Author's response to Reviewer#2 (Sarah Feakins)

The study is interesting, and would likely be suitable for Biogeosciences after moderate revision.

Response: We thank the Prof. Feakins for her positive overall assessment of the paper.

Summary points:

I agree with the other reviewer that I was surprised to find this was a bulk OC carbon isotope based study. In fact, I assumed the study was based on plant wax when I accepted the request to review based upon the paper coming from a biomarker lab. Of course using bulk methods doesn't invalidate the study, but it could be more clearly signaled for the reader. Using the word "bulk" at first reference to on line 32 "In this study we investigated the bulk carbon isotopic signature.." may suffice.

Response: This is a good suggestion, we will add the word 'bulk' in the abstract. We will also carefully consider the use of 'bulk carbon isotopic measurements' throughout the revised MS.

The authors appear to have neglected the changing atmospheric d13C over recent decades and how that would affect carbon in modern plants, and potentially older soils and fluvial SPM. Literature comparisons span 1970s to present and it needs accounting for. Please add discussion of (likely) age of materials and the Suess effect, throughout wherever relevant, and account for this numerically.

Response: We would like to thank Prof Feakins for pointing this out. We are actually amazed by the fact that none of the (co-)authors has thought about this issue. We will correct our data for the Suess effect, redo the analyses, and adjust the manuscript where appropriate. Note that we do not suspect our conclusions on vegetation to change, as all vegetation was collected during the same expedition and plant $\delta^{13}C$ values will thus be corrected to the same extent, leaving the trends with MAP reported in the manuscript intact. The same would be true for the correction of bulk soil $\delta^{13}C$, as soils in the upper and lower part of the Godavari basin are of similar age (Usman et al., 2018). We will also explore the implications of the Suess correction for the mixing model outcomes.

We did a preliminary assessment of the effect of the Suess correction on the comparison between our measurements on Godavari plants and data reported in literature, as well as for the plant end-members used in the mixing model. The Suess correction does not seem to affect our main conclusions. The mixing model outcomes are still valid, with a substantial underestimation of the %C4 plants when using global plant end-members compared to those based on Godavari vegetation. Without question, we will take care to include Suess-corrected data in the revised MS.

There is some duplication of graphs Figs 1c and 2a, Figs 2b and 3a – that would ideally be organized so that data are only presented only once graphically.

Response: We agree with the reviewer that the cited figures are superfluous. We will reconsider them and combine information in these figures as requested.

Detailed line by line comments follow:

Line 45 "Our analysis revealed that the reconstructed C3/C4 vegetation composition was sensitive to the plant δ13C end-members used as mixing model input." Please do not frame this as a new 'analysis revealed' as it is well known that the C3 'endmember' is a flawed concept as it has a very wide spread. Informed choices about more meaningful endmembers may be possible in some instances e.g. if it is known to be wet rainforest or dry C3 desert for example. However there have been other attempts to work around this mathematically including the Fwoody cover approach with a nonlinear fit [1].

Response: We agree with the reviewer that mixing models provide not perfect representation of the spatial C3/C4 distribution in a region and that it is important to make better informed choices about meaningful end-members. To the latter end, we explored how the use of different plant end-members and (correction for) the amount of MAP in a region influences the outcomes %C4 and C3 plants by a mixing model. We used a validated linear isotope mixing model for this (see Philips and Gregg, 2001), that includes source variability and error propagation, thus minimising the spread in mixing model outcomes. Such linear mixing models have been and are used worldwide for C3/C4 vegetation reconstructions, and we address a range of studies in the Introduction. We are aware that there are alternative methods such as the non-linear Fwoody approach to estimate C3/C4 distributions, that focuses on the vegetation structure and canopy shading effects. We argue, however, that for the Godavari basin, and many basins with intense human influence, such an approach is complicated by the fact that the natural vegetation has been replaced by agriculture resulting in a more open landscape (e.g. Wynn and Bird, 2008). For the Godavari basin, intensification of agriculture over the Holocene and deforestation since the 19th century mean that over 60% of the basin is used for agriculture, and only a small area is still covered by native (tropical) forest which would be sensitive to changes in Fwoody C3 vegetation.
--> We will rephrase Line 45 in the abstract to focus on the results of the C3/C4 reconstruction in the Godavari basin and not frame this as a new concept. In addition, we will incorporate the potential influence of the canopy effect on our vegetation d13C data in the discussion section.

Godavari specific endmembers, this would be more generally interesting if we were told right away if this is the wet or dry end of C3 etc, unlikely that there are regional plant species effects, likely it is just the usual canopy etc effects.

Response: We agree that extra information on where the Godavari basin can be placed in terms of dry or wet conditions is helpful to put our findings into a global perspective. Note, however, that we do not consider the canopy effect to play a significant role in the Godavari Basin (see reply to previous comment).
--> We will add information in the abstract about the MAP range in the Godavari basin. In addition, in the Methods (section 2.4) we will add information on Godavari basin and global occurring C3 vegetation in relation to MAP.

Line 49 " Hence, incorporating region-specific plant δ13C end-members and drought correction of the C3 end-member in mixing models need to be considered to determine C3 and C4 distributions of modern- and paleo-vegetation in monsoonal regions." Rephrase this sentence.

Response: We will rephrase these lines to reflect the discussion on the use of different plant end-members for vegetation reconstructions.

Line 56 – all the cited references refer to bulk plant tissue and are references that span 1970-2010. The difference in plant d13C between 1970 and 2020 is ~2 per mil. Please check and see what a recent collation of data has reported after correction for the date of collection, or do the work to update this to a consistent modern value suitable for comparison to your plants. Your soils and river samples may integrate more time however and thus the temporal shift may also be relevant to summarize here in the introduction.

Response: We will correct the $\delta^{13}C$ bulk plant tissue data from the cited papers for the Suess effect to allow comparison with the data we measured in the Godavari basin. We will also consider the age of the soils and riverbed sediments (^{14}C data from Usman et al., 2018 for a selection of samples and soil turnover times reported in the literature) and correct the plant end-members accordingly for the mixing model. This information will be included in the methods section as well as the discussion.

Line 89 – the concept of endmembers is flawed, especially for C3, instead it is important to describe the spread of C3 plants as context for any central estimate. This section of text is also flawed in that it misses the timescale of sampling. Internal to a study the C4 response to dryness has been found to be quite small 1 per mil (Cerling) not absent as concluded in this plant study in the results section, but perhaps the n is too small to be sure?

Response: We will provide additional argumentation on our choice to use an endmember model for our study, also including the aspects of fraction woody cover, and 'wet' and 'dry' C3 endmembers, and the timescale of sampling, as explained in our response to the earlier comment on Line 45. Note that we deliberately selected a mixing model that includes source variation and error propagation to overcome most of the above issues. As responded to Reviewer#1, we will expand on the impact of MAP on C4 plants and consider the sample size of the C4 plants we evaluated in the Godavari basin for a control by MAP.

Line 94 is on C4, then line 95 returns to C3 again, and another switch is found later on – the flow needs organizing.

Response: We will reorganise this paragraph to establish a good flow, and focus first on C3 and then on C4 plants.

Line 110 – I do not find the concept of a 'global average' C3 plant d13C to be useful.

Response: We will reconsider this concept after application of the Suess correction and see what the implications are for the difference in $\delta^{13}C$ data we measured in the Godavari basin and the commonly quoted 'global averages' for C3 and C4 vegetation.

Line 111 – regional average is also not very useful, more useful to think in terms of the vegetation category average e.g. closed forest, open woodland etc.

Response: We introduced the term Godavari-based or regional end-members to refer to (weighted) $\delta^{13}C$ values of C3 and C4 vegetation that evolve from the specific habitat conditions in the Godavari basin, which likely results from a combined effect of the (Indian) plant species, vegetation structure (density, distribution, canopy etc.), moisture, temperature and other environmental conditions. The field survey we did in the Godavari basin does not provide controlled conditions where we could assess the individual impact of these factors on vegetation $\delta^{13}C$ values. Hence, we use the term regional or Godavari-based.
→ We will include this motivation in the revised MS in the introduction, and in the Methods (section 2.5) we will define regional and global. Notably, we will re-evaluate the comparison between Godavari and global end-members after the Suess correction, and revise this section if appropriate.

Line 116-119 – sentence needs revisiting – rephrase. Note that this refers to a study that is also conceptually based on the endmember approach.

Response: We will rephrase these lines and include information that this result was based on an end-member approach which used specific plant $\delta^{13}C$ values based on samples of the regional vegetation.

Consider moving away from the outdated concept of a C3 endmember and moving to something like the non linear Fwoody cover approach that deals with the issues of spread in C3 plants. Or if you insist upon a linear mixing model make sure you propagate the uncertainties caused by the C3 distribution upon those C4% estimates. If you do error propagation, you'll see the issue.

Response: As explained in our response to your earlier comment on Line 45, we used the isotope mixing model from Philips and Gregg (2001) that includes the variability in the C3 and C4 vegetation (i.e., sources) as well as in the soils (i.e., mixture), with consideration of the uncertainties and error propagation in isotope mixing. As discussed before, the Fwoody approach is complicated by agriculture in the Godavari basin, which has created a more open landscape and drastically limited the area with native forest vegetation. As a result, we believe that the variation in the Godavari vegetation d13C cannot be attributed to changes in Fwoody cover, but are driven by changes in moisture availability instead.

Paragraph beginning 121 discusses plant to soil to river degradation fractionations well. It neglects to discuss the age of the OC and the Suess effect means that 2 per mil needs to be accounted for when comparing today's plants and a couple decade old OC in soil/sediment. Old OC would be 2 per mil more enriched compared to today's OC without any degradation fractionation.

Response: Thanks again for pointing this out. We will correct all our data for the Suess effect to enable a fair comparison between vegetation, soil, and sedimentary data, and incorporate subsequent changes in the revised version.

Line 153 why (paleo-)vegetation reconstructions? "vegetation reconstructions" suffices. Same issue throughout e.g. line 586 and conclusion title line 589.

Response: We will change this in the revised manuscript.

Methods

Plant and river sampling methods are appropriate and well described. The only question I'm left with is are the plant samples representative, when sampling bulk from a tree, the trunk is the bulk of the biomass, although the production of leaves may have a faster rate. When sampling leaf wax the leaves are appropriate, but when sampling bulk is the leaf sampling appropriate? I can see it is hard to homogenize a tree unlike sampling grasses (or leaf waxes) where the sampling task is simpler.

Response: See also our response to Reviewer#1 on this issue. Since all trees are deciduous, and shed their leaves annually, we have assumed that the leaves are the main contributor of OC to the soils, rather than the trunk. As for the representation of the plant species, we have collected the ~5 most common species at each site. We also made sure to select those species that were present in large(r) parts of the basin to be able to study the effect of MAP on their stable carbon isotopic composition.

Line 236 "robust relationship between MAP and d13C has been shown to prevail in C3 plants around the world" yes there is a trend but also a lot of scatter. This is acknowledged on line 249 a long way after for the reader, and the solution we are told is "binning'" on line 249 but binning is not explained, that I have found in the text.

Response: We will move the scatter in the relation between d13C and MAP up in the manuscript, and also better explain the approach that was used to bin our data.

Results and Discussion

Line 289 the plants falling in the "lower" end of the global range is consistent with the comparison of modern plants and an older global literature reference comparison. However just on numerical comparison "lower end" also seems to be a misrepresentation as closed tropical forest would be lower. Reconsider.

Response: We will reconsider this part of the discussion after we have corrected our data for the Suess effect. As mentioned earlier, the fraction woody cover is unlikely to play an important role in the Godavari basin, but we will add the explanation of why we believe that this is so to the revised manuscript.

Line 354 – binning – apologies, if I've missed it but I don't see this explained yet, and so I struggle to follow this.

Response: We will clarify our binning approach in the revised version of the manuscript. This information was briefly summarised in the caption of Fig 4, but will move this to method section 2.4 where the regression analysis is explained, and expand this information with more details about our approach.
--> We will include the following information: In order to deal with the uneven distribution of Godavari C3 plant $\delta^{13}C$ values over the MAP range, we applied a binning approach. The data were binned by calculating the average and standard error of C3 plant $\delta^{13}C$ values per MAP range of 100 mm y^{-1}. These binned Godavari C3 plant data were subsequently plotted against the average MAP of each respective range and utilised for regression analysis to assess the relation between C3 plant $\delta^{13}C$ values and MAP.

Line 439 remove "interestingly" which is subjective, and this well-known issue is one reason why reviewer 1 questioned the use of bulk, it becomes problematic in estuarine and marine settings as is well known (and perhaps no longer that interesting).

Response: We will make this change and rephrase this sentence where appropriate.

Line 529 – though we found some wood far offshore in the Bengal Fan [2]

Response: The Bengal Fan is fed by Ganges-Brahmaputra system can indeed carry coarse, woody materials far offshore (Lee et al., 2019), due to the high sediment transport potential with high flow velocities in the wet season along a relative steep altitudinal gradient from the Himalayas to the Bay of Bengal. In contrast, rivers with a limited altitudinal gradient such as the peninsular Indian rivers and the Godavari system appear to be more susceptible to depth-related sorting during river transport. As such, no wood was found in Holocene cores sampled in front of the Godavari mouth (Ponton et al., 2012; Giosan et al., 2017; Usman et al., 2018). Of course, this absence does not exclude the transport of wood by the Godavari River, but based on the shape of the river basin we believe that this transport will be limited compared to that by large(r) rivers, such as the Ganges-Brahmaputra.
--> We will include this information in the MS and specify the difference between the Godavari River system and the Bengal Fan that is fed by the Himalayan-derived Ganges-Brahmaputra.

Conclusions

Line592 – the discussion makes it sound like there is something regionally unique about the d13C when they fall within the global plants dataset and likely overlap with similar vegetation types. Thus it is more vegetation type/habitat/MAP considerations rather than geographic regions that should be emphasized, and so doing would make it more globally of interest than local.

Response: We will re-assess the differences between our Godavari dataset and the global compilation after we have corrected all data for the Suess effect. We expect that the Godavari dataset will be more similar to the global data after the Suess correction. Consequently, we will revise this section on the local vs global comparison if needed.

Figures:

Fig 1 – the map figures are useful, for the third panel showing MAP is the partition of the upper and lower basin based on the MAP, if so or otherwise, please give the numerical basis for the partition in the caption for this panel. Preferably change to a green-brown or blue saturations color scale rather than rainbow to be intuitive visually, and provide a legend that can be read in a quantitative sense, see comment on Fig 2a). Please note the repetition of data visuals, Fig 1c and Fig 2a are duplicative. Duplication should be removed. Fig 1c can be removed, as 2a conveys data at the site sampling points as well as the basemap.

Response: We will include information on the partition between the upper and lower basin, which is based on a difference in geology which also influences the vegetation, moisture availability and land use types – we will emphasise this difference in the method section 2.1 describing the regional setting. We will investigate if we can change the colour scheme to a green/brown/blue scale or a saturation of a single colour. Since Fig.1c and 2a give the same information, we will remove Fig 1.c, as requested.

Fig 2 a) apart from other concerns regarding the rainbow color scheme that have been widely reported, I would also not encourage the use of scale bar that is purely qualitative for the MAP data. It is not possible to read between the numbers 430 and 2300 mm/yr and know what ‘yellow’ or ‘green’ represents in terms of MAP. You can use a scale with incremental output and a color scheme that is a saturation of a single color which will help to allow for visual quantitative evaluation of where is wetter and drier.

Response: As responded for Fig 1, we will look into a different colour scheme to display MAP, preferably a saturation of a single colour, to improve the readability of the scale and better visualise drier and wetter areas.

d13C data points with the rainbow colors can be discerned by most readers using the legend, the coloring is not intuitive, for wet to dry try green to brown for example, and it would be better to pick a color scheme that can be seen by all readers.

Response: We will also look into a different colour scheme for the points depicting $\delta^{13}C$ values in Fig 2.

b) Why are upper and lower basins parsed. Are these much different, probably not as the C4 distribution in lower basin falls within that for the upper basin, and the same for C3 with the upper basin just having a bit more range. Maybe overlay the two bar charts or use violins, to display the data if you want to keep with this 2 category, but if you do an T or F test do you find they are significantly different? (this panel is repeated in fig 3) fig. 2b can therefore be deleted.

Response: As responded to the earlier comment on Fig 1, the upper and lower basin of the Godavari are distinctly different in terms of underlying geology, C3/C4 vegetation distribution, MAP, and land use types. We will expand on this in method section 2.1 describing the regional setting. The upper and lower basin are compared throughout the MS, significant differences in $\delta^{13}C$ values are revealed in Fig 3 and discussed thereafter.

Fig 3 – shows a bar chart of the same data as in figure 2b but in box and whisker format. The data only need to be shown once. As this plot is better this is the plot that should be retained and 2b deleted.

Response: We will remove the histogram in Fig 2b, as requested, and only keep Fig 3 which depicts the data most clearly.

Fig 4 – why show 'global C4' as a line = -12 per mil. Where does this derive from? Is it the mean of a collection of plants over several decades, without representation of the scatter in that dataset or correction for the accelerating d13C change in atmospheric CO2 over the last 2 decades. I assume your plants are simply showing scatter consistent with the global dataset, after correction for atmospheric d13C and pCO2 change over time.

Response: The global C4 and C3 lines represent commonly quoted 'average' $\delta^{13}C$ values reported in literature studies. We will investigate if a Suess correction is possible to update these values to modern conditions and look into the implications. Since the scatter in these data is not reported, we used the observed variation in the Godavari C3 and C4 plants when using these global averages as input for the mixing model.

References

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