

The impact of changing temperature scales on the climate record

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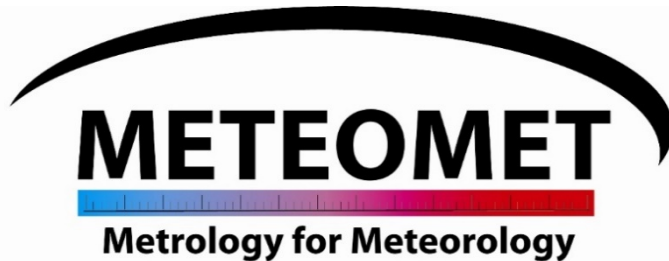
With thanks to Mauro Battuello and Graziano Coppa

The impact of changing temperature scales on the climate record

Spoiler:

There is no impact!

A deliverable of the MeteoMet joint research project



International Journal of Climatology



RESEARCH ARTICLE | [Full Access](#)

Effect of changes in temperature scales on historical temperature data

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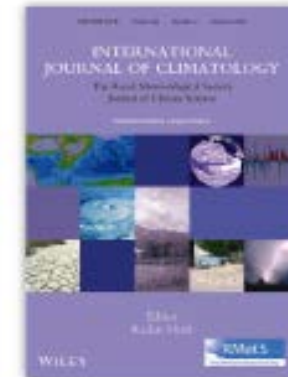
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ABSTRACT

Temperature has always been a central quantity in meteorology and plays a key role in weather forecast and climate determination. Long temperature series are a useful tool both as a direct indicator of global climatic trends and as input to climate models. However, ensuring the quality of the data records is challenging, with issues arising from the wide range of sensors used, how the sensors were calibrated, and how the data were recorded and written down. In particular, the very definition of the temperature scales has evolved. While the temperature scales have always been tied to phase transitions of substances such as the freezing and boiling points of water, the temperatures assigned to those phase transitions have been revised occasionally when new sensors and measuring techniques suggested discrepancies between the temperature scales and thermodynamic temperature. Invariably this has led to alterations in the reference scales of temperature that give rise to biases when compiling historic temperature records, an issue that appears to be neglected in the meteorological literature. The present work deals with this issue for 20th century data by proposing a mathematical model to allow the conversion from historical scales to the International Temperature Scale of 1990 (ITS-90). This work also presents the implementation of this mathematical model into a software tool, which can convert large files of historical records to the ITS-90. The correction equation is applied to example observations, and it is found that the correction becomes an issue in special cases involving aggregated temperature data. However, the corrections are significantly smaller than the global warming trend seen in the 20th century. The corrections applied have shown a level of change, which has not significantly affected the global warming trend.



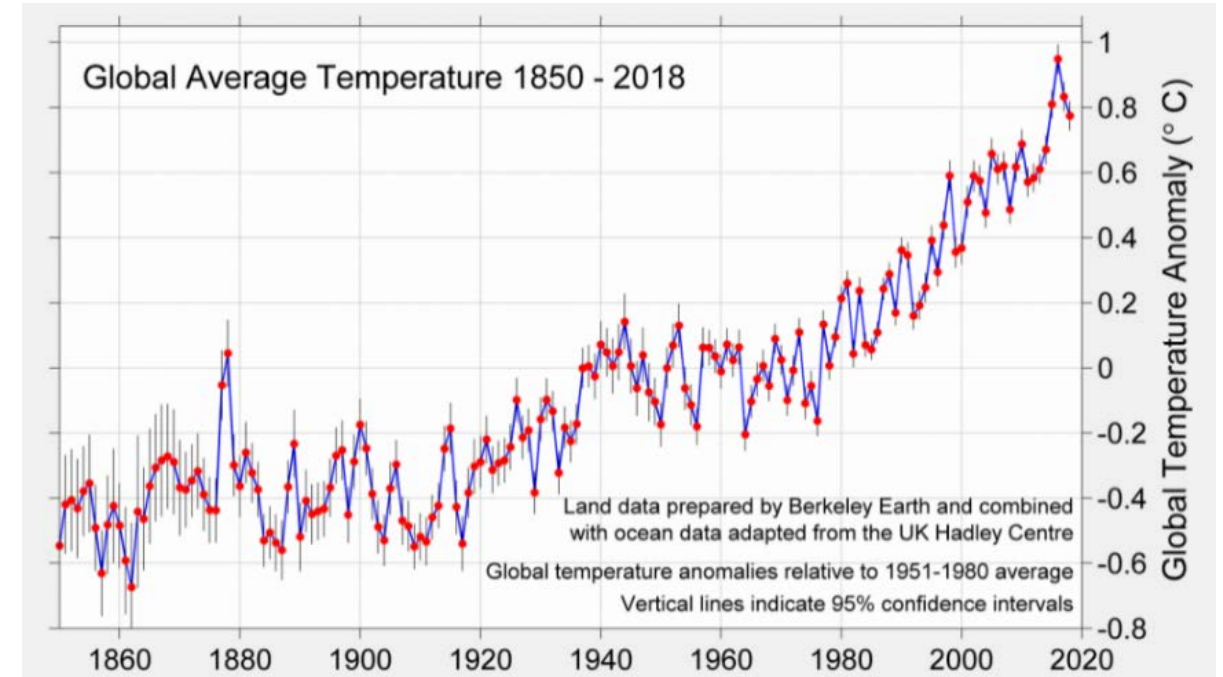
Establishing long instrumental temperature records is an important part of ongoing climate research.

Such records are used:

to constrain models of earth's climate system (Brohan *et al.*, 2012),

to establish long-term trends in temperature, (Morice *et al.*, 2012 on the HadCRUT4 data set),

and for validation of proxies used to extend the temperature record further back in time (Jones and Mann, 2004).



When the thermometer was invented there was still no accepted standard for calibration. The ways in which people tried to find a reference point were ridiculously arbitrary; they used standards as wide-ranging as the melting point of butter, the internal temperature of animals, **the cellar temperature of the Observatoire de Paris**, **the warmest or coldest day of the year in various cities**, and “glowing coals in the kitchen fire.”

<https://time.com/6053214/thermometer-history/>



In Climatology, a tacit assumption behind the homogenization of long temperature records is a consistent definition of the temperature scale.

This is more or less true for the freezing point of water, which has served as anchor points to calibrate thermometers since the 17th century.

However, all other temperatures have relied on the thermal behaviour of other substances, such as the expansion of mercury and ethanol/water mixtures, or electrical resistance.

The nonlinearity of the thermal properties means that the choice of instrument has a **subtle effect** on the temperature scale itself: it introduces a **bias in long temperature records**, which appears to be neglected in the meteorological (and now climatological) literature.



Daniel Fahrenheit, inventor of the mercury thermometer, established 0°F as the lowest consistent temperature he could replicate in his laboratory by mixing salt with water, a method that allowed him to create a reliably stable freezing point for calibration.

- 1724 Fahrenheit scale
- 1741 Celsius scale
- 1848 Thomson scale
- 1854 Kelvin thermodynamic scale

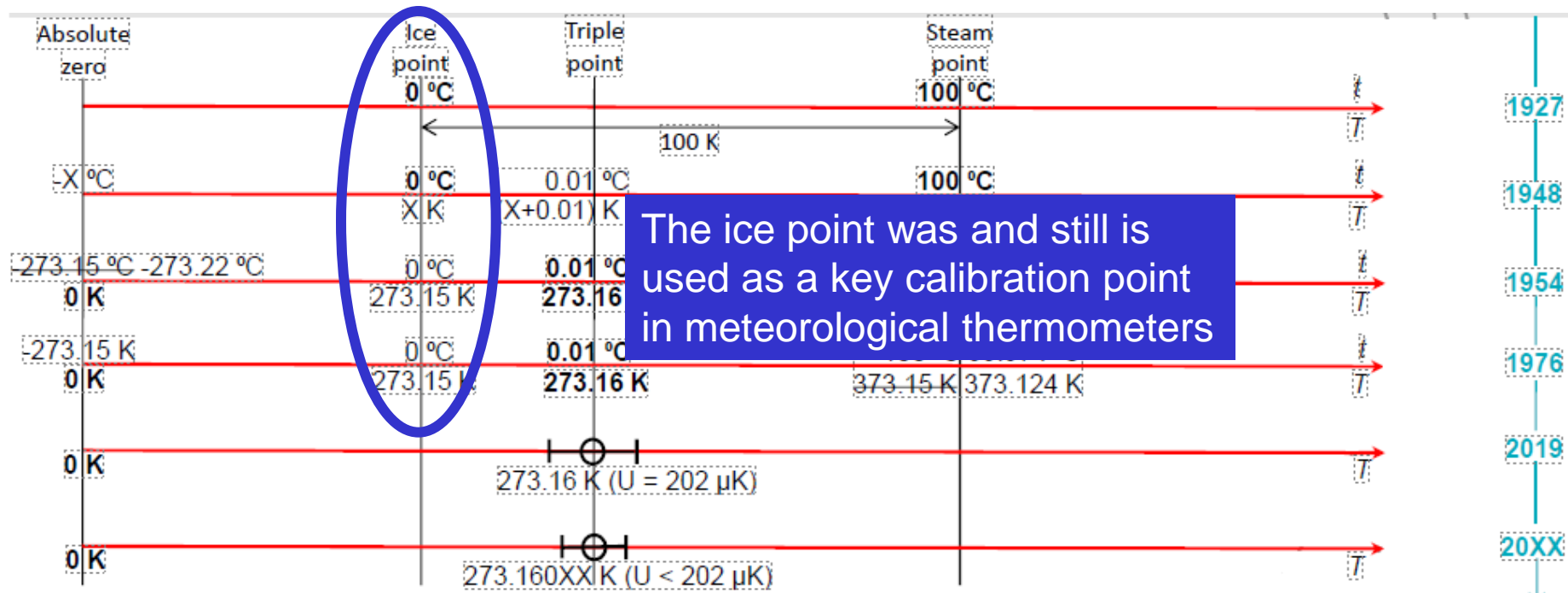
As (here) we know, during the history of temperature measurements, different temperature scales were introduced and used.

This fact means that a temperature readings taken from a calibrated thermometer before ITS 90 would be different from today's reading. This difference is caused by the usage of various fixed points and interpolating functions during the evolution of temperature scales.

Measurement theory:

- Empirical temperature scales are ordinal scales:
 - Historic Fahrenheit mercury-based scale
 - Historic Celsius mercury-based scale
 - Callendar scale
 - ITS-27, ITS-48, IPTS-68 and ITS-90

On the other hand, the freezing point of water remains correction free in all revisions



Thus, in the vicinity of 0 °C, it is possible to construct simplified mathematical functions to map from one scale to another: indeed, in the range from -50 to +50 °C, which is most relevant to temperature measurement on the earth, a simple polynomial is sufficient.

However, the empirical nature of the temperature scales precludes any simplified physical model to inform the choice of polynomial order.

The polynomial order is a compromise between a desire to decrease the number of degrees of freedom in the fitting procedure, and a desire to capture the nonlinear behaviour of the correction.

Table 1. t_C Polynomial coefficients.

	1927–1968	1969–1989
a_0	4.17095×10^{-4}	-8.31908×10^{-5}
a_1	-6.85871×10^{-4}	-2.07761×10^{-4}
a_2	4.84595×10^{-6}	-3.7404×10^{-7}
a_3	3.44392×10^{-8}	-5.78149×10^{-9}
a_4	-7.24503×10^{-10}	-1.09541×10^{-10}

$$t_{90} = t_H + t_C$$

$$t_C = a_0 + a_1 t_H + a_2 t_H^2 + a_3 t_H^3 + a_4 t_H^4$$

We have used the Akaike's information criterion (AIC) (Akaike, 1974) to aid in order selection.

Table 2. The differences $t_{90} - t_H$ in mK for typical temperatures.

Year	Difference in mK between historical data and ITS-90 for typical temperatures					
	at 25 °C	at 15 °C	at 5 °C	at -5 °C	at -15 °C	at -25 °C
1927–1968	-13.5	-8.8	-3.0	4.0	11.8	19.8
1969–1989	-5.6	-3.2	-1.1	0.9	2.9	4.9

In MeteoMet we developed a conversion program for converting historical temperature data from ITS 27, 48, 68 and 76 to the current ITS 90

This conversion program is capable of converting historical temperature data from the ITS 27 through IST 48, ITS 68 and ITS 76 to the current International Temperature scale of 1990 (ITS 90). The temperature range of the conversion is set from -50 °C to 50 °C. The program enables to convert single temperature values as well as whole data series in a predefined format which is described in the next tab (Data Files).

Historical temperature data in °C

Converted Historical data to ITS-90

ToITS 90

Year of temperature data

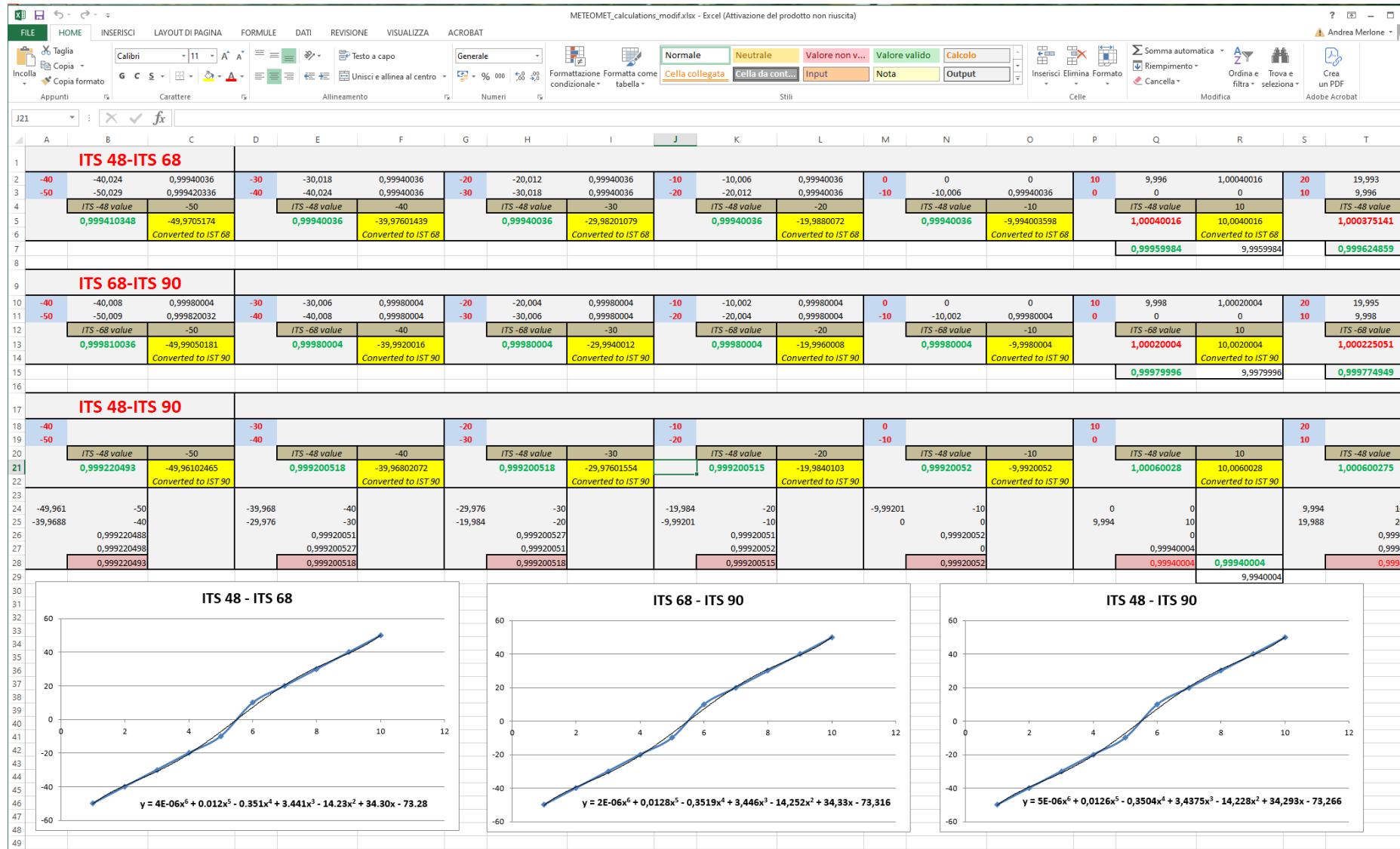
- 1927-1947 1968-1975
- 1948-1967 1976-1989
- 1990-Present

Temperature range of data

- 50°C to -40°C -40°C to -30°C
- 30°C to -20°C -20°C to -10°C
- 10°C to 0°C 0°C to 10°C
- 10°C to 20°C 20°C to 30°C
- 30°C to 40°C 40°C to 50°C

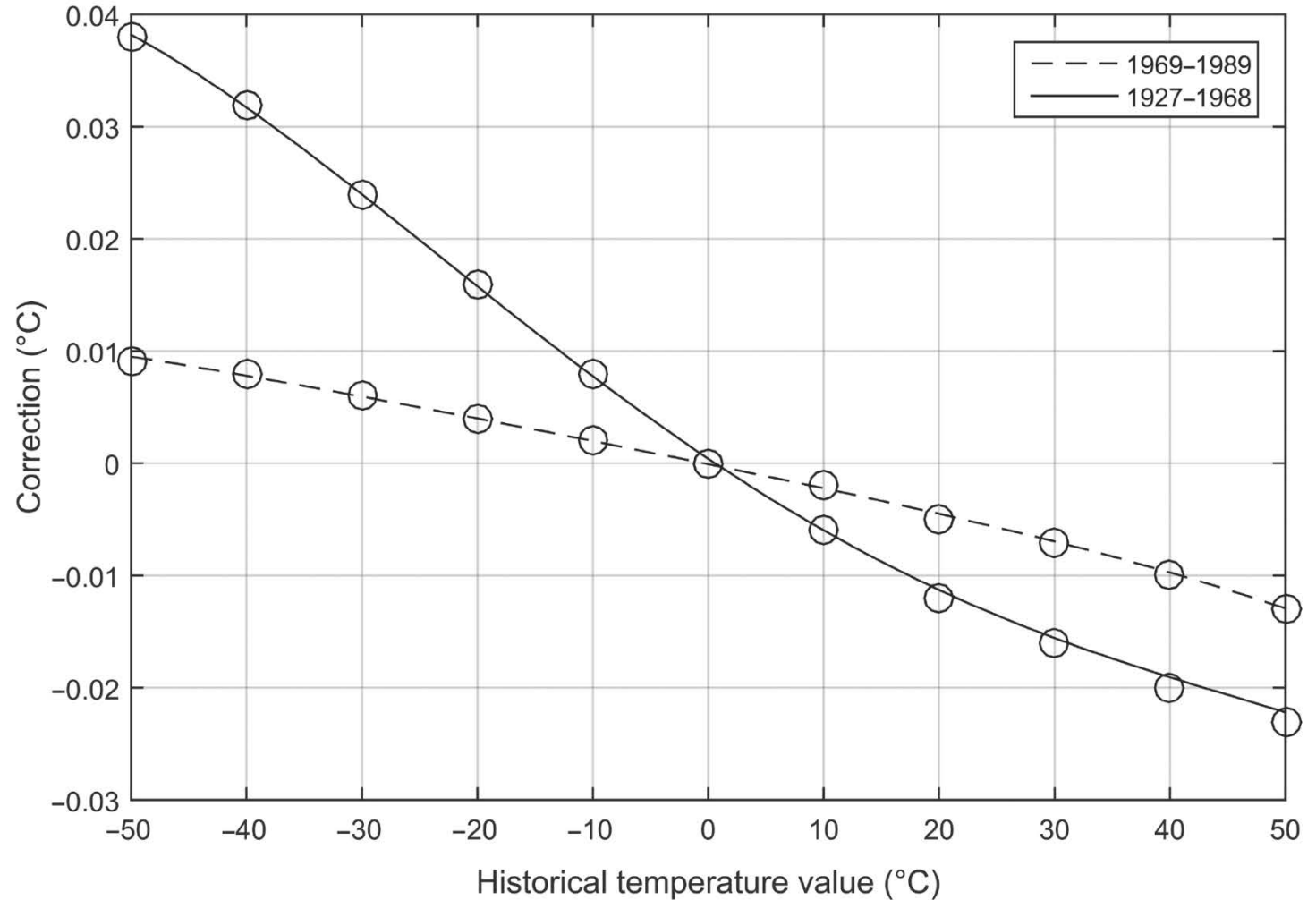
CLEAR **CONVERT**

[METEOMET project](#)



After selecting the year of temperature data and hitting the **CONVERT MULTI** button you will obtain the converted data set according to the selected year.

After using the **EXPORT** button simply select your new file's path and press the save button.



Giorni	Barometro		Iyrometro		Termometro		Stato del Cielo	P. Pieggi
	Mattina	Sera	Mattina	Sera	Mattina	Sera		
1	28.2 3/4	28.2.0	97.	95.	10 1/4 sopra	12 sopra	Nuvolo Vento N. N. O.	
2	28.2 3/4	28.1 3/4	90.	95.	10 sopra	14 3/4 sopra	Nuvolo Vento N. N. O.	
3	28.0.0	27.11.0	96.	97.	10 1/4 sopra	11 1/2 sopra	Nuvolo Vento N. N. O.	
4	27.5.0	27.9 1/2	95.	93.	8 3/4 sopra	7 3/4 sopra	Pieggi Vento N. N. O. 8'	16
5	27.10 3/4	27.11.0	92.	97.	7 1/2 sopra	8 sopra	Pieggi Vento E. S. E.	134
6	27.11 1/2	27.11 3/4	95.	91.	7 1/4 sopra	9 3/4 sopra	Pieggi Vento S. E.	135
7	28.0.0	28.0 3/4	90.	94.	6 3/4 sopra	7 1/2 sopra	Nuvolo Vento S. E.	
8	28.1 3/4	28.1.0	96.	94.	6 1/2 sopra	8 1/4 sopra	Pieggi Vento E. S. E.	
9	28.0 3/4	28.0.0	97 1/2	100.	7 1/4 sopra	8 1/4 sopra	Pieggi Vento E. S. E.	
10	27.9.0	27.9 3/4	100.	100.	10 sopra	13 3/4 sopra	Pieggi Vento impetuoso	
11	27.9 3/4	27.9.0	100.	100.	9 1/4 sopra	11 1/2 sopra	Sera 11 1/2 Nuvol Vento	
12	27.9 3/4	27.11.0	100.	100.	9 1/2 sopra	10 sopra	Pieggi Vento S. E.	

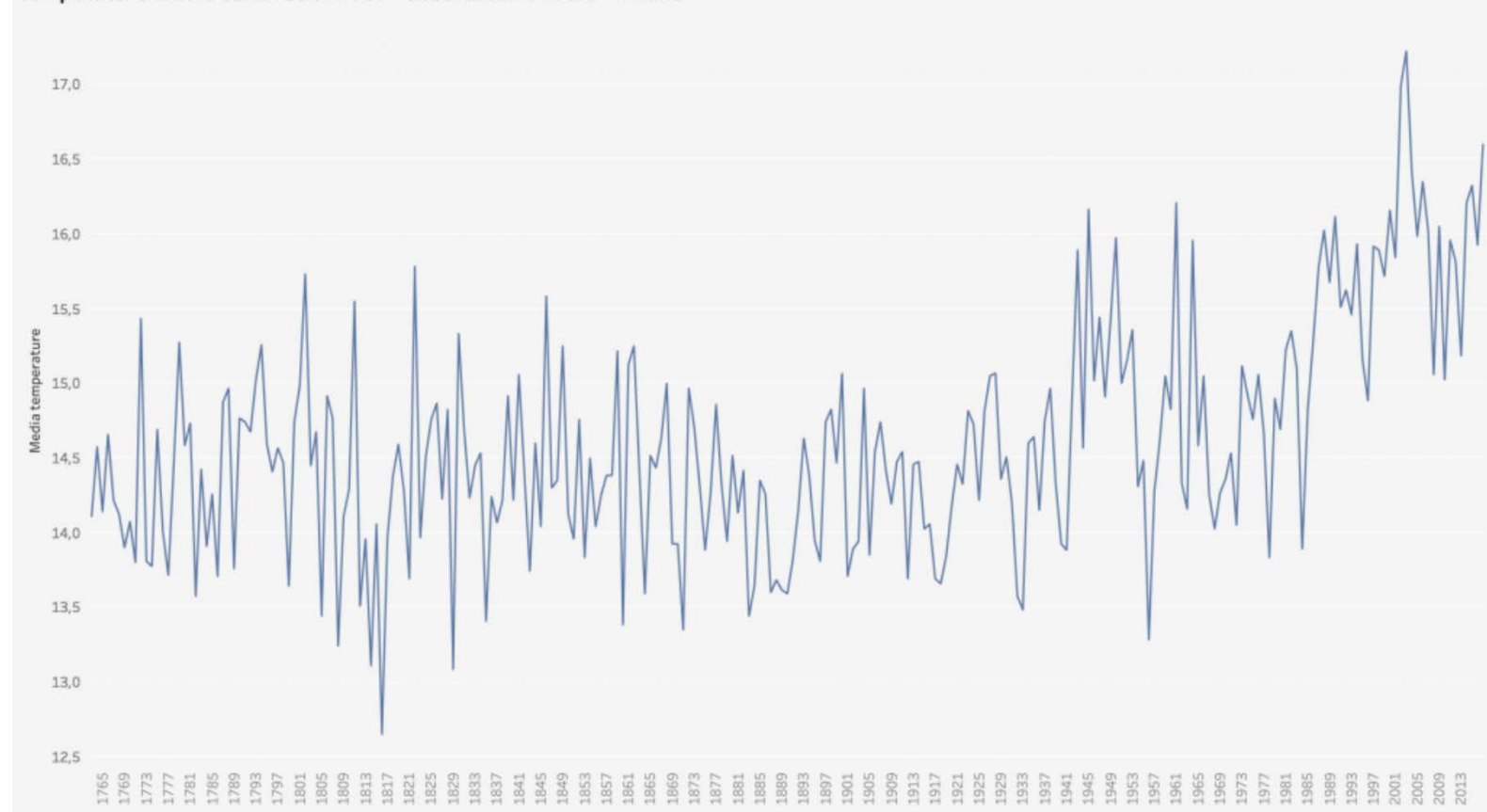
Centennial Observing Stations: State of Recognition Report – 2021 (WMO-No. 1296)

The brochure documents the status of WMO Centennial Observing Stations per continent, as of 2021. It also describes the background to the WMO Centennial Observing Stations initiative, the recognition criteria and mechanism, and the outlook for future recognition.

As an example, we examined the correction of the daily mean temperature record at Brera, Milano in Italy from 1927 to 2010.

The station has an almost uninterrupted instrumental record going back to 1763, with important and well documented meta-information available that includes the placement of the thermometer, shielding, the daily reading schedule, and dates when thermometers were replaced (Maugeri *et al.*, 2002a)

Temperature medie dal 1763 al 2017 - Osservatorio Brera - Milano



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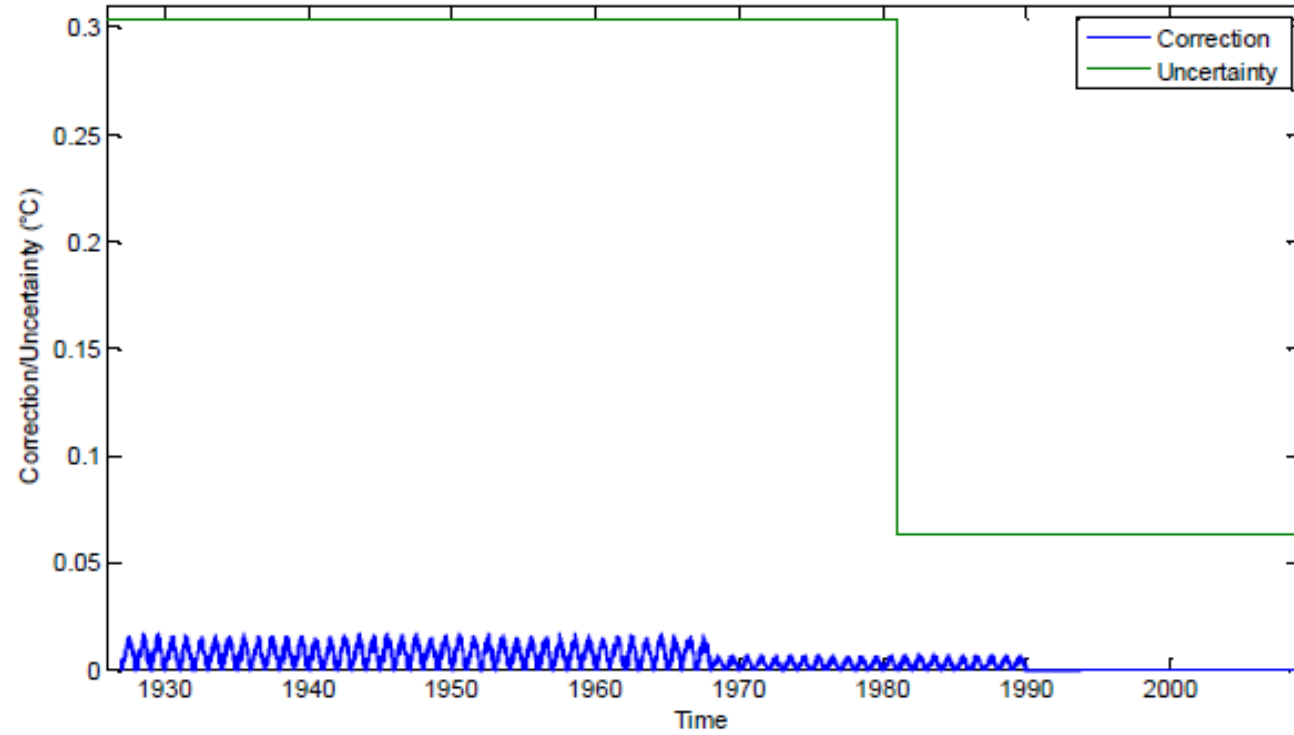


Figure 5 Uncertainty due to instrument and correction due to revisions of the temperature scale at Brera, Milano in Italy.

We have selected a station in Germany instead, Wasserkuppe, which has a record from 1936, interrupted by World War II. The uncertainty along with corrections is shown in Figure 4.

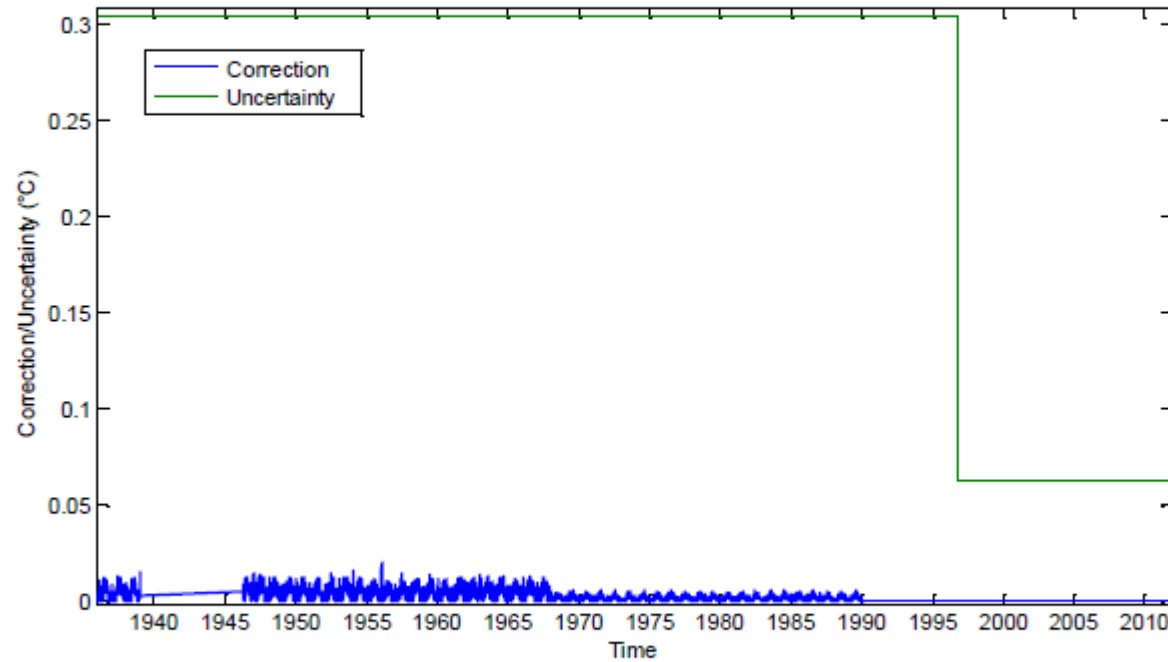


Figure 4 Uncertainty due to the instrument, and corrections due to revisions of the temperature scale, at Wasserkuppe, Germany. The measurement uncertainty dominates over the corrections

As we can see, the correction leads to negligible impact, with respect to sensor uncertainty and (more important) uncertainties on homogenization (statistical) and measurement methods.



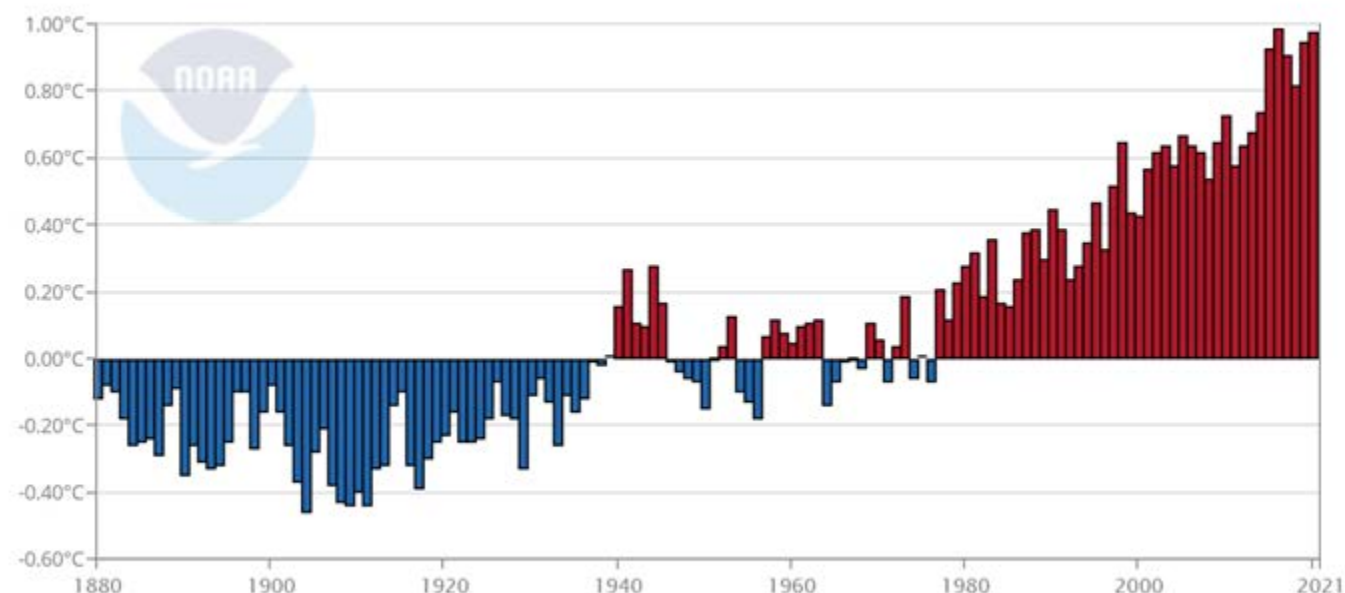
Pfiuuuu!!!

Moreover.

Climate trend analysis are based on relative differences in the evolution of anomalies, from baseline values of given periods, and intended as maximum and minimum values (normally related to a month) or «maximum of the maxima» and «minimum of the minima» of that given period.

Being the difference $t_{90} - t_H$ almost symmetrically distributed in negative and positive values, the correction leads to negligible impact, also considering the absolute values, being well within the instrumental or harmonization uncertainties.

Global Land and Ocean
January–December Temperature Anomalies





Nevertheless

A software was developed and is now available for any purpose and use. Try it if you like!

Nevertheless

We gained more in deep knowledge on how to deal with historical thermometers used in meteorology.

International Journal of Climatology 

RESEARCH ARTICLE |  Full Access

Temperature extreme records: World Meteorological Organization metrological and meteorological evaluation of the 54.0°C observations in Mitribah, Kuwait and Turbat, Pakistan in 2016/2017

[Andrea Merlone](#), [Hassan Al-Dashti](#), [Nadeem Faisal](#), [Randall S. Cervený](#) ✉, [Said AlSarmi](#), [Pierre Bessemoulin](#), [Manola Brunet](#), [Fatima Driouech](#), [Yelena Khalatyan](#) ... [See all authors](#) ▾

First published: 17 June 2019 | <https://doi.org/10.1002/joc.6132> | [VIEW METRICS](#)

Funding information European Research Area for Climate Services (ERA4CS); Copernicus for Climate Change Services (C3S)/European Centre for Medium Range Weather Forecast (ECMWF)

Nevertheless

We gained more in deep knowledge on how to deal with historical thermometers used in meteorology.

The UK-made very old thermometer still used in Turbat, Pakistan in 2017, having recorded the second highest temperature value ever measured in Asia. Calibrated, tested and validated at INRiM under WMO request, showing significant accuracy, with uncertainty in the order of 0.1 °C.



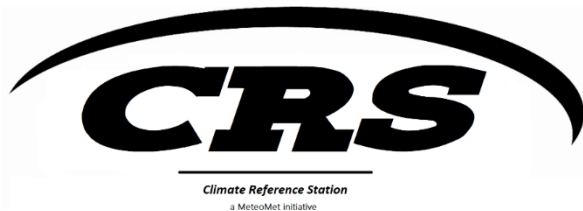
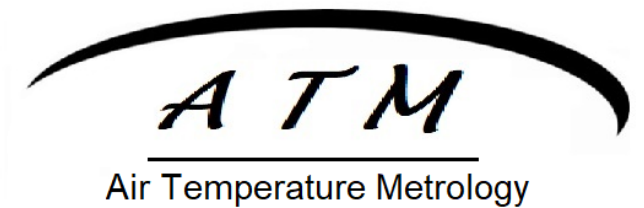
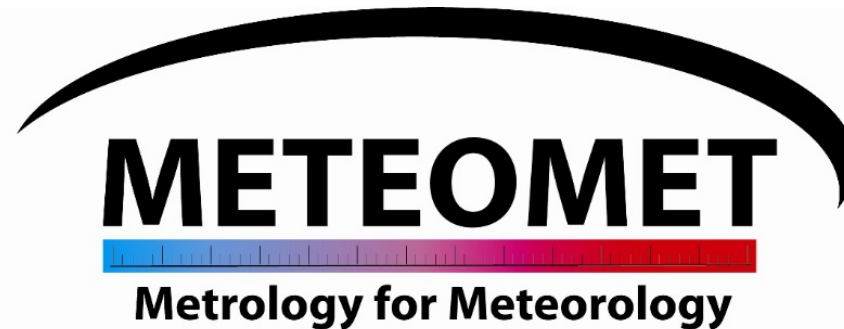
The uncertainty due to temperature scale is **less than the width of the ink** marks on the thermometer scale!!

Nevertheless

The work was a part of a wider effort, started at that time, for delivering metrological approach to climate studies. The birth of the MeteoMet «story».

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Nevertheless

Having demonstrated no impact or correction is a result. It contributes to further enforcing climate change analysis and the work of climatologists.



Finally, in science a negative or null result **is a result.**

Also when we answer to a question that no one posed!



Kusushigatake at Fuji top.

Kyushigatake Meteorological Observatory, Mt. Fuji, 1937.

Thank you



