RC1:

"Secular and orbital-scale variability of equatorial Indian Ocean summer monsoon winds during the late Miocene" by Bolton et al. (CEREGE, Aix-en-Provence, France)

The manuscript by Bolton et al. presents new proxy records and an astronomically-tuned age-depth model from a recently-drilled IODP deep-ocean sediment core (U1443). Proxy records span the late Miocene (9 – 5 Ma) and include downcore benthic isotope records (d13C and d18O) and XRF-derived productivity-related and detrital-related elemental data. All proxy records are of sufficient resolution to resolve precession cycles, i.e. the shortest astronomical frequency. Based on their results, the authors present three important conclusions:

First, the authors observe a 3-fold increase in $CaCO_3$ mass accumulation rates at 8.66 Ma, but no change in their export productivity proxy log(Ba/Fe). They interpret this pattern as the result of a contemporaneous increase in coccolith productivity and improved preservation. This interpretation supports a weathering alkalinity and nutrient change as the driver for the expression of the so-called "biogenic bloom" in this region. Second, the authors infer that monsoonal dynamics throughout the studied interval are dominated by eccentricity-modulated precession on orbital timescale. Third, the authors do not find an intensification of the South Asian monsoon over the late Miocene, as has been proposed by some previous works.

The Site U1443 proxy records in themselves are precious and already deserve publication in their own right. The three conclusions that accompany them are an important step toward a mechanistic and regionally-differentiated understanding of late Miocene monsoon dynamics on orbital and geologic time scales. I thus recommend this paper for publication in Climate of the Past after minor revisions. Indeed, I would like the authors to consider my three major comments that could potentially make their paper even stronger.

We thank the reviewer for their really positive and constructive comments on our work.

Major comments

[1] Throughout the paper, the authors filter precession with a Tanner-Hilbert filter with a bandwidth between 40 and 46 cycles/Myr (22 – 25 kyr periodicities). This bandpass is too narrow to encompass all relevant precession components (see Table 1).

Table 1. Frequency decomposition of the precession of the Earth's axis, using g frequencies from Table 3 in Laskar et al. (2004) and the precession frequency of the Earth p = 50.475838 arcsec yr^{-1}. (p+g3) and (p+g4) are in red because they are important components of the precession frequency decomposition, yet they are not included in the used bandpass filter.

	"/year	cycles/Myr	kyr	Planet
p+g1	56.065838	43.26067747	23.1156805	Mercury
p+g2	57.927838	44.69740586	22.372663	Venus
p+g3	67.843838	52.34864043	19.1026929	Earth-Moon
p+g4	68.391838	52.77147994	18.9496296	Mars
p+g5	54.73329	42.23247685	23.6784597	Jupiter
p+g6	78.720838	60.74138735	16.4632394	Saturn
p+g7	53.563789	41.3300841	24.1954504	Uranus
p+g8	51.148859	39.46671219	25.3378086	Neptune
p+g9	50.125898	38.67739043	25.8548984	Pluto

The inclusion of the (p+g3) and (p+g4) terms in a precession-centred bandpass filter is important for the correct amplitude demodulation. This is because the four most important terms that compose short eccentricity involve (p+g3) or (p+g4).

Table 2. Frequency decomposition of the four most important terms in the short eccentricity evolution of the Earth's orbit. These four frequencies all involve either (p+g3) or (p+g4). When these terms are not included in a precession-centred bandpass filter, the short eccentricity terms cannot be extracted from the filter's amplitude demodulation.

	"/year	cycles/Myr	kyr	
(p+g3) - (p+g2)	9.916	7.651234568	130.697862	
(p+g4) - (p+g2)	10.464	8.074074074	123.853211	
(p+g3) - (p+g5)	13.110548	10.11616358	98.8517032	
(p+g4) - (p+g5)	13.658548	10.53900309	94.885635	

The consequences of too-narrow precession filtering clearly appear in Figure 10. The amplitude modulation signals only exhibit low-frequency variations at the rhythm of the 405-kyr eccentricity cycle. The 405-kyr appears in the authors' amplitude demodulation because is created by (p+g2)-(p+g5) and both terms are included in the 22 – 25 kyr precession filter. The 100-kyr terms however do not appear because they require the inclusion of the (p+g3) and (p+g4) terms into the precession filter. I would thus strongly recommend the authors to widen their precession filtering settings. This will markedly improve the results since it can already be recognized by eye that there are ~100-kyr amplitude modulation cycles embedded in the Ba_{xs} and log(Ba/Fe) time series (as well as in the SITIG forcing of course).

We thank the reviewer for this useful comment, and for the very thorough explanation that accompanied it. The original decision to filter at 22-25 kyr was based on the presence of significant spectral peaks only within this band (and the absence of spectral peaks at ~19 kyr) in the MTM spectral analyses of Ba proxies, but we now see how this decision biased our results. We have widened the precession filter to include all of the relevant terms, and the new filter covers 18-26 kyr (frequency 46.5±8.5, 38-55 cycles/Myr). The 100-kyr amplitude modulation signal in now visible (as well as the 405 kyr one) in our filtered records in revised Fig. 10.

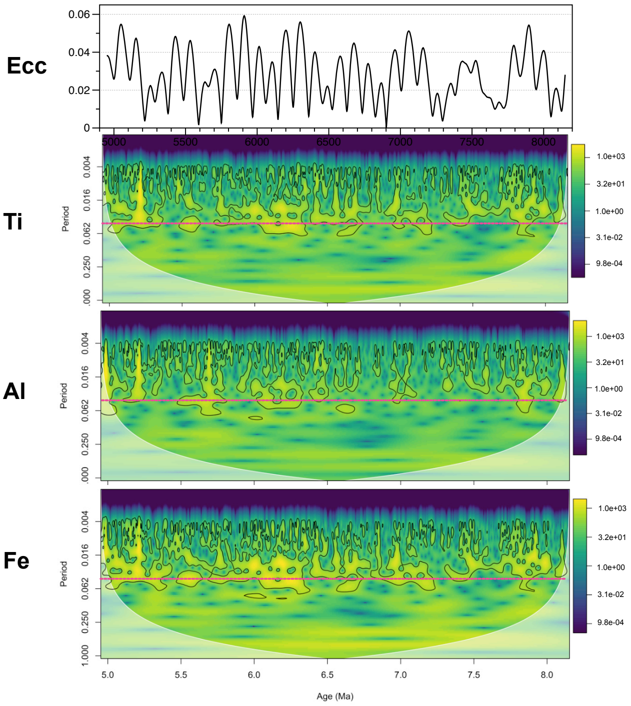
[2] I find the obliquity peaks in the detrital proxies (Ti, Fe and Al) in Figure 8a-c intriguing. They do have about the same spectral power than the precession peaks. The authors briefly discuss the possibility that this result might indicate a decoupling between monsoon winds (driving productivity on precession timescales) and monsoon precipitation (terrigenous variability on obliquity timescales) [lines 617 – 621]. I would encourage the authors to explore this observation a little deeper. Does wavelet analysis show that obliquity primarily appears when eccentricity is low? Are there any modelling studies that corroborate this idea?

We also find the stronger 41-kyr variability in detrital proxies really interesting, and despite digging into the literature on this subject, we have yet to find a satisfactory explanation for the stronger obliquity signal in the runoff-related elements than in the wind-driven productivity signal.

Clemens *et al*. (2021) show that 100 kyr and 41 kyr variability are at least as important as precession in Pleistocene proxy records of monsoon precipitation/runoff in the Bay of Bengal, and suggest that summer monsoon precipitation is strongly influenced by global boundary conditions related to ice-volume and greenhouse gas feedbacks (which in the late Miocene, fluctuate on 41-kyr timescales). On the other hand, obliquity forcing of tropical climate has been shown to occur independently of high-latitude ice-sheet growth and decay as a result of interhemispheric insolation gradients (Bosmans et al., 2015). Yet changes in cross-equatorial moisture transport (and therefore monsoon precipitation) on precession and obliquity timescales related to the SITIG are expected to be coupled to changes in South Asian monsoon wind intensity, so this does not help reconcile the stronger obliquity signal in runoff relative to wind proxies at Site U1443 (although we note that a lower significance obliquity peak is visible in the $[Ba]_{xs}$ spectrum, and the cross-spectral analysis of the ~6.2-5 Ma interval of the $[Ba]_{xs}$ record with the Site U1448 seawater $\delta^{18}O$ record shows significant obliquity – Fig. S3c).

A strong response to obliquity forcing was also recorded in late Miocene monsoonal runoff records in the eastern Bay of Bengal and was interpreted as related to changes in latitudinal and interhemispheric temperature gradients (Jöhnck et al., 2020). Model results show increased SE Asian summer monsoon precipitation and a northward shift of convection from ocean to land at minimum precession and maximum obliquity (Bosmans et al., 2018). The same set of fully coupled high-resolution models indicate a more complex and spatially heterogenous response of South Asian summer monsoon precipitation. In these models, wind speed is increased over the southern hemisphere tropical Indian Ocean for both precession and obliquity (Bosmans et al 2018), which likely is reflected in the orbital signature of the Site U1443 productivity records. A recent study using a coupled atmosphere–ocean general circulation model with emphasis on the relative roles of precession and obliquity changes also suggests that dynamic effects (changes in winds) dominate the monsoonal response to both precession and obliquity forcing in most monsoonal systems (Ding et al., 2020).

Wavelet analyses for Fe, Al and Ti (see below, contours are 95% confidence intervals and pink line shows 41 kyr period) do not appear to indicate a correlation between strong obliquity variance and low eccentricity.



We have expanded the discussion of obliquity forcing of monsoon runoff in the revised manuscript, although the mechanisms behind the relatively stronger obliquity signal in runoff (terrigenous sedimentation) records compared to summer monsoon wind (export productivity) records at Site U1443 remain unexplained.

[3] The introduction nicely displays how there are two productivity peaks per year in the Bay of Bengal. This annual course creates the potential for half-precession cycles in the Barium-related productivity proxies. Indeed, one might expect productivity to be fuelled both during a precession minimum (stronger summer winds) and during a precession maximum (stronger winter winds). This potential is not discussed in the paper, yet the temporal resolution of the Ba proxies (<1 kyr) does allow the authors to report on the presence or absence of such cycles.

We agree with the reviewer that the absence of a semi-precession signal in our high-resolution Ba records, despite the near-equatorial location of our site and the double annual primary productivity peak in the modern ocean, is really interesting.

In the late Pleistocene at Site 758/U1443, a strong half-precession signal is detected in upper-water column stratification proxy records (Bolton et al 2013). Based on our interpretation of modern oceanographic data, we expect upper-ocean stratification and productivity to be coupled at this location, however we currently lack paleoproductivity data on these same Pleistocene samples to verify this (this is something we are working on).

One explanation for the lack of a half-precession signal in paleoproductivity proxies at this location might be related to the fact that export productivity (i.e. the fraction of net primary productivity that ends up accumulating in underlying sediments) is heavily biased towards the late summer monsoon season, perhaps as a result of increased ballasting by the higher concentration of biogenic particles and by terrigenous particles carried into the BOB by runoff. In Figure 2, although net primary productivity displays two clear peaks over the annual cycle, particle fluxes to deep sediment traps (~3000m) show a much smaller ($CaCO_3$) or absent (particulate organic carbon and biogenic silica) peak associated with the winter monsoon. Thus, we think that the export productivity recorded in Site U1443 sediments represents first and foremost the summer monsoon (this is mentioned in Section 2). In the discussion (Section 5.2), we now explicitly discuss the lack of semi-precession signal in our records, and relate it back to the bias in particle export.

We also now note that the lack of a semi-precession signal in our records corroborates the idea that the SITIG (the summer inter-tropical insolation gradient), rather than local insolation (which contains a significant half-precession component between the equator and 5° latitude), was a primary driver of export productivity variations at our site.

Minor Comments

Throughout: A lot of acronyms are used. To my taste, a little too much. Please consider whether you could spell out some of them. For example: BOB, NER, SMC, MLD, NPP, …
We have removed the following acronyms from the main text to improve readability (some are still mentioned in figure captions only in relation to annotations): SMC, POC, NPP, SAR.

Lines 60-65: The use of X versus Y does not work well in all cases. I would recommend to spell out the contrast you would like the reader to consider.
We have tried to clarify this.

Line 91: Also check out Ding et al. (2021), Climate Dynamics 56
Thanks, we have added this reference.

Line 136: In … In … Delete repeated wording
corrected

Line 177: The geographic coordinates could be a little more precise.
Corrected (co-ordinates differ slightly for Holes A-D, we used Hole A co-ordinates)

Line 185: It is not exactly clear to me which splice has been used. There are two U1443 splices online on the IODP LIMS database, but both are already more than 5 years old. The authors should make the affine and splice tables available in the supplements, or on Pangaea, or cite a reference where the splice is available.
Sorry that this was not clear. We have added a table to the Supplementary File (new Table S1) listing splice intervals.

Line 204: avoid subjective qualifiers like "small"
This has been changed to 1° by 2° box.

Line 236: Replace "high-resolution" by "~1 meter resolution"
This has been changed to ~0.5-1m resolution

Line 345: What exactly is meant by "spectral analyses … on filtered records". Why would one do bandpass filtering prior to spectral analysis in this case?
What we mean here is that we carried out spectral analyses on records that had been detrended (filtered to remove signals with periods longer than one third of the length of the dataset (>1.6 Ma) using the "bandpass" function in Astrochron), so that long-term trends did not lead to a low-frequency period dominating the power spectra. We have clarified this in the text.

Line 371: The y-axes of the phase graphs are not very helpful, and even a bit misleading. Please cut them off at -180° and +180°. Of course, confidence intervals can go beyond this range, but it should be clear that -180° = +180° = anti-phased behaviour.
Thanks for this comment. We have changed the axes (and grid lines) on all cross-spectral phase plots so that they are limited at -180° and +180°, and have clarified that both 180 and -180° phases indicate anti-phased behaviour in the caption (Fig. S3).

Lines 444 – 456: I miss a statement here about the step-wise character of the MAR series. It should be acknowledged that these steps in MAR are related to age-model-induced stepped sedimentation rate changes.
We have added the following statement: "The stepwise nature of MAR records results from age model-imposed stepped changes in sedimentation rate."

Line 544: Section 5.3
Corrected

Line 1259: Section 3.1
Corrected

References cited

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