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Interactive comment on "Predicting evapotranspiration from drone-based thermography – a method comparison in a tropical oil palm plantation" *by* Florian Ellsäßer et al.

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Peer review for the manuscript: Predicting evapotranspiration from drone-based thermography – a method comparison in a tropical oil palm plantation by Ellsasser et al The manuscript under consideration reports a 9-days study of surface temperature measurements over an oil palm plantation in Indonesia using a thermal camera mounted on a drone. The authors used the temperature data to calculate the latent heat flux using three different models, with/out radiation inputs, and showed good agreement between one of the models and the latent heat estimated from an eddy-covariance (EC) calculation based on an on-site flux tower. The drone-based

temperature calculation is more flexible than the EC, also providing spatial information at high resolution. This is a very nice paper reporting an elegant study. The text and figures are carefully prepared and nicely presented.

Dear Reviewer,

Thank you for taking the time to revise our manuscript. We welcome your comments and think they have helped to improve our manuscript considerably. Please find our point-by point replies below.

Sincerely,
Florian Ellsäßer

I have only a few questions and suggestions:

1. Considering the rather narrow variation in air temperature over the tropical plantation, would you think that the fact that the study was performed at this site is a challenge? Or rather an easier case? I think that this point is touched upon, but further discussion would be appreciated.

We agree with the reviewer that there was rather narrow variation during the time of study (canopy air temperature ranged from 22.5 to 32.3 °C), as is typical for the region. Generally, the study site was rather challenging due to high temperatures and humidity and frequent occurrence of haze, as well as for logistical reasons. Additionally, many previous drone-based studies were conducted on grasslands (e.g. Brenner et al., 2018, 2017) or on low-growing crops such as wheat fields (Hoffmann et al., 2016), but not on crops with a rather complex canopy structure such as oil palm. However, our study site showed large temperature differences between soil and canopy, which simplified the distinguishing of each fraction.

As suggested, we will add a short section taking up these points to the discussion:

Generally, the study site was rather challenging due to high temperatures and humidity and frequent occurrence of haze, as well as for logistical reasons. Additionally, many previous drone-based studies were conducted on grasslands (e.g. Brenner et al., 2018, 2017) or on low-growing crops such as wheat fields (Hoffmann et al., 2016), but not on crops with a rather complex canopy structure such as oil palm. On the other hand, our study site showed large temperature differences between soil and canopy, which simplified the distinguishing of each fraction.

2. Considering the aggravating situation of deforestation in the studied region, and the implications on surface warming (L110-113), it would be highly interesting to make a comparison study between the palm plantation and the natural rainforest. I assume that the higher spatial heterogeneity in the latter would offer a better test case for the spatial distribution of ET (Fig. 5). Can the authors include such information?

We thank the reviewer for this very interesting point. Indeed the comparison of land surface temperatures and modelled evapotranspiration of natural rainforest and an oil palm plantations would provide valuable spatial insight into the current transformation of transpiration patterns caused by local- and regional-scale land-use changes, as e.g. described in Röll et al., 2019 and Sabajo et al., 2017. However, the present study focuses on the comparison of different drone-based methods as a baseline for future ecological studies, rather than applying the methods to different land-use

types. We will however follow up on this in the future, as we also performed flight missions over flooded and non-flooded natural forest sites and a variety of adjacent areas including mixed oil palm stands and small holder rubber and oil palm plantations.

To clarify this point in the manuscript, we will update the introduction section with the following sentence:

The present study focuses on the comparison of different drone-based methods as a baseline for future ecological studies, rather than applying the methods to different land-use types.

3. It would be good to include in the paper some information on the measured air-surface temperature differences as function of time and space.

The differences of mean land surface and air temperatures were rather low during our study period ranging from 0.005K to a single peak of 8.689K (ranging from daily means of 1.32K to 2.13K). As suggested by the reviewer, we provide some information on air-surface temperature differences over time in the attached Fig. 1.

The spatial differences of air-surface temperatures (Tmin and Tmax of the surface temperatures) extracted from the thermal maps are provided in the table below, averaged for the days of the year (DOY):

DOY	Dif. LSTmin and AirTemp16.3 [K]	Dif. LSTmax and AirTemp16.3 [K]
217	4.16	10.39
218	3.89	8.02
219	3.95	7.88
220	4.02	6.71
221	4.26	7.34

We will add the respective section to our manuscript in the results section:

Temperature differences between measured air temperature at 16.3m (top of canopy) and mean land surface temperatures ranged from 0.005K to a single peak of 8.689K for the single flights while the daily average differences ranged from 1.32K to 2.13K.

4. With 90% canopy cover, LST is mostly that of the leaf surfaces, i.e. reflecting the process of evaporative cooling of leaves by transpiration. Can the authors report these (evapo)transpiration values? A value is given in L360. Why are the units mm h-1 m-2? I thought that the mm already includes the area consideration (i.e., 1 mm = 1 L m-2).

We thank the reviewer for this insightful comment and agree that (evapo)transpiration should be provided in mm h-1. We will add more ET values to the respective section:

At the time of the drone flights, eddy covariance-derived evapotranspiration was, on average, 0.43 $\pm$0.21 mm h^{-1}, with peak evapotranspiration of up to 0.87 mm h^{-1} during midday.

5. By using the EC data as absolute reference, the text seems to assume that the EC data are independently true. However, the EC is also an estimate based on an indirect

measurement. If there are any additional measurements that could further constrain these data, it would be very helpful. Regardless, the text should be adjusted to reflect that two estimates are compared, rather than an estimate to a direct measurement.

We thank the reviewer for this comment and fully agree. Since we used an errors-in-variables model (Deming regression) in our analysis, we did account for these measurement errors in both the x- and the y-axis (eddy covariance and drone-based method, respectively).

To further clarify this in the manuscript, we will add the following sentence to the statistics section (2.6):

Both methods, the reference EC technique and the drone-based estimates, are associated with a certain degree of uncertainty. To account for the uncertainty in both, a model II Deming regression (Cornbleet and Gochman, 1979; Glaister, 2001) was applied for the analysis.

6. In case that one doesn't have radiation measurements, would the DTD model be the best option to make use of the thermal information? In L400 the authors should note that such sensors must be tested independently in a separate study.

In case that no radiation measurements at all are available, the radiation budget can potentially be modelled according to location, date and time and under the assumption of cloud and haze free skies, which we tested in our study for all three models. However, these assumptions were frequently not met during our time of study, resulting in relatively poor net radiation estimates translating to inaccurate results for the DTD, TSEB-PT and DATTUTDUT model.

The reviewer also makes an important point regarding the testing of potential on-board sensor schemes. We will adjust the sentence accordingly:

In our study, these measurements were taken with the EC equipment, but future stand-alone drone approaches are possible by using on-board miniaturized radiation sensors (Castro Aguilar et al., 2015; Suomalainen et al., 2018). However, the accuracy of such on-board radiation sensors should first be tested against reference methods, e.g. visually by scatter or inter-comparison plots (Castro Aguilar et al., 2015; Suomalainen et al., 2018) or with a model II regression procedure evaluating the interchangeability of methods and measurements (Passing and Bablok, 1983).

7. The authors discuss measurements in drier sites. It would be interesting to compare these results with measurements of palm water-use and its effect on temperature. Below are a few studies on date palm, evidencing the high transpiration rates in a plantation, and the effect on temperature in an urban context.

We thank the reviewer for this interesting suggestion. The new drone-based method can likely help to link surface temperatures, e.g. in urban settings, and vegetation water use; however, this falls outside of the scope of the presented study. As mentioned before, we focus mainly on a method comparison rather than on applied ecological questions for now.

To clarify this further, we added a sentence to the discussion:

Drone-based methods have a large untapped potential for ecological applications,

e.g. regarding ecohydrological optimization in land use systems and designing the climate-smart urban landscapes of the future.

8. Finally, another potential comparison could be made with a study of transpiration of forest trees estimated by spatial temperature data from a thermal camera (see reference below).

Sperling, O., Shapira, O., Cohen, S., Tripler, E., Schwartz, A., & Lazarovitch, N. (2012). Estimating sap flux densities in date palm trees using the heat dissipation method and weighing lysimeters. Tree Physiology, 32(9), 1171-1178.

Potchter, O., Goldman, D., Kadish, D., & Iluz, D. (2008). The oasis effect in an extremely hot and arid climate: The case of southern Israel. Journal of Arid Environments, 72(9), 1721-1733.

Potchter, O., Goldman, D., Iluz, D., & Kadish, D. (2012). The climatic effect of a manmade oasis during winter season in a hyper arid zone: The case of Southern Israel. Journal of arid environments, 87, 231-242.

Lapidot, O., Ignat, T., Rud, R., Rog, I., Alchanatis, V., & Klein, T. (2019). Use of thermal imaging to detect evaporative cooling in coniferous and broadleaved tree species of the Mediterranean maquis. Agricultural and forest meteorology, 271, 285-294.

We thank the reviewer for this suggestion; as mentioned previously, this manuscript focuses on a method comparison rather than on the ecological application of the method and a comparison to other land-use types; in the (near) future, further work will certainly also include further land-use types including old-growth and secondary tropical forest patches, agroforestry systems and smallholder plantations in lowland Sumatra and beyond.

We took up the reference suggested by the reviewer in the introduction:

Transpiration from leaf surfaces leads to evaporative cooling of the canopy; LSTs, along with air temperature, can thus be used as a reliable indicator of plant water use, both in monocultures and in spatially highly heterogeneous systems such as natural forests (Lapidot et al., 2019).

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Lapidot, O., Ignat, T., Rud, R., Rog, I., Alchanatis, V., Klein, T., 2019. Use of thermal imaging to detect evaporative cooling in coniferous and broadleaved tree species of the Mediterranean maquis. Agric. For. Meteorol. 271, 285–294. https://doi.org/10.1016/j.agrformet.2019.02.014

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