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The inter-glacial cycle is not a 100,000-year cycle, it is a shorter cycle with missing beats

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Abstract

The "100,000-year problem" refers to an apparent unexplained change in the frequency of inter-glacial periods which occurred about a million years ago. Before that, inter-glacial periods seemed to occur about every 41,000 years, in line with the obliquity Milankovich cycle. But after that, they seemed to occur about every 100,000 years, in line with the orbital inclination Milankovich cycle. Examination of the data shows that there never was a 41,000-year cycle, and that there is no 100,000-year cycle, but that the most influential cycle is the approx 21,000-year precession cycle which is the major factor in the cycles of insolation at higher latitudes. Insolation at 65N is generally regarded as the most significant of these. Inspection of the data shows that every glacial termination (start of an inter-glacial period) began at a time when insolation at 65N increased from a low point in its cycle. That not every such cycle triggered a new inter-glacial period underlines the chaotic non-linear nature of Earth's climate. Until about a million years ago, this cycle occasionally "missed a beat", making the inter-glacial frequency average about 41,000 years. After that, the cycle started missing more "beats", making the inter-glacial frequency average about 100,000 years. There never was an actual 41,000-year or 100,000-year inter-glacial cycle.

Keywords: Climate; Glacial Termination; Inter-Glacial; Milankovich Cycle; Non-Linear; Precession

1. Introduction

The 100,000-year problem is decribed in Wikipedia [1]: "The 100,000-year-problem refers to the lack of an obvious explanation for the periodicity of ice ages at roughly 100,000 years for the past million years, but not before, when the dominant periodicity corresponded to 41,000 years."

The IPCC (Intergovernmental Panel on Climate Change) [2] has stated: "The climate system is a coupled non-linear chaotic system, and therefore the long-term prediction of future climate states is not possible.". It is therefore important to be able to consider non-linear explanations for observations such as the 100,000-year problem.

Many studies have looked at the 100,000-year problem. Clark (2006) [3] is reasonably representative, saying: "The emergence of low-frequency, high-amplitude, quasi-periodic (~100-kyr) glacial variability during the middle Pleistocene in the absence of any significant change in orbital forcing indicates a fundamental change internal to the climate system.". The notion that the observed change must be due to a "fundamental change internal to the climate system" is essentially linear thinking. An alternative, non-linear, possibility is that there was no fundamental internal change at all, but that the observed change resulted from some minor variation within Earth's coupled non-linear chaotic system.

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The Wikipedia entry only states that the cycles are "roughly" 100,000 years and 41,000 years, and others (eg. Köhler & van de Wal 2020[4]) have noted that the cycles are irregular. This indicates that there may be explanations of these "cycles" based on factors with quite different cycle frequencies and with non-linear behaviour. This paper follows just such a line of thought. The conclusion of this paper is that there never actually were 41,000-year or 100,000-year cycles. This paper's significance is that it suggests a non-linear way of perceiving the long-established "100,000-year Problem".

Much of the analysis in this paper is consistent with much of Maslin and Ridgewell (2005) [5], which suggests that "the post-MPR (mid-Pleistocene revolution) '100 ka' glacial-interglacial cycles are more closely linked to precession, with the saw-toothed climate cycles being defined by every four or five precessional cycle[s]." Maslin and Ridgewell also suggest that the MPR itself is "somewhat misconceived". They were still, however, looking for a 100-000-year cycle.

This paper is not the first to suggest that the major cycle influencing glacial terminations is the precession cycle, but with missing cycles. The first such suggestion appears to have been made by Ellis and Palmer [6]. However, this paper tests their hypothesis over a longer timeframe.

2. Analysis

Ellis and Palmer [6] argue that the primary forcing agent regulating ice-age glaciation is precession, combined with albedo modulation controlled by desertification and dust contamination of ice sheets. Inter-glacial periods are linked to insolation at 65N, which is driven primarily by precession, modulated by both obliquity and eccentricity, but with missing cycles. A similar finding was made by Peltier and Marshall [7]. Loutre et al [8] confirm that insolation at 65N is strongly related to precession.

The observation that there are missing cycles is the relevant issue for this paper.

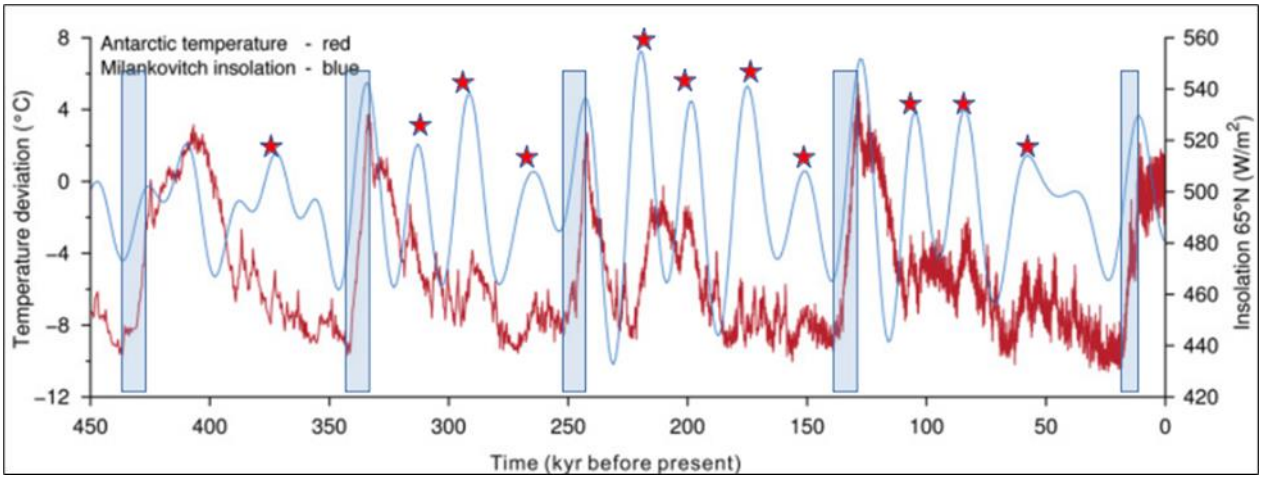

Figure 1 Ellis and Palmer's Figure 3, annotated with blue vertical bars highlighting the fact that each start of an inter-glacial period (glacial termination) coincided with an upturn in insolation at 65N, and with red stars indicating missed cycles. Dates run left to right

Note that some missing cycles did have a noticeable effect, but they failed to start an inter-glacial period.

In their recent study of the MPR, Yehudai et al [9] were not looking for missing cycles, but their Figure S2 (Figure 2 below) provides a chart which allows the "missing cycles" hypothesis to be tested over a longer period, back to 1.3m years ago.

The pattern identified by Ellis and Palmer does indeed continue over this extended period. That is, from 1.3m to 600k years ago, every one of the 12 glacial terminations coincided with an upturn in insolation at 65N. Together with the period covered by Ellis and Palmer with its 5 glacial terminations also coinciding with an upturn in insolation at 65N, there is clearly no possibility that this could have occurred by chance.

Reading Figure 2 below from right to left, the number of missed upward cycles (red stars) between glacial terminations is open to some interpretation but is something like 1,2,2,0,1,0,0,1,1,3,3,2. Much of the interpretation of the data depends on which periods of warming are considered to be glacial terminations. If, for example, nodes 27 and 28

(around 970-1000k years ago) were considered to be just minor fluctuations between inter-glacials, then the sequence of missed upward cycles becomes 1,2,2,0,1,2,1,1,3,3,2. If nodes 23 and 24 (around 920k years ago) were also considered to be just minor fluctuations between inter-glacials, then the sequence of missed upward cycles becomes 1,2,2,0,1,2,3,3,3,2.

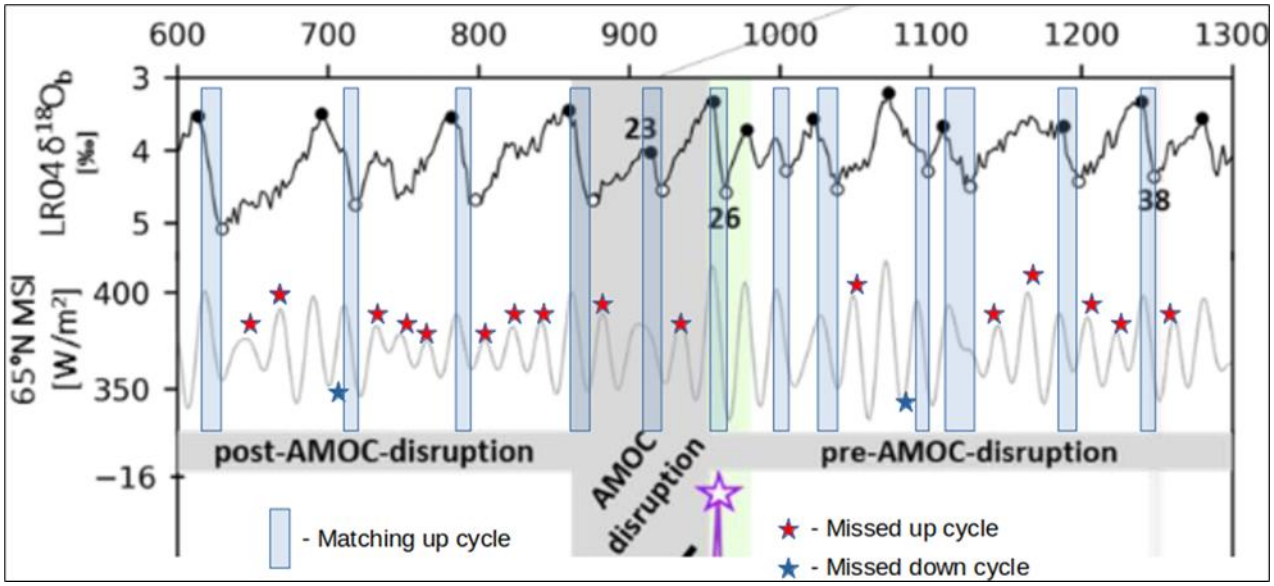

Figure 2 Part of Yehudai et al's Figure S2, annotated with blue vertical bars highlighting the glacial terminations, and with red and blue stars indicating missed up and down (resp.) cycles. Dates run right to left

From Ellis and Palmer (Figure 1 above, reading left to right), with the period 600-450k years ago missing, we can add the following to the above sequence of number of missed cycles: (?),1,3,4,3. The missing period is covered in Figure 3, which shows no inter-glacial between 600k and 450k years ago, although some periods come close.

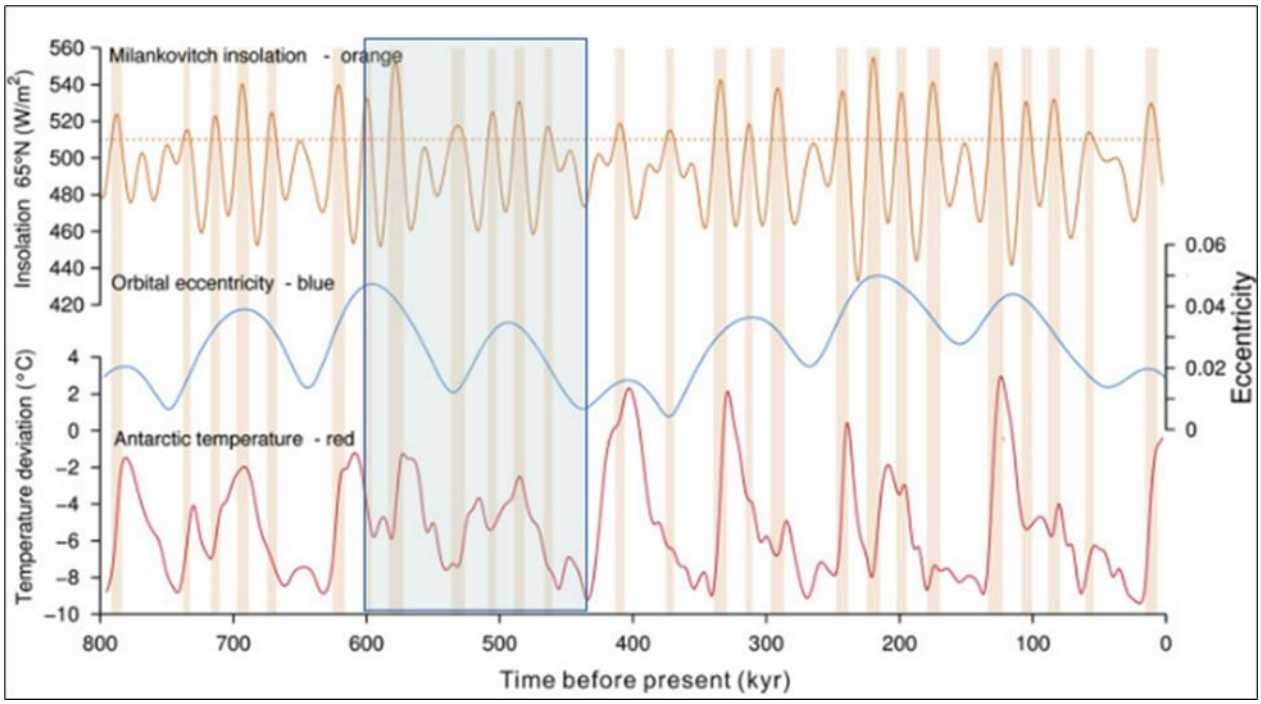

Figure 3 Ellis and Palmer's Figure 2, with the period 600-450k years ago highlighted. Dates run left to right

The number of cycles within the period 600-450k years ago is 7 or 8, but it is arguable whether they all "missed". It might even be reasonable to consider some cycles as "partly missed".

Clearly, the sequence of number of missed cycles is not precise, because the data is so open to interpretation, but the data clearly shows a pattern of missed cycles over time, with a generally greater frequency of missed cycles within the last 900k years.

Note that insolation at 65N may not be the only cycle involved in glacial terminations, but it is generally regarded as a significant factor in Earth's climate, and this paper has used it because both referenced studies (Ellis and Palmer [6], Yehudai et al [9]) conveniently showed insolation at 65N in their figures. There may well be more important factors that could have been used here, but insolation at 65N was sufficient for this paper's purposes.

3. Discussion

Earth's temperature has gradually declined over the last 5 million years.

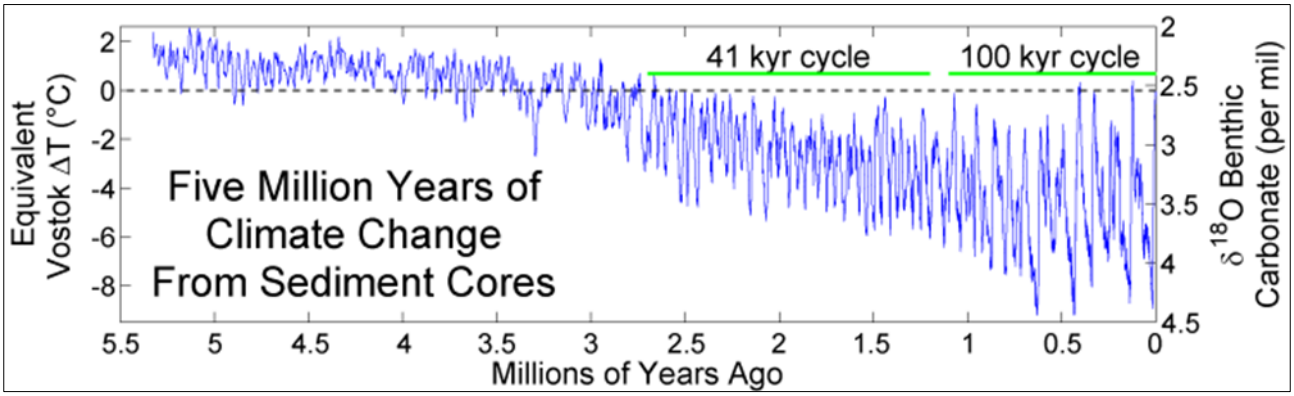

Figure 4 The 5m year temperature reconstruction from Liesecki and Raymo (2005) as presented by Wikimedia [10]. (This version is used instead of the original from Liesecki and Raymo, as it is presented more clearly)

The declining temperature may possibly be a factor in the increase in the number of missing cycles over time. It is also possible that the MPR event was more coincidental than instrumental. Also, while Ellis and Palmer's analysis of dust albedo applies for the period they studied, it is quite possible that other factors were at play in the earlier period and that dust albedo was much less of a factor before 1m years ago. As always, it is necessary to bear in mind the chaotic non-linear nature of Earth's climate.

If Earth's temperature does continue to decline as it has over the last 5 million years, then it may be worth considering the possibility that the number of missing cycles between inter-glacials might continue to increase and vice-versa.

4. Conclusion

There never was an actual 41,000-year or 100,000-year inter-glacial cycle. Instead, what the data shows is that glacial terminations align with the 65N insolation cycle, as driven by precession and modulated by both obliquity and eccentricity, but with missing cycles.

This finding underlines the chaotic non-linear nature of Earth's climate.

Compliance with ethical standards

Acknowledgments

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