Reply to Reviewer #2 (Sietske Batenburg)

Review Martinez-Braceras, CP, 2024

The manuscript on 'Orbitally forced environmental changes during the accumulation of a Pliensbachian (Lower Jurassic) black shale in northern Iberia' by Martinez-Braceras and co-authors investigates factors driving sedimentary rhythms in a Pliensbachian black shale interval. This is a timely approach, as sedimentary rhythms in Mesozoic successions are commonly used to construct astronomically tuned time scales, although the exact mechanisms driving lithological alternations (especially on the precessional scale) are often insufficiently understood. The authors present a multi-proxy study to discuss a suite of processes in detail, shedding light on the periodic nature of regional anoxia that resulted in the deposition of organic matter. This is a very thorough study and merits publication in Climate of the Past if some minor points can be addressed.

As the stratigraphic interval has been studied previously in the same region, it would be relevant to report any independent age information. This would include biostratigraphic, magnetostratigraphic and chemostratigraphic events, and if available (correlation to) radioisotopic ages. If no age information is available, the authors should make it clear that the interpretation of orbital forcing of the sedimentary rhythms is based solely on the cycle hierarchy.

RESPONSE: AGREE. We will improve the presentation of the chronostratigraphic data available for the studied interval, which is based on ammonite zones (Braga et al., 1988) and calcareous nannofossil zones (Fraguas et al., 2015). Unfortunately, the biostratigraphic age data does not provide the resolution needed to assess accurately the chronology of this relatively short succession at astronomical timescales.

The photograph of the section (Fig 2) shows very clear banding patterns, with individual lithological alternations varying in intensity and showing grouping in bundles. The time series analyses of the colour signal show periodicities at 6.6, 1.67, 1 and 0.37 m, where the 'intermediate' periodicities have some peculiarities. The periodicity at 1.6 m is not very strongly present in the time series analysis, whereas it is prominent in the log and view of the section. The periodicity at 1 m seems a bit different from what would be expected with a cycle hierarchy of eccentricity-modulated precession and obliquity (20:5:2:1). The longest periodicity that is strongly present in the spectral results likely reflects the influence of 405 kyr cycles, but its expression in the section is not clear. It would be good if the authors could comment on the reasons for the seeming discrepancies in the lithological patterns and the spectral analysis result.

RESPONSE: AGREE. It is true that calcareous couplets of 32-42 cm and bundles of approximately 1.65 m constitute the clearest bed arrangement in the outcrop, which correspond to the expression of precession (20 kyr) and short (100 kyr) eccentricity cycles, respectively. However, long eccentricity cycles (405 kyr) are also expressed in the section by the alternation of 3.3-m-thick intervals in which two successive short eccentricity bundles are clearly recorded (e.g., B9 and B10), and 3.3-m-thick intervals in which another two short eccentricity bundles are not so clearly defined (e.g., the underlying B7-B8 and the overlying B11-B12). The former intervals are interpreted as long eccentricity minima, the latter as maxima. We will add a new figure (Fig. S1A), where the record of 405 kyr cycles can be readily appreciated. As the physical expression of short eccentricity bundles is subdued at long eccentricity maxima, the power of the former is relatively weak in the time series analysis. This explains the relatively low intensity of the intermediate, 1.6-m-thick periodicity in the spectra.

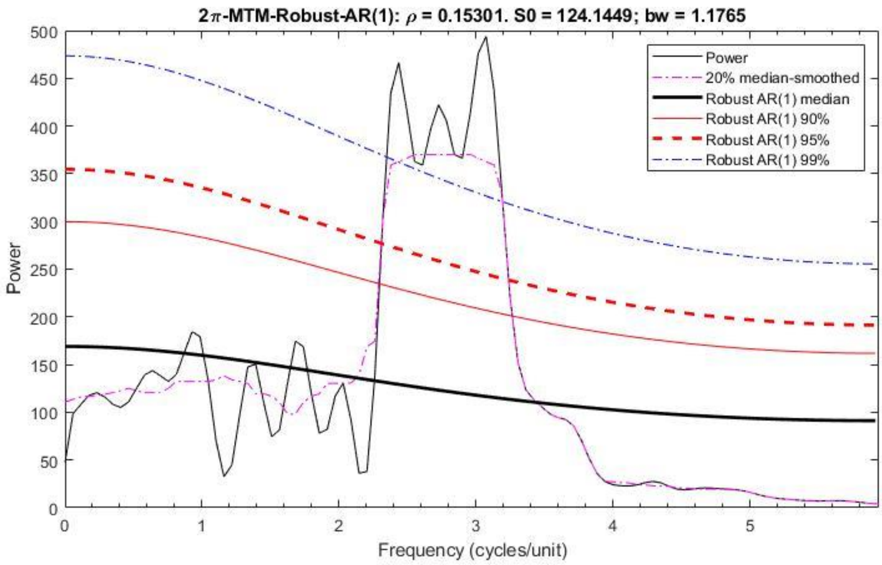
The time series analyses of the colour signal show a significant 1-m-thick cyclicity, which could not be identified visually in the outcrop. Based on an average duration of 20 kyr for each precession-driven couplet, this intermediate periodicity would represent 53 kyr, which could correspond to the 52.8 kyr term of obliquity (p+S6). This 1-m-thick cyclicity is not recorded in the MS spectra, but a less significant periodicity of 65 cm is identified. Based on the average duration of 20 kyr for each calcareous couplet, this intermediate MS periodicity would represent 35 kyr. The mean duration estimated from both proxies is 44 kyr, suggesting that they might be the result of obliquity. However, as the results of the two datasets are not fully coherent, these periodicities (marked as O? in Fig. 4) were not further considered in our discussion about the orbitally modulated environmental evolution of the area.

A related point is that the periodicities detected through time series analyses are consistently shorter than those observed. The number of interpreted bundles (14) in a 31 m interval suggest that the imprint of short eccentricity actually resulted in a 2.2 m cycle rather than a 1.6 m one. The 6.6 m periodicity has a much stronger peak in the spectrum but based on the number of individual alternations (62), it is only present 3 times in the studied section, and has a length of approx. 10 m rather than 6.6 m. The individual alternations have an average thickness of 31/62=0.5 m rather than 0.37 m. I do not understand the origin of this discrepancy. It has been observed that the highest amplitude cycles may have higher sedimentation rates (in the absence of dissolution) and these thicker couplets may dominate the time series analyses results. But here, the time series results indicate shorter periodicities. I would recommend the authors to evaluate other power spectra methods, to see whether these give similar results, and to report on the imposed settings more elaborately. Also, it would be interesting to generate a power spectrum for $CaCO_3$ in the studied high-resolution interval, to see whether the statistically identified periodicity driving the limestone marl alternations corresponds to the observed thickness of the alternations.

RESPONSE: AGREE. We apologize for conveying misleading information in our original manuscript. As pointed out by the other reviewer (Beatriz Badenas), the thickness of the studied section was not clearly presented. We analysed a 30.4-m-thick section in the outcrop, but the lowermost 7.9 m were excluded from the cyclostratigraphic analysis because of poor exposure. Thus, in our original manuscript the top of the stratigraphic log was located at 30.40 m, but it started at 7.9 m. This means that the studied succession is actually 22.5 m thick. In order to present this information more clearly, the bottom of the studied succession will be established at 0 m and the top at 22.5 m in the revised manuscript (Figs. 2, 4, 6, 7, 9, 10, 11, 14 and the supplementary material will be modified accordingly).

Taking into account the thickness of 22.5 m of the studied section, the periodicities detected in the time series analyses are consistent with those observed in the succession.

The 13.8 bundles identified in the 22.5 m thick succession present an average thickness of 1.63 m, which matches the 1.67 m periodicity deduced from the spectral analyses. Similarly, the 62 calcareous couplets display an average length of 36 cm, which is practically identical to the 37 cm peak and the average of the 32-42 cm band identified in the spectral analyses. Additionally, the 2π-MTM power spectrum of the $CaCO_3$ data of the bundle (B9) studied in detail (see figure below) identifies a significant peak between 31-42 cm (mean value of 36.7 cm), which also corresponds to the thickness of the limestone-marl couplets.

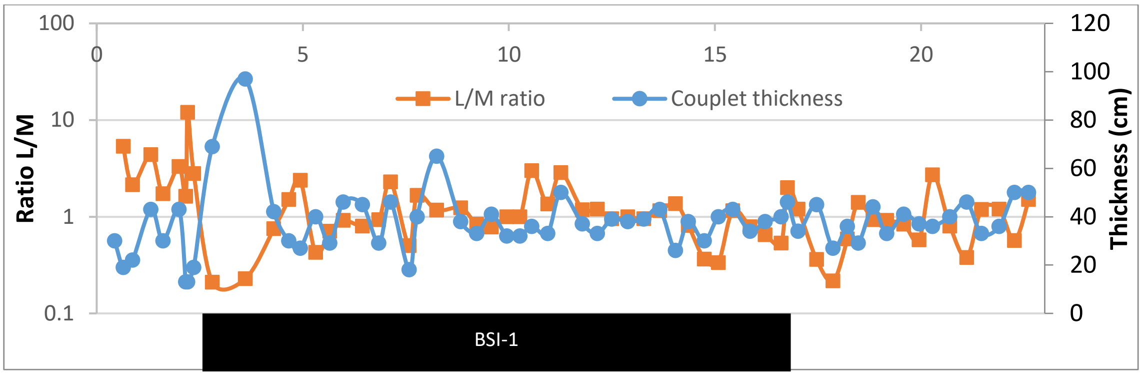


It would be good to indicate how couplets and eccentricity bundles are defined here precisely, along the lines of: 'The term couplet, as used here, refers to a lithological alternation, consisting of a resistant limestone bed with a more weathered marl or shale bed, starting at the base of the marl or shale. These couplets vary in their amount of lithological contrast between the marl/shale and the limestone. The variations in lithological contrast result in a grouping into bundles of five (four to six) couplets, counting from the base of the lightest coloured marls, reflecting the least lithological contrast with their bounding limestones.'

RESPONSE: AGREE. Following also the other reviewer's comment, a specific section (4.1.2. Bed arrangement) will be added in the revised manuscript.

The L/M ratio being close to 1 is taken as indication that carbonate productivity and dilution varied hand in hand. Besides this ratio, it would be interesting to plot the thickness of the couplets and the thickness of the individual beds, to see whether for example thicker couplets coincide with thicker limestones or not.

RESPONSE: DISAGREE. The interpretation that carbonate productivity and dilution varied together is not only based on the L/M thickness ratio, but also on other geochemical characteristics obtained from the interval (bundle B9 at 12.4-15.95 m) studied in detail. Such a comprehensive dataset is not available for the entire section (0-22.5 m), which means that it is not possible to deduce the variations in environmental conditions over time based solely on L/M thickness ratios. However, following the reviewer's suggestion, we calculated the L/M ration of the entire succession (0-22.5 m). The average L/M ratio of 1.08 obtained from the couplets of the entire Black Shale interval (C10 to C45 at 2.5-16.4 m) is similar to that obtained in bundle B9. The figure below shows the thickness and L/M ratio of all the couplets. There is not a clear or repetitive trend between the thickness of couplets and their L/M ratio. Consequently, we consider that this information does not contribute significantly to the main scope of our study.



A range of geochemical methods is applied to carefully investigate the factors controlling the production and preservation of organic matter. Changes in P-EF seem to suggest elevated productivity in the dark levels, but this is contrasted by δ15Norg, δ13Corg and Ba-EF, which are explained to suggest lower productivity. I wonder if the authors can comment on whether, instead of increased productivity, enhanced preservation would be sufficient to explain the observed patterns.

RESPONSE: AGREE. The fact that changes in the preservation of organic matter constituted the main factor that controlled the C_{org} content will be more clearly explained in the revised manuscript. The multiproxy analysis (δ^{15}Norg, δ^{13}Corg, trace elements, mineralogy and sedimentology) shows that the higher C_{org} content in marls/shales was related to less oxygenated sea-floor conditions, which enhanced the preservation potential of organic matter. The P_{EF} record suggests that the production of organic matter may also have increased during the formation of marls/shales, but this signal is not coherent throughout the studied interval. Given the close relationship between these processes and the lithological rhythmites, it can be concluded that there must have been an orbitally driven environmental factor that triggered fluctuations in bottom water oxygenation and, possibly, palaeoproductivity.

The δ^{13}C changes are addressed in many parts of the manuscript, and perhaps the readability would benefit from grouping all information about δ13C together, or a paragraph summarizing it.

RESPONSE: DISAGREE. It would be rather difficult to concentrate the discussion about $\delta^{13}C_{carb}$ data in one single section, because it is used to asses both the diagenetic overprinting and the orbitally modulated environmental changes (sections 5.1 and 5.3). Moreover, $\delta^{13}C_{carb}$ results were not more significant than other geochemical or mineralogical proxies (none of which is discussed in specific sections) for the development of the cyclic sedimentation model. In this regard, the only exception is the content in organic matter (specifically addressed in section 5.2), but this is due to the fact that the great organic matter content is the main feature that characterizes the Basque-Cantabrian Lower Jurassic successions and why we selected this interval for our study.

Minor points

L 21: change ‘involved processes’ to ‘processes involved’
RESPONSE: AGREE. The manuscript will be revised accordingly.

L 22: change ‘The study’ to ‘This study’
RESPONSE: AGREE. The manuscript will be revised accordingly.

L 23: change ‘black shales’ to ‘black shale intervals’, change ‘revealed’ to ‘reveals’
RESPONSE: AGREE. The manuscript will be revised accordingly.

L 25: the phrase ‘with the prevalence of precession, short eccentricity and long eccentricity cycles’ could be replaced by something a like: ‘and were likely driven by eccentricity-modulated precession’ to be more precise
RESPONSE: AGREE. The manuscript will be revised accordingly.

L 32: the comma has to be deleted to understand what the active verbs are in the sentence
RESPONSE: AGREE. The manuscript will be revised accordingly.

L 34: change waters to water
RESPONSE: AGREE. The manuscript will be revised accordingly.

L 36: change maximum to maximal
RESPONSE: AGREE. The manuscript will be revised accordingly.

L 37: typo in diminished
RESPONSE: AGREE. The manuscript will be revised accordingly.

L 38: delete seawater
RESPONSE: AGREE. The manuscript will be revised accordingly.

L 39: add and before contributed

RESPONSE: PARTLY AGREE. This sentence will be rephrased in another way in order to improve its meaning.

L 40: change exportation to export

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 43: change seawaters to water

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 46: change orbital to orbitally

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 50: change few to a few

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 51: add ‘and temporal’ after latitudinal

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 56: move ‘erode the seabed’ and ‘or’ to before ‘interrupt’

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 57: delete ‘, sedimentation’

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 80: delete on

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 82: replace Armorican by ‘the Armorican Massif’

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 83: replace being part of by ‘within’

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 99: delete was

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 106: Here and in other occasion: I recommend avoiding the abbreviation BS which is in English is commonly used to refer to bullshit.

RESPONSE: AGREE. BS will be replaced with BSI throughout the text to refer to “Black shale interval”.

L 111: replace United Kindom with ‘the United Kingdom’

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 116: put in before inland

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 120: replace on by of

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 208: weather resistant and weather recessive does not sound correct. You could delete ‘weather’ or you could explain that the beds are either resistant or susceptible to weathering.

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 216: as L 208

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 218: add the before marls

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 220: add and before trace

RESPONSE: DISAGREE. The information in brackets is a list of characteristics, separated by semicolons.

L 234: delete weather (2x)

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 277: replace which peaks at by with a main periodicity of

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 288: to help the reader, please mention the width of the filters in the main text, expressed as periodicities. Consider explaining why the bandwidths of the two filters are very different (half of the centre frequency vs one fourth of the centre frequency).

RESPONSE: AGREE. We agree that there was no coherence between the bandwidths of both filter outputs. Consequently, a new filter output will be extracted for the intermediate frequency and included in the new Figure 5, with a bandwidth close to one fourth of the centre frequency (similar to that used in the filter of the short periodicity).

L 293: I suggest to replace the word chronostratigraphy by cyclostratigraphic interpretation. Ideally, an integrated chronostratigraphy would include information from bioevents, magnetostratigraphy, chemostratigraphy, radioisotopic dating, etc.

RESPONSE: PARTLY AGREE. The chronostratigraphic information refers to the Jamesoni biozone of the Pliensbachian stage (obtained from Quesada et al., 2005, and Rosales et al., 2006), depicted on the left of the stratigraphic log. In Figure 4 we do not present our cyclostratigraphic interpretation of the Santiurde section, but only the results of our spectral analysis. In order to clarify this misunderstanding, we will add the reference for the chronostratigraphic data in the revised manuscript.

L 299: add cycles after m, replace corresponds by correspond

RESPONSE: AGREE. The manuscript will be revised accordingly.L 311: add ‘in $CaCO_3$’ after richer

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 313: delete counterpart

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 340: add with before maximum

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 375: replace ‘the amplitude of the oscillations’ by ‘amplitude of variability’

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 422: replace seawater by water, and ‘concentration was’ by ‘concentrations were’

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 434: replace whose by which, add of before their

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 557: add with before that

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 565: replace records by record

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 567: replace alternation by alternations

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 577: replace if by when

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 606: add than after higher

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 625: replace indurate by indurated

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 632: replace indurate by indurated

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 655: replace originate by lead to

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 660: add strength of before biological pump

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 664: replace distortions by alterations

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 672: replace come by coincide

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 676: replace 'and greater OM with relatively higher' by 'and more OM with a relatively higher'

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 681: the PEf record actually does not always have its maxima in black shales. Perhaps mention the P concentrations themselves to strengthen the observation.

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 706: typo in would

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 721: replace sea bottom by either sea floor or bottom water

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 766: replace bottom by floor

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 769: replace waters by water

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 785: typo in oxygenation

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 835: replace are no evidences by is no evidence

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 844: replace depth by depths

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 862: typo in diagenetic

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 885: add the before OM

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 1076: replace supplies by supply

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 1090: delete sea

RESPONSE: AGREE. The manuscript will be revised accordingly.

L 1096: typo in significant

RESPONSE: AGREE. The manuscript will be revised accordingly.

Figure 4: replace 'Relief in the outcrop' by 'weathering profile'. Consider reverting the colour axis back, so that the peaks coincide with protruding beds and are more easily compared with the log.

RESPONSE: AGREE. Figure 4 will be modified accordingly.

Figure 13: This is an excellent summary of your findings and the different orbital configurations are explained well. Instead of Ti/Al and Si/Al, I recommend using the enrichment factors that you use in the text and other figures. As the role of productivity is not so well constrained, I recommend using a question mark after the claim of increased productivity. Similarly, you could consider including only low/high OM preservation in the text within the figure (rather than including the transport)

RESPONSE: AGREE. Figure 13 will be modified accordingly.