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Interactive comment on "An astronomical correspondence to the 1470 year cycle of abrupt climate change" *by* A. M. Kelsey et al.

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An astronomical correspondence to the 1470 year cycle of abrupt climate change: reply to comments

We would like to thank the referees and others for their comments.

Replies to all comments on the authenticity of the 1470 signal

On the variable lengths of the cycle and error margins, statistical matters: The subject matter of this paper is an astronomical model and data that account for the ∼1470yr cycle (as a potential forcing mechanism), which is a mean length of the cycle for the Holocene and Glacial (Bond et al., 1999:43). We disagree with those arguments undermining the authenticity of the signal for a variety of reasons that would, in itself, form

a lengthy debate, which is not the subject of this paper. We do, however, recognise the debate on this cycle. Extensive evidence does exist for this cycle, which is not just confined to Greenland ice cores and North Atlantic IRD. At this stage, further evidence is required to confirm how the cycles impact on Earth's climate system and are linked to further teleconnections.

Consequently, we have adjusted our abstract to read:

"There is strong evidence for the existence of ∼1470-year cycle of abrupt climate change that is well-entrenched in academic literature, although debated. This evidence is seen in multiple ice cores as the Dansgaard-Oeschger atmospheric temperature cycle; as Bond ice-rafting debris (IRD) events; and as cyclical climatic conditions precursory to increased El Niño/Southern Oscillation (ENSO) variability and intensity."

From an astronomical perspective the variations in the length of the cycle and "error margins" provide interesting information on the nature of the harmonics and sub harmonics of the ∼1470yr cycle; these are captured by the interactive components of our model. This was briefly touched upon in our article with reference to the different mean lengths of the cycle in the Holocene, Glacial, and the Holocene-Glacial (lines 17-21, page 903). From our model, we expect these variations and error margins are dependent upon the interaction of the variables within the Milankovitch precessional cycle. The location of the return positions of periodic components relative to each other, their position with the Milankovitch precessional cycle, and the length of the sample period being tested are expected to influence these factors.

It is also likely that the strength the 1470yr signal is affected by the precision of aligning variables as they move into and out of phase. Stronger gravitational or solar insolation influences at various stages within the Milankovitch precessional cycle must also influence the strength and length of these signals; for example, the annual peak in solar generated tide and increased intensity of insolation associated with the position of perihelion relative to its occurrence within the seasonal or tropical year. Reduced intensity of the climatic response would result from this misalignment of contributing variables, as do broadened peaks and flattened signals in spectral data (cf. Damon and Sonett, 1991; Imbrie, 1985). For example, the ∼1800yr cycle was also explained in terms of the astronomical variable based on Earth's rotation-revolution relative to the anomalistic year (RRA) (line 5, p 4906). The base signal for this cycle (∼104yrs) appears in the isotopic spectrum of palaeoclimatic data (p 4900, line 25). Logically, variations can also be caused by variances from the mean values used; for example, the mean sunspot periodicity is 11.4yrs (Williams, 2013), but ranges from ∼10-12 years. Consequently, such variances do not undermine the ∼1470yr cyclicity but are informative of it.

Additional responses to Referee 1 - Ditlevsen

On climate associations and astronomical explanations with different aspects of the cycle: To provide a better understanding of climatic associations we have adjusted text at line 15, page 4904, to read:

"... the ∼1470yr cycle. This 133 yr periodicity is also evident in other climatic datasets such as tropical Atlantic cyclones, ocean sediments, and Nile water (Cohen and Sweetser, 1975; Damon and Sonett, 1991; Yousef, 2000), as well as in auroral records (Damon and Sonett, 1991), and drought and fire cycles in Spain and Indonesia (Biagioni et al., 2015; Vázquez et al., 2015; Xiaoying, 2008)."

Also inserted at line 24, page 4902:

"Climatic manifestations of these radioisotopic signals include the strength of cyclogenesis, land air and sea surface temperatures, sea-level atmospheric pressure, and equatorial wind patterns for the sunspot cycle (Bard et al., 1997; Friis-Christensen and Lassen, 1991; Kelly, 1977; Labitzke and Loon, 1988; Reid, 1987; Tinsley, 1994). Sunspot minima have also been associated with the Little Ice Age (LIA) (Damon and Sonett, 1991; Eddy, 1976; Stuiver, 1965, 1961; Stuiver and Quay, 1980). The SdV cycle, which is evident in palaeoclimatic records over at least the past 50kya (Summerhayes, 2015:325), is a cycle of cold/warm temperature fluctuations. It has been

found in dendrochronological records, glacier variations, monsoon intensity changes, and other climate-linked processes (Breitenmoser et al., 2012)."

Remove "Little Ice Age" from page 4904, line 24, as acronym is now defined earlier.

Also inserted at page 4903, line 27:

"In historical records, a 57 yr cycle has been associated with cyclical precipitation levels in Australia, Britain and Egypt, based on lunar declinations (Keele, 1910)."

Also at line 9, page 4902, in relation to the Metonic cycle:

"It's signal is found in in a number of relevant datasets: for example, as a prominent Be10 spectral peak in Holocene ice (Yiou et al., 1997); U.S. temperature peaks (Currie, 1993); air pressure and air temperature (O'Brien and Currie, 1993); rainfall data in Australia and South Africa (Vines, 2008); maximum tidal forcing (O'Brien et al., 1995:289); and volcanic eruptions (Hamilton, 1973)."

In relation to the 493yr Metonic-eclipse periodicity, insert at line 15, 4093:

"This periodicity corresponds to the Cartwright cycle in tidal sedimentation (cf. Munk et al., 2002:381)."

In relation to the Metonic eclipse series, insert at line 16, page 4905:

"Corresponding with the most recent set of Metonic eclipses, epochs of maximum tidal forcing occurred for two Japanese sites, corresponding with maxima in air pressure (O'Brien and Currie, 1993:289)."

On harmonics and frequencies and method:

As per my previous reply to Wolff, the nonstationary, nonlinear nature of the ∼1470yr cycle requires it to be first divided into its periodic components or sub harmonics (Mayewski et al., 1997; Schulz, 2002; see also Imbrie, 1985). The first necessary step was to provide a conceptual model that aided in the identification of the various constituents that can then be represented as sinusoidal curves (Imbrie, 1985). We have made this point clearer by adding at page 4898, line 2:

"The development of a conceptual model is also a necessary first step in dealing with nonstationary, nonlinear data and systems (Imbrie, 1985; Mayewski et al., 1997; Schulz, 2002)."

Described within our article (page 4897, lines 24 to page 4900, line 17) is this procedure that was followed in the production of our parametric model, in which the harmonics are axiomatic. The underlying data was tabulated at annual resolution and examined for superposition of the variables (page 4900, line 19) using sine curves and manual examination of each record.

It was hypothesised that in conjunction with the sunspot cycle, precession and rotation contributed to the production of the 1470yr periodicity and its sub harmonics (page 4897, line 24 ff.). Variables were then selected on this basis, their selection justified (page 4898, line 4 ff.), and their periodicities set at values sourced from NASA (page 4900, line 19 ff.). These values and their combined interactions were found in isotopic spectral data, confirming our hypothesis. Additionally, astronomical data based on solar and lunar declination cycles (Figure 1; page 4901, lines 2-5), also showed cyclical patterns that corresponded to isotopic spectral peaks and cycles in palaeoclimatic datasets, once again confirming our hypothesis, as well as the empirically based age model that evidences the 1470yr cycle. This process and results were also clearly explained in our article.

Also explained were the associations with gravitational and insolation influences associated with each of these variables in the background section of our article (page 4899, line 10 to page 4900, line 17; extensively on page 4902). Generally, there is consequently no need to further elaborate on these details. The same is also true for the model results (page 4903, line 9 ff.), which were differentiated from those derived from the astronomical data (page 4904, line 16 ff.). The graphed data of solar and lunar declinations appear in Figure 1, wherein eclipse occurrences are clearly visible at the intersections of these interacting sinusoidal curves, and from which the periodicity of the Metonic eclipse cycle can be easily determined by reference to the underlying tabulated data.

We would like to thank this referee for pointing out the error in reference to the 1490yr length of the cycle in Turney's article, which appear to have resulted from a typo or word processing error.

With regard to the Bond 1999 paper, please refer to previous replies to Wolff. This article was republished in 2013 and the citation used was downloaded in Endnote format from the publisher. Dates have been adjusted.

Additional response to Referee 2 – Anon

In reference to the Sothic cycle and clear method:

Based on the similarity between the chronological Sothic cycle (not climatological) (page 4897, line 24ff.), a hypothesis was developed on the basis of a potentially shared cause with the climatological cycle of similar length. Variables were selected on this basis and their usage was justified based on real known astronomical cycles that each has a defined unit of mean length based on NASA data, and each with a real impact on Earth's climate system (see response above to referee one for details).

On the methodology was not being clearly defined: see above.

As to whether the background to the Sothic cycle should be included as per this referee's comment, this is one of opinion. The background of the Sothic cycle is peripheral to the discussion in our paper. For anyone interested in following through on the nature of the Sothic cycle, a reference was provided. As stated in our article (lines 24, 25 on page 4897), the Sothic cycle is a chronological cycle associated with ancient Egyptian calendrical problems; it is not a climatological cycle and any discussion on climate effects would be purely speculative. To clarify this point, we are happy to add the following at page 4897, line 26.

“The Sothic cycle was caused by problems in tuning the ancient Egyptian calendar to the celestial phenomena against which they were measured, complicated by precessional movement of the equinox of which they were unaware.”

1. Celestial dynamics v. solar dynamo, and the hypothetical nature of the SdV cycle:

We disagree with these comments. There is extensive evidence of the SdV cycle and Hallstadt cycle (see page 4903, lines 10-23 of our article), which such evidence extending back 50ky (Summerhayes, 2015:325). For example, the SdV cycle is one of cold/warm temperature fluctuations, appearing as wiggles in the radiocarbon curve. Initially, these wiggles were considered questionable because of consensus that the radiocarbon curve was already well-understood (Suess, 1986). Furthermore, opposition to their acceptance was that there was no statistical justification to believe that these wiggles in the calibration curve were anything other than errors (Suess 1986). We now know these wiggles are legitimate: they appear in dendrochronological records, C14 flux, peat bogs, and sunspot, auroral, and O18 records (Damon and Sonett, 1991; Suess, 1986). In fact wiggle-matching of calibration curves is not only used in radiocarbon-dating (cf. Blaauw, 2012; Blaauw et al., 2004; Mauquoy et al., 2004; Muscheler et al., 2014), but also in the tuning of ice-core chronologies using the non-linear data provided by O18 isotopes (Svensson et al., 2008). Rather, it is the cause of long-term bolometric and radiocarbon chronological variability that is not fully understood (line 28, page 4897 to line 2, page 4898 of our article).

On “The sun-spot cycle is not regular (durations between 9.8 and 12.0 years) and it is known that the involved dynamics is chaotic.”

We disagree with the reviewer’s comments. It is reasonable to use mean values for the model’s variables and the length of the ∼1470yr cycle, and also permits the opportunity to explore variations in the length of the cycle. Our value for the sunspot cycle was sourced from NASA. Additionally, it is the heliomagnetics of the solar dynamo that are

chaotic (Hathaway, 2010:55) and not the sunspot cycle itself (for more information see Eddy, 1976).

2. On solar forcing:

This referee asks is solar forcing necessary in this paper, stating that it may not be the main player and suggesting that we leave solar forcing out of the model.

We disagree with the reviewer’s comments on solar forcing as solar insolation is the main driver of Earth’s climate (e.g., Vieira et al., 2011) and is part of our hypothesis. The reasons for doing so are clearly outlined in our paper on numerous occasions. Furthermore their climatic impacts are covered in our discussion, in particular on pages 4901-4903.

In response to this referee’s question as to what constitutes solar forcing; this is contained in the background section of our article. Please refer to page 4898, line 14:

“Solar forcing, through sunspot cyclicity and by association with the perihelion, was also incorporated in our model parameters. Sunspot activity modulates the cosmic ray flux in Earth’s atmosphere, whilst the perihelion plays an important role in the level of solar insolation reaching Earth. Earth’s rotation-revolution cycle relative to the anomalistic year, based on the perihelion (RRA), was also parameterised for this model.”

We have adjusted the manuscript to include the acronym here to make the association clearer.

In relation to page 4900, line 19, this referee states that the RRA is not associated with radiation:

We disagree. Being based on the anomalistic year, radiation levels are associated with the RRA. At the perihelion, solar flux (viz insolation) is denser due to Earth’s proximity to the Sun. The level of solar insolation varies throughout the year, and atmospheric tides are strongly affected by the level of isolation and its angular incidence (Berger, 1977; Imbrie, 1985). In accordance to clarify this position, page 4900, line 22 has been adjusted to read:

"...passage from perihelion to perihelion (365.2596 days); this last variable in turn determines the time of earth's rotation and revolution relative to the perihelion (RRA), i.e., the time for the perihelion to occur over the same geographic longitude on Earth."

This should clarify the position for the referee in relation to their comments relating to page 4904, line 5 and Figure 3. Both the perihelion based RRA-Metonic cycle and the RRA sunspot cycles are clearly associated with solar forcing. The description of the gravitational links to the Metonic lunation cycle appears in the background section on page 4899, line 11. Similarly the gravitational association with the perihelion is also explained (see page 4902, lines 1 and 24).

In relationship to understanding of the Metonic-sunspot cycle:

An adequate description has been supplied. Please see the following pages in our article - page 4899, lines 12-16; page 4903, lines 22-27; page 4905, lines 7-12, 21-24.

3. Unnecessary confusion

We disagree that nutation is not necessary as it is integral to the hypothesis that precession contributes to the ~1470yr cycle. We have altered the text in to make the link clearer between nutation and precession at lines 5-8, page 4898:

"As the Sun and Moon are responsible for the precessional cycle (Lowrie, 2007:58), they were clear candidates. The Moon contributes 2/3 of this influence and the Sun 1/3 through their gravitational pull on the Earth's equatorial bulge (Lowrie, 2007:58). Lunar nutation, which is the periodic wobbling of the Earth's axis that influences precession, results from the rotating lunar orbital place that is inclined at ~5.145° to the ecliptic (Lowrie, 2007:58), consequently altering the latitudinal perspective to incoming solar radiation. An 18.6yr periodicity is shared by the rotation of the lunar orbital plane; the associated nutation, lunar nodal cycle, and the occurrence of major lunar standstills, when the lunar declination is at its maximum. It is the lunar nodal cycle that has been

used extensively in climate research in conjunction with the Saros cycle of eclipses."

This nodal cycle is discussed further in our article a couple of paragraphs later, starting at line 1 on page 4899 through to line 17 on page 4900. The potential of the nodal cycle is realised through the series of Metonic eclipses revealed in our astronomical data (see line 3 page 4899 ff.) Evidence and effects of this are discussed from line 13-27, page 4903; from lines 19 on page 4904 through to line 16 on page 4904; in Table 2 and Figure 1.

On the movement of 9" in relation to nutation.

We disagree. This 9" of arc during the 18.6yr periodicity is one acting on the amplitude of the precessional motion, which sees the equinoctial points move retrogradely along the ecliptic (Lowrie, 2007:58). Whilst this impact on precessional movement may be small, of greater interest to our research is the rocking motion on the Earth's axis (perpendicular to Earth's equator) associated with nutation, resulting in continually changing declinations that are relative to the equator (as opposed to ecliptic). The current lunar declination range is twice that of the obliquity of the ecliptic (currently 47°), with extremities reached twice per month. The extremities of both solar and lunar declinations are determined by this wobbling effect, with a current range up to 28.5° north or south of the equator. Additionally, the assumption that small variations cannot have a significant influence is belied the small movements involved in solar declinations over the 133yr cycle (see above).

On the 1470yr cycle not being related to Milankovitch forcing.

We disagree. Nutation is a component of the precession of the equinoxes (Lowrie, 2007:58), which in turn produces the Milankovitch precessional cycle though interacting with the precessing apsidal axis (page 4902, line 23 to 4903, lines 8). Additionally, the extent of nutational influence is determined by the obliquity of the ecliptic.

4. Miscellaneous

See our reply to this referee in our comments on the Sothic cycle and clear method.

Response to Eric Wolff:

On Bond citation, variability of 1470yr cycle, usage of statistics in relation to 1470yr cycle: see above.

Response to S. Obrochta:

On the authenticity of the 1470yr cycle: See above.

Re Bond citation: See above.

On variability of nonstationary 1470yr cycle, “error margins” and statistics, see comments above.

Additionally:

Based on the factors outlined above, it is not surprising that different patterns appear in previous glaciations. Whilst an opinion exists that internal processes are more important in influencing sub-orbital climate change, evidence suggests that the subharmonics underlying the 1470yr cycle produce these climatic effects, as detailed in our article. There is an estimated 30% climatic influence on C14 variations (Steinhilber et al., 2012), which our research suggests is due to the influence of nutation and the various components of our model.

On the age of the body of work quoted:

Recent publications (since 2005) on the 1470yr cycle do exist (e.g., (Capron et al., 2010; Clement and Peterson, 2008; Darby et al., 2012; Turney, 2008). The use of older work is justified; it is often necessary to dig through that literature looking for the finer details of work that are not included in ensuing literature. It is also preferred that original sources are quoted in PhD work.

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