## General remarks

This paper presents a multifaceted approach for modelling and upscaling spot data to landscape level. It is a follow-up of a paper (Wangari et al. 2022, JGR: Biogeosciences, 127, e2022JG006901) that showed the measured GHG fluxes in more detail. It is noteworthy that the data from the spring campaign (March 14-15) was left out of this modelling exercise.
I generally like the setup and believe it brings useful information to landscape and land use type assessments. There is not much to space for critics. The methods seem sound, text is well written and easily readable. However, it could benefit from more clarity in showing the improvement in upscaling prediction performance and restrictions of the measured GHG data in seasonal and spatial scales in Ch. 4.1. *That would result in moderate changes only*.
**Response**: Thank you for your overall comments and suggestions. We have addressed most of them in the current version of our manuscript. Please find below the detailed responses. Your comments were beneficial in helping us to provide clarity on the strengths and limitations of our study, which collectively offered the basis for further discussions on future research gaps in the modeling of landscape GHG fluxes.

Upscaling of GHG fluxes measured from micro to macro scale is hampered by spatial and temporal uncertainties of varying biological and physical origins. At the same time, an adequate increase of the frequency of chamber measurements is hard. This paper uses flux data, soil physical and chemical characteristics from different types of ground vegetation-soil systems for high resolution upscaling to landscape level with help of remote sensed parameters and indices, and DEM for Random Forest modelling by different land use types separately. Measurements of soil characteristics and GHG fluxes included two rather short campaigns in 2020. GHG's were measured daytime using opaque chamber and "fast box" techniques during late June-early July and September 8-17. Those probably yielded estimates relative non-winter emission strengths rather than annual fluxes for the sites.
**Response**: Thank you for your comments. We agree on the limitation of the study in terms of temporal measurements throughout the year. However, our study primarily focused on capturing the spatial heterogeneities in soil GHG fluxes. For that reason, we had to limit our campaigns to only a few days to reduce the risk of intra and inter-daily variations being mistaken for spatial variability. Regarding the representation of the annual fluxes, we agree that our summer and autumn measurements do not represent the fluxes from other seasons, e.g., winter. For that same reason, we only talked about the spatial variability of GHG fluxes during the summer and autumn seasons throughout our manuscript and refrained from talking about annual fluxes from seasonally resolved measurements, which was not the focus of our study. To make clear the limitation of our measured GHG data in terms of representing the seasonal trends of soil GHG fluxes in our landscape, we have added the following sentences to the conclusion, which is a potential research gap for the future.

"While we identified hot and cold spots of soil GHG flux across the Schwingbach landscape through RF modeling, the entire exercise was limited to two measuring campaigns of a few days in two seasons (summer and autumn). For this reason, it is still unclear whether these hot and cold spots persist throughout the year and their overall contribution to the annual landscape GHG flux estimates. Future studies should, therefore, aim at increasing the temporal resolution of similar spatially extensive measurements to at least monthly scales, which, when combined with remotely-sensed data, may be able to create similar landscape flux maps and identify the contribution of GHG hot and cold spots to annual estimates."

In forest land, the trees may contribute to the measured soil $CO_2$ emissions through root respiration and add to uncertainties.

**Response**: Thank you for your comment. We agree that the contribution of root respiration to total soil respiration might be substantial in forests. We have now added a description in the methods section to reflect this view.

"The $CO_2$ fluxes quantified using the opaque chambers represented either soil respiration (SR) (root and microbial respiration) or ecosystem respiration (ER) (root, microbial, and plant respiration). The $CO_2$ measurements in autumn across the entire landscape were SR since above-ground biomass was not included in the chambers during measurements. In contrast, the summer $CO_2$ measurements on arable and grasslands were ER since the above-ground vegetation was incorporated using chamber extensions while the forest measurements remained as SR due to minimal above-ground vegetation on the forest floor."

For $CO_2$, the opaque chamber flux represents a somewhat artificial sum of heterotrophic and autotrophic gas release, but not ecosystem net $CO_2$ exchange that could be measured using e.g. using transparent chamber or eddy covariance over a landscape or within separate land use types. Thus, the $CO_2$ fluxes could be hard to compare with literature data.

**Response**: Thank you for your comment. We agree that comparing net $CO_2$ fluxes to only those from respiration is misleading. However, extensive $CO_2$ flux comparisons to past literature values were done in our earlier publication and were limited to only fluxes quantified using opaque chambers (See Wangari et al., 2022). In this study, comparisons were only made on the prediction performance of RF models, which we also noted to be uncertain because of the different validation methods. These reflections were also in the discussion.

"Nevertheless, caution has to be taken when interpreting any conclusions from these study comparisons due to the limitations of different model validation techniques, different predictor variables used for modeling, and the different ecosystems and spatial scales of measurement and predictions."

The authors should elaborate in discussion how their results could be applicable e.g., in land use planning or mitigation efforts, given the representativeness of their data.

**Response**: Thank you for your critical comment. We agree that the $CO_2$ fluxes we measured with opaque chambers were not net $CO_2$ ecosystem exchange and, therefore, do not represent the net fluxes for $CO_2$, which would be suitable for mitigation measures. However, the common hotspot regions of all three gasses, including $N_2O$ and $CH_4$, representing net values in our study, were primarily within arable lands. Therefore, these common hot spot regions can be a target for mitigation strategies, considering that around 60% of anthropogenic $N_2O$ emissions come from arable lands. At the same time, agricultural land use also lowers the ability of soils to sink atmospheric $CH_4$. Land use planning measures such as targeted fertilizer regimes or expansion of local forests can play a vital role as local GHG mitigation solutions. These reflections were also included in the discussion.

"Identifying common patches with elevated emissions of the three GHGs can inform priority areas for implementing localized mitigation measures within a landscape. These common patches covered only 1.5% of our landscape (~0.2 $km^2$) and had the highest GHG fluxes contributing around 5%, 1%, and 8% of the landscape $CO_2$, $CH_4$, and $N_2O$ emissions. The location of these patches primarily (99.9%) on arable land emphasized the significant role of focusing on mitigating GHG fluxes from arable soils. Because most of the common GHG hotspots in the arable soils were also in areas with high water content, mitigation strategies that aim at adjusting the fertilizer application rates at specific areas that hold more water may be successful in lowering the emissions (e.g., Hassan et al., 2022). In contrast to hot spot regions of elevated GHG emissions, $CH_4$ uptake hotspots inform future mechanisms for leveraging the GHG sink ability of soils, such as expanding local forests. This finding is supported by uptake hot spots identified on forest soils in this study, offsetting 8% of the total landscape $CH_4$ flux. The expansion of forested areas will also likely have a much higher mitigation impact via $CO_2$ sequestration."

The paper claims an improved prediction performance compared to other approaches in upscaling the mosaic of landscape GHG fluxes. Table 3 shows the approach of this study compared to that of other published studies using RF. It is however difficult to evaluate the *performance differences thereof with other types of approaches.*

**Response**: Thank you for your critical comment. We included Table 3 to compare with other studies that have used a similar RF approach. We agree that comparisons are difficult even with studies that have a similar RF approach due to differences in model validation, predictor variables, amount of data, etc. This limitation was also discussed in lines 380-383.

"Nevertheless, caution has to be taken when interpreting any conclusions from these study comparisons due to the limitations of different model validation techniques, different predictor variables used for modeling, and the different ecosystems and spatial scales of measurement and predictions."

Please explain clearly why the present approach is an improvement over others. Are there any relative qualitative or quantitative indices for such evaluation?

**Response:** Thank you for your critical question. Qualitatively, compared to the other studies, ours included more spatially well-distributed sites over a larger area that accounts for landscape GHG heterogeneities. In addition to remotely sensed data, we used more measured soil parameters to model the landscape GHG fluxes. This approach differed from previous studies focusing on remotely sensed data and a few soil parameters, such as soil moisture. All these points were highlighted in the discussion.

"Compared with other studies that have upscaled GHG fluxes using the random forest algorithm, we considered more site-measured data on soil parameters, all three GHG fluxes, and different land uses (Table 3). Moreover, point selections for measurements were done by implementing a stratified sampling plan that represented the spatial variability of several landscape characteristics, specifically land use, soil type, and slope (Wangari et al., 2022)."

Hot and cold landscape spots of emissions were identified and their contribution to overall GHG fluxes was evaluated. This is very useful for using the results in GHG mitigation.

**Response**: Thank you for the word of encouragement. It was indeed our hope that the information provided in our work could at least provide a starting work framework for the generation of detailed spatial maps, which in the future may be used to inform mitigation strategies.

## Specific remarks

Lines 24-25 Please complete the comparison sentence since you make comparisons between approaches in Ch. 3.5 (Fig. 6) and in discussion Table 3 and elsewhere. Be more specific.

**Response**: Thanks for pointing out the comparison confusion. We have added Random Forest to the statement to avoid confusion with the area-weighted mean approach in Figure 6.

"Based on these field-based measurements and remotely-sensed data on landscape and vegetation properties, we used the Random Forest (RF) algorithm to predict GHG fluxes at a landscape scale (1 m resolution) in summer and autumn. The RF results showed improved GHG flux prediction performance when combining field-measured soil parameters with remotely-sensed data."