

We thank reviewer #1 for taking the time to review our manuscript and for giving us constructive feedback on how to improve the manuscript. We address the five main comments below.

Comment 1

1. *The manuscript clearly presents two new BVOC emission datasets, but it did not state how these datasets advance beyond existing ones (e.g., CAMS-GLOB-BIO, MEGAN-MACC) in terms of process representation, especially regarding dynamic vegetation and soil moisture effects. A more direct comparison of methodological improvements and their impacts on emission estimates would strengthen the introduction or conclusions.*

Response

We agree with reviewer 1 and thank them for their comment. We are in complete agreement that this is relevant material to add to the paper. Moreover, when we created the concept of the SURFEX-MEGAN3.0 emissions we had the methodology of the CAMS-GLOB-BIO emissions, and its earlier iterations, in mind. We specifically tried to make some incremental improvements to the methodology. Specifically, we attempted to improve these aspects:

- **The satellite LAI data source.** We selected the Copernicus Land Monitoring Service (CLMS) LAI products in place of MODIS LAI. CLMS LAI products show consistently better accuracy (Sanchez-Zapero et al., 2018), precision, uncertainty, and temporal and spatial correlation than their MODIS counterparts.
- **Using a phenological vegetation model (Calvet et al., 1998) coupled with multi-layer diffusion-based soil moisture model in SURFEX (Decharme et al., 2019).** This meant that we could use the daily simulated and assimilated LAI values from SURFEX rather than monthly mean LAI values as was used in MEGAN-MACC and CAMS-GLOB-BIOv3.1.
- **Using a data assimilation approach.** A data assimilation approach combining satellite LAI data with a model offers the best of both worlds from both satellite observations and models. The observations offer more accurate, precise, and realistic estimate of the true LAI state, the model offers spatially and temporally contiguous fields with no data gaps, and the assimilation algorithm acts to smooth out and reduce uncertainties achieving an optimised estimation of the true LAI state.
- **Soil moisture effects.** The multi-layer (14 in this case) diffusion model for soil moisture is able to represent soil moisture accurately (Decharme et al., 2019; Blyverket et al., 2019). When this model is further improved by assimilation of LAI data, this improves the model's representation of evapotranspiration, which then indirectly improves the estimation of soil moisture (Albergel et al., 2017).
- **The spatial resolution.** A higher spatial resolution at $0.1^\circ \times 0.1^\circ$ compared to $0.5^\circ \times 0.66^\circ$ and $0.25^\circ \times 0.25^\circ$ in the case of MEGAN-MACC and CAMS-GLOB-BIOv3.1, respectively. Besides simply providing BVOC emissions at higher resolution, the spatial resolution is particularly important when representing land surface processes due to the heterogeneity of the land surface.
- **The temporal resolution.** The SURFEX-MEGAN emissions were produced with a temporal resolution of 1-hour. The MEGAN-MACC and CAMS-GLOB-BIOv3.1 emissions have a quasi 1-hour temporal resolution by combining the monthly mean emissions with a mean diurnal variability for the emissions for any particular month.
- **The meteorological data.** Besides the impact on the spatial resolution, this point is most relevant in comparison to MEGAN-MACC that used MERRA.

We have added this text to the introduction expanding on the listed incremental improvements to highlight the aspects noted above:

“We outline below advancements relative to previous work on BVOC emissions in the context of CAMS and European air quality (i.e., Sindelarova et al., 2014 and Sindelarova et al., 2022):

- i) Using a phenological vegetation model (Calvet et al., 1998) within SURFEX allows us to estimate LAI on a daily basis instead of only on a monthly mean basis as in the case of (Sindelarova et al., 2014 and Sindelarova et al., 2022).
- ii) A data assimilation approach combining satellite LAI data with a model offers the best of both worlds from both satellite observations and models. The observations offer a more accurate, precise, and realistic estimate of the true LAI state, the model offers spatially and temporally contiguous fields with no data gaps, and the assimilation algorithm acts to smooth out and reduce uncertainties achieving an optimised estimation of the true LAI state.
- iii) Using Copernicus Land Monitoring Service (CLMS) LAI products in place of MODIS LAI. CLMS LAI products show consistently better accuracy, precision, uncertainty, and temporal and spatial correlation than their MODIS counterparts when evaluated against independent observations (Sánchez-Zapero et al., 2018).
- iv) The multi-layer (14 in this case) diffusion model for soil moisture is able to represent soil moisture accurately (Decharme et al., 2019; Blyverket et al., 2019). When this model is further improved by assimilation of LAI data, this improves the model’s representation of evapotranspiration, which then indirectly improves the estimation of soil moisture (Albergel et al., 2017).
- v) A higher spatial resolution at $0.1^\circ \times 0.1^\circ$ compared to $0.5^\circ \times 0.66^\circ$ and $0.25^\circ \times 0.25^\circ$ in the case of MEGAN-MACC (Sindelarova et al., 2014) and CAMS-GLOB-BIOv3.1 (Sindelarova et al., 2022), respectively. Besides simply providing BVOC emissions at higher resolution, the spatial resolution is particularly important when representing land surface processes due to the heterogeneity of the land surface.
- vi) The emissions we present were produced with a temporal resolution of 1-hour. The MEGAN-MACC and CAMS-GLOB-BIOv3.1 emissions have a quasi-1-hour temporal resolution by combining the monthly mean emissions with a mean diurnal variability for the emissions for any particular month.
- vii) Using the state-of-the-art land cover maps over Europe, ECOCLIMAP-II (Faroux et al., 2013), which contain specific adaptations of the CORINE land cover to European conditions.
- viii) Updated MEGAN version to v3.0 (Guenther et al., 2020; Zhang et al., 2021). Many existing publicly available BVOC emission datasets and examples of applications in the literature use MEGAN 2.1.”

We have also added some additional discussion to the conclusions relevant to the expanded list of improvements:

References

Blyverket, J., Hamer, P. D., Bertino, L., Albergel, C., Fairbairn, D., & Lahoz, W. A. (2019). An evaluation of the EnKF vs. EnOI and the assimilation of SMAP, SMOS and ESA CCI soil moisture data over the contiguous US. *Remote Sensing*, 11(5), 478.

Calvet, J. C., Noilhan, J., Roujean, J. L., Bessemoulin, P., Cabelguenne, M., Olioso, A., & Wigneron, J. P. (1998). An interactive vegetation SVAT model tested against data from six contrasting sites. *Agricultural and Forest Meteorology*, 92(2), 73-95.

Decharme, B., Delire, C., Minvielle, M., Colin, J., Vergnes, J. P., Alias, A., ... & Voldoire, A. (2019). Recent changes in the ISBA-CTRIP land surface system for use in the CNRM-CM6 climate model and in global off-line hydrological applications. *Journal of Advances in Modeling Earth Systems*, 11(5), 1207-1252.

Sanchez-Zapero, J., Fuster, B., Camacho, F., Quality Assessment Report, (LAI, FAPAR, FCOVER, Collection 300 M, Version 1). Copernicus Land Monitoring Service. <https://land.copernicus.eu/en/technical-library/quality-assessment-report-leaf-area-index-333-m-version-1/>

Comment 2

2. *While the evaluation using ambient isoprene concentrations is valuable, the lack of direct comparison with eddy covariance or other flux measurements of BVOCs is a limitation. The authors should acknowledge this and discuss plans or possibilities for such evaluations in future work.*

Response

We thank the reviewer for this comment. We agree that this limitation should be made clearer in the manuscript. We would also like to note that, to our knowledge, the eddy covariance flux measurements of isoprene are only available as part of short-term measurement campaigns, which diminishes their usefulness for evaluating a multi-year emission dataset.

We have added this text to the discussion of the BVOC observations:

“We have not included a comparison between our emissions and eddy covariance flux observations of isoprene. This is a limitation of this work that prevents an evaluation of the magnitude of the emissions and of the observed variability in emissions. One reason for this is that such observations are only available as part of short-term campaigns, which limits their usefulness for evaluating multiyear emission datasets.”

In the time between the submission of this manuscript, the completion of the review, and our subsequent response, an article was published citing the preprint showing a spatially wider comparison between the emissions and isoprene, albeit for a 1-week, Europe-wide observation campaign. We have therefore added this text to the manuscript:

“The SURFEX-MEGAN3.0 open-loop emissions were evaluated in a recent study detailing a Europe-wide 1-week measurement campaign focused on VOCs (Aas et al., 2025). This evaluation showed that the SURFEX-MEGAN3.0 open-loop emissions correlated well with observed isoprene concentrations at roughly half of the sites included in the study, albeit for a short time period.”

We have also added text to the conclusions section in a paragraph where we discuss other limitations. We direct readers to see response to comment 5 below, which discusses limitations more generally.

Comment 3

3. *Although LAI assimilation could improve LAI estimates to some extents, its impact on total isoprene emissions might be modest. The authors should elaborate on why this is the case and whether this suggests that LAI assimilation is more critical for certain regions or compounds.*

Response

We thank the reviewer for their comment. We address their comments in two parts. First, on the question of modest impacts on isoprene emissions. It is true that the impact on the Europe-wide totals averaged on monthly timescales is very limited. This is likely due to taking averages over large spatial areas leading to cancelling out of positive and negative LAI assimilation increments. It is also true that the maps showing the monthly and annual mean differences between the analysis and open loop emissions are quite low in absolute terms. Part of this is likely because of the temporal averaging, which, again, likely has the effect of cancelling the positive and negative increments out for particular grid cells over time. If we were to look at shorter time scales, we would see larger differences in the emissions between the two datasets. Lastly, but not least, the ISBA-a-gs model is quite skillful already for natural vegetation types when driven by good quality meteorological forcing and has been well validated for such cases (Delire et al., 2020). Thus, the open-loop model can capture the vegetation phenology and LAI in absolute terms quite well already. This has the effect of reducing the opportunity for the LAI assimilation step to make large improvements to the open-loop.

We have added this text to the manuscript to address the reviewer's comment:

"The impacts of the LAI assimilation on total and the monthly mean isoprene emissions appear modest for four reasons. First, the total isoprene emissions are subject to both temporal and spatial averaging, which leads to an effect whereby positive and negative assimilation increments cancel out over time and space leading to only small deviations from the open-loop. Second, the monthly mean emission maps are subject to temporal averaging that will over time lead to cancelling out of positive and negative LAI increments in time.

Beyond these purely statistical reasons, a third reason is that the underlying vegetation model in SURFEX, ISBA-a-gas, is quite skillful already at representing natural vegetation types when driven by good quality meteorological forcing and has been well validated in such cases (Delire et al., 2020). When the base model starts out with a good estimate of the observed state, this reduces the opportunity for the LAI assimilation step to make large improvements to the estimated state variable. Indeed, this effect was seen when using SURFEX to estimate soil moisture over the continental United States (Blyverket et al., 2019)."

Blyverket, J., Hamer, P. D., Bertino, L., Albergel, C., Fairbairn, D., & Lahoz, W. A. (2019). An evaluation of the EnKF vs. EnOI and the assimilation of SMAP, SMOS and ESA CCI soil moisture data over the contiguous US. *Remote Sensing*, 11(5), 478.

Delire, C., Séférian R., Decharme B., Alkama R., Calvet J.-C., Carrer D., Gibelin A.-L., Joetzjer E., Morel X., Rocher M., Tzanos D.: The global land carbon cycle simulated with ISBA-CTRIP: improvements over the last decade, *Journal of Advances in Modeling Earth Systems*, 12, e2019MS001886, <https://doi.org/10.1029/2019MS001886>, 2020.

Second, we address the question of whether LAI assimilation is more critical for certain regions. The underlying vegetation model in SURFEX, ISBA-a-gs, is not a crop model. It is designed to simulate natural vegetation types. This means that it does not simulate ploughing, seeding/planting, and harvesting, only includes simple prescriptive irrigation processes, and does it simulate which cultivars are being planted, which can all impact the LAI simulation in significant ways. The LAI assimilation offers an approach that can therefore correct LAI over regions with large proportions of crop cover. Indeed, this has been demonstrated in previous applications of the SURFEX model (see for example Albergel et al., 2017, Rojas-Munoz et al., 2023, and Jarlan et al., 2023 articles below). It should be noted that crops are not usually the largest source of isoprene. Thus, this may offer an explanation for why the impact on isoprene emissions of the assimilation step is limited.

Albergel, C., Munier, S., Leroux, D. J., Dewaele, H., Fairbairn, D., Barbu, A. L., Gelati, E., Dorigo, W., Faroux, S., Meurey, C., Le Moigne, P., Decharme, B., Mahfouf, J.-F., and Calvet, J.-C.: Sequential assimilation of satellite-derived vegetation and soil moisture products using SURFEX_v8.0: LDAS-Monde assessment over the Euro-Mediterranean area, *Geosci. Model Dev.*, 10, 3889–3912, <https://doi.org/10.5194/gmd-10-3889-2017>, 2017.

Rojas-Munoz, O., Calvet, J. C., Bonan, B., Baghdadi, N., Meurey, C., Napoly, A., ... & Zribi, M. (2023). Soil moisture monitoring at kilometer scale: assimilation of sentinel-1 products in ISBA. *Remote Sensing*, 15(17), 4329.

Jarlan, J., Albergel, C., Bonan, B., Calvet, J.-C., de Rosnay, P., Ottlé, C., and Peylin, P.: Assimilation de données de télédétection pour le suivi des surfaces continentales in *Inversion et assimilation de données de télédétection*, 45-95, ISTE Editions, <https://doi.org/10.51926/ISTE.9142.ch2>, 2023

We have added this text to the manuscript to address this comment:

“A fourth reason is that the ISBA-a-gs vegetation model is not a crop model and is designed to simulate natural vegetation types. It lacks the means to simulate cultivation processes such as ploughing, seeding, and harvesting, and only includes a prescriptive irrigation process. This means that the open-loop model typically has much larger errors in its representation of the true vegetation state. This means that the LAI assimilation offers an opportunity to correct LAI over regions with large proportions of crop cover. Indeed, this has been demonstrated in previous applications of the SURFEX model (see for example Albergel et al., 2017, Rojas-Munoz et al., 2023, and Jarlan et al., 2023 articles below). Furthermore, it should be noted that crops are not usually the largest source of isoprene. Thus, this may offer an explanation for why the impact on isoprene emissions of the assimilation step is limited.”

Comment 4

4. *The manuscript mentions using MEGAN EFP with updated land cover but does not fully address potential biases from emission factors, especially given their significant contribution to uncertainty. The authors should discuss on how emission factors were validated or constrained for the European domain.*

Response

We agree with the reviewer that this is a relevant point to raise. We also agree with the reviewer that emission factors (EFs) are a significant contribution to the overall uncertainty in the emissions over Europe. This has been discussed in several papers (e.g. Simpson et al., 1999, Keenan et al., 2009, Rinne et al., 2009, Oderbolz et al., 2013, or Sindelarova et al., 2022) and future efforts are required to improve this area. However, it is important to note that the main purpose of this manuscript is not to evaluate the emission factors (EFs) used in MEGAN3, but rather to demonstrate the use of SURFEX and

assimilated LAI to calculate the emissions. We believe it is beyond the scope of this paper to try to do a full validation or to constrain the EFs that we used. As a general comment, it is hard to do specific validation of EFs due to the lack of direct measurement at the grid scale of our emission inventories and the underlying PFT data. It would require at least one other manuscript to address this topic with sufficient detail to properly address and highlight the important issues.

The best we can do here is to provide comparison of the EFs used to compile the SURFEX-MEGAN emissions, and those used in two of the prominent inventories that we compare against: CAMS-GLOB-BIOv3.0 (MEGAN2.1) and CAMS-GLOB-BIO3.1 (EMEP). This will give some information on the uncertainties in our emissions. Furthermore, it provides the first step towards motivating and identifying the further investigations that are needed for future studies. We carried out a comparison between the emission factors (EFs) used in the CAMS-GLOB-BIO datasets and those used to create the SURFEX-MEGAN emissions as part of background research for the paper. We have, therefore, now added figures showing the emission factors from CAMS-GLOB-BIO3.0 and 3.1 to the supplement. We also add some interpretation to this comparison to the manuscript (Sect. 3.3.2) that takes into account the findings from Sindelarova et al. (2022) that indicated that changes from the MEGANv2.1 to EMEP EFs led to reductions in the overall magnitude between the CAMS-GLOB-BIOv3.0 and CAMS-GLOB-BIOv3.1 emissions.

“The emission factors used in the different emission inventories contribute another important source of uncertainty and likely also play an additional role in explaining the differences in their magnitude. It is well established that uncertainties in emission factors are an important contributor to the overall uncertainty in emissions (Simpson et al., 1999, Keenan et al., 2009, Rinne et al., 2009, Oderbolz et al., 2013). Sindelarova et al. (2022) found that changing from the MEGANv2.1 to the EMEP emission factors, respectively, accounted for the higher estimated emissions over Europe of CAMS-GLOB-BIOv3.0 compared to CAMS-GLOB-BIOv3.1.

We compare the emission factors in this study (see Figure 7) to the emission factors for the CAMS-GLOB-BIOv3.0 and v3.1 emission inventories (Sindelarova et al., 2022) over Europe (see the supplement with CAMS-GLOB-BIOv3.0 in Figure S21 and CAMS-GLOB-BIOv3.1 in Figure S22). Due to differences in approach, it is not possible to compare the absolute magnitude of the emission factors shown in Figure 7 compared to those in Figures S21 and S22. This is because a different set of standard conditions were used by CAMS-GLOB-BIO from those used by SURFEX-MEGAN3.0. Furthermore, CAMS-GLOB-BIO, which is built on MEGAN2.1, uses a canopy-level approach instead of the leaf-level approach used in SURFEX-MEGAN3.0. Thus, the CAMS-GLOB-BIO emission factors include a multiplication by a standard LAI value of 5 m^{-2} for 3.0 and by a monthly climatological LAI derived from Yuan et al. (2011) for 3.1, whereas LAI is only treated within the activity factor calculations in SURFEX-MEGAN3.0.

Comparing Figures 7, S21, and S22, we determine that the SURFEX-MEGAN3.0/MEGAN EFP emission factors are more similar in their spatial distribution to those from CAMS-GLOB-BIOv3.0/MEGANv2.1 than the CAMS-GLOB-BIOv3.1/EMEP-based emission factors. The spatial patterns of the EMEP-based emission factors show much more heterogeneity than the MEGAN3.0 emission factors and show both maxima and minima in different regions. The EMEP-based emission factors show specific regions that have much higher relative values associated with broadleaf species in southern Europe on the one hand and areas that have relatively much lower values in central Europe and mountainous regions on the other. The MEGAN2.1 emission factors used in CAMS-GLOB-BIOv3.0 are more spatially smooth with less heterogeneity, which is a point of similarity with SURFEX-MEGAN3.0. The MEGAN2.1 emission factors do show peak values similar regions, e.g., mountainous regions like the Pyrenees, Alps, Balkans, and Carpathians, but differ by showing peaks in Russia, northern Norway, and Galicia.

Sindelarova et al. (2022) determined that the increased heterogeneity of the EMEP-based emission factors, particularly the large regions in Europe with relatively low values, contributed to the lower emissions that they calculated for CAMS-GLOB-BIOv3.1 compared to CAMS-GLOB-BIOv3.0. Following the same logic, and given the differences we see comparing SURFEX-MEGAN3.0 to the more heterogeneous EMEP-based emission factors, we attribute the higher SURFEX-MEGAN3.0 emissions compared to the CAMS-GLOB-BIOv3.1 emissions to be largely due to the effect of the emission factors.”

And also in the conclusions:

“Part of the difference in the absolute magnitude in the SURFEX-MEGAN3.0 and CAMS-GLOB-BIOv3.1 emissions was attributed to the difference in emission factors used to calculate both emission inventories. With the SURFEX-MEGAN3.0 emission factors generally having an effect that increased the isoprene emissions relative to those from CAMS-GLOB-BIOv3.1. This highlights the need for more study on emission factors in Europe and for us to update the emission factors in future work related to specific emitting vegetation species.”

In addition, we provide some details on ongoing research being done within two EU projects connected with CAMS (CAMS2-61,CAMAERA), which itself has identified challenges that limit progress on this specific topic.

“Work to evaluate and improve the European EFs in both EMEP and CAMS-GLOB-BIO is underway in other EU projects (CAMAERA, <https://camaera-project.eu/>, last access: 6 February 2026 and the continuation of CAMS2-61, Denier van der Gon, 2025), and any improvements can be incorporated in future applications of SURFEX-MEGAN3.”

References

Denier van der Gon: 2025, Documentation of CAMS emission inventory products, Denier van der Gon, H., Gauss, M., and Granier, C. (eds), CAMS261_2021SC1 – Product documentation, Copernicus Atmosphere Monitoring Service, 1 pp., <https://doi.org/10.24380/uag-0svt>, 2025.

Keenan, T., Niinemets, Ue., Sabate, S., Gracia, C., and Penuelas, J.: Process based inventory of isoprenoid emissions from European forests: model comparisons, current knowledge and uncertainties, *Atmos. Chem. Physics*, 9, 4053–4076, 2009.

Oderbolz, D. C., Aksoyoglu, S., Keller, J., Barmpadimos, I., Steinbrecher, R., Skjoth, C. A., Plass-Duelmer, C., and Prevot, A. S. H.: A comprehensive emission inventory of biogenic volatile organic compounds in Europe: improved seasonality and land-cover, *Atmos. Chem. Physics*, 13, 1689–1712, <https://doi.org/10.5194/acp-13-1689-2013>, 2013.

Rinne, J., Back, J., and Hakola, H.: Biogenic volatile organic compound emissions from the Eurasian taiga: current knowledge and future directions, *Boreal Environment Research*, 14, 807–826, 2009.

Wells, K. C., Millet, D. B., Payne, V. H., Vigouroux, C., Aquino, C. A. B., De Mazière, M., de Gouw, J. A., Graus, M., Kurosu, T., Warneke, C., and Wisthaler, A.: Next-Generation Isoprene Measurements From Space: Detecting Daily Variability at High Resolution, *J. Geophys. Res.*, 127, e2021JD036181, <https://doi.org/https://doi.org/10.1029/2021JD036181>, 2022.

Simpson, D., Winiwarter, W., Börjesson, G., Cinderby, S., Ferreiro, A., Guenther, A., ... & Öquist, M. G. (1999). Inventorying emissions from nature in Europe. *Journal of Geophysical Research: Atmospheres*, 104(D7), 8113-8152.

Comment 5

5. *The study shows many limitations. The authors should add more descriptions about the limitations in the discussions or conclusions.*

Response

We agree with the reviewer's comment. We have added a paragraph to the conclusions section that addresses limitations on the following topics: emission factors, the lack of flux tower measurement comparisons, limitations on the consistency of land cover datasets, using grid-level LAI to drive MEGAN rather than PFT-specific LAI, the necessary tradeoff between high resolution meteorological forecast versus coarser resolution reanalysis, and the lack of tests in an atmospheric model to compare to observations.

"We now address the various limitations of our work. First, we did not include a comparison with flux tower measurements nor did we test our emissions in an atmospheric model to simulate atmospheric concentrations of isoprene and secondary chemical species. Both would be valuable ways to extend our work in the future. There were also a series of methodological choices that affected the uncertainties of the presented emissions that could be addressed via sensitivity tests and form the basis of future work. For instance, we only used a single set of emission factors to calculate the emissions, and given their associated uncertainties, it would be worthwhile to investigate this further and test other emission factors in the future. We used the grid-averaged LAI output from SURFEX, but it would be worthwhile to test using the PFT-specific LAI values and then calculate the emissions separately for each PFT within each grid cell, e.g., following the approach of Oumami et al. (2024). Lastly, it would be worthwhile to test the trade-off of using coarser resolution meteorological reanalysis versus higher resolution meteorological forecast. We evaluated that the latter would be advantageous when designing this study but testing the former would help to evaluate that hypothesis further."

We have also added this text to the discussion of land use datasets:

"One further limitation of our work was the inconsistency between the land use datasets used in the SURFEX land surface model and the MEGAN EFP tool for calculating emission factors. This inconsistency should be corrected in future work following the example of Oumami et al. (2024) and Sindelarova et al. (2022)."

We thank reviewer #2 for taking the time to evaluate our manuscript and for providing very extensive feedback on how to improve it. We have addressed each of their comments in the responses below.

Main comments

Comment 1

From the introduction, I recommend clearly identifying which processes driving biogenic emissions are already well represented in models (such as temperature dependence, LAI, and water stress) and which have been recognized but are still poorly represented (such as plant defenses and signaling via attractor molecules).

We thank the reviewer for making this point and have modified the text (shown in red) in the introduction to discuss these points:

“Such modelling approaches could thus deliver spatial gap-filling in regions lacking observations, which would have scientific value for studying air quality, atmospheric composition, and climate. Given this need, there have naturally been different efforts and approaches developed to model BVOC emissions from vegetation. **Not all of the processes mentioned earlier that drive BVOC emissions are currently well represented in BVOC emission models. The effects of solar radiation, temperature, LAI, and in-canopy shading, are typically well represented (Arneth et al., 2007; Guenther et al., 2012; Naik et al., 2004). The effect of water stress is represented in models to varying levels of sophistication (Wang et al., 2022), but there are cases where water stress effects are not considered (Sindelarova et al., 2014, 2022; Stavrakou et al., 2009). Lastly, emission processes linked to plant defences and signalling are less well understood and are currently poorly represented in models.**”

Comment 2

The authors used the ECMWF HRES operational forecast; however, employing meteorological variables from a reanalysis dataset might have led to more robust results. The authors are kindly invited to comment on this methodological choice.

We thank the authors for their valuable point. Indeed, this was a question we reflected on during the initial stages of development in our study.

The emissions dataset that we present were created in the context of the SEEDS project, which was specifically aimed at supporting developments to the Copernicus Atmospheric Monitoring Service (CAMS). We had a specific focus on providing developments to the European, regional production in CAMS. The CAMS European production runs at a spatial resolution of $0.1^\circ \times 0.1^\circ$, which corresponds to the spatial resolution of the HRES forecast. Furthermore, some of the CAMS models use the HRES forecast on its native gridding. It was an important aim for us to try to follow the gridding used by HRES to facilitate testing of the emissions in the CAMS models. ERA5 reanalysis has a spatial resolution of $0.25^\circ \times 0.25^\circ$, and therefore was not suitable for this purpose. It should be noted that SURFEX can only be run at the same spatial resolution as the input meteorology.

In addition to the practical reasons outlined above, there are some sound scientific reasons why, in this case, favouring meteorological forcing based on forecasts at higher resolution over coarser resolution reanalysis is a sound approach. The land surface has a high degree of heterogeneity. Operating a land surface model at higher resolution allows one to represent this heterogeneity in a more thorough way within the model. This can be important in order to represent which particular land covers/vegetation types receive rainfall. This tradeoff was explored in a report by co-authors (Jarlan et al., 2023), which concluded that higher spatial resolutions improved drought monitoring over specific affected areas/vegetation and improved the representation of its effects on vegetation.

Jarlan, J., Albergel, C., Bonan, B., Calvet, J.-C., de Rosnay, P., Ottlé, C., and Peylin, P.: Assimilation de données de télédétection pour le suivi des surfaces continentales *in Inversion et assimilation de données de télédétection*, 45-95, ISTE Editions, <https://doi.org/10.51926/ISTE.9142.ch2>, 2023

Using a coarser model resolution also has downstream effects on the assimilation of LAI data. Coarser spatial resolutions in the model mean the satellite LAI data has to be spatially aggregated even more, which degrades the effectiveness of the assimilation step due to broadening of the number of land use classes within larger spatial pixels.

These points are now discussed in the manuscript within the Methodology section 2.4:

“We used the ECMWF HRES forecast as opposed to ECMWF’s ERA5 reanalysis (Hersbach et al., 2020) in this study for several reasons. The CAMS European production runs at a spatial resolution of $0.1^\circ \times 0.1^\circ$, which corresponds to the spatial resolution of the HRES forecast. Furthermore, some of the CAMS models use the HRES forecast on its native gridding. An important aim was to try to follow the gridding used by HRES to facilitate testing of the emissions in the CAMS models. ERA5 reanalysis with its spatial resolution of $0.25^\circ \times 0.25^\circ$ was, therefore, unsuitable for this purpose. Next, since the land surface has a high degree of heterogeneity, operating a land surface model at higher resolution allows one to represent this heterogeneity in a more thorough way within the model. This can be important, for instance, to represent which particular land covers/vegetation types receive rainfall. This was explored by Jarlan et al. (2023) who concluded that higher spatial resolution forcing improved drought monitoring over specific affected areas/vegetation and improved the representation of its effects on vegetation. Lastly, coarser model spatial resolutions have downstream effects on the assimilation of LAI data. Coarser resolutions mean that satellite LAI data has to be spatially aggregated even more, which degrades the effectiveness of the assimilation step due to broadening of the number of land use classes within larger spatial pixels.”

Comment 3

In Section 3.1 (Performance of the SURFEX land surface model), could the authors please provide more details on the LAI/SIF comparison? For instance, what is the temporal resolution of the two datasets?

Thank you for this suggestion. We agree that adding this information would improve the quality of the manuscript. The LAI and SIF data are compared on a time frequency dependent on the availability of the TROPOMI SIF data. The TROPOMI SIF data were the limitation in this case because the SURFEX model provided OL and analysis data continuously for every day with no data gaps. In practice the TROPOMI data were available in approximately 25 days in every month even though the SIF observations are nominally available once per day. The limitation is due to data gaps created by clouds and viewing angle, which in turn impact the retrieval quality. These limitations are more prevalent during the winter months and at higher latitudes. The comparisons are done as and when a model-obs data pair (LAI-SIF) is available.

We have added this text to clarify these details in section 3.1 of the where the performance of SURFEX is evaluated.

“The LAI and SIF data are compared on a time frequency dependent on the availability of the TROPOMI SIF data. The TROPOMI SIF data were the limitation in this case because the SURFEX model provided OL and analysis data continuously for every day with no data gaps. In practice the TROPOMI data were available for approximately 25 days in every month on average even though the SIF observations are nominally available once per day. The limitation is due to data gaps created by clouds and viewing angle, which in turn impact the retrieval quality (Guanter et al., 2021). These limitations are more prevalent during the winter months and at higher latitudes. The comparisons are done as and when a model-obs data pair (LAI-SIF) is available.”

Additionally, why is only Saint-Félix-de-Lauragais shown in the soil moisture comparison? Were other sites compared as well, and if so, did the comparisons yield similar results?

We thank the reviewer for raising this valid point. We looked at data comparisons for other sites within the SMOSMANIA network. Given that part of the time period we study occurred during the COVID-19 movement restrictions, some sites within the SMOSMANIA network were not properly maintained, which led to degradations of some sensors that could not be fixed. Inspection of the data showed large data gaps and/or large transient values, which was indicative of sensor degradation. We only presented

the comparison of the Saint-Felix-de-Lauragais dataset because this was one of the sensors for which we were most confident about the data quality. However, there are eight other sites within the network that have still have reasonable data quality and we have added these figures (Figures S1 through S8) to the supplement along with a table (Table S2) showing the correlation scores against SURFEX.

We have added text to section 3.1 to explain why Saint-Felix de Lauragais was selected: “Data from the Saint-Felix de Lauragais were selected and presented here because of the excellent data quality from this site. Unfortunately, the soil moisture sensors at some of the other sites in the SMOSMANIA network have degraded leading to data quality issues.”

We also explain the data comparison presented in the supplement:

“In addition to the comparison to the data from Saint-Felix de Lauragais, we carried out an evaluation of SURFEX soil moisture data with data from the other sites in the SMOSMANIA network (eight in total) that had reasonable data quality over the same time period. The results of this evaluation are presented in the supplement in Figures S1 to S8 and the correlation statistics between SURFEX and the soil moisture measurements are presented in Table S2. The correlation scores are all above 0.80 the comparisons with the data from each of these sites.”

Comment 4

In Section 3.3.2 (Evaluation using other emission datasets), could the authors please provide some explanation for the large differences observed between SURFEX-MEGAN3.0 and the MEGAN-MACC database? Are these differences mainly due to variations in the meteorological parameters, the emission factors, or both?

We thank the reviewer for this comment. Most of the difference between SURFEX-MEGAN3.0 and MEGAN-MACC is due to the different meteorology used in each case. We reach this conclusion based on two things. First, Sindelarova et al. (2022) determined that the MERRA/MERRA-2 reanalysis generally had higher values for 2-meter temperature and photosynthetically active radiation than the ERA5 reanalysis. MEGAN-MACC is based on the MERRA/MERRA-2 reanalysis while CAMS-GLOB-BIO is based on ERA5. Sindelarova et al. (2022) found that this primarily explained the larger emissions of the MEGAN-MACC emissions when compared to those of CAMS-GLOB-BIO. Second, we have performed a comparison of the temperature and radiation gamma (γ_{TP}) values calculated by MEGAN within SURFEX-MEGAN3.0 (based on HRES) and CAMS-GLOB-BIO (as part of the response to comment 5 here). This comparison showed that the γ_{TP} values from both inventories were very consistent with each other except in desert regions with low vegetation cover (e.g., north Africa and the Middle East), and in arid regions during the summer that had low summer emissions. Based on these two points, this points to the meteorological parameters from MERRA/MERRA-2 as being the main factor for the large difference between MEGAN-MACC and SURFEX-MEGAN3.0.

We refer the reviewer to the response to comment 4 from reviewer one where we discussed extensively the emission factors of MEGAN3.0, MEGAN2.1 (used in CAMS-GLOB-BIOv3.0 and MEGAN-MACC), and those based on EMEP used in CAMS-GLOB-BIOv3.1. In short here, we concluded that the MEGAN3.0 and MEGAN2.1 emission factors were likely not a large explanatory factor in the differences between SURFEX-MEGAN3.0 and CAMS-GLOB-BIOv3.0, and thus this applies to MEGAN-MACC also. See more detail below in response to comment 5.

We have added this text to the manuscript to discuss these points:

“This evaluation revealed several findings. The differences in the meteorology used in SURFEX-MEGAN3.0 (HRES) and CAMS-GLOB-BIOv3.0/3.1 (ERA5) were likely only a very minor factor in explaining the differences between these emission inventories. We directly compared the radiation-temperature gamma values from SURFEX-MEGAN3.0 and CAMS-GLOB-BIOv3.1 (identical to v3.0) in Figure S18 of the supplement. This comparison shows that the only significant differences in radiation-temperature gamma occurred in desert regions (e.g., north Africa and the Middle East) year round and in southern Mediterranean regions during summer when vegetation cover is very low and the emissions from these regions are relatively minor. With regards to the comparison between SURFEX-MEGAN3.0 and MEGAN-MACC, Sindelarova et al. (2022) found that the MERRA/MERRA-2 meteorological forcing (used to make MEGAN-MACC) had higher 2-meter temperature and PAR values than the ERA5 data (used in CAMS-GLOB-BIOv3-0/3.1) and that this explained why the MEGAN-MACC inventory had much higher isoprene emissions. We can apply that same finding here to conclude that the MEGAN-MACC emissions are much higher than the SURFEX-MEGAN3.0 emissions due to the different meteorological parameters of MERRA/MERRA-2. This is further supported by the good consistency of the radiation-temperature gamma values derived from HRES and ERA5 shown in Figure S18.”

Comment 5

The differences between SURFEX-MEGAN3.0 and CAMS-GLOB-BIOv3.1 are only partially explained by variations in LAI. This is particularly noteworthy since, although there is a difference in LAI between the SURFEX-MEGAN3.0 analysis and the SURFEX-MEGAN3.0 OL datasets, this difference does not appear to result in any noticeable change in emissions, at least none that are evident in Figure 16. I would therefore ask the authors to suggest plausible explanations for the discrepancies observed between these two datasets (SURFEX-MEGAN3.0 and CAMS-GLOB-BIOv3.1).

This is a very interesting line of discussion and we thank the reviewer for raising this point. We agree that it would be useful to have more discussions related to the comparison of the CAMS-GLOB-BIOv3.1 and SURFEX-MEGAN3.0 emissions. Indeed, reviewer one raised similar questions regarding emission factors. We added discussion in response to comment 4 from reviewer 1 that provide more explanation regarding the origins of the differences between SURFEX-MEGAN3.0 and CAMS-GLOB-BIOv3.1 that are linked to emission factors. We refer the reviewer to that response for other details.

We have explored the role of meteorology in explaining differences between SURFEX-MEGAN3.0 and other inventories including CAMS-GLOB-BIOv3.0/v3.1 in response to comment 4 here and we refer the reviewer to that response.

We explored the role of LAI in more detail in response to comment 6 and again we refer the reviewer to that response.

In summary, the differences between SURFEX-MEGAN3.0 and CAMS-GLOB-BIOv3.1 are mostly attributed to differences in emission factor and LAI, and to a more minor contribution due to differences in the HRES and ERA5 meteorology in southern Mediterranean regions during the summer.

We also respond to the reviewer’s general remarks about LAI. We are not sure to fully understand the relevance of the comparison of the analysis and open-loop to this comparison for understanding differences with respect to CAMS-GLOB-BIOv3.1. We understand that the reviewer is indicating that changes in LAI between the open-loop and analysis do not lead to changes in emissions, therefore the differences in emissions between SURFEX-MEGAN3.0 and CAMS-GLOB-BIOv3.1 cannot be due to changes in LAI. Our response to this specific point is that the changes in LAI between the analysis and OL are much smaller than those between the LAI dataset used in CAMS-GLOB-BIOv3.1 and either

SURFEX-derived LAI dataset. This is due to the differences in approach. For the open-loop, SURFEX itself already provides a skilful representation of daily LAI when forced with high quality meteorological forcing (Delire et al., 2020). In the case of the analysis, PROBA-V LAI assimilation in SURFEX gives daily LAI data. Compared to both of these, CAMS-GLOB-BIOv3.1 uses MODIS monthly climatologies.

Delire, C., Séférian R., Decharme B., Alkama R., Calvet J.-C., Carrer D., Gibelin A.-L., Joetzjer E., Morel X., Rocher M., Tzanos D.: The global land carbon cycle simulated with ISBA-CTRIP: improvements over the last decade, *Journal of Advances in Modeling Earth Systems*, 12, e2019MS001886, <https://doi.org/10.1029/2019MS001886>, 2020.

To add further to the discussion of MODIS-based LAI, the Copernicus Land Monitoring Service provides an extensive validation of the PROBA-V based LAI product used in the SURFEX analysis. The relevant validation report linked below documents the large discontinuities in the MODIS LAI product that are considered to be unrealistic.

land.copernicus.eu/en/technical-library/quality-assessment-report-proba-v-leaf-area-index-version-2/@@download/file

We have now added a short additional text to the manuscript to mention this:

“Lastly, validation of the CLMS LAI product from PROBA-V (Sanchez-Zapero et al., 2018) indicates that the that the MODIS LAI product has much higher uncertainty. Thus, one interpretation is that the larger systematic uncertainties in the MODIS LAI product drive some of these differences.”

Comment 6

In Section 3.3.2 ('Evaluation using other emission datasets'), it is mentioned that the differences in seasonality observed among the various emission datasets are mainly driven by LAI. The authors also note that “LAI datasets (based on Yuan et al., 2011) used to calculate the monthly emission factors in the CAMS-GLOB-BIOv3.1 emissions tend to peak later in summer than the LAI calculated by SURFEX.” Could the authors please provide additional details on this comparison, perhaps by including a figure or table to illustrate it more clearly?

Thank you to the reviewer for making this suggestion and we agree that this would improve the manuscript. We have added two figures to the supplement showing the LAI from the SURFEX analysis in 2019 and the LAI climatology from MODIS (Yuan et al, 2011) to support this point and added the following text to the manuscript.

“Evaluating LAI, we found that in general the LAI dataset (based on Yuan et al., 2011) used to calculate the monthly emission factors in the CAMS-GLOB-BIOv3.1 emissions tends to peak later in the summer than the LAI calculated by SURFEX. The CAMS-GLOB-BIOv3.1 emissions used this same monthly climatological mean of LAI (averaged over 2007-2016) derived from MODIS (Sindelarova et al., 2022; Yuan et al., 2011) to calculate the LAI used for the MEGAN activity factor calculations after 2016. As a result, in years where SURFEX estimated particularly extreme deviations in LAI from the historical climatology with an early peak in LAI, e.g., 2019, the divergent effect on the emission seasonality is even greater. The monthly mean LAI analysis data from SURFEX for 2019 are presented in Figure S19 of the supplement along with the LAI 2007-2016 climatological monthly means used in CAMS-GLOB-BIOv3.1 (Figure S20) for the purposes of demonstrating this point. Indeed, it is possible to see large reductions in the monthly mean LAI data from June into July and August in the SURFEX LAI data in important isoprene emitting regions (see Figure S15 showing the monthly mean isoprene in 2019 for reference) that are not visible in the corresponding panels of Figure S20.”

Comment 7

I suggest paying attention to the use of the term “dynamic vegetation”. This could be confusing for readers, as it may be interpreted as referring to “Dynamic Vegetation Models (DVMs)”. Such models represent the biosphere and are capable of simulating vegetation dynamics, that is, the transient development of vegetation composition and structure. This aspect is not addressed in your paper, where you primarily refer to plant phenology.

Thank you to the reviewer for making this suggestion. We have modified all cases of “dynamic vegetation models/modelling” to instead refer to “plant phenological modelling/models”.

See for example, the changes on lines 629, 633, 660 and 977.

Responses to minor comments

Line 208: *The reference should be to Sect. 2.2.2 and not Sect. 2.1.2*

We have corrected this.

Line 365: *In the sentence “with LAI having a more significant and beneficial effect for the estimation of root zone soil moisture”: do the authors really mean that LAI have a beneficial effect for the estimation of root zone soil moisture?*

Yes. This is correct. Albergel et al. (2007) show that improving LAI leads to indirectly improved soil moisture due to the improved representation of evapotranspiration that results from this.

Line 432: *In the sentence the authors say that “We perform this evaluation using three approaches:”, but in the list after there are 4 points.*

Thank you. We have corrected this error.

Line 434: *Please add a reference to TROPOMI satellite observations of solar induced fluorescence (SIF).*

Done. Thank you. We have added a reference to Guanter et al.

Line 454: *Please add a reference to SMOSMANIA in situ measurements.*

We have added a reference to Calvet et al., 2007, which is the reference paper for the SMOSMANIA network. Thank you for this advice.

From line 471 to 479: *The authors come back speaking about LAI. It is a little bit misleading. I’ll move these lines before in the paragraph where the authors introduce the comparison with LAI.*

We have re-ordered this section to reflect this good advice.

Page 19: *Please increase the size of Figure 5.*

We have increased the size of each panel within Figure 5.

Line 553: *Is the standard deviation calculated for isoprene average annual emitted mass over the 5 years?*

Yes. We changed the text that was on line 503 to say:

“The average annual emitted mass of isoprene for the open-loop emissions over the time period 2018-2022 was calculated to be 7.20 Tg yr⁻¹ with a standard deviation of ± 0.28 Tg yr⁻¹ **over this five year period**”

Line 510: *Could you please detailed more what do you mean with “gamma parameters for soil moisture, LAI, and radiation-temperature”. Do you mean the different activity factors (g)?*

Yes. By gamma parameters we mean the different activity factors. We have modified the text as follows to make this clearer:

“Indeed, the effect of these last variables can be seen in more detail within Figure 7 which shows the emission factors over the CAMS domain and the standard deviation of the interannual variability for the gamma **activity factors** for soil moisture, LAI, and radiation-temperature.”

We have changed all other instances of “gamma parameters” to “gamma activity factors”.

Page 22: *Figure 8, as far as I understood, shows the R2 that is calculated on a yearly basis. This means that the times series of variables have only 5 elements. A correlation calculated like this is not very strong. It should be discussed a little in the text.*

We have added this text to the manuscript to address this point:

“However, note that each R² value within these distributions is based on only five data points, so the statistical significance of these correlations is weak. This is offset by the large number of individual cases presented in each distribution, however.”

Page 27: *Please add country contours in Figure 12.*

Done.

Page 27: *In Figure 12 (plot on the right). Could you please give some explanation on why there are still some areas where correlation is negative (especially in Portugal)?*

We have added this explanation to the manuscript to address this point:

“There are still some areas with negative correlation where the LAI declines yet isoprene emissions increase in **Error! Reference source not found.**, e.g., in Portugal, and this is due to a strong increase in the radiation-temperature gamma variable over this region.”

Line 688: *Please correct “Figure 15Figure 15”.*

We have done this.

Line 759: *In the sentence “such as wind, turbulence, boundary layer height, and isoprene lifetime are implicitly ignored in this comparison.” I would remove “isoprene lifetime”, as you mentioned just before.*

We have done this.

Page 36: *Figure 16 could be more readable with a legend.*

We have now added a legend.

Line 824: *Please add reference to “SUMO emission inventories”.*

In fact we removed the SUMO emissions from earlier versions of the manuscript and this should have been removed. We have done this now.

Lines 809 and 813: *“Analysis” should be written in lowercase letters.*

We have corrected this.