Response to Reviewer#1

Premise:
We thank Reviewer #1 for his/her careful and constructive review of our manuscript. Overall, we have followed this referee's suggestions, although with some exceptions that we explain below. The commentary has improved the manuscript significantly.

This is a very interesting paper that presents integrated calcareous nannofossils and stable isotope data at high-resolution, and addresses paleoceanographical, paleoclimatic questions for one of the most impressive hyperthermal events of the Earth's history. I am quite impressed by the quantity and the quality of data presented in this paper. Of course, I have comments and remarks but these have to be seen by the authors as challenging questions aiming at improving their nearly excellent paper.

We appreciate this commentary.

Methods Preparation techniques.
Semi-quantitative abundance of nannofossils can be biased by a variable rock powder concentration in different slides, because the preparation technique used in this paper does not guarantee a perfectly homogeneous distribution or constant quantity of material on different smear slide. In order to be sure that powder amount is comparable form a slide to another, you can weight cover slides once rock powder is spread on or, alternatively, evaluate the particle density under optical microscope using some table for evaluating grain density in a rock (e.g., Baccelle & Bosellini 1965). Of course, as you have studied here 200 smear slides, you cannot re-study all of them. However, I suggest you to evaluate the rock powder density in some 20 slides that will allow you to test this parameter and probably obtain an error bar of % of variation in nannofossil abundances from one sample to another.

This is a good point. Actually, we do not say anything about but we have already tested if the number of specimens could vary significantly. The results highlight that a crucial role is played by the operator. The same sample was prepared 10 times by two different operators. Counts of the same sample are not significantly different one to each other (sd < 2-5%). Regarding the estimation of the particle density of the study samples, methods suggested by reviewer #1 can be better applied on pelagic calcareous oozes/limestones, which are made of 80-100% of $CaCO_3$ *(e.g., Minoletti, 2002; Stoll and and Bains, 2003; Minoletti et al., 2005), but our material shows instead a high variability in terrigenous content (22 to 90%), which implies that the dilution effect of terrigenous component could produce some distortions. For instance, clay-rich samples have a lower number of specimens (lower density) with respect to carbonate–rich samples having the same weight. This would be the result of dilution but also of low calcareous nannofossil productivity. Disentangling this issue, it is a quite difficult task though some authors have proposed that marls document higher temperature conditions with enhanced run-off and a higher discharge of nutrients to the ocean (higher productivity), while limestones record cooler temperatures with reduced run-off and lower nutrient availability (lower productivity) (e.g., Rossignol-Strick, 1985; Beltran et al., 2007). Back to our issue, a homogeneous/constant particle density or weight of our study samples could not assure for a correct estimation of calcareous nannofossil semi-quantitative abundance as a proxy paleoproductivity. Marls (higher productivity conditions) usually show a lower particle density for* *the dilution effect not because of the number effectively produced in a time unit. We have added a paragraph in the methods to explain why we prepared the same sample 10 times and which are the results in term of reproducibility. A second paragraph has been added on the possible effect in calcareous nannofossil abundance of variable terrigenous content*

PCA analysis. Although many nannofossil specialists, especially in deep time studies, apply PCA to calcareous nannofossil datasets, statistic and ecology specialists will tell you must not use PCA on this kind of dataset. There is a number of reasons why other techniques like non-metric multidimensional scaling or NMDS and CA are preferred over PCA, (1) PCA assumes that species have a linear regression with PCs, however, linear relationships in ecology are the exception and not the rule, (2) PCA is sensitive to zeros which is also quite common in palecological data on geological time scales, species that co-appear due to evolutionary patterns will group even if they inhabit different ecological niches. (3) Specifically, NMDS does not assume variable normality.â˘A ´l In spite of these arguments, you may prefer to use PCA, but I suggest you to at least transform % values into log values in order to avoid the closed-sum effect.

Yes, there are multiple statistical methods to capture changes in a given data set. And, as the reviewer correctly points out, the PCA has some drawbacks. However, other methods, such as NMDS, also have limitations. For example, in NMDS a small number of axes are explicitly chosen prior to the analysis and the data are fitted to these dimensions. A comment has added to the text to better explain why we have chosen the PCA analysis.
After thought, we have decided to use PCA, but we will incorporate the suggestion of Reviewer #1 and also use the log transformation of raw data in order to avoid the closed-sum effect.
Similarly to the previous PCA analysis, the new figures (Figure 10 and FigureS1) show that Paleocene samples are separated from Eocene samples and Component 1 can explain much of the variance (>40%) of the dataset. Moreover, the samples with lower values in Component 2 include all samples from across the PETM and some samples across other hyperthermals. All these patterns are consistent with previous statistical analyses. Since there are not substantial changes in the PCA results, there is no need to add/modify text but we have provided a new version of Figure 10 and a modified Figure S1 including a biplot and the loadings of Components 1 and 2.

References for PCA. References here are very partial. Do you only quote works on Paleogene (in this case you should cite it)? Either you cite all the papers using PCA on nannos (which would be too much) or you cite the oldest works plus 1-2 significant papers discussing limits and advantages of using PCA on nanno %.

Yes, this is always a good point. We have added several references to general papers (Aitchison, 1986; Davis, 1986; Kucera and Malmgren, 1998; Harper, 1999, Buccianti et al., 2006)

Discussion
Section 5.1 page 4347. Is this consistent with the fact that the PETM is preceded by several smaller CIEs? Would it be possible to make some simple mass-balance calculation in order to predict the mass of stored organic carbon needed to produce the PETM CIE after the B1/B2, C1/C2, D1/D2 CIEs occurred?

This exercise was tackled initially in Dickens (2003), but from a crude and awkward framework with an initial (already generated) carbon mass in the late Paleocene, rather than a truly dynamic model where shallow geosphere carbon reservoirs also grow through time. Lunt et al. (2010) elaborated upon this issue in more detail. Komar et al. (2013) revisited the problem, now including storage and release of carbon through time, but without specifically including rapid carbon injections during known and inferred hyperthermals. In fairness, all these models are pretty simplistic. The basic answer is "unknown".
There is a wonderful root problem embedded in records of the early Paleogene. Something is wrong in the community's (a) understanding as to how carbon cycles across Earth's surface, (b) interpretations of numerous records, (c) basic stratigraphy, of (d) a combination of all the above.
Although this comment lies beyond the scope of the current manuscript, it is a great one, and we appreciate. It is very much why we (and others) want to get lower Paleogene stratigraphic records properly aligned in detail. We have made no changes in the text on this issue (other than in the supplementary text, to address comments by Reviewer #2).

Section 5.5. This is a likely explanation, but the Cicogna section also received a more important terrigenous input than other "true" oceanic sites. Could this terrigenous input influence the13C record? What about the organic matter content of the section? Because, dissolved OM may release 12C and contribute to lower the 13C values. Please, discuss also these alternative hypotheses.

In principal, this is an important consideration. However, if one looks at C_{org} percentages available for the proximal Forada section, one can realize that C_{org} content is always very low, never exceeding 0.1% (Giusberti et al., 2007). Indeed, in most carbonate-rich sediment sections, both modern and in the past, the vast majority of total carbon is in carbonate. A discussion on the possible role played by C_{org} content in lowering the $\delta^{13}C$ value has been added in the text (paragraph 5.5).

Conclusions
This is rather a summary chapter. Either you name this 'Summary and conclusions' or you present the possible outlook of your work. E.g., the importance of studying more expanded sections in order to approach a paleoceanographic event, or the implications your work may have for a better comprehension of such events ...

OK, this is a good point. We have renamed the paragraph "Summary and Conclusions".

Minor corrections
Page 4334, line 6. At the seafloor, not at the CCD?

The sea floor is the place where CCD shallowing or deepening can be in fact recorded in the geological record. We have made no changes in the text.

Page 4334, line 24. Rost & Riebesell, maybe quote earlier references.

OK, this is a good point. We have added a couple of more references in the text (Milliman, 1993; Winter et al., 1994)

Page 4436, line 16, Why 1000 but not 1500 m depth? Please, provide a little explanation.

The paleodepth estimation is based on the benthic foraminiferal content (Giusberti et al., 2007; 2015). We have added this info to the text.

Page 4436, line 16, Height or thickness?
It is a stratigraphic height. We have added "stratigraphic" throughout the text.

Page 4339, line 19. Longitudinal?

We mean on the longer side of the slide. We have substituted "vertical traverses" with "long traverses"

Page 4343, line 7. Marginally?

Agree. We have corrected it in the text.

Page 4343, line 8. Absolute or semi-quantitative abundances?

Agree. This was not clear in the text, we meant "…relative, semi-quantitative and absolute abundance of calcareous nannofossil taxa". Semi-quantitative has been added to the text.

Page 4347, lines 8 and 9. You use twice 'must 'that is very strong. You can maybe use 'very likely' or something similar?

Agree. This has been changed in the text:"The compositional change must very likely represent…".

Page 4349, line 18. Means or mean?

Agree. We have changed it in the text.

Page 4350 and following. Please, explain the meaning of B, T, Tc etc. the first time you cite them. This may help non-specialists

Good point. This has been fixed in the 3.3 subsection of the materials and methods adding a sentence with this basic information.

Page 4353, line 9. Unsteady or transient? uneven?

Good point, the use of "unsteady" is ambiguous. We just mean that early Eocene calcareous nannoplankton lived in extreme environmental conditions, which effectively produced uneven and highly dynamic communities. We have substituted unsteady with uneven.

Page 4354, line 12 and following. Although K- and r-mode are terms used in works treating of fossil taxa, they must not. In fact, these are derived from measurements on living communities where the birth and death rates of organisms can be measured. I suggest you to use the terms 'specialist' and 'opportunist' instead.

This is true. We just perpetrated the incorrect used of these terms. The text has been modified in order to follow the reviewer #1's comment. K-mode and r-mode have been substituted with K specialist and r specialist.

Page 4354, line 28. Habitat partitioning?

Agree. We have added "habitat" in the text.

Page 4355, line 11. Can extreme conditions be stable? The PETM is characterised by intense but transient paleoceanographic changes. How can such conditions be favourable for a supposed K-selected taxon?

This is an interesting comment. However, we would emphasize that environmental conditions could be extreme, which means hostile for Life, for relatively long times. This implies that early Eocene calcareous nannoplankton probably have had to face with inhospitable conditions for long periods. Some K specialists, which are better adapted to these critic states, are able to develop favorable adaptations in response to, even minor, changes (e.g., discoasters). Some others, which are more far from their climax, initially try to adapt, then suffer some extinctions and, eventually, are not able to survive anymore (e.g., fasciculiths). In conclusion, harsh conditions has likely endured for relative long periods during the early Eocene and only taxa either better adapted to these conditions or highly tolerant could survive. We have made no changes in the text on this issue.

References

Aitchison, J.: The Statistical Analysis of Compositional Data. Chapman and Hall, London - New York, 12, 1-416, 1986.

Beltran, C., de Rafélis, M., Minoletti, F., Renard, M., Sicre, M.A., and Ezat U.: Coccolith δ18O and alkenone records in middle Pliocene orbitally controlled deposits: High-frequency temperature and salinity variations of sea surface water, Geochem. Geophy. Geosy., 8, Q05003, doi: 10.1029/2006GC001483, 2007.

Davis, J.C.: Statistics and Data Analysis in Geology. John Wiley & Sons, New York, 1-646, 1986.

Dickens, G.R.: Rethinking the global carbon cycle with a large, dynamic and microbially mediated gas hydrate capacitor, Earth Planet. Sc. Lett., 213, 169–183, doi: 10.1016/S0012-821X(03)00325-X, 2003.

Giusberti, L., Rio, D., Agnini, C., Backman, J., Fornaciari, E., Tateo, F., and Oddone, M.: Mode and Tempo of the Paleocene-Eocene Thermal Maximum in an expanded section in the Venetian Pre-Alps, Geol. Soc. Am. Bull., 119, 391-412, doi:10.1130/B25994.1, 2007.

Giusberti, L., Boscolo Galazzo, F., and Thomas, E.: Benthic foraminifera at the Paleocene/Eocene thermal maximum in the western Tethys (Forada section): variability in climate and productivity, Clim. Past Discuss., 11, 4205–4272, doi:10.5194/cpd-11-4205-2015, 2015.

Harper, D.A.T. (Ed.): Numerical Palaeobiology: Computer-Based Modelling and Analysis of Fossils and their Distributions. John Wiley & Sons, Chichester, 1-468, 1999.

Komar, N., Zeebe, R. E., and Dickens, G.R.: Understanding long-term carbon cycle trends: The late Paleocene through the early Eocene. Paleoceanography, 28, 650-662, doi:10.1002/palo.20060, 2013.

Lunt, D.J., Valdes, P.J., Jones, T.D., Ridgwell, A., Haywood, A.M., Schmidt, D.N., Marsh, R., Maslin, M.: CO_2-driven ocean circulation changes as an amplifier of Paleocene-Eocene thermal maximum hydrate destabilization, Geology(2010),38, 875, doi.org/10.1130/G31184.1, 2010.

Minoletti, F: Mise au point d'un protocole de séparation des assemblages de nannofossiles calcaires. Apports à la micropaléontologie et à la géochimie des producteurs carbonatés pélagiques. Application à la crise Crétacé-Tertiaire, Ph.D., Univ. Pierre et Marie Curie, Paris, 2002

Minoletti, F., de Rafelis, M., Renard, M., Gardin, S., and Young, J.R.: Changes in the pelagic fine fraction carbonate sedimentation during the Cretaceous–Paleocene transition: Contribution of the separation technique to the study of Bidart section, Palaeogeogr. Palaeoclimatol. Palaeoecol., 216, 119–137, 2005.

Rossignol-Strick, M.: Mediterranean Quaternary sapro- pels, an immediate response of the African monsoon to variations of insolation, Palaeogeogr. Palaeoclimatol.Palaeoecol., 49, 237-263, 1985.

Stoll, H. M., and Bains, S.: Coccolith Sr/Ca records of productivity during the Paleocene-Eocene thermal maximum from the Weddell Sea, Paleoceanography, 18(2), 1049, doi:10.1029/2002PA000875, 2003.