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# *Interactive comment on* "Topography-based modelling reveals high spatial variability and seasonal emission patches in forest floor methane flux" *by* Elisa Vainio et al.

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Here we answer all the comments by the Referee #1 in detail.

1. The modeling framework

RC: Line 225: How many observations did you have for May-July and August-October? Did you have many measurements from one point in your model (e.g., early May measurement, late July measurement)? Can you be certain that the soil moisture measurements conducted within one study period (e.g. in early May and late July) can be directly compared and used in the same model, even though the soils tend to get drier



during the summer? I think it's important that the measurements that you use for your response variable (i.e., soil moisture) are fully comparable with each other.

AC: There were around 6 measurements (median) from each sample point in both of the seasons. Our data is not temporally very comprehensive, and thus we opted to do two static periods. Still, we wanted to take into account that the soil does, in fact, get drier towards autumn. We assume that this two-seasons-strategy is good compromise with the data we have. We actually started the measurements in late May (line 132), so we missed the wettest period in the spring, and the most active measurement period was in June–August (line 135). However, we still ended up having approximately same amount of data for both seasons.

RC: 225: Could you also describe why you decided to use soil moisture as a predictor of fluxes instead of using the different topographic indices directly? Also, did you consider creating a continuous vegetation type raster based on your vegetation classes and the gridded layers for the study domain? This could have been a useful predictor for $CH_4$ fluxes as well.

AC: We re-evaluated our modelling approach and will change the modelling: we model the $CH_4$ fluxes directly with the RF technique and using soil moisture as a driver in the model (see Fig.1 in this document). This change was motivated by the fact that bulk of the criticism from the reviewers was directed towards the $CH_4$ flux modelling approach. The manuscript will be modified accordingly. We considered but did not create a continuous vegetation type raster, because there are many drivers affecting the vegetation, and we did not have data of all such drivers. There is no direct connection between e.g. vegetation and soil moisture (Fig. 4), nor with topography. A continuous vegetation type raster would have probably required more thorough mapping of ground vegetation of the entire area.

RC: 256: Why didn't you use the similar framework that you used for soil moisture to predict $CH_4$ fluxes with soil moisture? You could have created a RF (or a GLM/GAM or some other) model with the measured soil moisture as a predictor, and then used that model to predict fluxes across the landscape using the predicted soil moisture. And this could have been repeated over the different bootstrapped soil moisture maps to get CH4 flux uncertainty map as well.

AC: See the previous response, we changed our modelling approach to follow this referee suggestion.

RC: 240: Could you add the response graphs (partial dependence plots) describing the relationship of these indices and soil moisture to the Appendix?

AC: Yes, we can add these (see Figs. 2 and 3 in this document).

2. Description of the model performance

RC: Line 20: Somewhere here I would add a sentence about how the statistical models performed, and how reliable your results are.

AC: Yes, we can add this to the abstract.

RC: 377: I would be interested to see a scatterplot of the observed and predicted (CV) fluxes to see how well the model predicts high and low soil moisture values. Same applies to CH4 flux (line 406).

AC: We can add the scatterplot showing cross-validation results to the appendix (see Fig. 4 in this document).

RC: 542: Somewhere in the Discussion you should also discuss how well your up-scaling performed compared to previous studies. What are the main uncertainties, and how can these uncertainties be reduced? What predictors are you missing? How about other RS-derived indices, such as NDVI?

AC: According to our current impression, there are not many published studies trying to upscale CH4 fluxes from forest stand like ours. The previous study of (Sundqvist et al. 2015) used simple soil wetness and temperature relationship to upscale CH4



fluxes, whereas Kaiser et al., (2018) and Warner et al., (2019) studied more southern ecosystems. Furthermore, comparisons of e.g. cross-validation results are hampered by different cross-validation techniques used in different studies. In this manuscript, we utilized distance-blocked cross-validation since it is argued to produce more realistic estimates of cross-validation metrics than other techniques (Roberts et al., 2017). For instance, with traditional leave-one-out cross-validation the predictive performance of our RF model would seemingly improve (e.g. r2 increase from 0.51 and 0.26 to 0.67 and 0.56 for May–July and August–October, respectively). Therefore, we argue that direct comparison of cross-validation metrics between studies using different cross-validation strategies is not feasible. The discussion section of the manuscript does already discuss variables controlling CH4 fluxes, but we will modify the text so that it includes a section on how these predictors are missing in upscaling exercises. The scale where our measurements are carried out cannot be directly applied to similar spatial scale than remote sensing methods that is used to estimate NDVI, despite the rapid development of satellite products. However, we try include this to discussion.

Here are a few more minor suggestions to the manuscript:

RC: Title: I would consider adding the word "statistical modelling" somewhere in the title

AC: We consider to change the title to "Topography-based statistical modelling reveals . . ."

RC: Line 19: I would say "using digital elevation model-derived topographic indices" instead of "topography"

AC: We will modify this as suggested.

RC: 28: I was a bit surprised to see this methodological suggestion as a final sentence concluding your study. I would consider changing this to something more broader, e.g. to the sentence on line 565-572.

AC: We will modify this as suggested.

RC: 71: “Large amount of measurement points” is a rather subjective statement as for some people this might mean hundreds or thousands of observations. Maybe define the rough amount of measurement points instead, and mention that this is more than has previously been used.

AC: We will clarify this sentence in the following way: “In this study, we used relatively high number of measurement points (60 points on an area of ca. 10 ha) in order to fully cover the small-scale spatial variability in the CH4 flux and its driving forces. Similar type of studies using chamber measurements are rarely based on more than 20 measurement points.”

RC: 75: With one driving parameter (i.e. soil moisture), right? You didn’t have many driving parameters to make the upscaled CH4 flux map?

AC: Yes, originally we used soil moisture only. However, due to the Referee #1 comment we re-evaluated this approach and based on this re-evaluation opted to follow reviewer suggestion to use RF model also for CH4 fluxes.

RC: 76: But what about Kaiser et al., 2018?

AC: Yes, probably good to be more precise, we will modify the text to: “ Only a few studies (Kaiser et al., 2018; Warner et al., 2019) have applied similar approach, of which Kaiser et al. (2018) at a boreal coniferous forest, emphasizing the novelty of this study.”

RC: 105: You could add an index map to this figure showing e.g. the location of Hyytiälä, too.

AC: Yes, this is a good suggestion.

RC: 210: I would describe these gridded layers in their own paragraph, similar to the other environmental measurements, and dedicated this one to the models only.



AC: Good suggestion, thank you, we will separate these under a new subheading.

RC: 220: Could you provided a little bit more information about what parameters were chosen for the different indices? For example, TWI can change quite a bit depending on what parameters you use in the calculation.

AC: TWI was calculated as a natural logarithm of the ratio between local upslope area draining through the point in question and tangent of the local slope. The upslope area was calculated using multiple flow direction algorithm of Freeman (1991), and local slope was calculated using adjacent points in DEM. The calculations were made with TopoToolbox, please see more details in Schwanghart and Kuhn (2010). We will add some more information on these to the methods.

RC: 370: This figure could be moved to the supplementary – it’s not so useful for the reader because there are so many different points.

AC: We think that this figure gives a nice overview of the measured CH4 flux and its variation at the measurement points, and it is rather easy to see the spatial variation from this figure. (E.g. Fig. 4 is not giving this information, and a table would be more difficult to read.)

RC: 400: This is just an idea, but you could also replace these two maps by a map that describes the mean summer soil moisture and a map that describes its change over the growing season. It might be easier for the reader to spot the areas that are drying this way.

AC: This is an interesting thought and good to consider. However, we think that it might be more difficult for readers to understand what was done in this paper based on such a figure.

RC: 431: I would use the same color scheme that you used in Fig. 8 for the Fig. 9 as well, to make sure that you are using different color schemes for soil moisture and CH4 fluxes.

AC: Diverging colormaps (as the one used in Fig. 8) are suitable for data sets containing negative and positive values, because this way it is possible to emphasize the difference from zero. Hence, we opted to use a different colormap for Fig. 9 than Fig. 8 since random uncertainty cannot be negative. However, based on Referee #2 comment, we will modify Figs. 7 & 9 to show relative uncertainties, and as a result Fig. 9 colormap will be changed.

RC: 440: The discussion is rather long and without subtitles it is a little bit hard to follow. Could you consider adding a few subtitles and structuring it according to your main aims of the study (spatial variation, drivers and upscaling, hot spots)?

AC: Yes, this is a good suggestion, we will do this.

RC: 560: Again, I was a bit surprised to see this discussion here as it was not motivated in your introduction or it wasn't one of your main aims of the paper. Maybe include it to the introduction or remove it completely?

AC: This is a good remark. We will add shortly to the introduction that previously usually fewer measurement points have been used in soil chamber $CH_4$ measurements, with the assumption that they are representative for a larger area.

RC: 567: If you want to discuss the sampling strategy, I would provide some more details here. E.g., how should the sample points be selected (e.g. systematic grid, gradient, random sampling, researcher-defined)? What is the number of temporal replicates required to understand spatiotemporal variability in this system? Further, in the abstract you mention that capturing the environmental variability requires 15-20 sample points. But do you think using statistical methods (e.g. random forest) with 15-20 points is reliable?

AC: Thank you for this comment. We will add shortly in this paragraph about the selection of sample points: in our opinion, e.g. the elevation maps would be useful when selecting the sample points. With this study we were not able to reveal more



high-frequency temporal variability, but we can add a sentence here that more frequent measurements would be needed for that – ideally it would require automatic chambers measuring e.g. once per day, or at minimum manual measurements every week. The idea of the analysis shown in Fig. 10 in the manuscript was to evaluate how many chamber measurement locations were needed to get an accurate estimate of landscape-level flux by only averaging over the measured chamber data without any upscaling with RF. This will be clarified in the manuscript (e.g. lines 422–425), as this was also commented by Referee #2.

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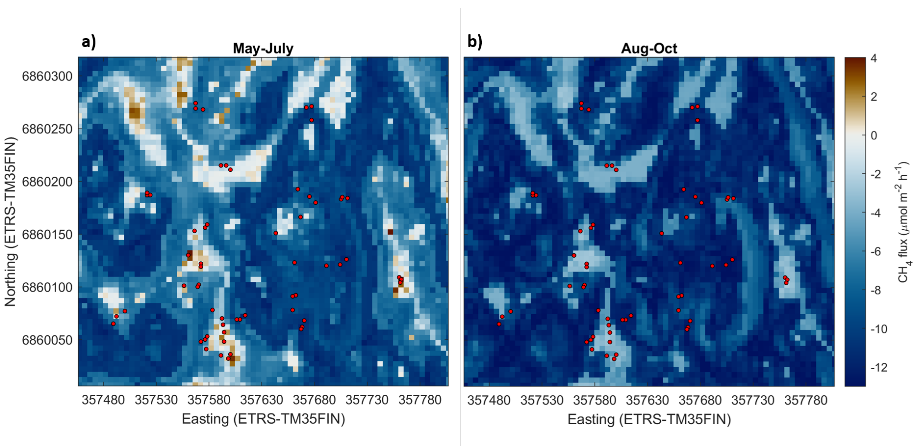


**Fig. 1.** New Fig. 8: Maps of CH4 Flux with modified modelling approach.

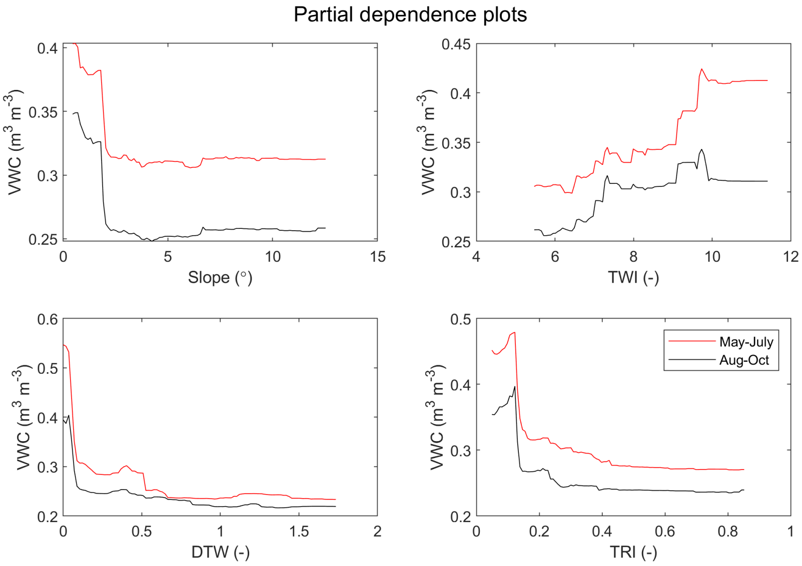


**Fig. 2.** Partial dependence Soil moisture



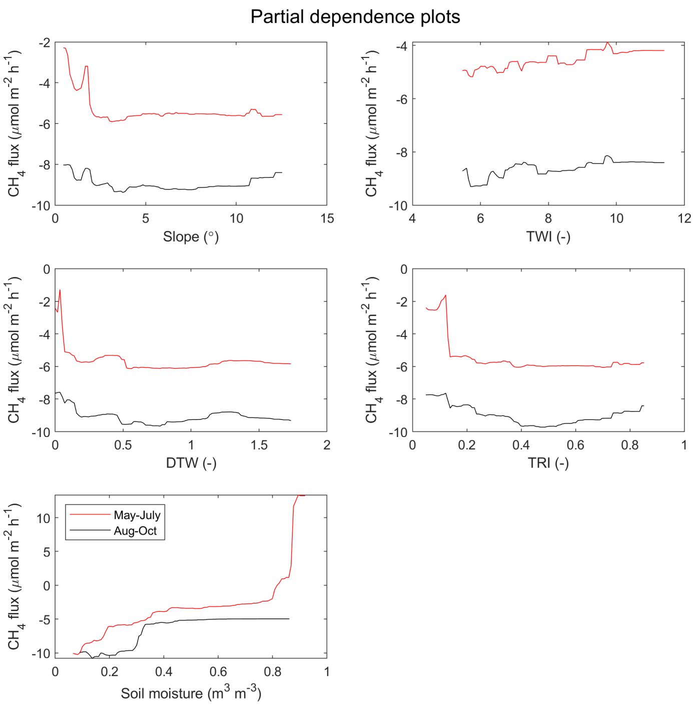


**Fig. 3.** Partial dependence CH4 Flux

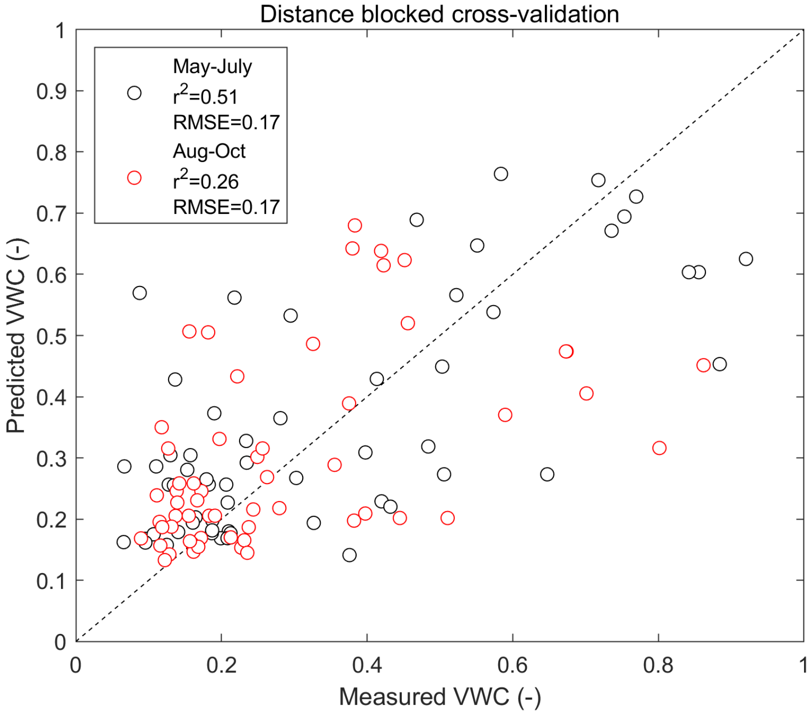


**Fig. 4.** Distance blocked cross-validation