1935-1944. doi: 10.1002/qj.2297

Hansen J, Ruedy R, Sato M, Lo K, 2010: Global surface temperature change, Reviews of Geophysics 48, RG4004. doi:10.1029/2010RG000345

Hantel M, Kraus C, Schönwiese CD, 1987: Climate definition. Springer Verlag, Berlin. ISBN 3-540-17473-7

Henley BJ, King AD, 2017: Trajectories towards the 1.5°C Paris target: modulation by the Interdecadal Pacific Oscillation. Geophys. Res. Lett., 44, 4256-4262. doi:10.1002/2017GL073480

IPCC, 2013: Climate Change 2013: The Physical Science Basis (eds Stocker TF et al.). Cambridge Univ. Press. https://www.ipcc.ch/report/ar5/wg1/

IPCC, 2018: Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. World Meteorological Organization, Geneva, Switzerland, 32 pp. https://www.ipcc.ch/sr15/

Jones P, 2016: The reliability of global and hemispheric surface temperature records. Adv. Atmos. Sci., 33(3), 1-14. doi:10.1007/s00376-015-5194-4

King AD, Black MT, Min S-K, Fischer EM, Mitchell DM, Harrington LJ, Perkins-Kirkpatrick SE, 2016: Emergence of heat extremes attributable to anthropogenic influences. Geophys. Res. Lett., 43, 3438-3443. doi:10.1002/2015GL067448

Knutti R, Rogelj J, Sedláček J, Fischer EM, 2016: A scientific critique of the two-degree climate change target. Nature Geoscience 9, 13-18. doi:10.1038/ngeo2595

Medhaug I, Stolpe MB, Fischer EM, Knutti R, 2017: Reconciling controversies about the 'global warming hiatus'. Nature 545, 41-47. doi:10.1038/nature22315

Morice CP, Kennedy JJ, Rayner NA, Jones PD, 2012: Quantifying uncertainties in global and regional temperature change using an ensemble of observational estimates: The HadCRUT4 dataset. J. Geophys. Res., 117. doi:10.1029/2011JD017187

NCCS (Hrsg.), 2018: CH2018 – Klimaszenarien für die Schweiz. National Centre for Climate Services, Zürich. 24 S. ISBN-Nummer 978-3-9525031-0-2.

Rohde R, Muller R, Jacobsen R, Perlmutter S, Rosenfeld A, Wurtele J, Curry J, Wickham C, Mosher S, 2013: Berkeley Earth Temperature Averaging Process. Geoinformatics and Geostatistics: An Overview 1:2. doi:10.4172/2327-4581.1000103

UNFCCC, 2012: Report of the Conference of the Parties on its Eighteenth Session, Held in Doha from 26 November to 8 December 2012 - Addendum - Part Two: Action Taken by the Conference of the Parties at its Eighteenth Session FCCC/CP/2012/8/Add.1.

UK MetOffice, 2018: An overview of global surface temperatures in 2017. https://www.metoffice.gov.uk/research/news/2018/global-surface-temperatures-in-2017

Vose RS, Arndt D, Banzon VF, Easterling DR, Gleason B, Huang B, Kearns E, Lawrimore JH, Menne MJ, Peterson TC, Reynolds RW, Smith TM, Williams CN, Wuertz DL, 2012: NOAA's merged land-ocean surface temperature analysis. Bulletin of the American Meteorological Society, 93, 1677-1685. doi:10.1175/BAMS-D-11-00241.1

Wen X, Tang G, Wang S, Huang J, 2011: Comparison of global mean temperature series. Adv. Clim. Change Res., 2(4). doi:10.3724/SP.J.1248.2011.00187

WMO, 1959: Technical Regulations No49, Vol. 1 (Bd. 2), 2nd edn. WMO, Geneva, Switzerland.

WMO, 2011: Guide to Climatological Practices. WMO-No. 100, 2011 edn. WMO, Geneva, Switzerland, ISBN 978-92-63-10100-6.

WMO, 2017: WMO Guidelines on the Calculation of Climate Normals, 2017 edition, WMO-No. 1203, Geneva, Switzerland. ISBN 978-92-63-11203-3.

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