SCC-Publishing

Michelets vei 8 B
1366 Lysaker, Norway

ISSN: 2703-9072

Correspondence:
lesh@cantab.net

Vol. 6.1 (2026)
pp. 1-8

Is a 1.1°C Rise in a Century Unusual?

A Study of Interglacials in the Epica-Vostok Dataset

Les Hatton

Emeritus Professor of Computer Science, Kingston University, UK

Abstract

Much public discourse in global warming centres around the oft-quoted rise in temperature of approximately 1.1°C in global average temperature in the post-industrial period. This is considered in some quarters to constitute a "Climate Emergency" demanding "Climate Action". In this paper we first dissect the background behind this number and what it means. Second, we use the Epica-Vostok Ice core dataset, a single proxy dataset for temperature data sampled every century for the last 800,000 years or so and ask the question "Is a 1.1°C temperature rise in a century unusual in this dataset?"

The answer is surprising. By considering interglacial onsets and decays as well as intermediating Ice Ages, it turns out that a rise of this amount would have been considered unusual more than 200,000 years ago, but this rise is *not* unusual in the current interglacial which started some 20,000 years ago with around 16% of all centuries since the last Ice Age exhibiting a temperature rise of at least 1.1°C. None of these could have anthropogenic components as they pre-dated the industrial era. This result suggests that attempts to partition the current rise into anthropogenic and non-anthropogenic components are questionable given that it is not even unusual.

Keywords: Greenhouse effect; interglacial temperature fluctuations; Increasing temperature variability.

Submitted 2025-05-22, Accepted 2026-01-15, https://doi.org/10.53234/scc202603/05

1. Introduction

The ratio of natural to anthropogenic components in the warming noted in the last 100 years is a matter of lively debate with arguments ranging from one extreme, that very little is down to us all the way to those arguing that it is all down to our fossil fuel CO_2 emissions, for example using complex model-based efforts (e.g. Forster et. al. 2023). If the former, then little can be done about the warming process so our efforts must be focused on dealing with likely effects. If the latter, then we can legitimately continue trying to limit the warming or even perhaps reverse it. However, there are prior questions which should be answered before arguments over attribution. First, what does a 1.1°C rise in global average temperature actually mean? Second, is a 1.1°C rise in a century unusual and if so, how unusual? If such a rise is highly unusual, then it is entirely valid to identify as far as possible the contributing elements. On the other hand, if it is not unusual, then we must question the relevance of seeking attribution.

Most of the discourse about a 1.1°C rise in a century relates to the global average temperature trend such as that shown in reports AR3 and AR6 of the IPCC (Intergovernmental Panel on Climate Change) for the last 1000 years, (also known as the "Hockey-Stick" graph). Such temperature trends are derived using various proxies for temperature, such as tree rings and corals, merged with modern thermometric data of the last 150 years. Unfortunately, a single global average temperature is a slippery concept to deal with in comparison with datasets acquired in a particular location as we do here. Unlike measurements taken at a single location, a single global average temperature is not the result of a physical experiment. Instead it is a statistical amalgam with many assumptions of numerous proxies for temperature. Some idea of the complexities in individual stations can be seen for example in Sonnadara (2020), where the average annual temperature at a Sri Lankan mountain station follows the IPCC reported trend but this is all found in a rise in the annual average *minimum* temperature. There is no change in the annual average maximum temperature in the last century. As such calculating a global average temperature is opaque at best and perhaps worst of all, it is effectively impossible to compare against comparable periods in the far past. It certainly seems to be a questionable measure on which to base policy. However it is at least calibrated in °C so we can reasonably compare it with the results of measuring a temperature record at a single location for which the Epica-Vostok Ice Cores give an excellent example. We note of course that like any individual location, Antarctica might not be representative of the "global average" temperature, but we are looking for temperature *changes*.

We will not therefore attempt to unravel the complexity of a global average. Instead a better-defined but closely related question will be asked and answered.

Is a 1.1°C rise in a century an unusual event in a "pure" dataset i.e. one recorded at a single location in a consistent manner over a long period?

In this paper we take a very simple data-driven view to answer this question, and we use the publicly available Epica-Vostok Ice Core datasets which stretch back some 800,000 years and specifically the dataset Epica-tpt-co2.csv[1]. This dataset lists the temperature change in *°C* and the CO_2 level in ppm for every intervening century.

1.1 Statement of reproducibility

This paper is accompanied by a downloadable package[2] which includes the original dataset used for analysis and the plotting and analysis software used to re-create all of the figures and conclusions following the strictures of Ince et. al. 2012 and Hatton & Warr 2016.

1.2 The Epica-Vostok Ice Core dataset

EPICA (European Project for Ice Coring in Antarctica) is a multi-national project for deep ice core drilling in Antarctica (Epica 2025) coordinating drilling at Dome C and Kohnen station. There are other coring sites in Antarctica such as Vostok, operated by Russia. Ice core data is a proxy for temperature in the following sense. The temperature and CO_2 levels at a particular level in the ice-core can be inferred from oxygen and deuterium isotope levels in the tiny bubbles trapped in the ice as the surface snow is buried and compacted over the centuries. The cores are analysed and data is output at the rate of one temperature and CO_2 sample per century. The data from Vostok extends back around 420,000 years before which the cores contain no climate information owing to the presence of ice re-frozen from the waters of Lake Vostok which lies underneath. The data from Dome C provides climate data reaching back some 800,000 years and correlates well with the Vostok data where they overlap in time (EPICA Community members 2004).

The ice core datasets remain one of the few consistent measurement handles we have on what was actually happening in the last 800,000 years or so. This may sound an age, but if we represent life on earth by one hour on a clock, this measurement dataset tells us what happened in the last second. We do not as yet have any better measurement data either more fine-grained or longer lasting, partly of course because the ice-core datasets in Antarctica where the ice is on average around 2km. thick, are just about as deep as it is possible to go on earth, although the project "Beyond EPICA – Oldest ice" due to report shortly may well extend this back to 1.2 million years before the present day (Beyond EPICA 2025).

---

[1] http://www.climatedata.info/proxies/data-downloads/, accessed 05-Dec-2025

[2] https://leshatton.org/ClimateChangeCenturyRise.html, accessed 09-Dec-2025

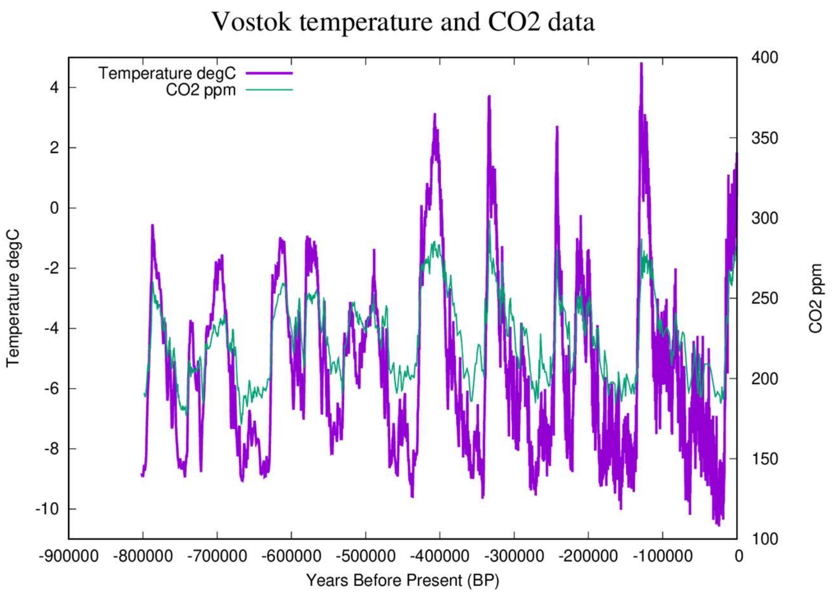

Figure 1: The Vostok ice core dataset for the last 800,000+ years. This dataset has not been processed in any way and is the original raw dataset. Note that although the temperature scale is shown around zero, the data must be biased by -55°C to produce a surface temperature estimate.

2. Analysing the data

Let's consider this dataset in more detail.

2.1 The current entire dataset 800,000 – 0 years ago.

Studying Fig. 1, we can see a number of features in the temperature, noting that only the last datapoint could contain any anthropogenic effects.

- Most of the time in the last 800,000 years or so, the earth has been significantly cooler than today (i.e. less than 0°C on this plot).
- There are a series of sharp peaks of temperature. These are known as *interglacials*.
- These peaks appear to be getting hotter. There is a significant rise 400,000 years ago with a generally increasing trend ever since.
- The peaks are followed by an equally steep fall in temperature. These periods are *Ice Ages* and generally last longer than the interglacials.
- The previous interglacial about 120,000 years ago was hotter than this one, (so far). It was in fact almost 4°C hotter.
- The last Ice Age, which finished about 20,000 years ago was the coldest of the last 800,000 years and more than 11°C cooler than pre-industrial times. Ice Ages are getting colder.
- CO_2 levels in this dataset vary between about 170 ppm and 280 ppm. In the last century, this has shot up to about 420 ppm.

We also note in passing that the lowest CO_2 level in this dataset is 171.6 ppm, not very much above the 150 ppm necessary to sustain land-based plant photosynthesis. If it had fallen this low, such photosynthesis would have ceased, almost certainly triggering a mass extinction of land-based life forms; a near miss. In fact in 556 centuries of this dataset, CO_2 levels were below 190 ppm. Beyond these comments, we say nothing more of the CO_2 data.

Let us now zoom in on the last two interglacials as shown in Fig. 2.

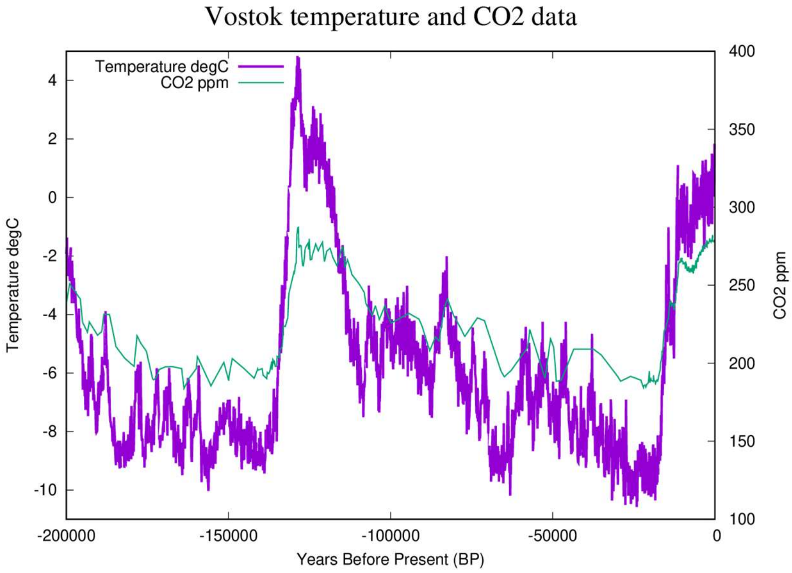

Figure 2: The Vostok ice core dataset for the last 200,000 years.

On this zoomed scale, it is beginning to become apparent just how variable the temperature is century on century. It is believed that global average temperatures have climbed by about 1.1°C in the last 100 years[3]. Let us therefore ask a couple of questions.

2.1 How unusual is a 1.1°C rise in one century?

We cannot answer this question with global average temperatures as described earlier, but statistically, this is a very simple question to answer with a single-proxy consistent dataset as good as this, but first we must extract all the rises and falls within a given period. Then we must understand how they are distributed before we use the distribution to make statements of how unusual a particular rise or fall might be.

As an aid to what follows, let us define four kinds of regime for this dataset based on a visual inspection of Fig. 1.

- **Interglacial rise.** This we define as the period of an interglacial when temperatures are climbing out of a preceding Ice Age.
- **Interglacial fall.** This we define as the period of an interglacial when temperatures are falling into a succeeding Ice Age.
- **Ice age.** The period between an Interglacial fall and an Interglacial rise.
- **Other.** Longer periods for comparison.

The motivation for this categorisation is that it would be expected that temperatures would be more likely to rise century on century in an *Interglacial rise* than for example in an *Interglacial fall*, but this we will test.

The last 20,000 years

It is important to note that we live in an *Interglacial rise*, a period of generally rising temperature. As can be seen in Fig. 2, temperatures have climbed by about 12°C since we emerged from the last Ice Age some 20,000 years ago. In other words, on average they have increased by about

[3] The graph on https://earthobservatory.nasa.gov/world-of-change/global-temperatures, accessed 03-May-2025, shows a rise from -0.25°C to +0.8°C between 1922 and 2022. This gives about 1.05°C. This has been rounded up to 1.1°C for this paper. See also the climate model simulation based study by Gillett et al. (2021) who quote a similar figure albeit over 150 years.

12/200 = 0.06°C per century. Just after the Ice Age ended, the rate of increase was almost twice as high at around 0.1°C per century. Since then it has continued to rise but more slowly although with considerable century on century variability. If we analyse this century on century variability as a histogram, we get Fig. 3. The vertical blue dotted line indicates where on this histogram a 1.1°C rise per century would appear.

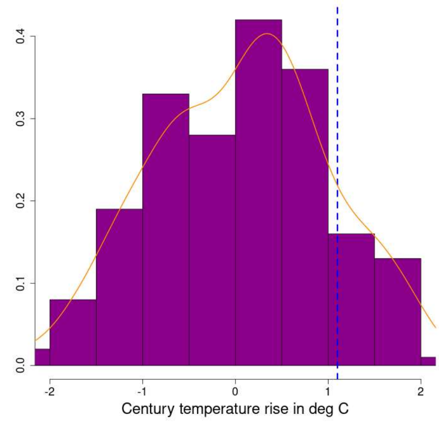

Figure 3: The ice core dataset for the last 20,000 years partitioned into a density histogram of temperature changes in each of the 200 centuries. The blue vertical line corresponds to a 1.1°C rise.

Fig. 3 has a look of normality so we will apply the Shapiro-Wilks test. This gives a p-value of 0.66. In the Shapiro-Wilks test, any p-value larger than 0.05 suggests we can assume normality as a reasonable guess. This conveniently allows us to use a simple Z test to see how unusual a 1.1°C rise actually is in this dataset.

When we do this, we find that the probability of a rise of at least 1.1°C is actually unexpectedly high at 0.16. *In other words, a rise of 1.1°C in the current interglacial is not significant at any accepted level*, (normally taken as < 0.05).

This immediately begs the question as to whether Interglacial rises are different from Interglacial falls and Ice ages with regard to temperature fluctuations.

Extending to the last interglacial

Table 1 shows an extension of this to different regions of Fig. 1 within the last 150,000 years to encompass the previous interglacial and the Ice Age in between it and the current interglacial. $p_{shapiro}$ is the p-value returned by the Shapiro-Wilks built-in test in R. Values greater than 0.05 indicate that normality is a reasonable approximation, which is the case for all these entries. *P(T > 1.1)* is the probability in the stated period in which a temperature rise greater than 1.1°C occurred.

Table 1: Shapiro-Wilks tests and significance tests for a T=1.1°C rise in a century for different periods.

Start	*End*	$p_{shapiro}$	*P(T ≥ 1.1°C)*	*Category*
-20,000	0	0.658	0.158	Interglacial-rise
-55,000	-20,000	0.199	0.086	Ice-age
-100,000	-30,000	0.131	0.082	Ice-age
-124,000	-110,000	0.284	0.056	Interglacial-fall
-130,000	-115,000	0.245	0.059	Interglacial-fall
-140,000	-130,000	0.107	0.112	Interglacial-rise

In all of the periods shown, a temperature rise of at least 1.1°C is not unusual at any acceptable level of statistical significance, although as we might expect, it is closest during an Interglacial fall when the temperature trend is generally downward.

Extending to times before 200,000 years ago

When we continue this analysis earlier in the dataset, we get the results shown in Table 2.

Table 2: Shapiro-Wilks tests and fraction of centuries with at least a T=1.1°C rise in a century for different periods starting earlier than 200,000 years ago.

Start	*End*	$p_{shapiro}$	*Fraction* ($T \geq 1.1$)	*Category*
-330,000	-310,000	0.034	0.000	Interglacial-fall
-390,000	-340,000	0.000	0.000	Ice-age
-400,000	-350,000	0.000	0.000	Interglacial-fall
-800,000	-450,000	0.000	0.000	Five-early-interglacials

The data in Table 2 show two important factors. The residuals are no longer normally distributed, so we just compute the fraction of centuries with which a 1.1°C rise occurs in each population, and this can be seen to be substantially less than that shown in Table 1.

Since the distributions of Table 2 are no longer normal, it is useful to show them graphically as we see in Figs. 4 and 5, which have the same horizontal scale as Fig. 3.

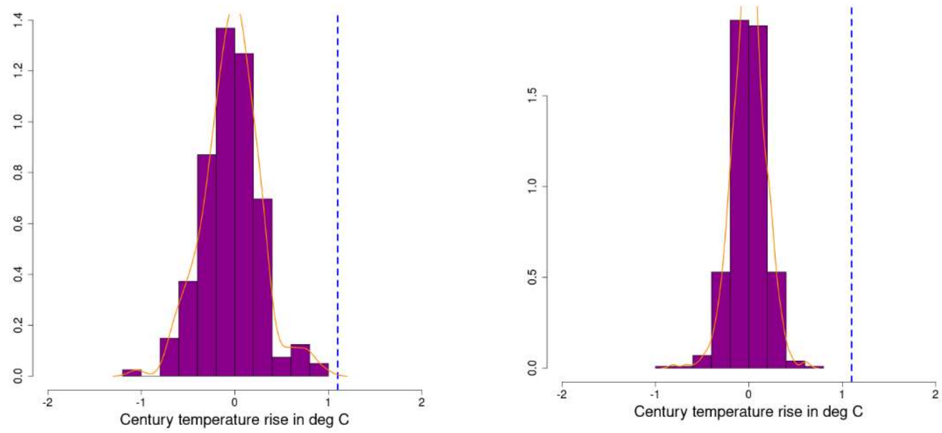

Figure 4: Comparison of distributions of temperature changes in a century for the following periods (left) 330,000 - 310,000 ya; (right) 390,000 - 340,000 ya. The blue vertical line corresponds to a 1.1°C rise.

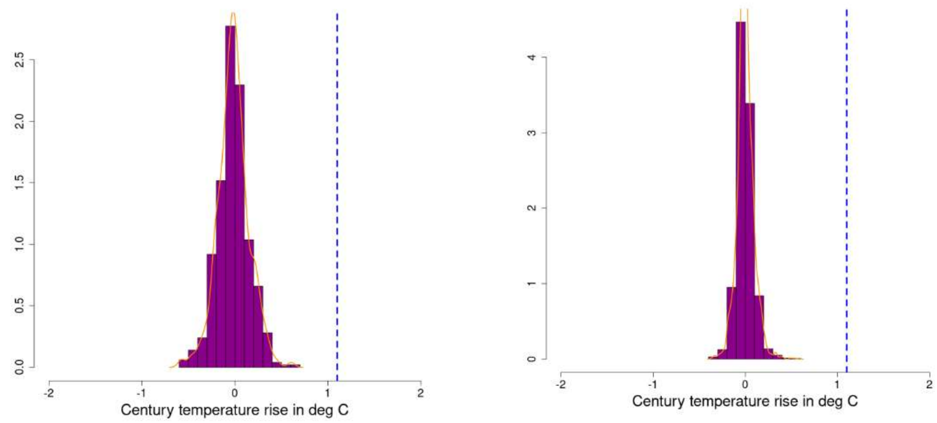

Figure 5: Comparison of distributions of temperature changes in a century for the following periods (left) 400,000 – 350,000 ya; (right) 800,000 - 450,000 ya. The blue vertical line corresponds to a 1.1°C rise.

The reduction in spread of temperature changes is very clear before 200,000 years ago and the further back we go, the smaller the spread. In all of these, a rise of 1.1°C would be considered highly unusual as in the periods shown it never happened.

Conclusions

The Vostok Ice Core data contains numerous interesting features which can be confirmed by anybody as the data is open. We can conclude the following:

- A rise of 1.1°C in a century is not unusual in the current interglacial. In fact 16% of the centuries since the end of the last Ice age show a rise at least as big as the current century and none of these could have been affected by anthropogenic action.
- A rise of 1.1°C in a century would have been considered unusual any time more than 200,000 years ago. For some unknown reason nothing to do with us, the temperature has become more volatile in century on century changes in the last 200,000 years. Whether this is a physical effect or an artifact of isotopic smoothing with time is unknown although there is no evidence for the latter on the peaks of the last four interglacials and there is an abrupt change in magnitude of about 4°C in between the last 5 interglacials and the preceding 4 which is atypical of a continuous smoothing process.
- The current interglacial is nothing special. It is currently still more than 3°C cooler than the peak of the last one about 130,000 years ago (which was by assumption entirely free of anthropogenic effect) and the degree of variability in this data is much the same now as then.

Given then that a rise of 1.1°C is quite commonplace in this current interglacial and that none of the earlier occurrences could have been affected by anthropogenic activity, this raises the question of why we are trying to attribute the current rise to anthropogenic effects as if it was unusual.

Funding

This study received no funding.

Co-Editor: Francois Gervais; **Reviewer 1**: J.-E. Solheim, **Reviewer 2**: anonymous.

Acknowledgements

The author would like to acknowledge numerous conversations with Dr. David King and Dr. Debbie Ancell. The reviewers also helped us substantially in framing the arguments. We would also like to thank the many scientists responsible for acquiring this extraordinary dataset and their foresight in making it publicly available.

References

Beyond EPICA 2025 *Oldest Ice Core: 1.5Myr of greenhouse gas – climate feedbacks*, https://www.beyondepica.eu/en/, accessed May 2025.

EPICA 2025, *European Project for Ice Coring in Antartica*, https://en.wikipedia.org/wiki/European_Project_for_Ice_Coring_in_Antarctica.

EPICA community members, 2004 *Eight glacial cycles from an Antarctic ice core*. *Nature* **429**, 623–628 (2004). https://doi.org/10.1038/nature02599

Forster P.M. and 59 others, 2023: *Indicators of global climate change 2023: annual update of key indicators of the state of the climate system and human influence.* Earth System Science Data, 16(6): 2625–2658, 2024.

Gillett, N.P., M. Kirchmeier-Young, A. Ribes, H. Shiogama, G.C. Hegerl, R. Knutti, G. Gastineau, J.G. John, L. Li, L. Nazarenko, N. Rosenbloom, Ø. Seland, T. Wu, S. Yukimoto, and T. Ziehn, 2021: Constraining human contributions to observed warming since the pre-industrial period. *Nat. Clim. Change*, **11**, no. 3, 207-212, doi:10.1038/s41558-020-00965-9.

Hansen, J.E., and S. Lebedeff, 1987: Global trends of measured surface air temperature. *J. Geophys. Res.*, **92**, 13345-13372, doi:10.1029/JD092iD11p13345.

Hatton L. and Warr G., 2016: *Full Computational Reproducibility in Biological Science: Methods, Software and a Case Study in Protein Biology,* ArXiv, doi: 10.48550/arXiv.1608.06897

Ince D. C., Hatton L., and Graham-Cumming J., 2012: *The case for open program code*, Nature, 482:485–488, 02 2012, doi:10.1038/nature10836.

Sonnadara U., 2020: *Long-term changes in extreme air temperature in Nuwara Eliya: a case study from Sri Lanka*, Weather, 75(9), September