Author: Below, we have copied the review by the referee, and have added our responses in blue and between square brackets.

R3 - G. Raquel Guerstein (Referee)

The Middle Eocene Climatic Optimum (MECO) is a global warming event at about 40 Ma that interrupted the long-term Cenozoic cooling trend. Up to now only a few studies have focused with enough resolution to evaluate the paleoenvironmental and paleobiotic consequences of this hyperthermal event. In this work Cramwinckel and coauthors have investigated the paleoecological and paleoceanographic repercussions of the MECO in the Southweast Pacific Ocean (SWPO) primarily based on organic walled dinoflagellate cysts (dinocysts) and TEX86 palaeothermometry. The most important site analysed in this study is the ODP Site 1170 located on the western side of the South Tasman Rise (STR). The area where this site was drilled is characterised by a notably high sedimentation rate, especially the stratigraphical interval here interpreted as part of the middle Eocene including the MECO. Despite the absence of key biostratigraphic markers to validate a robust age-depth frame, the results from this study, togeteher with the information from the Site 1172 (Bijl et., 2010, 2011 and 2013a), conform a dataset of very good quality and high potential to respond the questions posed by the authors. However, I have identified several unsubstantiated interpretations and important methodological shortcomings that reduce the relevance of the paper. In the following I list some points that may be of assistance to make the contribution stronger. I am positive that the authors can carry out the proposed modifications, and I recommend publication of the manuscript after major revisions.

[AR: We thank the referee, G. Raquel Guerstein, for her positive evaluation of our dataset and manuscript, and critical but constructive concerns and comments. We hope to adequately respond to these below and in a revised version of the manuscript.]

My primary concern is related to the lack of physical arguments to explain the proposed change in the Southern Ocean's surface circulation through the MECO. According to the authors (page 13, lines 8 to 11): Throughout the studied middle Eocene interval, dinocyst assemblages at Site 1170 are dominated by Antarctic-endemic taxa. This implies that the Tasman Gateway was influenced by westward atmospheric and surfaceoceanic circulation (i.e., the polar easterlies) around 40 Ma, with the 60 S front thus located to the north of the gateway and the proto-ACC flowing through the Tasman Gateway (Figure 1b). Then (page 13, line 19), the authors suggest that during the MECO the East-Australian Current (EAC) waters would reach paleolatitudes somewhat less than 60 S, represented by the dinocyst assemblages at Site 1172 on the East Tasman Plateau (ETP) (Fig 1C). Such changes in the path of a Western Boundary Current (WBC) have to be driven by a substantial modification of the global wind pattern.

[AR: In this study, we use our fossil dinocyst data as a tool to reconstruct surface ocean currents. In the MECO interval we find cosmopolitan dinocysts at Site 1172 but not Site 1170, and consequently explore ocean circulation changes that can account for this biogeographic distribution. We explore several mechanisms and identify the one we consider most likely (southward extent of the EAC). Indeed, such changes in surface ocean circulation would follow changes in the wind pattern - given bathymetric and geographic constraints. We would like to emphasize that the bathymetric/paleogeographic constraints are just as important as the wind patterns, and both are much less well-constrained than the existing model simulations seem to suggest. As discussed below, we thank the referee for bringing another potential mechanism to our attention and will add this to the discussion.

We respond to the specific comments a-d below.]

a. Add a squematic wind distribution in Fig. 1 A, B and C indicating the latitude of zero wind stress curl.

[AR: While we agree that it would be insightful to draw in the prevailing wind directions in the Eocene, unfortunately these reconstructions do not reliably exist, so we respectfully refrain from drawing them. The middle Eocene ocean circulation patterns that we draw are based on fossil plankton biogeography, but we prefer to not infer wind circulation patterns from this, as this additional step would introduce a lot of uncertainty. Alternatively, drawing wind circulation patterns as derived from model simulations does not provide a solution either. Atmospheric simulations as derived from fully-coupled coarse resolution GCMs (that are tuned to reproduce modern conditions), are still limited by the poorly-constrained Eocene boundary conditions. Detailed model output is too dependent on these poorly resolved boundary conditions in order to be leading in drawing atmospheric reconstructions.]

b. Explain the physical mechanisms conducting to the intensification and southward displacement of the the EAC shown in Fig. 1C.

c. If the changes in the EAC are wind driven, then explain the physical mechanisms by which the MECO was able to change the present distribution of wind stress.

[AR to b and c: We thank the referee for noticing we did not elaborate on this mechanism. Given the present constraints on MECO temperature (Bohaty et al. 2009 Paleoceanography; Bijl et al. 2010 Science; Boscolo-Galazzo et al. 2014 Paleoceanography; Cramwinckel et al. 2018 Nature; Giorgioni et al. 2019 Scientific Reports), the MECO was likely a global warming event, possibly driven by atmospheric CO_2 increase (Bijl et al. 2010 Science; Steinthorsdottir et al. 2019 Geology). For the modern ocean, climate model simulations using modern boundary conditions indicate that increased CO_2 forcing (with associated global warming) causes changes in zonal wind stress (maximum change around 60 °S) and large increases in positive wind stress curl south of the Tasman Sea and New Zealand (Cai et al. 2005 GRL). In these simulations, the changes in wind stress curl drive changes in ocean surface circulation characterized by intensification of the southern midlatitude circulation, including strengthening and further southward extent of the EAC. Indeed, observational data indicate a strengthening of the South

Pacific Gyre over the past six decades, including a southward extent of the EAC at the expense of the Tasman Front (Hill et al. 2008 GRL; Hill et al. 2011 GRL). SST anomaly reconstructions over the peak interglacial Marine Isotope Stage 5e (~125 ka) similarly indicate strengthening and further southward extent of the EAC to offshore Tasmania (Cortese et al. 2013 Paleoceanography). We propose a similar atmospheric and oceanographic response to global warming occurred during MECO and will add the above discussion to our discussion paragraph on ocean circulation change during MECO.]

d. According of Fig. 1C (representing the MECO situation) the latitude of zero wind stress curl should be about 10-15 to the south of its present location. In that case the southern portion of the Australo-Antarctic Gulf (AAG) would have been under the influence of the westerlies instead of the polar easterlies. Explain how a proto-Antarctic Counter Current (proto-ACC) would flow through a shallow, partially open Tasman Gateway (TG) as proposed by Bijl et al (2013a and b) under such conditions.

[AR: Notably, the 60 °S line we draw in Figure 1C has quite some uncertainty. First, there is the choice of (and discussion on) which reference frame to use in order to reconstruct paleolatitude, with the first-order choice being between mantle- and paleomagnetic-based absolute reference frames. Second, there is an intrinsic error or uncertainty associated with the paleolatitude reconstructions of every chosen reference frame. For example, in Figure 1C, Site 1170 is drawn at 61.6 °S at 40 Ma, according to the Torsvik et al. (2012) paleomagnetic reference frame, but the uncertainty margins on this are between 58.76 °S and 64.55 °S (www.paleolatitude.org; Hinsbergen et al. 2015). Using the Besse and Courtillot (2002) reference frame gives a range of 57.52 °S – 64.12 °S. Given these uncertainties on the precise location of the 60 °S paleolatitude that approximately separates the westerlies from polar easterlies, we prefer to instead follow the paleobiogeographical data in order to infer circulation. These data suggest westward flow through the southern portion of the Tasmanian Gateway, which is within the uncertainty limits of the paleolatitude reconstructions (pointing more towards the more southerly latitudes within the uncertainty). To clarify the above, we propose to add uncertainty to the lines of paleolatitude in Figure 1.]

I suggest to consider another hypothesis to explain the observed dynocysts distribution. Bearing in mind a TG area located at 60 S during the middle Eocene, the cosmopolitan taxa could actually have been transported eastward through the northern portion of an incipient TG from a PLC source, very much like similar interpetations for an early incipient opening of the Drake Passage (see Scher and Martin, 2006; Livermore et al., 2007, Lagabrielle et al., 2009, González Estebenet et al., 2014). This weak flow would reach the ETP (Site 1172) but not the STR (Site 1170), dominated by the TC and a proto-ACC (Fig 1B with slight modifications). Then it would be easy to explain why the surface temperature rise during the MECO would have resulted in increased production of the cosmopolitan Enneadocysta multicornuta on the ETP but not on the STR, where the dominant species is Enneadocysta dictyostila. This species is the member of the Antarctic endemic assemblage most tolerant to warm surface waters (Fig 4C). The data matrix included in the SI reinforces this hypothesis: E. multicornuta is present in Latrobe-1 borehole but has not been recorded in Hampden Section.

This interpretation doesn0t need Figure 1C but implies changes in the title and a reorganization of some of the sections accordingly.

[AR: We thank the referee for this suggestion. We agree that weak continuous eastward flow through the northern portion of the Tasmanian Gateway, or discontinuous eddy transport, could have been a mechanism that brought cosmopolitan dinocysts to Site 1172, but not Site 1170. We will add this potential mechanism to our discussion section in the revised version of the manuscript. We note that this explanation, similar to the EAC extending further south, raises the question why this process would only occur during MECO warmth. We propose that eastward eddy or weak continuous transport could principally occur throughout the middle Eocene, but transported species were only able to dominate the assemblage under sufficiently warm temperatures during MECO. We will add the above considerations to our revised text.]

There are also some methodological weaknesses that are important to take into consideration:

Data and Statistical analyses

a. According to the supplementary information it seems that the statistical analyses are based on proportions (not on counts) and this should be indicated. If they are actually based on proportions the total number of dinocyts counted in each sample should be included in the data tables.

[AR: Indeed, the ordination analyses are based on proportions, or relative abundances. In the revised version, we will clearly state this in the methods section. Furthermore, we will add the total number of dinocysts counted per sample to the data tables, as we agree this is important information.]

b. Figure 3 illustrates the relative abundances of selected dinocyst biogeographic groups using 4 categories. In the Figure 3B (site 1172) the sum of the 4 categories is not 100% but is not far from it. However, in Fig. 3A (site 1170) it appears that some important information is not taken into account. Indicate which species or groups have not been considered in these cumulative plots and why.

[AR: Unfortunately, especially the younger part of the Site 1170 record contained a high proportion of poorly preserved *Deflandrea* specimens that we could only determine to the level of genus. Therefore, these could not be given a biogeographic grouping, as described on page 7, lines 26–30 of the present manuscript. We will note the relevance of this to the Site 1170 dinocyst record in the caption of Figure 3 in the revised version of the manuscript.]

c. In view of the high number of species included in the data tables and that many of them are underepresented is reasonable that only some of the species were plotted in Figures 4A and 4B. Indicate which criteria were followed for the selection of species.

[AR: This is indeed the case. In the figure caption, the sentence “For visual clarity, only the most abundant taxa (taxa that occur in >10% of the samples, have a mean relative abundance >1%, and have a maximum relative abundance of >5%) are shown in these plots” contains our criteria. We will change “in these plots” to “in all three panels” to clarify this applies to panel A and B as well as C.]

d. Only 4 samples from the Latrobe-1 borehole were studied and the number of of cyts counted in each sample is very small (based on a minimimum of 50 cyst in each sample). The data available from this site is not of good quality for statistical analyses nor are some of the Hampden Beach samples (based on a minimum of 90 cyst in each sample). I hardly recommned not to include these samples in the unconstrained NMDS analysis, unless additional counts can make these dinocyst assemblages part of a reliable dataset.

[AR: We agree with the referee that caution should be taken in doing statistical analyses on assemblage counts of <150–200 palynomorphs. We prefer, however, to present the results for the reader to assess, adding the cautionary note that these analyses are based on low count data.]

e. Figure 5. Explain the meaning of Enneadocysta – Oligosphaeridium. What is Enneadocysta spp besides Enne-Oli, E.dic and E.mul?

[AR: We encountered these *Enneadocysta-Oligosphaeridium* intermediates (as we have designated them) only at the Latrobe-1 borehole. These specimens have a morphology in between *Enneadocysta* (*multicornuta*) and *Oligosphaeridium* spp., being dorsoventrally compressed and following the tabulation pattern of *Enneadocysta* spp. and having several processes conform *Enneadocysta* (thin, solid, distally radiating), but also having multiple processes conform *Oligosphaeridium* (much thicker, tubiform, distally less complex). The preservation and quantity of the material is not sufficient for description of this as a new species, which is why we describe them as *“Enneadocysta-Oligosphaeridium* intermediate”. To clarify, we will add a short description to our datafile, in the sheet “Dinolist” column “notes”. *Enneadocysta* spp. are species of *Enneadocysta* with insufficient characteristics preserved to bring their determination to the species level, but that do not fall into the category of *Enneadocysta-Oligosphaeridium* intermediates.]

Indicate the criteria followed for the selections of species or groups to be plotted in this figure.

[AR: The criteria are the same as for Figure 4, which we will add to the caption of Figure 5.]

Illustration of key markers, taxonomy and dinocyst paleogegraphic affinity

a. The middle Eocene dinocysts assemblages are mainly composed of cysts of extint dinoflagellates. Thus, the illustration of key biostratigraphic and palaeoenvironmental markers is a matter of major relevance and should be part of the main paper or included as Supplementary Information.

[AR: Referee 1 also commented that a plate with key markers would make a useful addition to the manuscript. We propose to add a plate with key palynomorph species to the revised manuscript as a supplementary figure, including the below mentioned *Dracodinium rhomboideum*.]

b. The taxonomy of the Subfamily Wetzelielloideae is an issue of discussion, which is still open (Williams et al., 2015; Iakovleva, 2016; Bijl et al., 2016; Williams et al., 2017). In this context the ilustration of the key biomarkers is essential. As things are stand now different research groups can use the same name for different morphotypes and the same morphotype can be named in different ways. One of the key biostratigraphic markers for the MECO, here called Dracodinium rhomboideum, has previously found only at Site 1172 and has not been illustrated by Bijl et al. (2013a). Every research group can call this taxa with different names, but a good illustration allows the dinocyt specialist to know if they are talking about the same thing or not. Unquestionably, the authors have the right to follow the taxonomy they consider better and more useful. However, if they reference a "Comment on a paper", they cannot ignore that there is a "Response to that comment" and it should be mentioned (Williams et al., 2017). The authors are free to follow Fensome et al., 2004 for the wetzelielloid taxonomy, of course, but they have to do it for all the members of the subfamily. For example, Rhombodinium rhomboideum had already been transfered to Dradodinium rhomboideum 15 years ago. A taxonomic appendix should be included to avoid these mistakes.

[AR: We will add an illustration of *Dracodinium rhomboideum* to a supplementary plate. In the supplementary datafile, we will add author references to the dinocyst species, to change this into a taxonomic appendix. Furthermore, we will add a citation to the response to the comment at the appropriate place in the text.]

c. Which is the difference between "endemic SO" and the "so called TF"? I suggest to consider all these taxa as "Antarctic endemics" in order to leave the old name "Transantactic Flora" behind.

[AR: We agree and will group the "endemic SO" and "so called TF" as "Antarctic endemics.]

d. Dinolist (Excell file of SI): Indicate the meaning of "biogeo alt" and "g" and "p" Add a column indicating the source of the biogeo (Bijl et al., 2011, Bijl et al., 2013b, Frieling, Appy Sluijs, 2018... or others).

[AR: We will make these additions to the datafile.]

Terrestrial palynomorphs from the Latrobe-1 borehole

This section is the weakest part of the manuscript. The authors overinterpreted a poor set of data coming from the Latrobe-1 borehole based on only 4 samples within the interval representing the MECO. The section 4.2.2 Terrestrial Palynology (pages 11-12) is merely descriptive using an open taxonomy with broad links to the modern types and no references to their present-day distribution. The section is closed with the following report: "Within the sporomorph assemblages, there is a slight dominance shift between the major pollen groups towards the top of the interval: the percentages of saccate pollen increase from 15–20 % to 40 % upsection, while angiosperms decrease from 40–60 % to 25 %".... Actualy, it is not consistent to describe a palaeoenvironmental trend based on four samples. Moreover, an avaluation of the vegetational modifications as a consequence of the climatic change during the MECO with no records of the pre and post MECO intervals does not have any sense. Furthermore, the authors concluded (page 17, lines 23-25): "Terrestrial palynomorph assemblages suggest a warm temperate rainforest with some paratropical elements that grew along the southeast Australian margin during the MECO", which can be possible, but the statement clearly does not arise from this unsupported analysis. I suggest to remove this section unless it can be substantially improved.

[AR: While we agree with the referee that 4 palynological samples comprise a limited set of data, we respectfully disagree that this would make the data less suitable for publication in our manuscript. While limited in number, these palynological assemblages provide crucial additional information on middle Eocene warmth on the nearby continent, supporting the marine-based reconstructions. This is important, as land and ocean temperatures did not necessarily change synchronously in this region throughout the Eocene (e.g., Pancost et al. 2013 G^3; Bijl et al. 2013 PNAS). The presence of dinocyst marker species *Dracodinium rhomboideum* strongly indicates a MECO age (see the author response to Referee 2). Nevertheless, we agree that our description of trends based on 4 samples might not be sensible, so we propose to omit this in the revised version.]

Other comments

When different sources are used to reference a concept the references have to follow a chronological order, from the oldest to the youngest. (not in alfabetical order). Example: Page 2, line 22: (Kennett et al., 1974; Cande and Stock, 2004) instead of (Cande and Stock, 2004; Kennett et al., 1974). Check this aspect thoughout the manuscript since there are many of these mistakes.
Page 2, line 28: (Scher and Martin, 2004; Lagabrielle et al., 2009; González Estebenet et al., 2014) instead of (Lagabrielle et al., 2009; Scher and Martin, 2004)
Page 3 line 9: (Wrenn and Beckman, 1982; Wrenn and Hart, 1988; Mao and Mor, 1995; Guerstein et al., 2008; Bijl et al., 2011, 2013a) instead of (Wrenn and Beckman, 1982; Wrenn and Hart, 1988; Bijl et al., 2011, 2013a)

[AR: Although the CP formatting guidelines leave these decisions to the authors, we will adjust to a chronological reference order.]

Page 3. Lines 8 and 9: organic walled dinoflagellate cyst assemblage instad of organic dinoflagellate cyst assemblage
[AR: we will change the text accordingly]

Page 3, line 18: dinocyst assemblages instead of dinocyts assemblages
[AR: we will change the text accordingly]

Page 5, line11: delete a repeted "was not"
[AR: we will change the text accordingly]

Page 5, line: The overlying Wilson Bluff transgressive deposits have an age.... instead of "The overlying Wilson Bluff transgression has an age"
[AR: we will change the text accordingly]

Page 5, line 28: Narrawaturk Formation instead of Narrawaturk formation
[AR: we will change the text accordingly]

Page 6, line 7: Narrawaturk Formation (or Fm) instead of Narrawaturk formation
[AR: we will change the text accordingly]

Page 6, line 13: The Hampden section at Hampden Beach, New Zealand (Figure 2a).... which could have recorded influences of both TC and/or EAC. Explain.
[AR: we will change this sentence following the suggestion by Referee 2, who also commented on it]

Page 7. Line 6: wetzelielloids or Subfamily Wetzelielloideae insted of "Wetzellioid family"
[AR: we will change to "wetzelielloids"]

Page 7. Lines 16-18: "We label taxa without a clear temperature affinity as cosmopolitan, such as those taxa with a distribution that is primarily controlled by other parameters like salinity (e.g., Senegalinium cpx.) or nutrient availability (e.g., protoperidinioids) Add references
[AR: we will add appropriate references to Sluijs et al. 2005; Sluijs and Brinkhuis 2009; Frieling and Sluijs 2018.]

Page 7, line 31: where the only species of Deflandrea recorded was D. antarctica insted of: where only the Deflandrea species D. antarctica is present
[AR: we will change the text accordingly]

Page 9 lines 31 -32: Middle Eocene palynomorphs at Site 1170 are generally well preserved and assemblages are dominated (>95%) by marine forms, mainly dinocysts. Terrestrial palynomorphs occur consistently, but in low relative abundances (<2% of palynomorphs). 95 or 97%? vs. 2 or 5%?

[AR: we will change "<2%", to "<5%". This was a small inconsistency, because there is only one sample with 95% marine and 5% terrestrial palynomorphs.]

Page 10, lines 2: "possibly from the north". Why?
[AR: because this was a relatively nearby land mass for offshore transport of material]

Page 10, lines 6-8: "High abundances of Enneadocysta spp. and peridinioid dinocysts in combination with low diversity indicate a somewhat restricted, eutrophic assemblage with possible low-salinity influences." Add references
[AR: we will cite Sluijs et al. 2005 for these environmental inferences]

Page 11, line 3: MECO cooling ?
[AR: we will change this to "MECO recovery"]

Page 17, lines 2 and 3: Annenberg Formation.... Helmstedt Formation .... Annemberg Formation instead Annenberg formation.... Helmstedt formation .... Annemberg formation
[AR: we will capitalize "Formation" here]

Illustrations Be consistent using upper or lower case for the figures. Figure 1 shows A, B and C and the figure caption explains the Figure 1 a, b and c. See also Figs 2, 3, 4, 6 and supplementary figures.
[AR: we will be consistent and change these to lower case between brackets, in accordance with the CP house style]

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