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Letter to the editor

Reply to the comment on "Rock magnetic cyclostratigraphy of the Doushantuo Formation, South China and its implications for the duration of the Shuram carbon isotope excursion"

Smith and Bailey (2018a) (henceforth SB2018) indicate in their comment on our recent study (Gong et al., 2017) that all of the cycles we identify as astronomically-forced in spectral analysis of rock magnetic data collected from the Doushantuo Formation from South China are instead "false positives". SB2018 state that we have not done an adequate job of testing the null hypothesis that the peaks are the result of random noise. SB2018 support their contention by generating a synthetic sequence of data points that is completely random noise, with no signal added, and apply the robust red noise model (Mann and Lees, 1996) that we used in our work to generate power spectra. Their analysis shows that no spectral peak rises above what are described as "periodogram-wide" confidence limits of the robust red noise. Furthermore, SB2018 state that the strong 4-m peak (in the stratigraphic domain) which we observe in our magnetic susceptibility (MS) and anhysteretic remanent magnetization (ARM) series is an artifact of the low-pass Gaussian notch filter that we used to prepare our data for spectral analysis.

SB2018 have made similar comments on a number of cyclostratigraphic studies using spectral analysis to identify astronomically-forced (Milankovitch) cycles: Bailey et al. (2009) on Kemp and Coe (2007); Smith et al. (2016) on Fang et al. (2015); Smith and Bailey (2017a) on Howe et al. (2016); Smith and Bailey (2017b) on Andrews et al. (2016); Smith and Bailey (2017c) on Perdiou et al. (2016); and Smith and Bailey (2018b) on Ruhl et al. (2016). The reply to the Smith et al. (2016) comment on Fang et al. (2015) by Hinnov et al. (2016), in particular, challenges the concerns raised by SB2018 about hypothesis testing similar to that in our work. We refer the reader to that reply rather than repeating the rigorous arguments made there.

Instead, first we address SB2018's comment that the long period spectral peak we interpreted as 405-kyr long orbital eccentricity is an artifact of low-pass Gaussian notch filtering the rock magnetic data in preparation for spectral analysis. We generated a synthetic astronomical signal (SAS) by combining sine waves with frequencies at 1/405 (long eccentricity), 1/128 and 1/95 (short eccentricity), 1/41 (obliquity), and 1/24, 1/22 and 1/19 (precession). To simulate the Doushantuo rock magnetic series, we tripled the amplitude of long and short eccentricities. The SAS assumes an accumulation rate of 1 cm/kyr, has 451 data points sampled at a 0.1 m spacing with a Nyquist frequency of 5.0 cycles/m, to mimic the Doushantuo rock magnetic series (Fig. 1a, left). Red noise (lag-1 autocorrelation coefficient $\rho = 0.5$) created using Analyseries software (Paillard et al., 1996), was added along with a mean and a linear trend to the SAS (Fig. 1b and c, left). Finally, we added a long-period variation equivalent to the > 45-m variation that was originally subtracted by the > 45-m low-pass Gaussian notch filter from the Doushantuo MS series (Fig. 1d, left). This > 45-m variation was rescaled with respect to the variance of SAS. Multitaper spectral analysis of these synthetic series was carried out in the Astrochron R package (Meyers, 2014; Fig. 1, right). Of note in Fig. 1b, right is that obliquity frequency power drops dramatically due to interference from the red noise (another realization of red noise might not cause such a drop). The addition of a mean and a linear trend significantly reduces the prominence of the long eccentricity in the spectrum (Fig. 1c, right); these effects are easily removed by detrending prior to the analysis. The strong intrusion of > 45-m power into the low-frequency portion of the spectrum causes the long eccentricity frequency to be completely buried in the red noise model (Fig. 1d, right), even after detrending (Fig. 1e). In fact, if we apply the original low-pass Gaussian notch filter in Gong et al. (2017), the interference of > 45-m variance is effectively removed (Fig. 1b, right).

It is clear that the influence of these very low frequency components requires countermeasures for their removal prior to the spectral analysis (detrending and low-pass notch filtering). SB2018 argue that the significance thresholds that we used should be raised for a "periodogram-wide" search for peaks above 95% and 99% confidence limits (CL's). These "periodogram-wide", or "global" CL's (99.9777% and 99.9955%) are displayed in the SAS analysis (Fig. 1, right) and show that by this measure, the long eccentricity peak is no longer "significant" in any of the spectra (Fig. 1b–e, right), and the longer of the short eccentricity terms also loses significance when detrending and low-pass notch filtering is not applied. The extreme null model CL's advocated by SB2018 should not be used if, as in this case, signal frequencies known to be present cannot be detected.

Next, we present multiple taper spectral analysis (Fig. 2) of our MS and ARM data using the Astrochron R package (Meyers, 2014) that employs both CL's of robust red noise and harmonic F-tests (Thomson, 1982) to identify significant spectral lines. In particular, the harmonic F test affords another statistical means for detecting significant spectral lines buried in noise and in part answers SB2018's criticism that our analysis lacked "periodogram-wide" testing. The data have been low-pass Gauss notch filtered for > 45-m variations (as in Gong et al., 2017) prior to the spectral analysis. This approach is justified based on the results given in Fig. 1.

Finally, we use average spectral misfit (ASM) analysis (Meyers and Sageman, 2007) to fit the spectral lines detected in the MS and ARM stratigraphic series, to a set of astronomically-forced periods ("astronomical target"). This target consists of long eccentricity (LE; 405 kyr), short eccentricity (SE; 95 kyr), obliquity (O; 31.9 kyr) and precession (P; 20.3 kyr), with O and P periods from Waltham (2015) for the Ediacaran (550 Ma), and assuming that long eccentricity has remained essentially invariant at 405 kyr through geologic time (Laskar et al., 2011). A target period for short eccentricity is less certain since it is normally made up of two main periods (128 kyr and 95 kyr) that vary in influence through time. We chose 95 kyr, which has the dominant power of the pair in astronomical solutions (e.g., Table 6 in Laskar et al., 2004), as our target for the ASM analysis.

The spectral analysis identifies the same spectral lines discussed in

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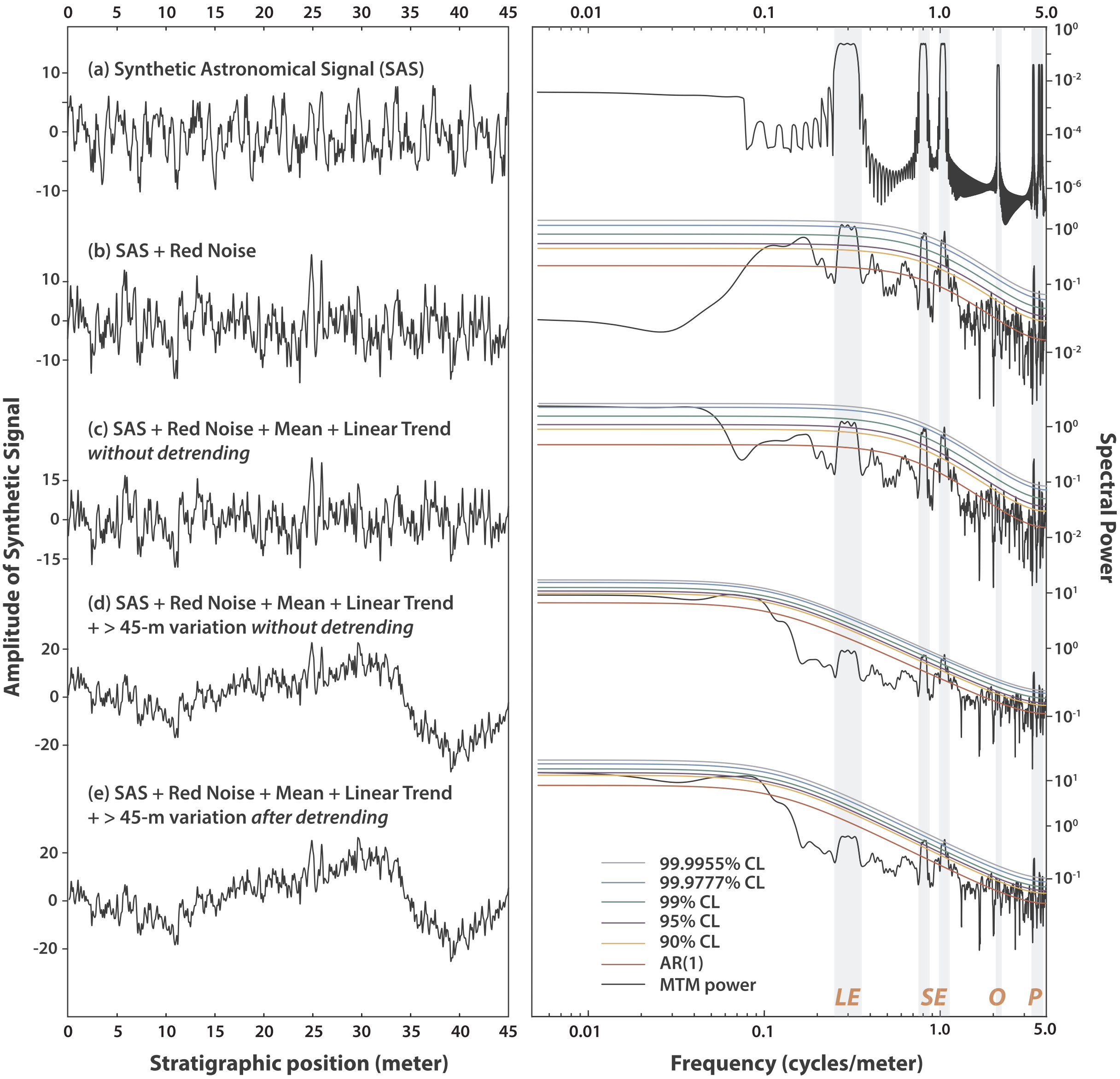

Fig. 1. Synthetic astronomical series (SAS) and 3π MTM spectra with AR1 robust red noise modeling using the function "mtmML96" in Astrochron R package (Meyers, 2014). CL = confidence limit, SAS = synthetic astronomical signal, LE = long orbital eccentricity, SE = short orbital eccentricity, O = obliquity, and P = precession. The mean and the slope of linear trend used are 0.039 and 0.001. The variance of the signal (σ^2 = 15.67), the variance of the red noise (σ^2 = 38.82), and the variance of the > 45-m variation (σ^2 = 316.7).

our previous work (Gong et al., 2017) for both the MS and ARM stratigraphic series, and the ASM analysis has fit these lines to the target astronomical periods with similar sediment accumulation rates (1.186 cm/kyr for MS and 1.285 cm/kyr for ARM; Fig. 2). The hypothesis testing indicates that these fits in both cases exceed the critical significance level for no astronomical signal. These results support our previous interpretation that we successfully identified a signal in our data, and that this signal records Ediacaran-age astronomically-forced climate cycles.

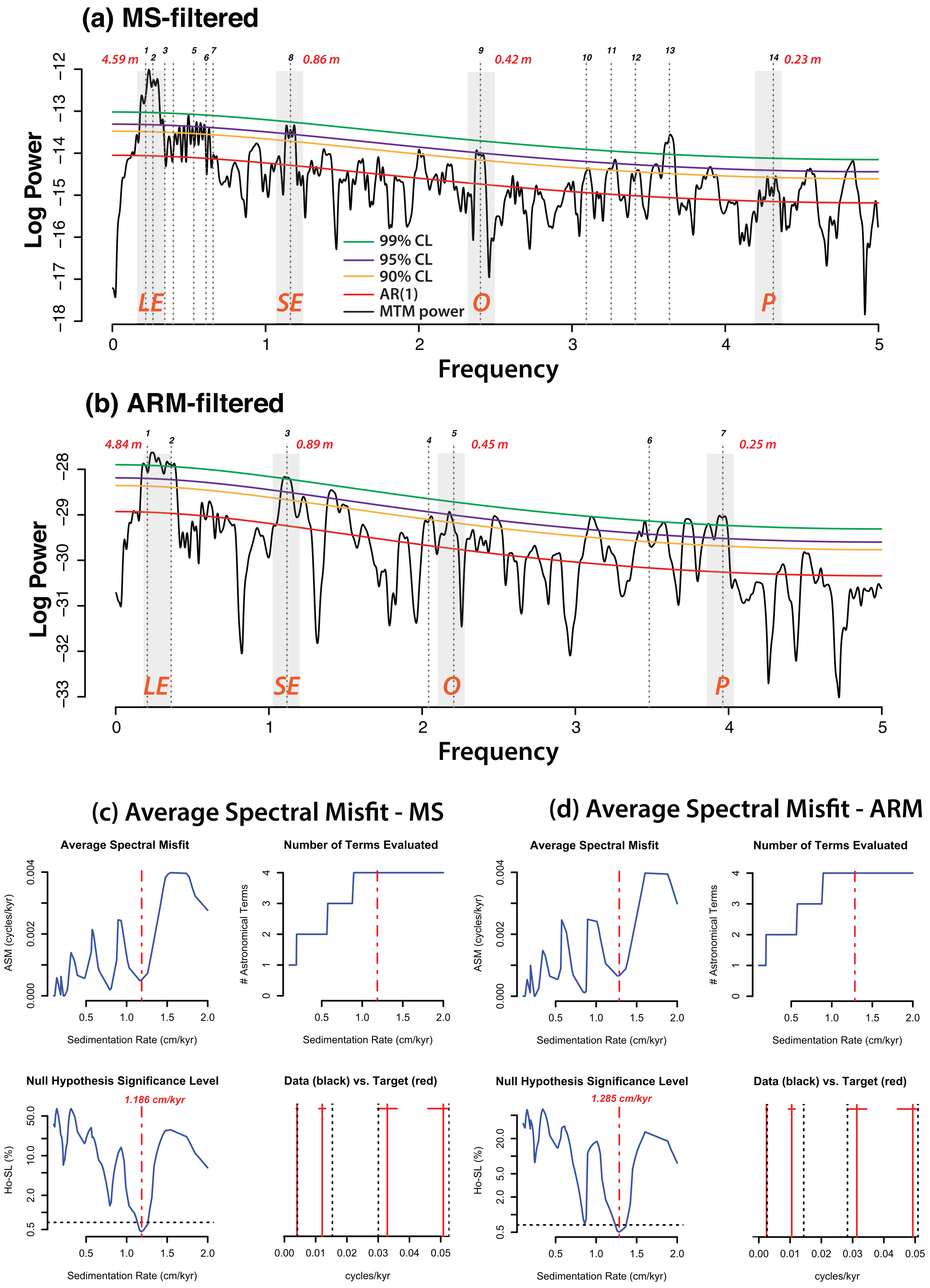

Fig. 2. 3π MTM spectra with significant harmonic lines using "mtmML96" in Astrochron, and ASM results for the notch-filtered rock magnetic series using "asm" in Astrochron R package (Meyers, 2014). The vertical dashed lines in (a) and (b) are identified significant spectral peaks. The wavelengths of identified significant peaks are labeled in red numbers. CL = confidence limit. LE = long orbital eccentricity, SE = short orbital eccentricity, O = obliquity, and P = precession. The horizontal dashed lines in (c) and (d) indicate the H_0 "critical significance limit" needed to reject the null hypothesis of no astronomical signal (Meyers and Sageman, 2007, p. 780).

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Discussions with Linda Hinnov greatly improved and focused this reply to SB2018's comment on our work.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.precamres.2018.03.008.

References

Andrews, S.D., Cornwell, D.G., Trewin, N.H., Hartley, A.J., Archer, S.G., 2016. A 2.3 million year lacustrine record of orbital forcing from the Devonian of northern Scotland. J. Geol. Soc. Lond. 173, 474–488.

Bailey, R., Smith, D., Kemp, D.B., Coe, A.L., 2009. A non-marine record of eccentricity forcing through the Upper Triassic of southwest England and its correlation with the Newark Basin astronomically calibrated geomagnetic polarity time scale from North America: COMMENT and REPLY. Geology 37, e186–e187.

Fang, Q., Wu, H., Hinnov, L.A., Jing, X., Wang, X., Jiang, Q., 2015. Geologic evidence for chaotic behavior of the planets and its constraints on the third-order eustatic sequences at the end of the Late Paleozoic Ice Age. Palaeogeogr. Palaeoclimatol. Palaeoecol. 440, 848–859.

Gong, Z., Kodama, K.P., Li, Y.X., 2017. Rock magnetic cyclostratigraphy of the Doushantuo Formation, South China and its implications for the duration of the Shuram carbon isotope excursion. Precambr. Res. 289, 62–74.

Hinnov, L.A., Wu, H., Fang, Q., 2016. Reply to the comment on "Geologic evidence for chaotic behavior of the planets and its constraints on the third-order eustatic sequences at the end of the Late Paleozoic Ice Age" by Qiang Fang, Huaichun Wu, Linda A. Hinnov, Xiuchun Jing, Xunlian Wang, and Qingchun Jiang [Palaeogeography Palaeoclimatology Palaeoecology 400 (2015) 848–859]. Palaeogeogr. Palaeoclimatol. Palaeoecol. 461, 475–480.

Howe, T.S., Corcoran, P.L., Longstaffe, F.J., Webb, E.A., Pratt, R.G., 2016. Climatic cycles recorded in glacially influenced rhythmites of the Gowganda Formation, Huronian Supergroup. Precambr. Res. 286, 269–280.

Kemp, D.B., Coe, A.L., 2007. A non-marine record of eccentricity forcing through the Upper Triassic of southwest England and its correlation with the Newark Basin astronomically calibrated geomagnetic polarity time scale from North America. Geology 35, 991–994.

Laskar, J., Fienga, A., Gastineau, M., Manche, H., 2011. La2010: a new orbital solution for the long term motion of the Earth. Astron. Astrophys. 532, A89.

Laskar, J., Robutel, P., Joutel, F., Gastineau, M., Correia, A.C.M., Levrard, B., 2004. A long term numerical solution for the insolation quantities of the Earth. Astron. Astrophys. 428, 261–285.

Mann, M.E., Lees, J.M., 1996. Robust estimation of background noise and signal detection in climatic time series. Clim. Change 33 (3), 409–445.

Meyers, S.R., 2014. Astrochron: an R package for astrochronology. http://cran.rproject.org/package=astrochron

Meyers, S.R., Sageman, B.B., 2007. Quantification of deep-time orbital forcing by average spectral misfit. Am. J. Sci. 307, 773–792.

Paillard, D., Labeyrie, L. D., Yiou, P., 1996. AnalySeries 1.0: a Macintosh software for the analysis of geophysical time-series. Eos, 77, 379.

Perdiou, A., Thibault, N., Anderskouv, K., Van Buchem, F., Buijs, G.J.A., Bjerrum, C.J., 2016. Orbital calibration of the late Campanian carbon isotope event in the North Sea. J. Geol. Soc. Lond. 173, 504–517.

Ruhl, M., Hesselbo, S.P., Hinnov, L., Jenkyns, H.C., Xu, W., Riding, J.B., Storm, M., Minisini, D., Ullmann, C.V., Leng, M.J., 2016. Astronomical constraints on the duration of the Early Jurassic Pliensbachian Stage and global climatic fluctuations. Earth Planetary Sci. Lett. 455, 149–165.

Smith, D.G., Bailey, R.J., 2018a. Comment on " Rock magnetic cyclostratigraphy of the Doushantuo Formation, South China and its implications for the duration of the Shuram carbon isotope excursion". Precambr. Res. http://dx.doi.org/10.1016/j.precamres.2017.04.016.

Smith, D.G., Bailey, R.J., 2018b. Comment on "Astronomical constraints on the duration of the Early Jurassic Pliensbachian Stage and global climatic fluctuations" [Earth Planet. Sci. Lett. 455 (2016) 149–165]. Earth Planetary Sci. Lett. 481, 412–414.

Smith, D.G., Bailey, R.J., 2017a. Discussion on 'Orbital calibration of the late Campanian carbon isotope event in the North Sea'. J. Geol. Soc. Lond. 173, 504–517.

Smith, D.G., Bailey, R.J., 2017b. Discussion on 'A 2.3 million year lacustrine record of orbital forcing from the Devonian of northern Scotland'. J. Geol. Soc. Lond. 173, 474–488.

Smith, D.G., Bailey, R.J., 2017c. Discussion: Howe, T. S., Corcoran, P. L., Longstaffe, F. J., Webb, E. A., and Pratt, R. G., 2016. Climatic cycles recorded in glacially influenced rhythmites of the Gowganda Formation, Huronian Supergroup. Precambr. Res. 286, 269–280.

Smith, D.G., Bailey, R.J., Vaughan, S., 2016. Comment on "Geologic evidence for chaotic behavior of the planets and its constraints on the third-order eustatic sequences at the end of the Late Paleozoic Ice Age" by Fang, Q., Wu, H., Hinnov, L. A., Jing, X., Wang, X., & Jiang, Q. [Palaeogeography, Palaeoclimatology, Palaeoecology, Volume 440, 15 December 2015, 848–859 (2015)]. Palaeogeogr. Palaeoclimatol. Palaeoecol. 461, 472–474.

Thomson, D.J., 1982. Spectrum estimation and harmonic analysis. Proc. IEEE 70, 1055–1096.

Waltham, D., 2015. Milankovitch period uncertainties and their impact on cyclostratigraphy. J. Sedimentary Res. 85, 990–998.

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