

Clim. Past Discuss., author comment AC2
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Reply on RC2

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-AC2>, 2022

Author's response to referee 2:

The author thanks referee 2 for their comments.

1. General

Ignoring the *ad hominem arguments*, which are both irrelevant and unsubstantiated, some valid points were made that the author acknowledges could improve the manuscript (discussed below). The author also agrees that the character of the climate system is complex and there is a dearth of climate proxies. However, there are many points made by referee 2, with which the author disagrees.

In the course of this response, the author will deliver a response to all of referee 2's comments. However, the author would like to highlight a couple of other areas of major disagreement with referee 2:

- referee 2's erroneous redefinition of "mechanism" to mean "forcing"
 - the resultant creation of a pseudo competition between external and internal forcing
- lack of a new mechanism or understanding it provides
- accusations of
 - bias
 - pretentiousness

In places, referee 2's comments are disorganised and also appear contradictory. On one hand, referee 2 acknowledges real novelty in this paper based on "*i.e., the description of the solar irradiance and the Earth-moon distance cycles on millennial time scales*". Referee 2 also recognises the value in the model, describing it as "*satisfactory*". Furthermore, referee 2 recognises the worthiness and major importance in establishing a "robust solar irradiance and lunar cycle oscillation around 1500 years", although disagreeing with the paper's presentation of that material. Yet, confusingly, the model is described as "pretended" and the author as "pretentious".

2. Differentiation between mechanism and forcing

Contra referee 2's redefinition:

A “mechanism” is the combination of components that creates the forcing, whilst “forcing” is a product of the mechanism. As the title of the article indicates, this is astronomical mechanism. This mechanism produces forces that act on all players within the mechanism (i.e., Sun, Earth, and Moon), and is a primary driver of Earth’s climate, impacting significantly on Earth’s internal climate system. Many astronomical forcings are well known, such as those produced monthly, seasonally, annually, and at orbital time scales.

Using their redefinition, referee 2 subsequently bases criticism of this paper on their misunderstanding of this difference, rendering those comments invalid. This includes:

- Alleged competition between internal and external forcing, whereas in reality Earth’s climate is not isolated from its celestial neighbourhood and its influences
- Allegations of a pretended mechanism
- Allegations of bias and lack of humility
- Classification of incomplete models of internal or hypothesised systems as mechanisms of climate change, when it is still unknown as to what triggers these systems or where model variables are missing

Limitations on the extent of current scientific knowledge and potential variables for GCM models (non-exhaustiveness of variables) contribute to an incomplete understanding of the operation and triggers of internal climate systems. Comments in literature, including recent articles, are indicative of these limitations of knowledge. Menviel et al. (2020:689) state “current Earth system models do not include all necessary components” and that the causal mechanisms that trigger D-0 variability are still highly debated. Meanwhile, an astronomical mechanism has been provided here with results confirming its existence, along with direct links to climatic records. This mechanism triggers responses in Earth’s climate system through tidal forcing of ocean and atmosphere, and determines levels of heat input into that system. This astronomical mechanism has the potential to enhance GCMs and inform on missing triggers/variables in current models.

Whilst it would be very nice to be able to provide all the answers at once and evidence of all links between these astronomical mechanics and internal climate systems, this is not possible in one article, which is already lengthy. Being that climate research is such a huge interdisciplinary field, this article simply presents initial results with the view to opening discussions in the future and promoting further research. A significant start has been made with comparison of physical models of gravitation to the occurrence of Bond events, as well as the highly significant correlation between the physically-based and chronologically-anchored model to cosmogenic indicator of climate change in an Antarctic ice core.

3. Addressing allegations of bias

Where is the bias, accusations of which seem to be rather nebulous? Perhaps the referee is referring to internal versus external forcing? Firstly, for bias, there needs to be competing systems. However, this is not the case. Earth’s internal climate is symptomatic of and responsive to external forcing and not the origin of the forcing itself. In the case of the 1470-yr quasi-periodicity, links between the astronomical mechanism described herein and relevant indicators in the paleoclimatic record were provided.

As a competing factor to the astronomical mechanism and external forcing of the 1470-yr quasi-periodicity, referee 2 gives an example of Earth’s internal system: increased tidal amplitudes within the Labrador Sea. Referee 2 also describes the main method of energy dispersion as being caused by the tides, as an internal process. These two tidal factors mentioned are cases in point that show the relationship between external and internal forcing of Earth’s climate.

The solar and lunar influences on Earth's tides are commonly known and understood. We know that the Sun is the main source of heat and energy in our solar system, and that the effects of solar power are felt through Earth-Sun distance, gravitation, solar irradiance, solar flares, sunspot variability, and the solar wind. Proximity (distance) to the Sun influences the intensity of this influence. We also know of the Moon's impact:

- steadies Earth's axial tilt (obliquity) and seasons.
- Influences the earth's axial tilt
- acts as a brake to Earth's rotation,
- influences timing of events (such as the perihelion)
- has a greater tidal influence than the Sun on Earth's oceanic tides due to its proximity to Earth.

It is also commonly known that the Earth's oceans are strongly influenced by the gravitational influence of both the Sun and Moon, creating Earth's tides; that the combined influences of the Sun and Moon produce tidal peaks. These combined influences occur at key lunar phases, lunation at perihelion, and are commonly known, e.g., high and low tides, neap tides, spring tides, king tides. It is also known that physical geographic features shape the height of tides.

It is also commonly known that the oceans provide the major storage of Earth's heat and act as the major transporter of heat around the globe; that the ocean's distribution of heat is influenced by land mass; that atmospheric transport of heat and moisture is influenced by solar and lunar tides as well as land form.

It is commonly known that the physical geography of the Earth also contributes to the level and timing of these tides, e.g., latitudinal position (in combination with the Moon), shapes/depth of ocean basins, bays etc, path of the thermohaline current, accumulation and loss of heat, deepwater formation, and input of freshwater into the oceanic system. Additionally, gravitation, heating and cooling also contribute to atmospheric dynamics and the functioning of the thermohaline current.

So, it naturally follows that variations in Earth-Sun, Earth-Moon distances, affect all of these above-mentioned factors through variations in gravitational and solar forcing (TSI and insolation). The author does not believe that these factors need to be spelt out for readers, especially in an already lengthy article. This article is about external forcing and the author has provided a background relevant to this research in Section 2 of the manuscript, including referencing to articles of the same age as those suggested by referee 2.

The author also provided responses to existing criticisms against the 1470 year 'cycle', yet the only comment referee 2 provides is that this quasi-periodicity could be stochastic and makes no mention of any other point. The real competing ideas were whether this cycle exists or not (Section 2 of the article), which were addressed in Section 2 of the article. The results from this study (Section 4 of the article) show that it does; the referee acknowledges that the comparison is satisfactory.

4. Links between the astronomical mechanism and Earth's internal systems.

Contra referee 2 that no mechanism or links were provided, both the abstract and introduction briefly describe this mechanism. This mechanism is elaborated upon in the Sections 3, 4, with links established to palaeoclimatic indicators: (1) physical model of lunar gravitation to the occurrence of Bond events and (2) the chronologically-anchored, and astronomically- based model of interacting astronomical cycles that produce a 1470-yr 'cycle', which is statistically coherent with cosmogenic indicators of climate change in an Antarctic ice core. The basis for this mechanism in the Milankovitch cycles,

as a high frequency expression of the Milankovitch precessional cycle, is well known in the literature, e.g., associations with sea-level change, geomagnetic flux, MIS stages, etc.

In this article, the physical associations of the two cited cycles (209 and 133 yrs) were identified. The 209yr (SdV) cycle, results from the combination of perihelion (anomalous year) with Metonic lunation and sunspot cycle (solar luminosity cycle) (Lines 93, 110, 254-255, 477-480) to effectively produce a peak in gravitational and solar forcing (TSI/insolation) due to reduced Earth-Sun and Earth-Moon distances. The 133-yr astronomical cycle (lines 104-107), which is also found in climate records, is the result of changes in Earth-Sun and Earth Moon distances (lines 280, 415-435, 508), that directly influence gravitational and solar forcing and the tilt of Earth's axis. Both cycles influence the patterning of cosmogenic isotopes. A physical basis to the forcing of Earth's climate has been identified, explained, and shown to correlate to the timing of Bond events and the patterning of TSI reconstruction (14C) (and the 10Be isotopes on which the reconstruction was based). It builds upon the work of Braun, Bond, and others, and confirms the existence of the 1470-yr quasi-periodicity, and their hypotheses as to the potential cause as a combination of periodicities (Lines 72, 75).

5. Points of agreement between author and referee 2

- The reasons of such a poor understanding lie on the **complex character of the climate system** together with **the sparse character of the climatic proxies** which do not fully allow for **a robust discrimination of causes and effects**.
- **DO and H events are** complex and intriguing manifestations of the climate system and the literature describing the attempts of explaining their physical origin is vast and rich.
- Duplicated paragraph at **line 116-120: edit or remove**
- **Lines 258 and 268.** Nova and Skychart III were the planetarium software being used and require referencing: NOVA 2.13, (Hand, 1989-1994) and SkyChart III (DeBenedictis, 1993-2004).
- **Legend of Figure 5:** "The black solid line is the model"? Or the red one? Typo – should be **red**
- **Line 499:** The Broecker 2003 reference should read (cf. Broecker 2003). Disagreement with the rest of the comment (see sections 4, 6 of author's response)
- **Line 514:** Referee 2 is correct in identifying this error and the correct length is as the author stated on line 59, that Heinrich events occur on a 11 ± 1 ky 'periodicity'. This value here is a subharmonic of Heinrich events and can be seen as a phase of that oscillation.

6. Points of disagreement between author and referee 2

In general

One option for an improvement to this paper and its reworking proposed by referee 2 was to forget the climate aspect of this model, whose connection with Earth's climatic record was confirmed (Sections 3, 4 of the manuscript). This suggestion is unreasonable and illogical. The Earth must be considered in the context of its celestial neighbourhood, especially considering that orbital and obliquity factors are known to affect Earth's climate and internal systems and the Moon's influence in these matters. The author does not agree that this manuscript needs a major reshaping.

Referencing: It is not possible to recognise all other work on a subject matter, just key articles that exemplify progress or new ideas. There are other papers of the same age as suggested by the referee that are referenced in Section 2 of the manuscript. Also refer to author's comments in Sections 1, 4 and 5 of author's reply to referee 2 (also see comments on Introduction in technical notes).

Introduction: The manuscript's introduction is brief and introduces broad concepts that are later developed in the article (Sections 3, 4). Note that the 1470-yr cycle has been dismissed/questioned as real, and samples of main arguments are discussed in Section 2 of the article (background). Regarding missing internal climatic theories explaining millennial-scale variability, see Section 3 of authors' response.

Line 34: On mechanism description and synchronisation of solar and tidal records

A full explanation of the astronomical mechanism is not provided in the introduction. It is briefly described here and in the abstract and is later elaborated in Section 3. This is not conjecture, as the hypothesis is tested and confirmed (see Sections 3 and 4).

Regarding the synchronisation of solar and tidal records, this is fact. For example, look to the history of the Milankovitch cycles and their calibration to uplifted coral terraces, geomagnetic record, and isotopic variations in deep sea cores. There is a host of literature available on this subject. Also see Bond et al (2001) where the deposition of IRD, due to oceanic influences associated with the thermohaline current (of which AMOC is part), has a close correlation with isotopic flux caused by the Sun (see line 221 of this article).

Line 44: "Based on a premise that precession causes..." On what is this premise based? So far nothing has been described with a higher temporal resolution than Milankovitch (referee 2).

This is a deductive study. A premise does not need to be inductively based but if it is, it needs to be expressed in an objective framework, as is the case here. The premise is that the Bond quasi-periodicity is caused by the same factors that cause the Milankovitch precessional cycle (lines 39-46 of the article). These factors are the solar and lunar gravitational forces acting on the Earth's equatorial bulge. Previously, nothing of higher temporal resolution has been described, which is why this concept is novel – hence this article. Note that gravitational influences are strongest at perihelion and perigee, and that aggregation of data and level of resolution can mask trends and alter the appearance of oscillation.

Line 59: "... and are therefore linked to.." Why? Sentence not justified. (Referee 2)

Heinrich 1988, referenced in line 59, states the debris from these events shows a strong precessional signal at 11 ± 1 ky. This sentence is at the start of a new paragraph and immediately follows on from the preceding paragraph, which also provides the justification. With Bond et al demonstrating that the 1470-yr 'cycle' is a pulse underlying both DO and Heinrich events. Precessional links at different temporal scales exist:

- Milankovitch precessional cycle
- Heinrich events
- DO events
- Bond cycles

The results (Section 4 of the article) from this research reinforce those findings.

Line 64: This phrase is not speculative and whilst each of these authors try to make the situation "less cloudy" the fact still remains that the physics of abrupt climate change is still poorly understood. The referee also agrees in their opening sentences that it is not well-understood and gives a reason.

At the end of this sentence (line 64), are quotes that reference authors who refer to the poor understanding of the physics of abrupt climate change (Ditlevsen and Ditlevsen, 2009, Banderas et al., 2015, Turney, 2008). Not much has changed since then. Menviel

et al 2020 highlights that the cause of DO climatic variability is still highly debated, with no model produced so far being able to fully replicate these events. All of this taken together is indicative that the physics of abrupt climate change is poorly understood. Specifically, the authors listed in this article stated:

- Turney (2008): it was still unclear as to (1) what caused the Heinrich events (2008:95) and (2) in relation to AMOC, the cause of ocean circulation slow down and restart.
- Ditlevsen (2009) (see line 196 of this article): "Dansgaard-Oeschger (DO) events of rapid climate shifts in the glacial climate observed in the Greenland ice cores are still not well understood."
- Banderas (2015): "the origin of these AMOC reorganizations remains poorly understood."

Line 116 – whilst stochastic resonance is a possibility, other causes first need to be eliminated. This article, research, deductive study, and results provide an explanation and evidence supporting it (Sections 3, 4 of the manuscript).

Line 470: "... it is now evident lunar gravitational..." Why? Explain and reference please (referee 2)

Refer to author's response in Section 4 of the author's response. No need for referencing – this is the author's own work.

Lines 497 and 499: Regarding referee 2's comments about the mechanism and links, please refer to Section 4 of this reply. These lines are not highly speculative and Line 497 is based on the one immediately preceding it. The models are physically-based, chronologically anchored, and parameters justified. Statistical testing between the trigonometric model and an independent TSI reconstruction from climatic data (observed versus expected behaviour) confirms the hypothesis (Sections 3, 4 of the article). Additionally, Figure 4 shows the occurrence of Bond events in association with peak lunar forcing associated with the 133-yr cycle. These events are associated with reduced Earth-Sun, Earth-Moon distances, and fluctuations in solar declination and TSI.

This article also elaborates on the lunar role in precession (see author's response to line 44), which forms part of the Milankovitch precessional cycle and consequently its role in the 1470-yr quasi-periodicity. By virtue of its various gravitational influences, the Moon affects TSI, insolation, and associated patterns through time. With peak gravitational forces caused by perigee (Moon) and perihelion (Sun) (and their combination) (lunations and lunar phases), variations will occur in tides depending on the proximity of the lunation and perigee to the perihelion. Variations in tidal and insolation levels are thus associated with both Milankovitch precessional and Bond cycles.

Regarding the reference to Broecker, there is a comparison to Broecker 2003, where there is a discussion on the debate between the two potential causes for abrupt climate change. In Broecker 2003, there is a description of the influence of physical geography in determining the cause of these events. Furthermore, Broecker points out the deficiencies in both theories: the incapacity of one to change suddenly and the incapacity of the other to be able to lock the mechanism into an alternative state. However, the Broecker 2003 reference on line 500 should read (cf. Broecker 2003).

Line 529: Your study does not elaborate newly on the physics of climate change (referee 2).

These models are unique and new – how do they not elaborate newly on the physics of abrupt climate change? See section 4 of this response.

Line 533: Your study does not provide a “mechanical explanation” it would be an “explanation of the timing” at most. Moreover, “none existed”? Was not there any “mechanical explanation for abrupt climate change”? (Referee 2)

Please refer to Section 4 of author’s response. Additionally, whilst correlation is not causation, a deductive study was undertaken and the hypothesis confirmed. It remains for future scientific studies to falsify it.

7. Other points

- With regard to Earth’s internal climate systems, please refer to author’s response to referee 2 (Section 3)

8. Explanation

- **Line 22:** “capacity to inform” = To illuminate, to give information
- **Line 127-131:** reinforces an argument in a lead into discussion on the Ditlevsen paper

9. Referee 2 opinions

Referee 2 holds an opinion that “even if such a forcing on a 1470 yr quasi-periodicity exists, it might be irrelevant in triggering the abrupt climate changes”. However, results and implications provided in Section 4 of this article are sound and “satisfactory” according to referee 2. Whilst correlation is not causation, a deductive study was undertaken and the hypothesis confirmed. It remains for future scientific studies to falsify it.