Climate of the Past Discussions

Clim. Past Discuss., author comment AC1
https://doi.org/10.5194/cp-2022-49-AC1, 2022

Reply on RC1

Alison Kelsey

Author comment on "Abrupt climate change and millennial-scale cycles: an astronomical mechanism" by Alison Kelsey, Clim. Past Discuss., https://doi.org/10.5194/cp-2022-49-AC1, 2022

The author thanks Reviewer 1 (R1) for their comments. However, there are several flaws and oversights in R1's comments and these issues are highlighted in this author's response as follows. This reviewer establishes three points on which to judge the merits of this article:

- A question of existence of the 1470-yr quasi-periodicity
- Need for external forcing
- Evidence of astronomical factors that influence Quaternary millennial-scale climate variability

Point 1:

Observation of the ~1470-yr quasi-periodicity in climate records is essentially an argument about whether this periodicity exists or not. On the matter of existence of the ~1470, Wolff (2015) states that, on the 1470-yr quasi-periodicity, the jury is still out and the matter has not been settled, reiterating his 2010 position (Wolff et al. 2010) that the matter was not resolved. One of the previous reviewer's, Ditlevsen (2015), said "even though I am not convinced about the findings, I still find the paper interesting and worthy of publication" despite the debate over the existence of this quasi-periodicity.

This question really forms part of a complex and lengthy debate, with the issue being that the timing and number of Dansgaard-Oeschger events depends on the time-scale used (Wolff et al., 2010) and how they are defined (Alley et al., 2001; cf. Ditlevsen et al., 2005). Arguments for and against this periodicity are covered in Section 2 of this article, with attention given to countering existing arguments against the ~1470-yr quasi-periodicity (Section 2.1). Additionally, further chronological matters have been discussed in this article (Section 3.5) that have been ignored by R1.

Importantly, the results of this author's research confirm the existence of this quasi-periodicity through statistical testing of a chronologically-anchored, normalised trigonometric model that is compared to an independent, Be10-based reconstruction of Total Solar Irradiance (TSI). This trigonometric model is underpinned by physical models of gravitation and TSI that are linked by distance (see this author's response to point 3).

In all instances during the time interval of astronomical data, Bond events occur at times of maximum gravitational forcing (Kelsey 2018:119), associated with minimum Earth-

Moon distances (Figure 4) that are magnified by minimum Earth-Sun distances occurring at perihelion. Fluxes in gravitation and TSI are inherently linked because of the reliance of both sets of calculations on distance. These results confirm Bond's suggestion that the potential cause of Bond IRD events was an ocean-atmosphere link through solar forcing (Bond et al., 2001; cf. Braun et al., 2005; Schulz, 2002).

R1 does not comment on or acknowledge any of this material in justifying their answer to this question. Rather R1 talks about fashions and corroboration of the quasi-periodicity. It is not unusual for science to progress through waves of dominant paradigms, often with intevening decades between times of popularity such as occurred with the Milankovitch cycles (cf. Imbrie 1979; Summerhayes, 2015). This factor also affects referencing and the age of many sources. Lack of corroboration is not equivalent to proof of non existence. Research results presented here corroborate the existence of this quasi-periodicity.

Point 2:

R1's argument of necessity in regard to point 2, is invalid and does not reflect what was said in the referenced article used to support their statement (cf. Menviel et al. 2020). Whilst R1's assertion that numerical models fully explain the causes of millennial-scale variability emerging from the ocean-atmosphere system and icesheets, without resorting to external forcing, Menkiel et al 2020 state that "Palaeorecords and numerical studies indicate that the AMOC, with a tight coupling to Nordic Seas sea ice, is central to D–O variability, yet, a complete theory remains elusive." They further state that "the sequence of events that led to D–O climatic variability is still highly debated." Whilst several mechanisms have been proposed to account for D-O variability, none can account for all DO's characteristics.

Menkiel et al highlight that "current Earth system models do not include all necessary components (for example, biogeo-chemistry, ice shelves, ice- sheet dynamics), inadequately represent important processes or cannot be integrated long enough under intermediate glacial conditions to simulate self- sustained D–O cycles. NADW formation in climate models is highly parameterized and not well constrained by observations, so there is little confidence in simulated changes in the strength and location of NADW formation in response to climate change, both past and future."

An important factor in DO events is the Atlantic Meridional Overturning Circulation (AMOC), which is central to Earth's climate and internal systems (Menviel et al. 2020). AMOC is part of Earth's Meridional Overturning Circulation and is the major transporter of heat around the world. Wunsch (2010) suggests that the simple conveyor belt idea [Figure 2.4] is much more complex than often presented and that "only a tiny minority" has attempted to understand the underlying physics.

External forcing cannot be dismissed as unnecessary. Earth is not an isolated unit and must be considered in the context of its celestial neighbourhood (Kelsey 2018:48-83), as its neighbours (primarily the Sun and Moon) influence Earth's internal systems through gravitational forcing and heat input. These factors influence both atmospheric and oceanic tides and are another piece of the puzzle, acting as a teleconnection between the two hemispheres. Internal systems work alongside external forcing and are not competing interests – they are interlinked.

Point 3:

Regarding evidence of astronomical factors that influence Quaternary millennial-scale

climate variability, this author is surprised at R1's comments. Abundant evidence has been supplied and appears to have been ignored by R1. This includes:

- The model of superimposed 209-yr and 133-yr cycles that emulates the ~1470-yr quasi-periodicity was statistically tested against an independent TSI reconstruction of Be10 data, producing X^2, r values. Variance (r^2), and significance (p) values (Section 4.2 and Table 4)
- The results of tests in (a) show a significant result with a strong correlation between the model and the Be-10-based TSI reconstruction.
- Visually, there is a striking visual similarity between the model presented here and the TSI reconstruction, as well as the Be10 flux (Section 4.2; see also Kelsey 2018:141).
- The parameters of the chronologically-anchored model and their values were justified and discussed within this article (Sections 3.4 and 4), including the incorporation of the 0.1% solar flux that R1 has deemed "too weak" to have an appreciable impact. Contra R1's comments, results presented here show otherwise, as it plays an appreciable role in the amplification of the superimposed model's patterns.
- Data presented here of Earth-Moon distances (Figure 4) show that Bond events of ice-rafted debris occur at minimum Earth-Sun distances that are associated with times of maximum gravitational forcing (cf. Figure 5.13, Kelsey 2018:119). The relationship between distance and gravitation is clearly stated within the article and this relationship is a commonly known scientific axiom.
- Data presented here (Figure 4) also shows pulses of cyclical 133-yr minimal Earth-Sun distances, viz maximum gravitational forcing. Contra R1's comment that this cycle does not appear in climate records, this cycle is found in numerous climatic records referenced in section 2 of this article.
- The gravitational pull of the Moon influences the tilt of the Earth's axis and consequently the 133-yr cycle also appears in solar declination data (Section 4.1).
- The strength of the 133-yr cycle is associated with the proximity of the lunation (New Moon) to the perihelion (closest point in the Earth's orbit to the sun) (Section 4.1), when gravitational forcing and TSI are at their maximum.
- It is also commonly known that atmospheric and oceanic tides are also caused by the Sun and Moon and there is ample evidence of solar and lunar forcing in the palaeoclimatic record.
- Contra R1, an explanation of how distances can affect climate was provided.

On the previous article:

Regarding the general comments made by the reviewer re the previous article, R1 is wrong in inferring it is the same as the current article or that the main issue was about semantics that had only recently been accepted. The two articles are very different but related, forming integral parts of the same unpublished PhD thesis (Kelsey 2018). They share one figure in common, which was referenced in the second article.

The previous article presented research showing that an interacting combination of astronomical variables related to Earth's orbit may be causally related to the ~1470-yr quasi-periodicity and several associated key isotopic spectral signals. It was a conceptual model and did not rely on statistical tests between the model and data. Its purpose was to present a framework of understanding. These variables were the ~11.4-yrs Schwabe sunspot cycle, the Metonic lunation cycle of 19 yrs, and an anomalistic year forcing at ~104 yrs.

The article presented here presents a different, more complex model that uses different variables as described within this article. This model presents a lower temporal resolution of solar and lunar forcing, which is underpinned by physical models (based on astronomical data) of TSI and gravitational flux (see author's response to R1's comments for point 3). Note that aggregation and different temporal resolution influence the

appearance of spectral signals and oscillations in the palaeoclimatic record (Kelsey 2018:137-139). The purpose of this article was to describe the astronomical mechanism associated with the millennial-scale climate oscillations, and to provide evidence of the link between the two using statistical testing.

In relation to referencing, there are 10 references to material published in the last decade, and there should be additional references to Kelsey (2018). Also refer to author's response to point 1 regarding age of references; for advancement in Quaternary millennial-scale variability, refer to author's response to point 2. The issue regarding well-established and highly-debated/controversial was accepted at the time and is not a recent development.

References:

DITLEVSEN, P., 2015 Past Discuss., 11, C2224–C2226, 2015 www.clim-past-discuss.net/11/C2224/2015/

KELSEY, A. 2018. *Astronomical forcing of sub-Milankovitch climate oscillations during the late Quaternary.* PhD Thesis, School of Earth and Environmental Sciences, The University of Queensland. https://doi.org/10.14264/uql.2018.186

Other references appear within the currently submitted article.