Comment on cp-2021-103: Abrupt climate changes and the astronomical theory, by Rousseau, Bagniewski and Ghil

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OVERVIEW

The authors carry out recurrence analysis of two paleoclimate proxies from the North Atlantic core U1308, covering the past 3.2 million years. One proxy represents global ice volume and deep ocean temperature, and the other proxy represents ice raft debris deposition. They also analyze the NGRIP water ice $\delta^{18}O$ record representing temperature at the top of the Greenland ice sheet for the past 110,000 years. The authors identify thresholds in RP topology that coincide with previously inferred paleoclimate transitions.

RECOMMENDATION

The authors attempt to accomplish two things at once: (1) review the history of Cenozoic climate change research, and (2) newly analyze the past 3.2 million years of climate change with recurrence plots. This does not work very well, and in my estimation (1) should be abandoned, and (2) should be singularly pursued with its novel and illuminating possibilities.

There are dozens of vaguely relevant facts and factoids mentioned only once and never tied to anything else in the paper, such as the long commentary on the history of the astronomical theory of climate change, and the description of the unused change-point method of one of the co-authors. These could easily be removed from the paper.

The CENOGRID recurrence analysis by Westerhold et al. (2020) provides a convenient starting point, in that the RP topology there is governed by major climate reorganizations. The authors could pick up on that as a lead into their discussion of climate reorganizations and thresholds over 0-3.2 Ma and over the Last Glacial Cycle (0-100,000 years bp).

It would be helpful to discuss the meaning of the various patterns in the recurrence plots. For example, in the NGRIP recurrence plot (Figure 4), there is a region with a highly periodic signature, from 30 ka to 60 ka, that does not occur anywhere else. Turning one's head 45º so that the diagonal is in the vertical position has a powerful effect on visualization. It would be interesting to point out this and other features along all three of the analyzed time series.

Finally, much is discussed about modeling DO and Bond cycles, but the recurrence plots have a very limited role in these discussions. It would be helpful to show how these recurrence analyses supplement our knowledge about millennial-astronomical climate change connections.

COMMENTS

The comments below are linked to line numbers. Additional editorial suggestions (blue and red markings) and comments (yellow sticky notes) are provided in the annotated version of "cp-2021-103-LAH.pdf".

Abstract

Most the text here is information that is better suited for the Introduction. The results of the present study should be summarized here.

Lines 12-18: Rephrase perhaps as follows: Abrupt climate changes are defined as sudden climate changes that took place in tens to hundreds of years and/or recurred at millennial time scales, involving processes that are thought to be internal to the climate system. By contrast, astronomically forced climate changes involve parameters that are external to the climate system and whose multi-millennial quasi-periodic variations are well known from astronomical theory.

Line 26: What is a Bond cycle? This should be defined earlier in the text, prior to the introduction of "amended Bond cycle".

1 Introduction

The Introduction includes an unexpected and long historical commentary on the astronomical theory of climate change, which can be abbreviated considerably by deleting Lines 49-95 in favor of focusing on the intersection of abrupt and astronomical climate changes. Most of the Abstract as presently written would be relevant here. Other topics that could improve the introduction:

• Explain the connection between CENOGRID, U1308 and NGRIP (referring to Fig. 1)
• Comment on the recurrence plots of CENOGRID by Westerhold et al. (2020) as a way to introduce recurrence analysis, and application of the methodology in the work here.
• Previous work on astronomically paced ice volume link to millennial scale climate variability.

Lines 39-43: Change to something short like this (with apologies for suggesting some of my publications): Geological data indicate that the Earth has experienced astronomically paced climate changes throughout its history (reviews by Hinnov, 2013, 2018).

2 The Past 3.2 Myr History of the Northern Hemisphere Climate

Lines 115-116: Briefly describe the "new relationship" between the carbon cycle and climate proposed by Turner (2014).

Line 118: Include the geographic coordinates of the U1308 site (49.87N, 24.24W) and NGRIP (75.1 N, 42.32 W).

Lines 120-123: Rephrase, perhaps as follows: …and reflect the benthic marine $\delta^{18}O$ record stack of 57 marine cores from the world's oceans (Lisiecki and Raymo, 2005).

Lines 156-158: The statement here is perplexing, when there are hundreds of quantitative studies of Cenozoic paleoclimate proxy records, especially of the past 3 million years, that have been made over the past 50+ years. These lines could be deleted.

Line 158: At this point a new section should be started entitled, "Materials and Methods" which should continue from Lines 158-181, and add text here about the time series being investigated. It looks like NGRIP is also analyzed (Fig. 4) and should be introduced here.

Line 182: This should be the start of a section entitled "Results".

Lines 201-205: The meaning of "sea level variations of about 25-50 m below the present-day" is unclear. Does "below" mean that sea level was below present-day sea level (of 0 m) or that the sea level variations during 2.8-1.2 Ma were 25-50 m smaller in amplitude compared to 1.2 Ma to present? Same confusion for "After 1.25 Ma…etc".

3 Millennial-Scale Variability

Line 220: Is there a reliable reference for the increase of IRD at 1.5 Ma?

Lines 229-233: Strong DO cycles found in GISP2 and GRIP ice $\delta^{18}O$ (also in marine core MD95-2042) over the Last Glacial Cycle occur in a very narrow frequency band centered on 1/(1470 yr) (Hinnov et al., 2002). Schulz (2002) and Rahmstorf (2003) likewise noticed that DO cycles have a persistent 1470 yr period, and that if a DO warming event was missed, one then occurred in the future at a multiple of 1470 yr. So, the phrase "DO cycles of variable duration" needs further explanation/qualification. When/where are there submillennial DO cycles? Or, is this meant to indicate the short events that occur within DO cycles (shown in Fig. 5)?

Lines 253-263: This passage describes ongoing work by Bagniewski et al. on a new method using a Kolmogorov-Smirnov test to identify abrupt transitions ("change points") in time series, available as a short presentation at https://www.essoar.org/pdfjs/10.1002/essoar.10506097.1 However, it is unclear if the test has been used anywhere in this paper. Is it used to identify the transitions shown by the vertical "threshold" lines in Figs. 2, 3 and 4? (Apparently not.) I propose to remove this from the paper.

Lines 264-266: The work of Hinnov et al. (2002) on methane-linked GISP2 and Byrd included statistically constrained spectral coherency analysis to demonstrate the global reach of the DO cycles, as well as what at the time were called the "Antarctic warming" cycles (with a 4.44 kyr period), each with interesting lead-lag relationships.

Lines 268-269: How will this statement that Antarctic warms before Greenland - who said that; Hinnov et al. (2002) did, but who else? - be reconciled in the next paragraph that argues that Greenland climate leads Antarctica by approx. 200 years.

Lines 273-275: Consider mentioning the results of the never-cited Hinnov et al. (2002): coherency analysis reveals a time lead of Byrd DO (Antarctic) cycles over GISP2 DO (Greenland) cycles by 384±70 yr (2σ level), and of the North Atlantic benthic DO (AABW) cycles over planktonic DO cycles by 208±33 yr (2σ level).

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Line 285: What is meant by "subsumed by the 65ºN summer insolation"?

4 DO events and Bond cycles

Lines 300-301: The recurrence plot of NGRIP shows very pronounced well defined patterns, whereas those of the U1308 $\delta^{18}O$ records are harder to understand.

Lines 343-344: It is not clear what the difference between the traditional Bond cycle (e.g., Alley, 1998) and the "amended" Bond cycle proposed here. A figure contrasting the two models would be helpful, e.g., add Figure 1 of Alley (1998) next to current Fig. 6a.

5 Concluding Remarks

Lines 407-408: Here it is stated that this paper is an "overview of millennial-scale climate variability over the last 3.2 Myr." But the authors really only discussed millennial scale climate for the past 0.1 Myr (the Last Glacial Cycle).

Lines 420-421: Here it is indicated that millennial scale variability has been observed in glacial periods previous to the Last Glacial Cycle, "at least since 0.8-0.9 Ma." There was mention of EPICA modeling of Greenland suggesting that DO cycles should have continued throughout the past 800 ka – but has geological evidence been recovered yet? There is a new report of millennial scale variations in MIS 19 Interglacial, 0.760 to 0.790 Ma (Head, 2021), so limiting the discussion to glacials only may not be sufficient or accurate. Finally, where did HEs first appear in the record?

Figures

Figures 2 and 3: In Figure 2, the top of the figure has the title "Recurrence U1308 benthic δ180"; in Figure 3, the top of the figure has the title "Recurrence U1308 bulk carbonate δ180". These are helpful designations and could be included in the figure captions. In both figures, there is a blue curve called "Cibicidoides sp. δ18O bulk (VDP)" and presumably this is analyzed only in Figure 2 and is the U1308 benthic δ18O. There is a green curve called "δ18O bulk carb (PDB)" and this is analyzed only in Figure 3. I recommend showing only the relevant time series in these two figures (blue curve in Figure 2 and green curve in Figure 3).

Figures 2-4: Remove the sentence: "The RP web site is http://www.recurrenceplot.tk" and add once in the text where the recurrence plot method is discussed.

Figure 6a: This "amended Bond cycle" illustration should be enhanced by adding the "traditional Bond cycle", e.g., Figure 1 of Alley (1998) to highlight the differences.

Figure 6b: Add locations of U1308 and NGRIP.

Other

Upper vs. Late, Lower vs. Early is always confusing: geologists are very particular in the use of this terminology: Upper and Lower refer to rock, and Late and Early refer to time. In this paper, there is no comprehensive description of a stratigraphic section in terms of a rock/sediment formation, therefore only the "time" terms should be used, i.e., Early and Late. (Middle is conferred to both rock and time.)

NEW REFERENCES

Hinnov, LA, 2018. Chapter 1: Cyclostratigraphy and Astrochronology in 2018, in Montenari, M., ed., Stratigraphy and Timescales, 3, 1-80.

Hinnov, LA, 2013. Cyclostratigraphy and its revolutionizing applications in the Earth and Planetary Sciences, 125th Anniversary Volume, Geological Society of America Bulletin, 125, 1703-1734.

Hinnov, L.A., Schulz, M., Yiou, P. 2002. Interhemispheric space-time attributes of the Dansgaard-Oeschger oscillations between 0-100 ka, Special Volume: Decadal to Millennial Climate Change, Quaternary Science Reviews, 21, 1213-1228.

Head, M, 2021. Review of the Early–Middle Pleistocene boundary and Marine Isotope Stage 19, Progress in Earth and Planetary Science, 8:50, doi:10.1186/s40645-021-00439-2

Rahmstorf, S., 2003. Timing of abrupt climate change: a precise clock, Geophysical Research Letters, 30:10, 10, 1510, doi:10.1029/2003GL017115