Review of

"Synchronizing early Eocene deep-sea and continental records – new cyclostratigraphic age models from the Bighorn Basin Coring Project"

by **Westerhold and co-authors**
submitted to **'Climate of the Past'** (Initial submission, august 2017)
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Overview:

Westerhold and co-authors performed a 'late Paleocene to early Eocene' cyclostratigraphic study on sedimentary terrestrial (fluvial-paleosols) records from continental drill cores of the Bighorn Basin Coring Project (BBCP, Wyoming, USA), then they compared the inferred cyclostratigraphic timescale to previous timescales obtained from sedimentary marine (deep-sea) records, from ocean drilling programs (ODP).

The main purpose of Westerhold et al.'s study is to face cyclostratigraphic timescales from continental and marine realms in order to reconcile the duration of the PETM. Secondarily, Westerhold and co-authors proposed an astronomical timescale for the interval prior to the Elmo (ETM2) event, then discussed a potential link between "Biohorizon B" mammalian turnover and the perturbation in the marine biotic cycle (in calcareous nannofossil assemblages, in particular).

For cyclostratigraphy, Westerhold and co-authors used high-resolution XRF iron (Fe) scanning data and sediment color redness (a***** reflectance) together with previously published soil nodule $\delta^{13}C$ data in order to estimate the duration of the PETM (from Polecat Bench and Basin Substation cores), and secondarily to establish an orbital timescale for the interval prior to the Elmo event (from Gilmore Hill cores).

A highly resolved 'late Paleocene to early Eocene' cyclostratigraphic timescale is needed to enhance our comprehension of the associated abrupt, severe changes in Earth's surface systems at the PETM and Elmo events.

Overall, the manuscript is well written and structured, and the discussion with previous age models was well conducted, though some improvements should be done (see 'specific comments'). All of these qualities make the manuscript a significant contribution to '*Climate of the Past*'.

Below are some specific (but not major) points that I classified into five items, and minor points taken out from the text. Among the specific points I raised, two capital issues should be clearly addressed, which are related to: (i) the additional precession cycle to the clay-layer interval, and (ii) the definition of the end of CIE in both deep-sea and terrestrial realms.

Specific comments:

1) The definition of the end of CIE-PETM in the Polecat Bench $\delta^{13}C$ record.

Duration estimates of the PETM and comparison with previous studies depend tightly on how the stratigraphic extent of CIE is defined. While it is easier to define the onset of CIE at both realms, the definition of its end is more problematic, especially in the continental $\delta^{13}C$ record.

In the present form of the ms, it is not clear how the authors (or may be by referrig to previous papers) set the end of CIE in the $\delta^{13}C$ terrestrial record. Based on their figure 5, I can place it appropriately at 60 mcd depth, and largely at 55 mcd depth. This implies respectively 7.5 to 8 precession cycles, yielding respective durations of 157.5 and 168 kyr (21 kyr mean precession period). These durations are close to the 171 kyr estimate inferred from deep-sea records (Röhl et al., 2007).

In all figures dealing with CIE's correlation between terrestrial and deep-sea records (Figures 7, S12 and S13), the onset of CIE is clearly shown at the abrupt negative $\delta^{13}C$ shift, whereas the end of CIE is not obvious neither at ODP sites nor in PCB terrestrial record. It's even sometimes confused

when reading the cyclostratigraphic interpretation against the proposed age model, and what is said in the text. For instance, in figure 7, the duration of the entire CIE is assessed at about 180 kyr (120 kyr for the clay layer indicated by the brown rectangle plus 59 kyr till the end of CIE shown by light blue rectangle). In the text, the authors discuss a longer duration of 200 kyr..

Again, considering a very likely end of CIE in the terrestrial $\delta^{13}C$ data at the top (maximum) of precession cycle no. 8 (Fig. 7), a duration of 168 ky (21 kyr x 8 cycles) could be inferred...

A focus was also given on the duration of clay-layer interval. The clay layer is characteristic of deep-sea environment. What is the degree of reliability of correlation between terrestrial and deep-sea (using $\delta^{13}C$) data that led to the projection of equivalent clay-layer interval into the terrestrial records? Note that this correlation is crucial for the assessment of duration of the clay layer. Could the authors add uncertainties on their stratigraphic correlation?

In summary, the authors should state clearly in the manuscript how they define the stratigraphic extent of the entire CIE (especially its end) and the projected clay-layer into the terrestrial records, and accordingly they could compare duration estimates between the two realms.

2) Comparison with previous age models

In the outcrops (Bighorn Basin) in the Polecat Bench section, Abdul-Aziz et al. (2008) arrived to a duration of 157 kyr for the entire CIE-PETM.

Westerhold and co-authors cited Abdul-Aziz et al.'s (2008) study, but they did not explain the 157 kyr shorter duration compared to their longer duration of 200 kyr obtained from Polecat Bench drill cores. Given both studies are based on precession cycle counting from the same basin (and the same Polecat Bench site), I strongly recommend that the authors explicitly discuss the source of such significant difference. Although the authors evoked promptly this difference (Page 7, lines 21-23), but it is still ambiguous how they found a longer duration with regard to a shorter duration provided by Abdul-Aziz et al. (2008) (see also 'Comment 1' above).

Note that Abdul-Aziz et al.'s (2008) duration estimate (i.e., 157 kyr) is close to the 171 kyr duration of Röhl et al. (2007) inferred from deep-sea records.

3) Amplitude modulation (AM) of the precession by the eccentricity

The authors outlined 'AM of the precession by the eccentricity' in the text body and they also pointed it out in the abstract and conclusions, however, there is no statistical test (or even an attempt by visual inspection) to show or retrieve such modulation. If the authors would still retain this result, then they should demonstrate it, at least at the short eccentricity band.

The authors stated (Page 7, lines 8 and 9) : "*The filter of the precession cycles of ~8.2 m in both data show modulations that are consistent with eccentricity*". Filtering is not sufficient to draw such conclusion. Here a Hilbert transform is required to extract such AM envelopes...

4) Half-precession

Precession vs half-precession ratio is not consistent with the selected bandwidths used for filtering (see for e.g., Fig. 5). Visual inspection in figure 5 indicates that several precession cycles do not match two 'half-precession' cycles, making the hypothesis of 'half-precession' implausible. Also, if the precession central wavelength is 8.2 m, then 'half-precession' central wavelength should be around 4 m (not 3.45 m).

Can the authors resolve this mismatch, by changing the bandwidth for example, or abandon the hypothesis of 'half-precession'.

In addition, the authors stated (Page 5, Lines 28-29) "*The two longer cycles around 8 and 3.5 m have been interpreted as precession and half precession cycles also present in Plio-Pleistocene successions (see Abdul-Aziz et al., 2008).*"

Abdul-Aziz et al. (2008) did not interpret the 3.5 m cycles as half-precession. Instead, they interpreted them as sub-Milankovitch (or millennial). They even stated in their paper « However, the exact origin of sub-Milankovitch cycles remains enigmatic. ». Sub-Milankovitch (or millennial-scale) cycles do not imply half-precession cycles...

5) Significance of changes in sediment a* color reflectance and Fe content in terrestrial records

Although the authors evoked very promptly the potential significance of XRF iron intensity in terrestrial sediments by referring to previous studies (Abels et al., 2012), [and this topic is beyond the scope of the present study], I suggest that the authors develope a little bit the significance of such proxies in terms of climate change (astronomically forced climate). Orbitally driven fluctuations in Fe content in deep-sea sedimentary records have generally (and extensively) been attributed to the relative contribution from carbonate deposition versus detrital-clay inputs. However, the origin of cyclic change in Fe content in terrestrial environments is not well addressed in the litterature...

Minor points:

Page 1, Lines 19 to 20:
"A consistent stratigraphic framework is required to understand the effect of major climate perturbations of the geological past on both marine and terrestrial ecosystems."

Should better be:

"A consistent chronostratigraphic framework is required to understand the effect of major paleoclimate perturbations on both marine and terrestrial ecosystems."

Page 1, Line 25:
"Bighorn Basin Drilling Project (BBCP, Wyoming, USA)"

Please change into:

"Bighorn Basin **Coring** Project (BBCP, Wyoming, USA)"

Page 1, Lines 29 to 30 :
"The duration of the PETM is estimated at ~200 kyr for the CIE and ~120 kyr for the pelagic clay layer."

Should better be:

The duration of the PETM is estimated at ~200 kyr for the CIE and ~120 kyr for the **associated** pelagic clay layer.

Page 2, Lines 7 & 8:
"Both have been studied in great detail in both in deep-sea sedimentary and terrestrial successions (Zachos et al., 2005; Abels et al., 2016)."

Into:

Both have been studied in great detail in deep-sea and terrestrial sedimentary successions (e.g., Zachos et al., 2005; Abels et al., 2016)."

Page 2, Lines 10, 11 & 12:
"The hyperthermal events in outcrops and ocean drill cores can be identified by the characteristic negative carbon isotope excursions (CIEs), although these differ in magnitude (McInerney and Wing, 2011; Bowen, 2013)."

Magnitude of PETM CIE should also refer to Sluijs and Dickens (2012) (Global Biogeochemical Cycles 26, GB4005).

Page 2, Lines 12 & 13:

"The CIEs are interpreted as massive inputs of $\delta^{13}C$-depleted carbon to the exogenic carbon pool (see Dickens et al., 2011 for discussion)."

Into:

"The CIEs are interpreted as **due to** massive inputs of $\delta^{13}C$-depleted carbon to the exogenic carbon pool (see Dickens et al., 2011 for discussion)."

Page 2, Line 21:
"... understanding the future of climate on Earth ..."

into:

"... understanding Earth's future climate ..."

Page 2, Lines 27 & 28:
"Deep-sea records have a much lower sedimentation rate (cm/kyr) compared to the terrestrial records (m/kyr), but have been deposited continuously."

Into:

Deep-sea records have much lower sedimentation rates **in the order of** cm/kyr compared to the terrestrial records **having sedimentation rates in the order of** m/kyr...

Page 2, Lines 28 to 30:
"Sedimentation at the terrestrial successions very likely was more dynamic due to the different types of deposition (see Bowen et al., 2015)."

Into:

"Sedimentation in terrestrial environments was very likely more dynamic due to the different types of deposition (see Bowen et al., 2015). "

Page 2, Lines 30 & 31:
"To interpret rates of changes and processes before, during and after the events a detailed age model is required."

Into:

"To interpret rates of changes of geological processes before, during and after the events a detailed age model is required."

Page 2, Lines 34 to 36:
"Estimates for the duration of the PETM from deep-sea records are complicated by severe carbonate dissolution, which forms a clay-rich layer at the onset of the event (Röhl et al., 2007)."

Into:

"Cyclostratigraphic estimates of the duration of the PETM from deep-sea records are hampered by the lack of carbonate-rich sequences, which are characaterized on sites nearby the paleo-CCD with a clay-rich layer at the onset of the event (Röhl et al., 2007), resulting from severe carbonate dissolution (Zachos et al., 2005)."

Page 3, Lines 11 to 15 :
"The purpose of this report is to establish high-resolution age models for the BBCP drill cores based

on cyclostratigraphy and integrate existing age models from outcrops. Second, these new BBCP drill cores age models will be combined with deep-sea records to synchronize and improve the available astronomical age model for the PETM and Elmo interval."

Remove "Second" or change into:

"The **main** purpose of this report is to establish high-resolution age models for the BBCP drill cores based on cyclostratigraphy and integrate existing age models from outcrops. Second, these new BBCP drill cores age models will be combined with deep-sea records to synchronize and improve the available astronomical age model for the PETM and Elmo interval."

Page 3, Line 31:
"*... the BSN and GMH and PCB sites*."

Into:

"... the BSN, GMH and PCB sites."

Page 4, Lines 12 to 26:
All this paragraph deals with isotope data acquisition, which were already presented in Bowen et al. (2015). Thus, such paragraph should be removed or shortened or moved to the supplementary materials.

Page 5, Line 15:
"3.2 Timeseries analysis of BBCP drillcores", please add a hyphen to ‘Time-series’ and to ‘drill-cores’ (or a space ‘drill core’)

Page 8 (Line 34) and page 9 (Line 1):
"During the PETM, massive dissolution of carbonates in the deep sea truncated the record (Zachos et al., 2005), complicating the age model constructions."

Into:

"During the PETM, massive dissolution of carbonates in the deep sea truncated the cyclostratigraphic record (Zachos et al., 2005), complicating the construction of age models. "

Page 9, Lines 31 to 34:
Adding a precession cycle in deep-sea records to the clay layer is not well argued (see specific comments).
It is likely to miss cycles in XRF Ca records because of the clay layer. However, in Fe and Ba XRF data, cycles are well expressed (see ODP Site 690 in Röhl et al., 2007).

Page 10, Lines 5 to 7:
Charles et al. (2011) found 8.5 precession cycles at BH9/05 Core for the entire CIE, similar to Röhl et al. (2007), who used ODP 1263 data.

Page 11, Line 25:
"Fe intensities, core images, and color reflectance data were used ...."

into:

"**Sedimentary records** of Fe intensities, core images, and color reflectance data were used ...."

Page 19 (Figure 1 caption)

" Location map for ODP sites 702, 1260 and 1263 on a 40 Ma paleogeographic reconstruction in Mollweide projection (from http://www.odsn.de)."

into:

"Location map for BBCP (Bighorn Basin Coring Project, Wyoming, USA), ODP Leg 208 (Sites 1260 and 1263) and ODP Leg 113 (Site 690) on a **56 Ma** paleogeographic reconstruction in Mollweide projection (from http://www.odsn.de, Hay et al., 1999)."

should also refer to the original paper of Hay et al. (1999), and not only to the website

Page 20 (Figure 2 caption):
The Wilkens et al.'s (submitted) ms referred in Figure 2 caption, but cited in the reference list as Wilkens et al. (2017); the paper already appeared, so should be 2017.

Page 23 (Figure 5 caption)
Line 4: '(lines)' into '(solid lines)'
Line 5: 'at the PETM' into 'at the onset of PETM'

Page 25 (Figure 7 caption)
Line 5: "... extracted Gaussian filter of the PCB XRF Fe intensity data"
would better be "... extracted precession cycles using a Gaussian filter of the PCB XRF Fe intensity data".
Could the authors please point the end of the CIE directly on $\delta^{13}C$ data of PCB and deep-sea records?