

Interactive comment on “Investigating vegetation-climate feedbacks during the early Eocene” by C. A. Loptson et al.

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Thank you for the comments and suggestions. We have addressed these point-by-point below:

“the authors generally do not make the connection between changes in vegetation and the climate response. For example, on p. 4714, they state that changing the vegetation distribution from SHRUB to DYN has the effect of increasing high latitude temperatures by 1C. This is possibly due to decreases in albedo from the direct replacement of shrubs with trees and snow masking by canopy in the winter. However, no explanation is offered. Another (but not the only) example is on p. 4718, l. 8, where it is stated that vegetation has the greatest effect on temperature over terrestrial equatorial regions in JJA but give no description of the change in vegetation (shift from broadleaf trees

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and grasses to grasses and bare ground) and no climatological explanation (likely a reduction in soil moisture and enhanced sensible heating). Along similar lines, and regarding point (ii), climate changes are often attributed to a change in albedo or clouds or water vapour (e.g. p. 4716, l. 20; p. 4718, l. 4-5; p. 4718, l. 12-13; 4718, l. 26-27; p. 4721, l. 6-8; p. 4722, l. 4-5), but these changes are never described in detail, quantitatively or shown in a figure. And, at times, the reasoning can be circular. For example, on p. 4716, a decrease in sea ice is inferred from a temperature change. (Presumably the authors examined sea ice and know that it did decrease, in which case the issue is the description of the results rather than the analysis). The benefit of using a climate model is that you can evaluate the mechanisms that cause the changes.”

This is a fair point, and we have now expanded on these to give further descriptions and explanations of physical processes behind the changes in climate.

p. 4718, l. 8 - The description of the vegetation change (trees replace grasses and shrubs) and climatological explanation (reduced soil moisture and evapotranspiration) has been added into the paper.

p. 4716, l. 20 - We have now changed the wording here so it is clear the extent of sea ice is known, and not inferred from the temperature change, and have included a plot of sea ice changes to demonstrate this.

p. 4718, l. 26-27 - Values of NPP are larger in DJF compared to JJA, indicating increased productivity. This has been added into the results section to back up this statement.

For the other points, further explanation of how changes in cloud cover, water vapour and surface albedo contribute to the changes in temperature can be found in the Energy Balance Model (EBM) section. We are aware that this is not immediately obvious when reading the paper, as the EBM section follows these results sections. We have modified the paper to refer the reader to the EBM section where relevant. We have also include a more in depth discussion of cloud cover within the results in order to

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make more of a link between changes in climate and cloud cover.

"Additional information about the boundary conditions (CH₄, N₂O, O₃, aerosols, orbital parameters, solar luminosity, etc.) should be added to the Methods. Perhaps this information can be found in Lunt et al. (2010), but it's so fundamental to the modeling effort that it should be included here. In addition, information about the PFT characteristics should also be included, as well as the bioclimatic parameters that determine their establishment. Both of these are important, both for understanding the results and for comparing vegetation and climate responses between studies using different models."

Done.

"Other studies have discussed the role of vegetation on ocean circulation and overturning (Ganopolski et al., 1998; Lohmann et al., 2006; Zhou et al., 2012). Does dynamic vegetation have any affect on overturning in HadCM3L?"

Yes, ocean currents and MOC change in this region in a similar way to Zhou et al., (2012), and regions of deep water formation also change with CO₂/vegetation. In order to address this point we have added a subsection called "Ocean Dynamics" to the results section to explain the changes in ocean circulation between the different simulations.

"A paragraph should be more than one sentence. There are numerous places in the text, where this rule is not followed. In almost every case, the sentence could easily be incorporated into the paragraph that it either precedes or follows."

OK. We have now fixed this.

"p. 4708, l. 4. Include a reference for poleward heat transport, e.g. Covey and Thompson (1989)."

This is a valid point, and we have now included a reference for this.

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"p. 4708, l. 5. In addition to these mechanisms, Beerling et al. (2011) show the possible role of other greenhouse gases (CH₄, NO₂, O₃) and Poulsen and Zhou (2013) suggest that overestimate of low cloud amounts may play a role in warming high latitudes."

These references have been added to the introduction.

"p. 4709, l. 20-25. In the discussion of problems with oxygen isotopic data, I was surprised that the uncertainty of the isotopic composition of seawater was not also included, since this was likely different in the past. This has been addressed in at least two studies (Roche et al., 2006; Zhou et al., 2008)."

OK. This has been added in to the discussion of oxygen isotopic data

"p. 4713. It would be very useful to plot the location and type of fossil evidence. This could be added as a panel to figures 1 and 2."

OK. We have plotted these fossil locations and added this into the paper.

"p. 4714, l. 3. "uncertainties associated with the RMS error." This implies to me that the RMS error calculation/equation is uncertain, when in fact the authors mean to express that there are uncertainties associated with the data."

We have now clarified this, explaining that the RMS error is due to uncertainties in the data.

"p. 4715, l. 2-3. "...vegetation feedbacks have a larger influence on temperature at higher CO₂ concentrations. . ." Explain why this is. Is it because there is a larger difference between the simulated PFTs and shrubs at 4xCO₂ than 2xCO₂? Or is it because the mean state is warmer and more sensitive to thresholds, e.g. melting of sea ice?"

The EBM section was included to explain the differences in temperature between simulations. Looking at figures 13c and 13d, the main difference between them is in

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Antarctica and is due to changes in surface albedo, i.e. vegetation. The difference in vegetation on Antarctica is much greater at 4x than at 2x, as at 2x a lot of shrub is still growing on Antarctica. As we have mentioned already, we know that this is not immediately obvious at this point, and have now referred the reader to the EBM section here for an explanation of this temperature change.

"p. 4715, l. 25-27. This calculation is not appropriate. There is no reason to think that climate sensitivity changes systematically (e.g. Caballero and Huber (2013))."

We agree that there is no reason to assume a linear increase in temperature with the log of CO₂. However, this calculation was carried out for HadCM3L (and other models) in the Eocene modelling intercomparison project (Lunt et al., 2012) and their results showed that climate sensitivity was either linear or increased with increasing CO₂. The results for HadCM3L were close to being linear between 2x and 6x pre-industrial CO₂. As a result, it's not unreasonable to take the calculated "ideal" CO₂ levels as an upper bound for the CO₂ level that would make the model results most consistent with temperature data. Although this calculation does require some assumptions, we think it's interesting to include these values for comparison relative to the EoMIP models.

"p. 4717, l. 3-4. Please comment further on the 10 C warming over the northwestern Pacific in Fig. 8a. It's interesting to note that Zhou et al. (2012) show a similar feature (Fig. 4b), which they attribute to the poleward displacement of the western boundary current."

It is the result of changing ocean dynamics (similar to the findings of Zhou et al). We have commented on this in the "Ocean Dynamics" section, which has been added to the paper.

"p. 4720. The energy balance analysis requires more description. The energy balance, itself, doesn't require explanation. Most readers will be familiar with this, or can review Lunt et al. (2012). But, a few sentences explaining the procedure for moving from the GCM to the EBM would be helpful."

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Agreed. We have added the following to this section to introduce the EBM better: "By analysing radiation fluxes instead of just looking at surface temperatures within each gridbox, changes in temperature can be attributed to different mechanisms within the climate system. This is because changes in a given aspect of the planet or atmosphere will only affect certain fluxes (e.g. changes in albedo affect shortwave radiation fluxes, whereas changes in greenhouse gases only affect longwave radiation). These changes in radiation fluxes can be converted into temperature differences using the energy balance model."

"Also, why discuss (in lines 11-16) changes in albedo due to atmospheric effects if no other details of the model are given?"

It's a point that is worth clarifying, as it is not explicitly stated in Lunt et al. (2012), and if the thickness of the atmosphere or orographic height at a gridpoint varies between simulations then the EBM would have to be interpreted slightly differently.

"p. 4720, l. 18-24. It might be helpful here to indicate that the results aren't shown."

We think that a better solution might be to add these results to table 3, with the other EBM results, which has now been done.

"p. 4720. "two dimensional energy balance analysis" Is the model one or two dimensional? If this isn't a misprint, more explanation is needed."

It is one dimensional. We have now corrected this in the paper.

"p. 4721, l. 14. "may be due to the root systems of some PFTs being more effective. . ." The authors shouldn't have to guess here. The physiological differences in PFTs should be documented."

Agreed. The root systems do differ between PFTs, making some more effective at retaining water than others. We have changed the wording of this statement from "may be" to "is".

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"p. 4722. l. 11. Cloud responses are mentioned in several places in the text. Please comment on how vegetation changes are affecting clouds."

OK. We have added descriptions of changes in cloud cover where we have mentioned cloud responses.

"Table 2. To be consistent in terminology, perhaps "FIXED" could be "4 x FIXED"? This would help the reader remember that the CO₂ values was 4 x, and make figure captions easier to comprehend."

We agree with this point, and have made this change.

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