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Climate of the Past Discussions

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

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2. The error model

Linda Hinnov (LA): The authors call on the gamma probability density distribution to characterize stratigraphic sampling. Here there could be more explanation, e.g., a simple illustration of the problem, i.e., in Figure 1 add a diagram of a hypothetical stratigraphic section, different sampling sequences, and their histograms – perhaps the same ones as presented in Figure 2);
» The authors: We thank the reviewer for this interesting suggestion that will help the reader to understand the problem. We actually have prepared a figure to illustrate the problem showing a hypothetical series with positions of samples obviously non

equally spaced. The diagrams used in real examples will be reused here, as suggested

LA: in Figure 1 caption indicate "gampdf(x, k, θ)" and label horizontal axis as "x". The models presented in Figure 2 displayed in F, G and H: what values of k and θ do these correspond to?
» The authors: k and θ can be easily calculated using equations (3) and (4) of the manuscript. The mean sample distance is 1 unit in this case, and we performed the gamma test using setting the standard deviation at 0.05, 010 and 0.15 units respectively. In the 3 cases, k and θ values are as follows:
- standard deviation=0.05 units: θ=0.0025 and k=400
- standard deviation=0.10 units: θ=0.01 and k=100
- standard deviation=0.15 units: θ=0.0225 and k=44
This piece of information will be added in the revised version of the manuscript

4. Implementation of the models in the stratigraphic-uncertainty tests

LA: This reviewer can personally attest to the difficulty in measuring a consistent thickness for the same outcrop by different researchers - in my experience in one case: 112 m vs. 132 m! For overturned sections, any dip error committed will contribute to a positive bias in stratigraphic thickness measurements. There is undoubtedly such a problem in the steeply dipping Cretaceous section at La Charce examined in this paper.
» The authors: We thank the reviewer for this comment that was reused in the answer to referee 1. This example supports our idea that reaching a constant sample step on geological data is not trivial.

LA: On issues concerning methods, it is important to restrict interpolation to mean or median rate when applying AR noise models with MTM spectra (such as used in SSA-MTM Toolkit). The Devonian section has a mean sample rate of 0.38 m – not clear what the median rate is – and this is much larger than the interpolation to 0.01 m. The Cretaceous section has a mean sample rate of 0.20 m, so has a similar problem. The authors should recalculate the MTM analysis with interpolation to the median sample spacing of the two sections. (The red noise spectra will be significantly different because of the way the autocorrelation lag-1 coefficient is calculated.) The other parameter that requires reporting is whether "log" or "linear" fitting was enabled in the calculation of robust red noise for the MTM spectra.

» The authors: The other reviewer (Christian Zeeden) has also commented on the overinterpolation procedure. Basically, we will provide a new method of interpolation, in order to optimize this step and limiting the loss of power in the high frequencies, that naturally occurs when resampling at the mean sample distance (see Hinnov et al., 2003).

As for the comment on the linear or log-fit, we employed a linear fit, from Meyers' astrochron ML96 function. In this function, the method for calculating the background median smooth fit has been modified by entering a Tukey's robust end point rule for the very low frequencies, which allows the level of lag-1 coefficient to be increased. This is below what the help of mtm.ML96 function says:

"*This function conducts the Mann and Lees (1996; ML96) "robust red noise" analysis, with an improved median smoothing approach. The original Mann and Lees (1996) approach applies a truncation of the median smoothing window to include fewer frequencies near the edges of the spectrum; while truncation is required, its implementation in the original method often results in an "edge effect" that can produce excess false positive rates at low frequencies, commonly within the eccentricity-band (Meyers, 2012).*

To help address this issue, an alternative median smoothing approach is applied that

implements Tukey's robust end-point rule and symmetrical medians (see the function runmed for details)."

5. Application to a sum of sinusoids

LA: This section quantifies the loss of power at high frequencies with increasing uncertainty of (variability in) the sample step sequence for a simulated sum-of-sinusoids series. The absence of windowing in the Lomb-Scargle (LS) spectra would be expected to result in higher spectral variance compared to multitaper-windowed MTM spectra, and may account for the elevated grey spectra from the LS Monte Carlo simulations (compared to those of the MTM spectra). Interestingly, for 10% and 15% σ, loss of power occurs at practically the same frequencies in both MTM and LS spectra. Would it be possible to indicate the expected variance in Nyquist frequency for the 3 cases (5%, 10%, 15%) in order to understand the accuracy of the MTM and LS spectra? A new order of the graphs in Figures 2 and 3 might benefit the presentation:

- New Figure 2: display Figs. 2F, G, H only, and explain how these relate to k and θ (or put them into a Figure 1B).
- New Figure 3: in top row, display Fig. 2A, B, C, D; bottom row display Fig. 3A, B, C, D.
- Figs. 2E and 3E could be placed into a new figure.

» The authors: We will modify the figures as suggested and ask the reviewer to further clarification about the variance question.

LA: What did we learn from this exercise and how will it help with the interpretation of the geological datasets to follow?
» The authors: This exercise is performed on a pure sinusoid signal, not related to any geological data, and having an arbitrary sample step. It shows the general pattern of disturbing the sampling interval on the power spectrum, independently of the nature of the geological data (finite length, noisy and non-strictly periodic). In this case, the power spectrum can be controlled and be fixed as equal for all spectral peaks, which helps to examine the relative change in power throughout the spectrum.

6. Application to geological datasets

LA: The MTM spectrum of the Devonian series (Figure 4D) shows a robust red noise model with extremely elevated low frequencies, implying that a "log" fit was calculated in SSAMTM Toolkit, and that the model suffers additionally from the 0.01 m interpolation (see comments for Section 4). Some of the text in this section about differences in red noise calculations (which by the way are not meaningfully explained) may not be needed once the interpolation problem is addressed.
» The authors: To calculate the spectrum of the La Thure section with the confidence levels, we used the mtm.ML96 function from astrochron package. A linear model of background fit wasd used (please find below the code line we applied:

```
ML96_1 = mtmML96(dat_pad1,tbw=2,ntap=3,padfac=1,demean=T,detrend=T,medsmooth=0
opt=3,linLog=1,siglevel=0.95,output=1,CLpwr=T,xmin=0,xmax=1/(2*dtmoy),
sigID=F,pl=2,genplot=F,verbose=F)
```

linLog=1 means we used a linear fit model.

Definitely, we will re-fix the resample step at the median sample distance, which is 0.30 m.

7. Discussion

LA: The main point of this study is that sampling is the critical decision that must be made when evaluating a stratigraphic sequence for paleoclimate signals. Almost all problems can be controlled with high-density sampling, e.g., 6-10 samples per putative precession cycle. It appears that one can easily expect 5% errors in stratigraphic position measurements, which combined with sedimentation rate variations, will mix the highest frequencies of a sampled sequence. Thus we are always alarmed at how low in power – and misaligned – precession cycles are in stratigraphic spectra. In the end, one never knows if a sample that has been collected has been assigned to its true stratigraphic position. This is an important limitation that is under-appreciated by the geological community and the authors should be commended for tackling this problem.
» The authors: We thank the reviewer for this very positive comment, which will probably feed the discussion of the revised version of the manuscript.

LA: A number of issues have been left unexplored: (1) how does systematic sample position error, such as can occur with receded marls alternating with prominent limestones in outcrops, affect stratigraphic spectra; (2) can astronomical tuning bypass the positional uncertainty problem (notwithstanding the recent approach described in Zeeden et al., 2015); and (3) how does the positional uncertainty problem affect the red noise model estimates?
» The authors: For question (1), we have shown to the other reviewer that the error is not systematic but fully random, even in the case of alternating sedimentation.

» For question (2), the error in the sample position acts on average like variations of the sedimentation rate: it decreases the power spectrum in the high frequencies, and distributes the power of the obliquity and precession over a large range of frequencies. The approach of Zeeden et al (2015) applies a very wide bandpass filter which should limit the effect of such error, because a large of frequencies are taken into account in the filter. However, we acknowledge that in spectra of sedimentary series, it is common to observe a band of frequencies between the obliquity and precession for which we don't know if they are related to one or the other cycle. A combination of methods involving wide filters and evolutive spectral analysis should help in resolving this issue.
» For question (3), this is an interesting question, and actually at this point, we do not have the answer to this question. However, this could be the topic of a follow-up study.

Other comments

LA: Lines 23-24: The Multi-Taper Method (Thomson, 1982) might be more accurately characterized as a spectrum estimator that is based on the Fourier Transform – not as a derivative of the Fourier Transform.
» The authors: The reviewer is right. The multi-taper method is roughly the average of Fourier Transforms of the series studied weighted by windows called Slepian sequences.

LA: Line 27: A recent massive improvement to the Jacob's staff in outcrop studies is terrestrial laser scanning with precision positioning at the mm level (Franceschi et al., 2011; Franceschi et al., 2015).
» The authors: We thank the reviewer for having provided us with this reference.

LA: Line 101: Change to "Pas et al., 2015".
» The authors: OK

LA: Lines 264- 265: what does the output of the "long-term trend of the variance" look like, and what was used to compute the "LOWESS regression with a 10% coefficient"?
» The authors: The figure of the detrend procedure will be added in the next version of the manuscript, and more information on the detrend procedure will be added

LA: Line 350: For monotonous stratigraphy yielding Milankovitch signal see also Latta et al., 2006.
» The authors: This reference is elder than the one we have cited in the original manuscript. OK to add this citation.

LA: Line 355: Change "require" to "requires"
» The authors: OK

LA: Line 361: Delete "Note than".
» The authors: OK

LA: Supplementary File: R package dplR appears to be used but not referenced in the main text. R is used to calculate REDFIT– is it provided in the dplR package?
» The authors: The authors are really sorry for having forgotten to cite dplR package. The other referee, Christian Zeeden, has also noticed that. As we cited the astrochron package from Stephen Meyers, we also have to cite cite dplR package, which will be done in the revised version of the manuscript.

References:

Hinnov, L.A., Schulz, M., Yiou, P., 2002. Interhemispheric space–time attributes of the Dansgaard–Oeschger oscillations between 100 and 0 ka. Quaternary Science Reviews 21, 1213-1228.

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