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Interactive comment on "Frequency, magnitude and character of hyperthermal events at the onset of the Early Eocene Climatic Optimum" *by* V. Lauretano et al.

V. Lauretano et al.

v.lauretano@uu.nl

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We thank Prof. Lee Kump for his constructive comments on our manuscript. We have addressed his comments below (reviewer comments: "RC"; author comments: "AC"), and have revised our manuscript accordingly. RC: Lauretano et al. present a valuable update to the previous assessments by Stap et al. (2010) and Kirtland Turner et al. (2014) of coupled carbon cycle and climate variations in the lead-up to the Early Eocene Climate Optimum, as revealed in the carbon and oxygen isotopic compositions of benthic foraminifera. The analyses are of high quality and the interpretations sound. They show that the d13C and d18O variations at eccentricity time scales are in

sync and follow similar trajectories, implying similar drivers of change. Slightly steeper slopes for the second of one-two punches (ETM2-H2 and I1-I2) are interpreted to imply that a heavier carbon source contributed to the follow-up events. My only broad suggestion is to make more of the data at hand; rather than simply reporting the correlations, interpret them more deeply and quantitatively. I'll expand upon this as I progress through the manuscript, but it seems to me that the slope is telling us about the source, given what we understand about climate sensitivity. And it seems like a lack of lag between d13C and d18O tells us about reservoir sizes and pacings.

AC: We thank the reviewer for this comment, in agreement with reviewer #2, Dr. Sexton, as it gives us the opportunity to expand on the possible carbon sources in a more quantitative way. Although carbon cycle/climate modeling is beyond the scope of this paper and our expertise, we try here to address it with some speculation and simple computations.

We applied the suggested "back of the envelope" approach, following model results by Panchuck et al. (2008) for the different sources. Based on the observed CIEs for our six events, we calculated the estimated amounts of carbon involved for each event (550 Gt C for a -60‰ source or 1700 Gt for -22‰ required for an observed 1‰ change in δ13C). We applied a conversion factor of $\sim$2.12 Gt (or Pg) of C per 1 ppm of CO2 (Hansen et al., 2013). As baseline conditions, we assume a pCO2 of 750 ppm, as this is considered within the range of estimates for late Paleocene pCO2 (Panchuck et al., 2008). We then compared the observed temperature changes with the results obtained for different scenarios (1.5°–6°C) of climate sensitivity. Assuming climate sensitivity to be invariant on short-term timescales, the -22‰ source would produce the same temperature response we observe for H2 and I2 based on benthic δ18O for a 3°C change per doubling of pCO2, which is the canonical value for fast-feedback sensitivity (IPCC, 2007). In the case of the other events (ETM2, I1, J and ETM3) a mass of C with a -22‰ source would overestimate the temperature response while a methane source would underestimate it.

However, this kind of reasoning might be misleading if solely based on our data. Our calculations derive from assumptions concerning the initial baseline conditions, which were probably higher than 750 ppm after the PETM, based on the warming baseline observed in the long-term δ18O records (Littler et al., 2014). Also, it is not clear whether benthic foraminiferal isotope data alone can actually be used to support this sort of discussion, as climate sensitivity necessarily depends on atmosphere/surface temperature. Constraining the specific contributions of each source and/or climate sensitivity would be very difficult to defend with the existing data. We have added to the manuscript a similar sort of discussion as proposed in our comments above.

RC: "p. 1797 line 21 and elsewhere: ..ly modifiers don't take hyphens" AC: Changed accordingly

RC "p. 1799 line 3-5: Site 1263 suffered some dissolution and developed a clay layer during the PETM, so it didn't remain well above the lysocline throughout the Paleogene." AC: Thanks for the remark. This sentence has been removed, as it was inaccurate.

RC: "p. 1803 line 26: Need to be clear what the Oligocene-Miocene mechanisms were; expand this sentence." AC: We are referring to the mechanisms proposed by Pälike et al. (2006) for the Oligocene, and Holbourn et al. (2007) for the middle Miocene that link variability in the carbon cycle and climate system response to orbital forcing, specifically at eccentricity periods. This sentence has been expanded in the revised version and references to those papers added.

RC: "p. 1804 line 14: It should be quite straightforward to take this constancy of slope a step further, to predict the temperature response (simply multiply d18O by the 4.38 slope of eq. 1) per Pg of C added for a given source (following, for example, Panchuk et al., Geology 2008, v. 36, p. 315-318). A source of about -60 per mil (methane) requires about 550 Pg per permil change (Panchuk et al., 2008) whereas a source at -22 per mil requires about 1700 Pg per permil. So one can estimate the warming

inferred by a slope of 0.5 or 0.6 to be about 2.2oC per (either 550 Pg or 1700 Pg) carbon emitted. You can further use the airborne fractions revealed in the Panchuk et al. paper to calculate a climate sensitivity, and see if that's reasonable presuming either a methane or organic matter source for the CO2.

RC: "p. 1805 line 6: The difference in slope is so small (0.5 vs. 0.6) compared to the lever between -60 and -25 per mil, that I don't think you can say much about the need for a heavier source. Maybe a better way to put this, and consistent with the comment above, I think the paper would benefit from some quantification based on these slopes and the sort of back of the envelope approach I describe."

AC: We have combined both of these comments in the broader recommendation made by the reviewer at the start of our response.

RC: "p. 1806, line 3: I don't know what the authors mean by "scaled biotic response." Perhaps they could state this more clearly." AC: We are referring to the work of Gibbs et al. (2012) where the authors investigate marine biotic variability over 3 Myrs, across five hyperthermals (PETM to I2). Applying a coefficient of variation technique, the authors quantify rates of variation in nannofossil abundance records and compare the results with different planktonic groups. Their findings reveal that the levels of assemblage variability in planktonic data are linearly related to the magnitude of environmental changes associated to these hyperthermal events. That is, the biotic disruption associated with the hyperthermals is declining as the CIEs decrease in size. Moreover, H2 and I2 do not show anomalous values in the coefficient of variation suggesting that the biotic sensitivity of these nannoplankton communities displayed a "threshold behavior". This may be linked to CIEs greater than 0.6 ‰ and a thermal threshold of $\sim$2°C of global warming.

In the revised version of our manuscript this sentence has been expanded to clarify the concept of "scaled biotic response" to the reader, as we agree that it could have been confusing in such a short statement.

RC: “p. 1806, line 16: The ocean doesn’t necessarily get colder with depth, it gets denser. So the authors can’t make the conclusion here that the shallower water is saltier (and hence higher d18O). Site 1263 waters could be colder but fresher than site 1262 waters, or saltier but warmer; you can’t use the relative depths to differentiate those two possibilities for why the forams at 1263 have heavier isotopic values. AC: This is a fair comment, and something we are well aware of. Our assumption of depth-dependence temperature change is just one interpretation. We cannot rule out other combinations of temperature and salinity with the data at hand. However, we do suggest that two different water masses are involved. This section has been rephrased in the revised version.

RC: “p. 1807, line 3: Organic carbon isn’t being released into the ocean-atmosphere system; CO2 generated from the oxidation of organic matter might be. . . be more precise with the language.” AC: Thank you for the remark. The sentence has been rephrased.

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