Author's response to comments from Anonymous Referee #1:

"BVOC emission flux response to the El Niño-Southern Oscillation "

by Ryan Vella et al.

We thank editor and referees for taking the time to review our manuscript and for the valuable feedback. Here, the comments from Anonymous Referee #1 (from June 01, 2023) are reproduced in black, while our comments are presented in blue.

From Anonymous Referee #1's response:

In this study, the authors analyse potential links between climate variability induced by the El Nino Southern Oscillation and BVOC emission fluxes in a coupled GCM framework with interactive vegetation. They focus on different aspects of ENSO and the associated impacts on the terrestrial biosphere and BVOC emissions. The study is well written and presents interesting results, and I appreciate that the model runs must have been a huge effort to set up. However, I have some concerns that need to be addressed before the manuscript can be accepted for publication and included some general and specific comments below.

Thank you for your positive comments. We acknowledge that the concerns raised here are valid and the recommended amendments greatly improved our manuscript. Please find our detailed responses below.

General comments

My major concern is the Results/Discussion section because the discussion is a bit thin. I might have miscounted, but there are only four references to contextualise the results! That's not enough for a discussion and I would like to see a more critical view on the model set up and outcomes in the study. I wonder whether it would help to split the results and discussion into two separate parts of the paper (but this is up to the authors).

We agree that the results presented in the submitted manuscript lacked a thorough discussion. The updated version has a separate section for the Discussion. The discussion compares our findings with several studies including the ones cited in the Introduction. More details are provided below, however, we invite the reviewer to refer to the updated manuscript.

Some things that could be discussed are:

You used a coupled simulation stressing the importance of land-atmosphere interactions but you don't really dig into describing processes that might influence the BVOC emissions (and how) except for the last sentence in the conclusions.

More details about the model setup and parametrisation of the BVOC emission module used are now provided in Section 2.2. We also mention this in the Discussion section. E.g.:

"The positive correlation between BVOC emissions and surface radiation could be explained by increased rates of photosynthesis, resulting in enhanced BVOC emissions from vegetation (Sharkey et al., 1996; Harley et al., 1999). It has recently been suggested that limited soil water access seems to influence isoprene emissions predominantly through growth stress and, to a lesser extent, closure of stomata, while monoterpene emissions are mostly restricted via stomatal closure (Bonn et al., 2019). Similarly, temperature stress also substantially influences BVOC emission fluxes, as can be seen, e.g., by the power law functions of temperature in the description of isoprene emissions (Guenther et al., 2012). Areas with higher vegetation productivity tend to exhibit increased isoprene emissions as more carbon resources may be available for isoprene synthesis within actively growing vegetation. Higher LAI values indicate greater foliage density and, consequently, increased potential for isoprene production."

Has your coupled GCM set-up been evaluated and demonstrated to capture BVOC responses sufficiently compared to observations (if observations are available)?

This study builds on the work by Forrest et al. (2020) and Vella et al. (2023); is is now mentioned in the updated manuscript. BVOC flux measurements are generally scarce and it is hard to constrain global budgets from measurements. However, our model setup has been evaluated against several global BVOC emission models where it well-reproduced isoprene and monoterpene emissions. As the current model configuration does not include detailed land-use scenarios, the simulated vegetation corresponds mostly to "natural" vegetation only.

Details on this were presented in Vella et al. (2023), using the submodel ONEMIS (Kerkweg et al., 2006) in our modelling system EMAC (Jöckel et al., 2016) for biogenic emissions:

Isoprene

Over the 10-year simulation period considered, the global annual total isoprene fluxes from ONEMIS were found to be 546 Tg yr-1 (standard deviation (SD) = 8 Tg yr-1) with dynamic vegetation and 558 Tg yr-1 (SD = 7 Tg yr-1) with climatological inputs. Jöckel et al. (2016) reported isoprene annual emissions of 488– 624 Tg using ONEMIS, while other studies estimated fluxes of 642 Tg yr-1 (Shim et al., 2005) using 73 prescribed vegetation types, 571 Tg yr-1 (Guenther et al., 2012) using inventories and Olson ecoregion land covers, 467 Tg yr-1 (Arneth et al., 2007) using 10 PFTs from LPJ-GUESS and, more re- cently, 594 Tg yr-1 using 16 PFTs (Sindelarova et al., 2014).

Monoterpenes

Annual totals from ONEMIS were found to be 102 Tg yr-1 (SD = 1 Tg yr-1) with dynamic vegetation inputs and 175 Tg yr-1 (SD = 2 Tg yr-1) with climatological inputs. MEGAN prescribes 54 Tg yr-1 (SD = 0.7 Tg yr-1) and 76 Tg yr-1 (SD = 0.9 Tg yr-1) with dynamic and climatological inputs, respectively. Guenther et al. (2012) gives a global annual monoterpene emission of 157 Tg, while Sindelarova et al. (2014) reported annual total emissions of monoterpenes ranging between 89 and 102 Tg yr-1 over a 30-year simulation period. Arneth et al. (2007) reported 36 Tg yr-1 .

How do other land surface schemes model BVOC emissions and would you expect different results using a different LSM or GCM? Would you expect that your model framework is more suitable to address your research question compared to other coupled models that enable BVOC simulations?

Several Earth System Models (ESMs) and Chemistry-Climate Models (CCMs) employ similar algorithms, such as the Guenther algorithm (Guenther et al., 2012), to simulate Biogenic Volatile Organic Compounds (BVOC) emissions. While some variations exist, these schemes generally yield comparable results, with slight differences in the importance of input parameters, namely radiative fluxes, temperature, soil moisture, and vegetation. Therefore, it is crucial to accurately represent these parameters in the models.

Global scale models generally have a good representation of temperature and radiative fluxes. However, there are larger discrepancies among models when it comes to the hydrological cycle. Nevertheless, the EMAC model has demonstrated a good representation of the hydrological cycle, although it exhibits a moist bias at the southern edge of the Himalayas and a dry bias in Amazonia.

On the other hand, the representation of vegetation parameters (e.g., NPP, Leaf Area Index, leaf density) is less well-described, particularly in chemistry-climate models. Often, these parameters are either imported as climatological or observationally constrained datasets or described using highly simplified parameterizations. To address this weakness, some models have incorporated a dynamic vegetation model within the CCM, allowing for a fully interactive response of vegetation and its influence on BVOC emissions, even under varying climate conditions.

Consequently, our model framework enables the investigation of multiple aspects, extending beyond the scope of the presented study. Various ESMs incorporate atmosphere-land interactions, such as NorESM, EC-Earth, ECHAM, and UKESM. These models utilise the Guenther emission algorithms (e.g., MEGAN or similar) to estimate BVOC emissions. In our recent study (Vella et al., 2023), we demonstrated that our model setup is suitable for investigating land-atmosphere interactions through BVOC emissions. Doubling CO_2 sensitivity experiments revealed that BVOC emissions from our model are sensitive to changes in vegetation and temperature. While some models include CO_2 inhibition on BVOC emissions (Arneth et al., 2007), the uncertainties surrounding this process remain high, and other studies suggest that CO_2 inhibition is not significant compared to the strong dependencies on temperature (Sun et al., 2013). In our setup, CO_2 inhibition on BVOC emissions is not included.

There is a wide range of estimates for global isoprene and monoterpene emissions in the literature. A recent study comparing NorESM, EC-Earth, and ECHAM revealed that NorESM has the lowest isoprene emissions at approximately 435 Tg yr^{-1}, while EC-Earth and ECHAM exhibit slightly higher emissions at 572 Tg yr^{-1} and 526 Tg yr^{-1}, respectively. Regarding monoterpenes, NorESM has the highest global emissions at 118 Tg yr^{-1}, followed by EC-Earth at 96 Tg yr^{-1}, and then ECHAM at 77 Tg yr^{-1} (Sporre et al., 2020). The models also show significant differences in aerosol radiative effects resulting from BVOC-SOA treatment, primarily due to different parameterizations and SOA treatments employed.

In conclusion, we have confidence in the robustness of our setup to study biosphere-atmosphere interactions arising from ENSO. However, we acknowledge that other model setups may capture these interactions differently. We hope that this study encourages further modeling efforts to evaluate such interactions.

Are there any caveats in the study itself or shortcomings in the model that could have inflated/ underestimated the results?

We highlight the fact that our approach has limitations as it simplifies the complexity of the climate system by disregarding the influence of other climate drivers that may interact with ENSO, for example feedbacks via chemistry, SOA, radiation, and aerosol-cloud interactions. We elaborate more on the fact that the Sustained ENSO simulations result in inflated BVOC emissions as they also capture long-term changes in the biosphere. However, these simulations are mostly intended for the statistical evaluation of the driving variables response to ENSO and the subsequent changes in BVOC emissions. Furthermore, as mentioned above, the simulated vegetation does not include anthropogenic deforestation, such that the simulated vegetation patterns mostly resemble a potentially natural vegetation.

I want to stress that I don't expect detailed answers to all the questions above, they are just some suggestions for potential discussion points.

After reading the discussion and conclusions, it is not clear to me what the implications of the study are. By that I don't mean it the study set-up and results are not sufficiently interesting, but in my view the authors could expand more on the significance of their study in the current climate and future. i.e. if in fact ENSO events do become more sustained and/ or more extreme in a changing climate, you expect increased BVOC emissions. But what does that mean for associated processes in the atmosphere?

Now mentioned in the Conclusion: "As BVOC emissions are projected to rise in a warming climate, it becomes imperative to understand and quantify these disturbances to accurately predict future BVOC emissions, SOA formation, and their climate feedbacks. Additionally, BVOCs are crucial players in the formation of tropospheric ozone and other harmful air pollutants, posing risks to human health and regional air quality, especially in communities located close to dense forests. Furthermore, BVOCs can act as precursors for greenhouse gases like methane, exacerbating the overall radiative forcing and contributing to climate change. Therefore, it is crucial to understand the intricate interplay between

ENSO, BVOC emissions, atmospheric chemistry, and climate for accurately predicting, and mitigating the far-reaching impacts of these ENSO in the climate system."

Your analysis relies on both isoprene and monoterpene emissions but the monoterpene emissions are largely neglected in the manuscript. Do the two types of emissions play different roles in the atmosphere or are they quite similar? You could pick this up in the discussion.

Monoterpenes were mostly not discussed in detail as their response to the factors driving emissions is similar to that of isoprene. In the ONEMIS parameterisations, the only differences between isoprene and monoterpene emission calculations is the emission factors used. We also explain why this could lead to differences, and also asymmetry in the isoprene and monoterpene emissions:

"In some regions, e.g., SEAsia (all scenarios except Moderate Niña) and the Amazon (Moderate Niña scenario), see Fig.7 & Fig. S5, we notice asymmetry in the isoprene and monoterpene emissions. The isoprene and monoterpene parameterisations in ONEMIS only differ in the emission factors and the correction factor based on the number of carbon atoms per molecule. This means that the different emission factors can lead to variations in the overall emission rates between the two compounds, even when other variables are the same. For example, if the emission factor for isoprene is assigned a higher weight compared to monoterpene, the model will amplify the effect of the corresponding variable (e.g., temperature) on isoprene emissions, resulting in a larger increase in isoprene fluxes compared to monoterpene fluxes. Conversely, if the emission factor for monoterpene is given a higher weight, the model will prioritize the effects of that variable, potentially leading to a larger decrease in monoterpene emissions compared to isoprene emissions."

In terms of atmospheric chemistry, oxidation products from monoterpenes are more likely to partition into the particle phase, but are emitted in much smaller quantities. Nevertheless, some plant types are more likely to emit isoprene whereas others are stronger sources of terpenes.

Specific comments

L1: It might be nicer to start with the umbrella term (BVOC emissions which is also in your title), and then divvy it up into isoprene and monoterpene emissions later on? But this is my personal preference and up to the authors.

Text now reads: "Emissions of Biogenic volatile organic compounds (BOVCs) from the terrestrial biosphere play a significant role in major atmospheric processes."

L1: Can you give one example that explains the 'significant role' BVOC emissions play?

Yes, text updated: "BVOCs are highly reactive compounds that influence the atmosphere's oxidation capacity and also serve as precursors for the formation of aerosols that influence global radiation budgets."

L5: ENSO is the most important mode of climate variability and you could state this in the abstract to motivate your study

Now included in the abstract: "It perturbs the natural seasonality of weather systems on both global and regional scales and is considered the most significant driver of climate variability."

L35: Typo (?) ‘The El Nino-Southern Oscillation (ENSO) is a periodic oscillation’

Typo fixed.

L58: Are there any assumptions that might explain the impact of ENSO on BVOC emissions in higher latitudes?

ENSO does not only affect the low latitudes, but via global teleconnection patterns, also alters the meridional temperature gradient and precipitation patterns, even in Europe (Martija-Díez et al., 2023).Consequently, ENSO has to be regarded as a global scale phenomenon, though the impact in the low latitudes is substantially stronger.

With reference to the cited study, Müller et al. (2008) found correlations of ONI with isoprene emissions over higher latitudes (correlation coefficient between (-0.3 and 0.3) especially when a 6-month shift was applied. The study does not go into details on the assumptions that might explain the impact of ENSO on BVOC emissions in higher latitudes, however, BVOC fluxes in higher latitudes are generally low so the impact on anomalies should not be so significant. This is also why in this study we focus on regions close or in the tropics.

L83-84: The citations are a bit off - ‘aerosol-cloud interactions (e.g. Tost, 2017). In this study, version [. . .] used in comprehensive model intercomparison studies (e.g. Joeckel et al., 2016)’

The citations used here have been selected to describe the comprehensive modelling system and to show potential of follow-up studies using the interactive BVOC emissions.

L87: Could define LPJ-GUESS in the first line of the section (L86, sorry for being pedantic)

Now defined in the first line.

L96: Why did you exclude land-use change? The use of PNV could also be a discussion point

This is a limitation of or current model setup. The new version of LPJ-GUESS will include land use functionality. Now clarified in manuscript.

L98-105: You very superficially describe the different components of the model, fair enough – but given this study is focussed on the BVOC it'd be nice to know if there is one core process or something that describes the BVOC module and how it links land surface and atmosphere in your model set up.

More details about the model coupling and the BVOC emission module were provided in Section 2.2.

"While efforts for a fully coupled configuration are ongoing, in this work, we use the standard EMAC-LPJ-GUESS coupled configuration, where the vegetation in LPJ-GUESS is entirely determined by the EMAC atmospheric state, soil, N deposition, and fluxes (Forrest et al., 2020). After each simulation day EMAC computes the average daily values of 2-meter temperature, net downwards shortwave radiation, and total precipitation and passes these state variables to LPJ-GUESS. Vegetation information (LAI, foliar density, leaf area density distribution, and PFT fractional coverage) from LPJ-GUESS is then fed back to EMAC for the calculation of BVOC emission fluxes using EMAC's BVOC submodules (Vella et al., 2023), namely ONEMIS (Kerkweg et al., 2006) and MEGAN (Guenther et al., 2006). Both ONEMIS and MEGAN are based on the Guenther algorithms (Guenther et al., 1993), where the BVOC emission flux (F) is calculated as a function of the foliar density and its vertical distribution (D [kg dry matter m^{-2}]), ecosystem-specific emission factors (ϵ), and a non-dimensional activity factor (γ) that accounts for the photosynthetically active radiation (PAR) and temperature:

$$F = [D]\ [\epsilon]\ [\gamma] \tag{1}$$

In this work, we evaluate fluxes from ONEMIS, which is the standard and most established emission module in EMAC. Emissions are calculated at four distinct canopy layers, which are defined by the leaf area density (LAD) and the leaf area index (LAI). The attenuation of the PAR is determined for each level by considering the direct visible radiation and the zenith angle. Using the proportions of sunlit leaves and the overall biomass, emissions from both sunlit and shaded leaves within the canopy are estimated. Further technical details for canopy processes employed in ONEMIS can be found in Ganzeveld et al. (2002). While validating pure BVOC fluxes from models using observations remains challenging, this setup was evaluated and demonstrated to well-capture global BVOC estimates and responses when compared to other modelling studies (Vella et al., 2023). As described in Eq. 1, BVOC emission calculations in this setup are governed by vegetation states (D) from LPJ-GUESS that are largely based on temperature, radiation, and soil moisture. Furthermore, the instantaneous surface radiation and temperature levels (γ) have a large impact on the emission rates. On the the basis of such model parameterisations, we explore the impact on BVOC emission anomalies by evaluating changes in the surface temperature and radiation, the aridity index (AI), the NPP, and the LAI."

L107: Have you defined AMIPII somewhere?

Now defined.

L111: Are your thresholds defining weak, moderate and strong common practice? I.e. can you support this decision with a citation pointing to other research using the same thresholds?

There is no officially published thresholds, however, these are used by NOAA and also in several publication. Now explained in Section 2.3.

"Even though not officially published, this ONI threshold classification has been used by the National Oceanic and Atmospheric Administration (NOAA) (www.climate.gov/news-features/blogs/enso/united-states-el-niÃśo-impacts-0, last access: 03 July 2023) and also in several research articles (e.g., Jimenez et al., 2021; Abish and Mohanakumar, 2013)."

L125: Not sure I understand the last sentence on the page. Are you saying you chose the seven regions because they are mostly in the tropics which are typically areas with high BVOC emissions (can you include a reference to support this statement)? You could further motivate the choice of regions by mentioning that they conveniently happen to be ENSO hotspots as well (except NE Australia)

This is now mentioned as follows: "The regions considered are hotspots for ENSO (apart from NE Australia) and places with generally high BVOC emissions in the tropics (except from SW USA) (Bastos et al., 2013; Vella et al., 2023; Sindelarova et al., 2014). Additionally, we used the BVOC anomaly distribution maps (Fig. 7) to establish the exact dimensions of the bounding box for regions with relatively consistent BVOC anomalies."

L129: Have you defined the 'base conditions' somewhere?

Now defined in Section 2.3

L132: Does this mean that in the 31st and 32nd year you perturb the atmospheric circulation with your ENSO anomalies?

Yes. Text amended.

L142: Typeo - 'Even though'

Fixed, thank you.

L151: Could you write out Jan and Dec to January and December please:)

Now written in full.

L151: Capital Event?

Fixed.

L167: A bit convoluted.. Maybe something like ‘however, following the ENSO perturbation fluxes diverge’

Updated.

L189: The definition of the aridity index belongs in the methods section

Moved to Section Section 2.3.

L190: Throughout your manuscript you’re not consistent with italic/ not italic ‘base’ scenarios/ conditions

Italics were removed completely. Now the scenarios are consistently referred to as "base", "Moderate" and "Very Strong" El Niño/La Niña.

L191: Are r-values the correlation coefficients?

Yes, updated.

Table 2: I like that you give both percentage and absolute changes for temperature in Table 2 to get a sense of magnitude. Can you also include the actual values for change in Radiation and AI in the table? It might make it easier to link the table to Figure 4.

All tables now include absolute an % changes.

Figure 3: I think the figure is very small and it’s quite hard to see anything on it. Maybe you could rearrange the panels. There is also a lot of white space at the top that maybe could be trimmed? But maybe I just can’t see the datapoints. Could you spell out the abbreviations in the caption too (AI, NPP, LAI)?

The panels were rearranged to make them bigger. Looks better now. Abbreviations in the figure captions are spelled out.

Section 3.2.1. is a description of the results – where is the discussion here? For example, are the anomalies shown in Figure 4 what you expect [. . .]? As I said above, it might be easier to split results and discussion but that is up to you.

This is now discussed in the separate Discussion Section.

"It has been suggested that changes in weather patterns during ENSO events are linked to the rearrangement of the Walker circulation convective centers and teleconnections with midlatitude westerlies (McPhaden et al., 2006; Dai and Wigley, 2000). Our simulations agree with previous studies suggesting that during El Niño the tropics become warmer and drier (Gong and Wang, 1999; Dai and Wigley, 2000), while some areas such as Western North America and East Asia tend to be cooler and wetter (Ropelewski and Halpert, 1986; Wu et al., 2003). Bastos et al. (2013) investigated the variations in temperature, radiation, and precipitation during El Niño and La Niña events from 2000 to 2011 and revealed significant changes in these climatic factors. Positive temperature anomalies exceeding 1 °C were observed in the Amazon, Central and South Africa, and northern Australia during El Niño, while cooler temperatures were detected in the USA and Europe. In our study, we also observed similar trends, with the strong signal over Australia coming from the significantly cooler temperatures during La Niña. However, we did not observe such a pronounced influence on European temperatures. Furthermore, our results align with the findings of Bastos et al. (2013) in terms of surface radiation changes. Regarding precipitation, the signal in Bastos et al. (2013) was less distinct, but a decrease in precipitation in the Amazon region during El Niño was suggested. Consistent with these findings, our study revealed higher aridity in the Amazon, supporting the notion of decreased precipitation in this region during El Niño events."

Figure 4: I appreciate the value of including anomalies over the ocean as the temperature and radiation plots show the typical ENSO anomalies over the ocean quite nicely. However I wonder, given this study is mostly focussed on land processes, whether you would consider to mask the ocean and include a supplementary figure of the SST anomalies to demonstrate that your experiment captures ENSO. Especially for the radiation anomalies, it is quite hard to see what's happening for the majority of the land surface because the colorbar is maxed out to fit to the ocean anomalies. In this figure, I'm surprised that the bottom panels do not show a signal in Australia which pops up as one of the most impacted regions in Figure 5. Does the water limitation signal disappear because you use the aridity index here rather than direct precipitation anomalies? None of the other anomalies seem to able to explain the strong signal.

All figures now updated with an ocean mask to make anomalies on land clearer. The SST plot that depicts ENSO conditions is included in the supplement.

Thanks for noting the abnormal signal over Australia in Fig. 5. LPJ-GUESS tends to assign very tiny, but non-zero, values over regions without vegetation. We usually apply a small threshold to discard such values over desert regions. I checked my code and realised that this threshold was being applied after the two-tailed Student's t-test. So the "significant correlation" shown was actually coming from these tiny insignificant values. Once the thresholds are applied properly this signal over Australia disappears. See updated Fig. 5.

L219: You use the abbreviation SEASIA here but in Table 2 for example it is SEAsia. I'm not sure whether this happening in other places in the manuscript, but can you make sure you are consistent within the manuscript?

SEASIA is a typo. All consistent now.

Figure 5: I'm a bit surprised about this figure but maybe I'm misreading it. The middle panels contrast vegetation anomalies in an extreme El Nino with that of an extreme La Nina right? The patterns almost look identical, especially for NPP, and I had to zoom in to see that they the top middle and right panel are not identical but show small differences in the hatching. I wonder whether there might have been a mistake in the plot. Typically for an extreme El Nino, you would expect a negative signal at least for parts of Australia due to increased water limitation while for a La Nina it would be positive as you show here. I also would have expected a negative signal in the tropical rainforests in South America and South East Asia. Figure 4 shows a somewhat contrasting signal in the Aridity Index and to some degree in the incoming SW radiation (but it's hard to tell due to the colorbar, see comment above). Can you confirm that Figure 5 indeed shows the 'correct' distribution of anomalies, and if so can you explain the signal given it is quite counter-intuitive?

Fig. 5 shows the spatial distribution of NPP and LAI as well as the El Niño anomaly (El Niño − Base conditions) and La Niña anomaly (La Niña − Base). There was indeed a bug in the script for this plot, where the differences were not calculated properly. The updated plots are coherent with your remarks about El Niño / La Niña effects on vegetation. The colour scheme was also updated to shades of blue and red as this better depicted the anomaly distributions.

L.234-235: Can you rephrase this? Nearly instantaneously and rather quickly sound like quite similar timescales to me. Are you showing the lag in vegetation response somewhere? If so can you point the reader to that information? If this is meant to be a more general discussion point, could you include a reference to support this statement?

Rephrased to "rather slowly". We do not explore vegetation lags in detail here and this a more general comment to emphasise the changes seen in Fig. 6. As the model formulation allows for new establishment of PFTs only at the end of the year (see the LPJ/GUESS description for more details), some changes in vegetation distribution patterns show a longer lag in the correpsonding emission driving parameters compared to the direct response of e.g., soil water stress.

L263: I probably just missed it, but where did you mention before that the emission changes may be exaggerated? I think this could be a good discussion point, can you unpack this more?

Emissions from the Sustained simulations may be exaggerated in the sense that they include long term changes in the vegetation. More clearly mentioned now.

L279: What does this mean – high NPP and LAI = high isoprene emissions?

Yes, this means that higher NPP and LAI results in more BVOC emissions.

L271-284: Following this section, you define ‘strong correlations’ as values greater than 0.4? Often correlation coefficients are split into weak/moderate/strong classes, and values around 0.5 would typically considered moderate. I think you should be more careful with your phrasing here and/or define somewhere where your differentiation is coming from (based on significance?). You do need to be consistent with the actual values of the correlation coefficients though; the ones in written in the text do not always match the ones in the figure (small differences only).

We are now consistent throughout by using the following classification: 0.00-0.29 as negligible, 0.30-0.49 as weak, 0.50-0.69 as moderate, 0.70-0.89 as strong, and ≥ 0.90 as very strong for positive correlations and similarly for negative correlation between 0 and -1.

L289-295: You found relationships based on a Pearson correlation, but you don’t explain why temperature anomalies drive isoprene fluxes in Africa, and LAI in the southern USA, north east South America, South Africa, Central Asia and Australia. Is this a surprising result? Is it what you expected? Do you know why this is emerging from the model?

The dependencies from the correlation analysis are discussed in the Discussion section.

These dependencies are complex but can be associated with the magnitude in the anomalies of the driving variables as well as how different plant species with in a specific microclimate respond to such changes. For example, in Central Africa during El Niño, we have a strong positive temperature anomalies, but anomalies in surface radiation and aridity are not so great (see Fig. 4). This observation potentially elucidates why temperature serves as the primary driver of BVOC anomalies in this particular area. On the other hand, in northeast South America, we observe a substantial impact on temperature, accompanied by significant alterations in surface radiation and AI. These combined effects likely contribute to the robust signal in net primary productivity (NPP) and, more specifically, to the changes observed in leaf area index (LAI) in this region.

Our findings indicate that in the southern USA, northeast South America, South Africa, Central Asia, and Australia, BVOC anomalies are primarily influenced by changes in leaf area index (LAI) resulting from the adaptation of vegetation to new climate states. Although LAI is inherently influenced by atmospheric conditions, the prolonged alterations in LAI resulting from changes in precipitation patterns, temperature, and radiation regimes associated with sustained ENSO conditions have a significant impact on BVOC emissions. It is important to note that the changes presented in this study do not account for anthropogenic influences, such as land-use changes, deforestation, and increasing CO_2 concentrations which would also influence the response of the biosphere and BVOC emissions.

Boreal forests, at higher latitudes, are typically characterised by colder climates with shorter growing seasons. In these regions, the availability of sunlight, represented by surface radiation, plays a crucial role in determining photosynthetic activity and plant growth. Changes in surface radiation, such as alterations in cloud cover or atmospheric conditions, can directly impact the amount of solar energy reaching the vegetation canopy. Increased surface radiation can enhance photosynthesis and, subsequently, BVOC emissions in boreal forests, where plants are sensitive to changes in light availability.

L312: Your current data availability statement is not sufficient for Earth System Dynamics. You should at least make your analysis code publicly available. For the time being I'm sure a github link (or similar) will be enough but for publication you will be asked to publish a zenodo link anyway so you might as well get started on that now!

Data and analysis code will be made available on zenodo. Model code could not be made public.

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