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Interactive comment on "Elevated CO_2, increased leaf-level productivity and water-use efficiency during the early Miocene" *by* Tammo Reichgelt et al.

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Response to Anonymous Referee #1. We thank the anonymous reviewer for an insightful and thoughtful review. Below are our responses.

Referee 1: Are fluctuations in calculated CO2 caused by layer-specific differences in stomatal data or delta13C, or both? Are there significant differences in stomatal conductance or delta13C?

Author response: Indeed, in the traditional approach to atmospheric CO2 reconstructions using changes in plant physiology, inferred CO2 variations can be traced directly

to either leaf carbon isotopic composition or changes in stomatal density. However, the approach that we try to advocate relies on gas-exchange modeling and it 1) is sensitive to any combination of changes in carbon isotopic composition and stomatal conductance, and 2) takes into account the cumulative response of different plant species (i.e. all the plant species determined from the plant fossil locality). This approach thereby accounts for the complexities that arise from non-linear, and even non-uniform physiological responses to changes in the climate, something that CO2 reconstructions using only stomata, or only leaf δ13C values, and only a single species cannot do. Moreover, as we note in the manuscript this comprehensive approach leads to a more accurate accounting of uncertainty in ultimate CO2 estimates than traditional approaches.

However, to address the reviewer's question, we conducted ANOVA linked with TukeyHSD to test differences in leaf δ13C and Stomatal Density between zones. We approached the ANOVA – TukeyHSD with three different null hypotheses (H0): 1) leaf δ13C and stomatal density combining all species is the same for all zones, 2) leaf δ13C and stomatal density for all canopy species, after Z-score scaling of inter-species variation, is the same for all zones, and 3) leaf δ13C and stomatal density for the most abundant species, Litsea calicarioides, is the same for all zones. The p-value in all cases is higher than 0.05, indicating that H0 cannot be rejected in any of these scenarios, and that leaf δ13C and stomatal density do not individually change significantly between zones. Thus, variations in estimated CO2 are the result of the combination of leaf carbon isotopic composition, leaf conductance, and intra-species variation of physiological response to atmospheric carbon. The original carbon isotope and leaf conductance measurements are available in the supplementary material. We include new a section in the manuscript to further clarify how our approach means that a change in model output may be impossible to trace to a uniform change in input variables, and on a related note we emphasized the need for further evidence to further evaluate the role of a CO2 increase in driving Antarctic Ice melt at the Oligocene/Miocene boundary.

Referee 1: It would be also interesting to compare stomatal data of the fossil plants with those of their extant representatives. Are there significant differences?

Author response: We agree that this is an interesting research question, and it is currently considered in the context of a separate study. The comparison between fossil plants and their extant representatives is not of fundamental relevance to this manuscript and we prefer to keep it separate from the research results we are reporting here.

Referee 1: The treatment of intrinsic Water-Use Efficiency is too simplistic and should include consideration of the changes in fatty acid δD of the Foulden Maar record, in particular with regards to the influence of changes in humidity on plant water-use efficiency reconstructions.

Author response: We do have ïĄďD values and ïĄď13C values from leaf waxes in this record that can provide some guidance for making inferences about changes in hydroclimate across the 100,000-yr period of sedimentation (Reichgelt et al., 2016). However, our discussion of iWUE is not meant to address variations that occurred during this interval, but instead focuses on contrasting the early Miocene values with modern values. To support our southern temperate reconstructed iWUE, we include results from the same transform functions on previously published records from Ethiopia and Panama, which showed similar offsets from modern. That said, we agree with the referee that in a warmer world, whether you are in the tropics or in the southern temperate region, you would expect higher vapor pressure deficits, which would also drive up the iWUE signal. We have therefore expanded the discussion to address this uncertainty and included Fig. S3 in the supplement to show that while temperatures Miocene New Zealand are higher than modern, the relative humidity reconstructed for Foulden Maar is well within the range of modern New Zealand forested biomes.

Referee 1: It is difficult to extrapolate leaf-level productivity to the canopy and vegetation level. It is suggested that the authors mention and discuss the research on modern CO2 fertilization experiments that highlight the complexity of physiological response in

forests to increased atmospheric carbon dioxide.

Author response: We expanded discussion on the confounding factors observed in modern CO2 fertilization experiments.

Referee 1: P. 2, l. 42 “will make more C available to the terrestrial biosphere”. This is an awkward description of the anticipated fertilization effect of elevated CO2.

Author response: This sentence has been amended for clarity.

Referee 1: P. 4, l. 98 “For conductance measurements” This is not exactly correct. With fossil leaves, anatomical data are determined which then allow to approximate conductance (on the basis of various assumptions). This is not the same as measuring conductance of living leaves. P. 4, l. 103 See previous comment.

Author response: amended.

Referee 1: P. 8, ls. 194 – 195 There seems to be something wrong with the structure of this sentence.

Author response: amended.

Referee 1: P. 10, l. 229 - 231 “including a measure for the relative time the leaf is assimilating”. What is the final value for this relative time? How was it determined? Additionally, the symbol for this relative time appears to be the same as for the operational conductance.

Author response: amended.

Referee 1: P. 10, ls. 238 - 239 “is derived from Maire et al. (2015) which included coordinates, habit, An and Gw data from which we could then calculate” It is not clear (from this sentence), how the calculations were conducted in detail. Why were “coordinates” used and for what? Why where Gw data from Maire et al. (and therefore of extant plants) used, and not conductance data derived from stomatal data of the fossil plants?

Author response: amended.

Referee 1: P. 15, ls. 355 – 357 “In contrast to iWUE . . . Gw for Miocene trees is similar to the modern day range.” Since Gw is derived from Gc and therefore from fossil material, this would mean that “structural” conductance is not that different for the fossil plants and their extant relatives?

Author response: That is correct. We have expanded the discussion on this. We note (here and in the manuscript) that the extant relatives are not the same as the plants that currently occur at this latitude. Due to cooling the warm-temperate to subtropical diverse Lauraceae dominated rainforests of Miocene New Zealand no longer exist.

Referee 1: P. 15, ls. 357 - 359 “Increased atmospheric evaporative demand in combination with a longer growing season”. The authors describe that they used CLAMP to reconstruct growing season length. As far as I know, CLAMP provides also data on humidity. See also general comments.

Author response: Thanks for this excellent suggestion. CLAMP data on humidity have now been included in the supplementary material and are now included in our discussion.

Please also note the supplement to this comment:
https://www.clim-past-discuss.net/cp-2020-30/cp-2020-30-AC1-supplement.pdf

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