

## ***Interactive comment on “Testing the impact of stratigraphic uncertainty on spectral analyses of sedimentary series” by Mathieu Martinez et al.***

**Mathieu Martinez et al.**

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**Christian Zeeden (CZ): the La Thure series shows both precession and obliquity. Could you exemplarily discuss what the result from your test means for this example record, and how it aids the interpretation?**

» The authors: This example is indeed interesting because both obliquity and precession have been observed (De Vleeschouwer et al., 2015), with obliquity having higher powers than precession. Several studies suggested that a dominance of obliquity in tropical sediments reflect cooling or icehouse conditions, while dominance of precession would be associated to greenhouse conditions (Zachos et al., 2001; Westerhold and Röhl, 2009; Boulila et al., 2011; ). With the implementation of our test we show that precession nearly vanishes at 15% of uncertainty. As a result, if one does not take into account this sampling bias on power spectrum one can misleadingly

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interpret a dominance of obliquity in sediments, which impacts in turn on the climatic interpretations.

**CZ: explain what the Nyquist frequency represents.**

» The authors: The Nyquist frequency is the highest frequency (or smallest period) that can be detected. It corresponds to the inverse of twice the sample step. This information will be added in the next version of the manuscript.

**CZ: you suggest uncertainty to be fully random. I propose to briefly discuss why you assume this – and what effect(s) systematic uncertainty may have.**

» The authors: We assume a fully random error, based on comparisons with actual data of sample distances repeatedly measured on the La Charce series. This comparison went as follows: In a first step, the thicknesses of the individual beds were measured and a lithologic log was drawn based on these measurements. In a second step, samples were taken from the studied section every 20 centimetres and the sample positions were indicated on the lithologic log. After this second step, we observed that the distances between two successive samples was not exactly 20 cm, but rather ranged from 10 cm to 30 cm, with an average of 19.7 cm and a standard deviation of 2.5 cm. This observation was made by comparing the expected stratigraphic position of the  $n$ th sample ( $n \times 20$  cm) with the stratigraphic position of the bed the sample comes from in the lithologic log. The mismatch in sample position between the lithologic log and the bed from which the sample was taken can be quantified for every sample within the studied stratigraphic interval. We evaluated the distribution of every sample's mismatch and observed a log-normal distribution. This observation is the basis for our suggestion to consider the stratigraphic uncertainty to be fully random.

In addition, the total thickness of the series was measured at 109,33 m. With this thickness we expected to take 547 samples. Instead, we took 555 samples. We thus

have an error of 8 samples out of 555 samples, either 1.4% difference. This is of course much lower than the actual thickness measurement error for individual sample distances, which implies no systematic error.

We will briefly discuss the absence of systematic error in the revised manuscript

**CZ: Lines 117-120: 106-116m is the overall spread in section thickness. From a conceptual point of view I think that this spread can hardly directly be used to estimate uncertainty in sample distance, because you see a result of  $\sim 550$  (gamma distributed) sample distances summed up. Several of these will be shorter and longer than 20 cm – so your relative uncertainty will probably be higher – or fully systematic.**

» The authors: The reviewer is right. On average, the error made to measure the entire section is lower than the error made to measure sample distances. On entire sections, systematic errors will have for consequence overestimate the thickness of certain parts of the section while other parts will be have underestimated thicknesses. Thus, the error made to measure the total thickness of the section will be lower than the distance between two successive points. Here, the error made to measure the total thickness of a section is rather used to provide a minimum amount of thickness uncertainty. It will be indeed very hard to do better on short distances than what is done on a long, average distance.

**CZ: Lines 143, 223: Do I understand correct that you interpolate all time series (also with spacing of  $\sim 0.2$  m and  $\sim 0.38$  m) at 0.01 m intervals? Is this necessary and useful, and does this oversampling influence your results?**

» The authors: When linearly interpolating at the average sample step of the original series, we can reduce the amplitude of the high frequencies, independently of the error made on measuring the sample distance (Hinnov et al., 2002). So we overinterpolated at 0.01m to not create this bias in the analysis. However, we acknowledge that this

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procedure results in an inflation of the AR-1 coefficient of the red-noise fit. In the revised version of the manuscript, we will linearly interpolate the series at the median sample distance, as also suggested by Linda Hinnov (the other referee). To limit the loss of power in the high frequencies, we designed an optimized interpolation scheme, that will be applied in the revised version of the manuscript. This optimized strategy will be based on the minimal average offset between the original sample positions and the interpolated sample positions.

**CZ: Lines 159-164: Your approach is good, but personally I would propose to also determine 95% confidence intervals of power by considering not only the average power spectrum from simulations. This may facilitate to compare (integrated) precession and obliquity power for paleoclimate studies.**

» The authors: This is a great idea! That will be applied in the next version of the manuscript

**CZ: 175ff: a table summarizing the results presented may be helpful in addition.**

» The authors: Another great idea to make the results clearer and present them in a concise form that will help the readers

**CZ: In Fig. 4 the confidence levels of the MTM and Lomb-Scargle spectra are different. I would propose to mention this in the figure caption.**

» The authors: That's true! We will explicitly mention that in the next version of the manuscript

**CZ: 10, 13: maybe express Nyquist frequency as sampling interval to be clearer**

» The authors: This is another good idea to make the things clearer! Knowing the fact that the Nyquist frequency is twice the sample step, it is very easy to convert the

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percentage of the Nyquist frequency to number of sample steps. For instance, 20% of the Nyquist Frequency represents 10 times the sample step.

**CZ: 15-17: “In addition, the simulations indicate that taking at least 6-10 samples per precession cycle should allow calculation of robust power spectra estimates in the Milankovitch band.” – This is not limited to precession I think, what about a more general statement as ‘In addition, the simulations indicate that taking at least 6-10 samples per cycle should allow calculation of robust power spectra estimates in the respective cycle band’?**

» The authors: The reviewer is right. This requirement is actually valid for shortest cycle to be analysed, whatever its origin and period (obliquity, eccentricity or solar cycles).

**CZ: 28-29: “In core sediments, uncertainties in the sample position are also observed when performing physical sampling at very high resolution or because of core expansion phenomena (Hagelberg et al., 1995)” – suggestion: ‘In cored sediments, uncertainties in the sample position are also observed when performing physical sampling at very high resolution or because of core expansion phenomena (Hagelberg et al., 1995) or imperfect coring (Ruddiman et al., 1987):’**

» The authors: We would like to thank the reviewer for this suggestion. It is indeed very important to say that core sections are not devoid of bias. We will rephrase as suggested.

**CZ: 37-38: “In this study, we address this problem by quantifying the impact of such errors on the frequency, as well as the power of higher-frequency cycles.” ! the second part of this sentence (“the frequency, as well as the power of higher-frequency cycles”) may be ‘the frequency and power distributions’?**

» The authors: We thank the reviewer for this suggestion, which makes the sentence

much clear. We will rephrase as suggested.

**CZ: 42-44: This sentence seems in contradiction to the last sentence of the abstract, more consistent phrasing may solve this.**

» The authors: I think the reviewer refers to this sentence: “Based on our results, we suggest that one should take at least ~10 measurements per high-frequency cycle in order to provide robust estimates of the power of the high-frequency cycles.” And that is in contradiction with the last sentence of the abstract in which we said 6-10 samples per thinnest cycle targeted are necessary to identify all necessary cycles in the band we wish to explore. The authors apologize for this inconsistency and we will change “~10 measurements” by “6-10 samples per highest-frequency cycle...” for more consistency with the abstract.

**CZ: 48: delete ‘correctly’? 64: remove ‘easily’**

» The authors: OK for both

**CZ: 98/99: could you mention that these are Devonian, and give a rough age as for the La Charce section?**

» The authors: OK for precisising the ages of the sections. The ages of the La Thure section (Givetian, middle Devonian) are around 380 Ma (De Vleeschouwer and Parnell, 2014).

**CZ: 108: are the two brackets necessary?**

» The authors: Sorry for that misspelling. We will remove one of the brackets in the next version

**CZ: 119/120: “with an average of 110.3 ± 5.1 m, and a relative uncertainty of**

**4.6%” I would propose to mention that the “5.1 m” and “uncertainty of 4.6%” are estimated from only three experiments, and that these are regarded as representative, but may not be actually.**

» The authors: The comment from Linda Hinnov in page C2, bullet point 4, perfectly illustrates your comment: their team measured the La Charce section twice and found 112 m and 132 m thicknesses, either an average of  $122 \pm 10$  m. The uncertainty is  $(10/122 \cdot 100)$  8.2% of the total thickness of the series. So our estimate is based on published data, but according to the personal comments from Linda Hinnov, available online in the second referee comments, this can be larger from a team to another.

**CZ: 146: maybe give also reference to the R package used (‘dplR’)**

» The authors: We will mention that Lomb-Scargle analyses have been done with the dplR in the next version.

**CZ: 155: “The confidence levels of the datasets were calculated before randomisation and directly plotted to the simulated spectra.” I am unsure how this is meant, and I would suggest phrasing this more clearly.**

» The authors: The authors apologize for this unclear phrasing. That only means that we plotted in the 1,000 randomized spectra the AR1-confidence levels calculated in the original series to make easier the comparison of powers.

**CZ: 160-164: “Pori: the power spectrum before randomization” – as you calculate this for individual frequencies, following may be more clear: ‘Pori: power before randomization for a specific frequency’, same for Pave (if I understand this correct).**

» The authors: The reviewer is right. The rigorous phrasing should be: Pori(f): power before randomization at frequency f. The same for the others. We will rephrase in the next version of the manuscript

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**CZ: 172 “with 5% uncertainty” – maybe clarify as ‘with 5% stratigraphic uncertainty’**

» The authors: This change will be done

**CZ: 200: with “first frequency” ‘lowest frequency’ is meant I assume – could you clarify this?**

» The authors: The reviewer is right, and we now see that our phrasing was ambiguous because it depends if we read the spectrum from the left or from the right. The phrasing suggested by the reviewer should eliminate our ambiguous phrasing.

**CZ: 205-211: Please make clearer that geological data usually have no precise frequencies, but frequency ranges. You mention this, but I am not sure if everyone will understand this easily.**

» The authors: We suggest to mention after the sentence line 210: “For instance, because of variations of the sedimentation rates, the sedimentary expression of the orbital cycles is not focalised on specific frequencies but rather expressed on ranges of frequencies”

**CZ: 217: I am not sure if you need to mention “that the stratigraphic order of the samples in the raw series is preserved after randomisation” again. You develop this earlier in the manuscript.**

» The authors: We agree that this statement has been repeated and is superfluous in this line. We will delete this statement at 217 in the next version of the manuscript.

**CZ: 220f: “This difference realistically simulates small thickness errors, which accumulate when measuring successive sample steps.” – this can in my opinion**

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**be formulated better, and should highlight that errors may accumulate, or may also not accumulate but level out.-**

» The authors: We suggest the following sentence to rephrase: “this difference is interpreted as the simulation of small thickness measurement errors, which accumulate when measuring successive sample steps”.

**CZ: 241: “above 40% of the Nyquist frequency”, I would suggest to also mention the frequency, maybe in brackets after this statement. Maybe bring these ratios in direct reference to precession (e.g.  $\frac{1}{3}$ rd of precession frequency/wavelength), so that this is more clear for readers not so familiar with time series analysis.**

» The authors: ok for both suggest, and we will also precise the equivalent in terms of number of sample steps, as suggested in a previous comment from the reviewer.

**CZ: 258/59: “As in the case of the La Charce series, the stratigraphic order of the samples is preserved in the randomised series” – In my opinion this is clear by now in the manuscript, and does not need to be repeated.**

» The authors: OK for removing this piece of information

**CZ: 304: replace “powers” by “power”**

» The authors: OK

**CZ: 310: “result suggest” – one of these need an “s” in the end**

» The authors: result needs an “s” in the end

**CZ: 312/13: “This requires that more than 6 samples per precession cycle have to be taken” - samples or measurements?**

» The authors: The authors see the ambiguity and regret it. We are talking about number of samples to take per precession cycles. This will be clarified in the manuscript

**CZ: 355: 356: maybe also refer to (Meyers, 2015; Shackleton et al., 1995)**

» The authors: OK for adding the references

**CZ: 396: “on the field” – in the field?**

» The authors: The correct expression is “in the field”. Will be corrected in the next version

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