Reply to Reviewer #2

Review on Aalto et al. Strong influence of trees outside forest in regulating microclimate of intensively modified Afromontane landscapes

This research topic is interesting and important, and data analysis is described clearly. However, the results interpretations and conclusion parts need to be improved. The main finding of the research is that canopy cover reduces the microclimate temperature, and this cool-down regulation decreases with elevation. For me, the former finding (i.e. canopy cover down-regulates microclimate) is not very novel, which has been reported in many earlier studies (e.g. Zellweger et al., 2020; Fig. S2 and S5). In contrast, the latter finding (i.e. the influence of canopy cover on microclimate is regulated by the elevation or ambient temperature) is novel and very interesting, but the authors did not say much about this result. I think this part should be emphasized and enhanced descriptions are needed (e.g. discuss that what are the potential mechanisms? refer to Zeng et al., 2019). Meanwhile, some other things also should be clarified, such as macroclimatic temperature also largely affects the microclimate, how did you address or consider this issue in your work? The effect of canopy cover on microclimate and satellite LST is very different in mechanistic (please see the general comments and specific comments).

Reply: We would like to thank the reviewer for the comments and suggestions and believe that they have helped us to improve the manuscript tremendously. Particularly, we have improved the discussion of the results based on the reviewer comments, as well as the definitions and descriptions of relevant terms and concepts. We also want to thank for the two great reference suggestions; we have included them in the manuscript.

We have addressed and answered all the comments; please see detailed replies below.

General comments:

1) Macroclimatic temperature also largely affects the microclimate (e.g. Fig. 1c in Zellweger et al., 2020), how did you address or consider this issue in your work? Or you think the topography has included the macroclimatic influence? Please clarify

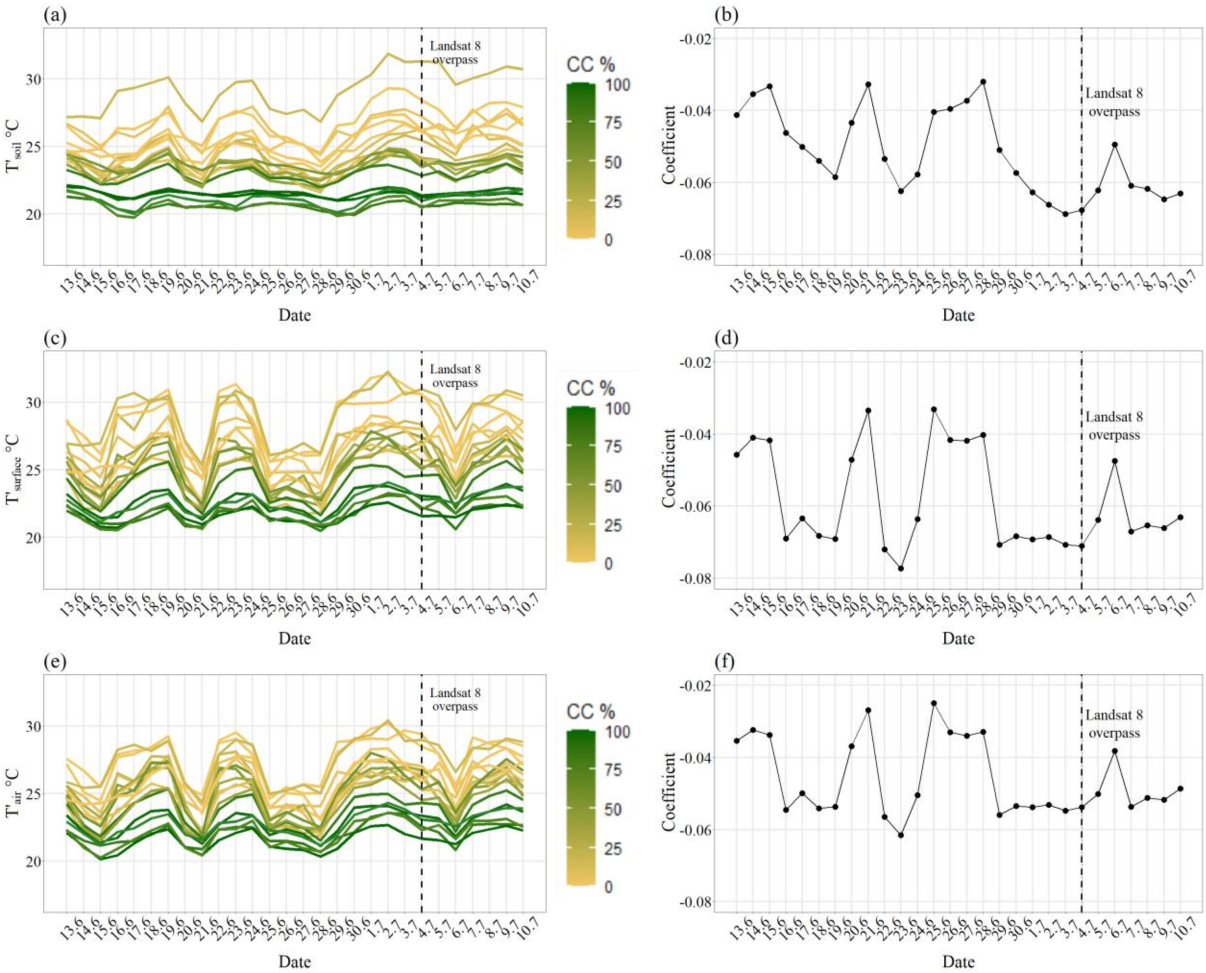
Reply: All microclimate data were collected at the same time and plots were relatively close to each other. Therefore, we concluded that the macroclimate was similar in every plot and we would only need to account for topographic differences. We have clarified this in the text.

2) The effects of canopy cover on microclimate and LST are different from the mechanistic perspective. The effect on microclimate is mixing and shading. The effect on LST is the temperature difference between vegetation canopy and background surface temperature (e.g. soil). Microclimate and LST just have a similar negative correlation with canopy cover. Thus, should take cautions when expanding the LST pattern or findings to microclimate, and *vice versa.* Please clarify

Reply: We agree with the reviewer that the mechanics of microclimate and LST are different. We have used both microclimatic measurements and LST to study CC and temperature, and whether they are telling the same story in our study area. Previous research has not demonstrated the relationship between LST and the understory in dense canopies, and our results have shown that LST can be representative of the understory conditions. We have improved the manuscript to clarify the difference between microclimate and LST, and described our result more carefully.

3) The effect of canopy cover on microclimate is regulated by ambient temperature (and the effect on LST is regulated by elevation) are very interesting findings. Maybe better to provide more evidence and descriptions. Such as the across diurnal timescales, ambient temperature change a lot (from low temperature to high temperature), how CC on microclimate change, give the relationship panels (e.g. x-axis mean temperature, y-axis: CC effect on microclimate, I guess there is a positive correlation between them, i.e. higher temperature, higher CC effect).

Reply: Thank you for the excellent suggestion. We added a panel to the figure describing the temporal T in the study period (see figure below), where we plotted CC's cooling effect (regression coefficient) against the dates. The cooling effect varies from approximately 2.5°C to 8 °C, showing how the cooling effect increases during hot days and vice versa.



4) The analysis of LST should be more rigorous. For Landsat 8 satellite, although you have taken some corrections, only one thermal band could be used, and the uncertainty remained large. Maybe you should add the comparison between MODIS LST (three thermal bands are available, 1km resolution, which has also been widely used) and Landsat 8 LST to validate the accuracy of Landsat 8. Meanwhile, you only analyze the LST at 10:30, the analysis of 13:30 LST is also necessary, since it corresponds to the near-maximum temperature within a day, and the effect of CC on LST may be larger at 13:30 than that at 10:30.

Reply: Thank you for the comment. While we recognize the risks of only using Landsat 8 band 10 to calculate LST, the literature suggests it to be an accurate enough method (see for example Wang et al. 2019, He et al. 2019, Yu et al. 2014, Jiménez-Muñoz et al. 2014). The errors reported in previous studies are mostly coming from atmospheric effects. The water vapor content during the taking of the Landsat image was 1.7 g/cm^2, which makes the SC method more reliable; Jiménez-Muñoz et al. (2014) conclude that the SC errors become unacceptably high at water vapor contents >3 g/cm^2. Fortunately, the SC method is more accurate for TIR channels that are close to 11 µm than 12 µm due to atmospheric transmittance, which makes channel 10 more suitable for SC method than the use of channel 11 (Jiménez-Muñoz et al. 2014). Jiménez-Muñoz et al. (2014) report an error of 1.5 K; in Ndossi & Avdan (2016) SC and Planck function were the most accurate methods for LST retrieval for Landsat 8.

We find MODIS spatial resolution not great (1 km vs. 30 m) for our study, especially with the heterogeneous topography in the area. In one kilometer, the elevation can vary up to several hundred meters, and consequentially the LST would vary by several degrees based on the elevational lapse rate. Because we are interested in a scale where even individual trees matter to LST, we do not see MODIS to be suitable for our purposes, not even to validate Landsat 8 LST.

Unfortunately, there is no Landsat data available at 13.30, but we do agree that it would be very useful and interesting to analyze LST at the time when trees are expected to have the highest cooling effect. We have added a sentence in the discussion about this. May that remain a future research idea.

References:

He, J., Zhao, W., Li, A., Wen, F., and Yu, D.: The impact of the terrain effect on land surface temperature variation based on Landsat-8 observations in mountainous areas, Int. J. Remote Sens., 40, 1808–1827, https://doi.org/10.1080/01431161.2018.1466082, 2019.

Jiménez-Muñoz, J. C., Sobrino, J. A., Skoković, D., Mattra, C., and Cristóbal, J.: Land Surface Temperature Retrieval Methods from Landsat-8 Thermal Infrared Sensor Data. IEEE Geosci. Remote S., 11, 1840–1843, https://doi.org/10.1109/LGRS.2014.2312032, 2014.

Ndossi, M. I., and Avdan, U.: Application of Open Source Coding Technologies in the Production of Land Surface Temperature (LST) Maps from Landsat: A PyQGIS Plugin, Remote Sens., 8, 413. https://doi.org/10.3390/rs8050413, 2016.

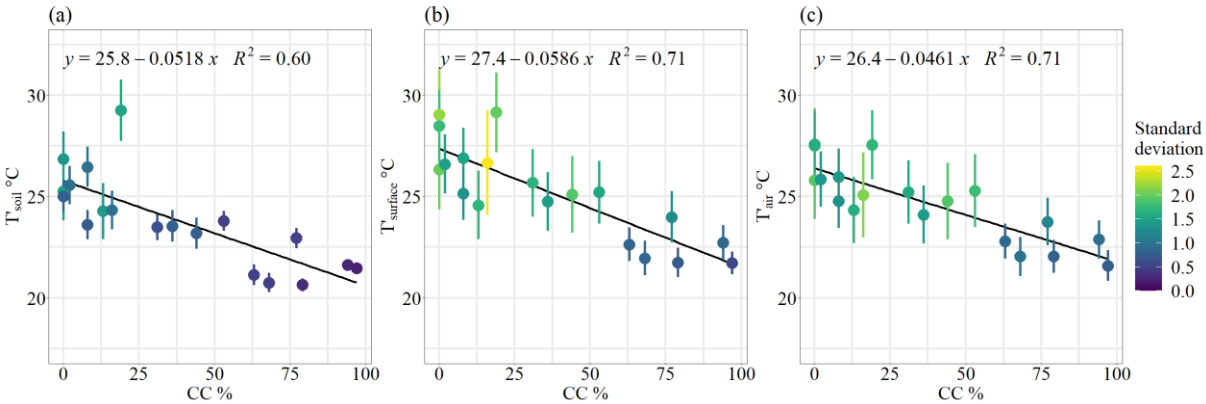
Wang, L., Lu, Y., and Yao, Y.: Comparison of Three Algorithms for the Retrieval of Land Surface Temperature from Landsat 8 Images, Sensors, 19, 5049, http://doi.org/10.3390/s19225049, 2019.

Yu, X., Guo, X., Wu, Z.: Land Surface Temperature Retrieval from Landsat 8 TIRS—Comparison between Radiative Transfer Equation-Based Method, Split Window Algorithm and Single Channel Method, Remote Sensing, 6, 9829-9852, https://doi.org/10.3390/rs6109829, 2014.

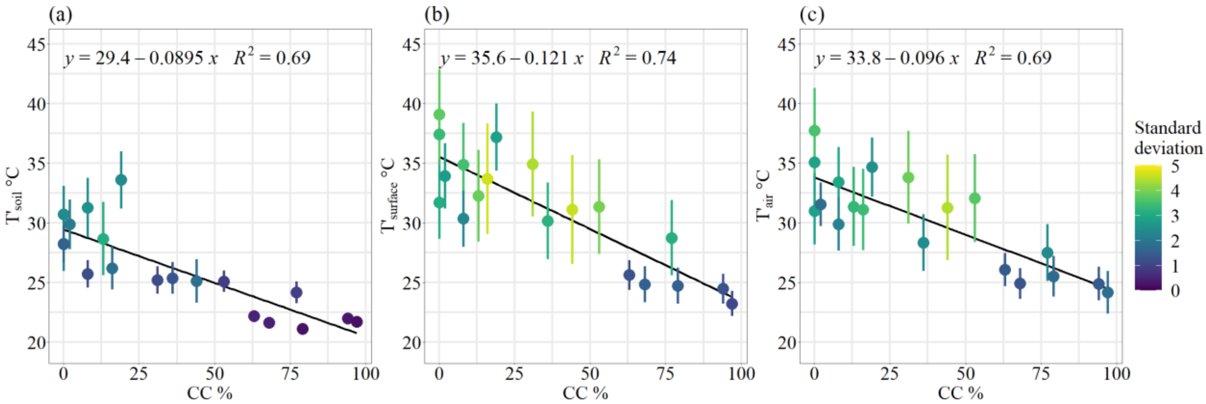
5) The results or visualization about the effect of canopy cover on microclimate variability should be improved (Line:191-195).

Reply: We agree with the reviewer that the part regarding the temperature variability should be strengthened. We have added a more thorough description of the results and edited figures of Tmean and Tmax to include standard deviation:

Tmean:



Tmax:



Specific comments:

Line 22-23: "……vary strongly with elevation and ambient temperatures". It's unclear to me, what're the ambient temperatures refer to? (if it is macroclimatic air temperature? I guess you did not measure this indicator)

Reply: Thank you for the comment, we agree that our description of macroclimate/ambient temperatures should be improved. With ambient temperatures, we mean the macroclimate, such as measured by weather stations. We did not use weather station data in our analysis to describe macroclimate, but rather reached a conclusion of the macroclimatic conditions from the temporal TOMST data (since macroclimate is a strong influencer on microclimate).

Line 24: what do the macroclimatic conditions mean?

Reply: Please see previous reply.

Line 78: how to quantify the stability of microclimates?

Reply: We have used standard deviation of mean temperatures during the study period to quantify the stability. We added a sentence in the methods to describe this approach and clarify what we have done.

Line 86-87: please provide the LAT, LON location information, although this could be interpreted from the Fig. 1

Reply: We added the LAT, LON information in the sentence.

Line 103-107: this information would be better to be assimilated into the introduction part

Reply: Thank you for the suggestion, we agree that the part fits better in the introduction and have moved it there.

Line 122-124: Please provide more information about microclimate sensors installed environments, they will affect collected microclimate data. For example, at low CC sites, the sensor was installed shadow area or sunlit area, and there are large temperature differences between sun and shade, meanwhile sunlit or shadow saturation also changes with sun angles, how did you consider these issues?

Reply: We acknowledge that microclimate is spatially variable in small scale, and that the placement of the sensor will affect the recorded temperatures. However, there is no perfect way to install the sensors, particularly when the number is limited. We put the sensors in places that represented the CC and environment as well as possible: in open areas they were exposed to the sun throughout the day, while in closed canopies they were shaded most of the day. In moderate CC, the sensors received both sunlight and shade, and we believe that the differences evened out during the day and would not detrimentally affect the results. We aimed to put sensors in places that were flat and not right next to trees or other artifacts. In some sites, the soil properties hindered us from putting the sensor in an optimal place, but we considered that the location we had to settle for was still adequate for the purpose. We have added a sentence about this in the methods section.

Line 129-131: macroclimate also largely affects microclimate (e.g. Fig. 1c in Zellweger et al., 2020), how do you consider this issue or how do you eliminate the influence of CC on microclimate? Meanwhile, whether the elevation and CC independent (independent assumption of the linear model)?

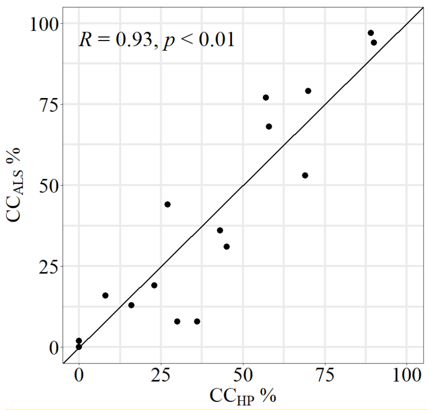
Reply: Please see reply to 1. We also chose field sites to have different canopy covers in different elevations to avoid multicollinearity of CC and elevation.

Line 134: please add the values.

Reply: Thank you for pointing out the mistake! We have added the missing values to the text.

Line 137-141: please clarify whether the mismatch of the collection date between ALS data and microclimate data could influence your research results, or evaluate its uncertainty?

Reply: Thank you for the comment. We accounted for the different data collection dates by comparing the ALS data to hemispherical photographs from the sites to see if the CC had changed substantially in 5-6 years. We could not find significant differences and therefore concluded that the data mismatch would not make a significant difference in the results. We have clarified this in the text and added a sentence and the following figure showing the differences in the Appendix A.



Line 159: how do you calculate the land surface emissivity?

Reply: We calculated emissivity based on an algorithm using the NDVI image (Ndossi & Avdan, 2016). Each pixel was given a pre-defined emissivity value based on the NDVI of the pixel:

NDVI < -0.185 → LSE 0.995; -0.185 ≤ NDVI < 0.157 → LSE 0.985; 0.157 ≤ NDVI ≤ 0.727 → LSE 1.009 + 0.047 * ln(NDVI); NDVI > 0.727 → LSE 0.990

We have added a description in the text.

Ndossi, M. I., and Avdan, U.: Application of Open Source Coding Technologies in the Production of Land Surface Temperature (LST) Maps from Landsat: A PyQGIS Plugin, Remote Sens., 8, 413. https://doi.org/10.3390/rs8050413, 2016.

Line 170-174: I am worried about this correction: this method could be regarded as three independent steps: the first step is removing elevation influence by minus dTh; the second step is removing slope influence by minus dTh; the third step is removing aspect influence by minus dTa. It makes sense if these three factors are independent, if they are highly correlated, this method will over-correct the LST?

Reply: Thank you for the excellent remark. We have removed equation 7 from the manuscript, because it described misleadingly what we did to correct for the topographic effect. There was not one method we used, but instead we estimated four different models, from where we have derived our results. In the models, we used different approaches, and have accounted for the possible interactions of topographic variables and CC. Especially slope and elevation could be highly correlated; steep slopes are likely found most in the mountains. Moreover, aspect and slope can have high interaction, because the azimuth angle will affect LST. We tested the correlations between the topographic variables and CC, and none exceeded ±0.6. We have also reassessed our models and modified model 4 by including the interaction between slope and aspect classes instead of the interaction between CC and aspect. The model performance did not improve, and there was no big difference in the CC coefficient. The elevational effect of CC remained approximately the same.

Line 191: 'affected also' → 'also affected'; please give the full definition of SD when it first appears

Reply: Thank you for the remark. We changed the order of words and added the definition of SD.

Line 191-195: where are these results from? I guess maybe from the Figure, this information may not be obtained by readers directly. please clarify.

Reply: Please see reply to 5.

Line 258-261: what's the underlying reason the cooling impact of CC decease with elevation? Table 4 may be moved into supplementary

Reply: As temperatures decrease with lapse rate, also the demand for evapotranspiration and VPD decreases. The effect resembles the latitudinal shift from strong cooling in the tropics to strong warming in boreal regions. Consequently, on cooler days, plant evapotranspiration is lower than on hot days. The total incoming radiation is high on clear vs. cloudy days, and due to tree cover, the understory receives proportionally less radiation compared to open areas on sunny days. (Geiger, 1980; De Frenne et al., 2021). We have improved the manuscript by discussing the underlying mechanisms more.

We also moved Table 4 into the supplementary material.

References:

De Frenne, P., Lenoir, J., Luoto, M., Scheffers, B. R., Zellweger, F., Aalto, J., . . . Hylander, K.: Forest microclimates and climate change: Importance, drivers and future research agenda, Glob Chang Biol., 27, 2279–2297, https://doi.org/10.1111/gcb.15569, 2021

Geiger, R.: The climate near the ground, 4th edition, Harvard University Press, United States of America, 1980.

Line 286-287: Not clear to me, the sensible flux of canopy means the sensible heat exchange between canopy surface temperature and surrounding air temperature. Only when canopy temperature equals surrounding air temperature, we can say no sensible effect.

Reply: Thank you for the discernment. We agree on the definition of sensible heat. What we meant is a substantial or significant effect rather than sensible. We have corrected our poor choice of word and reformulated the sentence for more clarity.