Response to Review 1

Anonymous Referee #1 Received and published: 16 November 2020

General Comments: The article uses a thermal imager on a UAS flown at 500 m over boreal peatland to extract surface temperature fluctuation using methodology from Christen et al 2012.

Several corrections are applied to the dataset to allow accurate assessment of turbulent statistics. From the temperature fluctuations TIV is performed to extract 2D velocity fields and a spectral analysis is performed to identity eddy size and shape for eddies of the order of 10-100 m. Further analysis looking at the size and aspect ratio of the eddies is compared to relevant turbulent statistics. I applaud the authors on their methodology and problem-solving skills to treat this dataset to bring it to the point where turbulence analysis can be performed. I too have dealt with many of the issues described here without any publication to speak of. I see the science within this document as a reflection as step forward for UAS-TIR measurements in atmospheric boundary layer research. While the results and methodology of the document are worthwhile of publication, I have provided a series of major and minor comments below. I find the merit and methodology of the work very high, but the presentation and text to only be fair, thus the comments accumulate to a minor revision. Primarily, I find that the manuscript is lacking a strong review of the literature. I recommend the authors spend more time in the introduction and text to provide citations on turbulent structures. Specifically, the LES community has been studying this topic for some time and should be included. Additionally, the text is very informal, often using inconsistent abbreviations and acronyms. The authors should re-read and work the text to improve its quality and consistency.

- Thank You very much for the very positive evaluation of this work and providing many useful comments. We have made the requested improvements and edits throughout the text.

Major Comment: Line 53: Be careful, throughout the document you interchangeably
use IR and TIR. I understand the overlap, but IR is reserved for short-wave while TIRis reserved for mid-to-long wave infrared radiation. I am only going to comment hereon this but will need to change throughout the document.

- All instances of IR were replaced with TIR.

Major Comment: How did you handle the transmissivity? At such an altitude (500 m)there is likely some degree of error introduced from the transmissivity of the air on the accuracy of the measurement. I believe the FLIR software has a default correction based on the air temperature and humidity, did you use this to correct for the transmissivity?

- That is correct, we entered the 500 m distance and the measured RH and Tair in the ResearchIR software when processing the thermal data, which provided a robust estimate of the atmospheric effect. A small error in the transmissivity assessment, even if present, would not significantly affect the results of this study – it would mainly affect the absolute level of the temperatures, while temperature fluctuations are mainly discussed. A future study may attempt to calculate a time-varying change in transmissivity due to the passage large eddies with different properties.

Major Comment: Many informal sentences. Please use input from co-authors or a reputable grammar editor like Grammarly to help improve make the text more formal. Please rewrite any sentence with the word “so” or beginning with the word “Because.” Such phrasing leads to informal sentences.

- Thank You for pointing this out, we tried to improve the language throughout the manuscript.

Minor comment: What is the anticipated error from the noise introduced leaves? Are there leaves? How does the surface look?

- the surface is effectively flat, as the microtopography is quite undeveloped (elevation difference between hummocks and hollows <15 cm). The vegetation is short-stature, being mainly represented by sedges and shrubs. The combined leaf area index of the sedges and shrubs was about 0.4 on the measurement days, which is a low figure typical of open fens. While the sedges contribute the most to the site-average LAI, their stems are thin and vertically oriented (before the start of senescence), so that when observing the peatland in a top-down perspective of the UAV, one sees mainly the moss surface. The ground photo (new Figure 1c) may be misleading in that sense, as at this angle, the sedges have a much greater projected area. So the temperatures presented in the manuscript are largely those of the moss cover.
- Also, no strong wind was recorded on the measurement days. Therefore, the expected magnitude of thermal noise resulting from wind-induced leaf flapping the is only minor, and it gets further reduced by the spatial averaging over a 1x1 m grid.

A high quality (larger than Figure 4) visual image or satellite view would be very helpful.
Minor comment: Can you add a photo of the flux tower setup?

- Both maps have been added (new Figure 1).

Minor comment: Please provide more details on how the imregister function (as well as other functions) work. Please remember that Matlab is a paid programing languagesuch that the methodology should be explained as to someone is reprograming this methodology with another language like C++.

- Done. However, I am positive that other programming environments offer analogous functionality using the same (or similar) approaches.

Minor Comments:
Line 15: comma after (UAS) - Done
Line 19: Please change “whilst” to “while” - Done
Line 23: The UAS thermal imagery is collocated with a ground-based eddy-covariancesystem. - Done
Line 45: Remove “made” - Done
Line 50: Replace regretted with reported - Done
Line 58: Remove “Evidently” - Done
Line 67: Replace 2-day to two-day - Done
Line 70: Rewrite for clarity: “..and the available eddy-covariance (EC) tower...” - Done
Line 75: Please include the spectral response of your camera - Done

Line 82: Remove “quite well” - Done
Line 82-83: Rewrite - Done
Line 91: Replace “.,.” with a period “.” - Done
Line 91: Can you comment on the time synchronization more? For long averaging periods (>5 minutes) it may not be a concern, but for detection of large eddies this is rather important. Was this method with the aluminum sheet synchronized with a watch? Was there on an onboard GPS available? Was the EC tower GPS synchronized. – the corresponding explanations were added. The drone had an onboard GPS; the EC coordinates are known from a measurement with a survey-grade GPS.

Line 93: Remove “easily” - Done
Line 98: Please provide a literature source for the emissivity value used. – Unfortunately, as literature values do not seem to be available for *Sphagnum* moss (or effective moss-dominate ecosystem) emissivity, we are forced to work with the generic value of 0.98. This value of 0.98 is chosen based on expectation that highly moisturized capitulum of Sphagnum has a high emissivity approaching 99%. Leaf emissivities of deciduous species are about 98%, e.g. Kim et al. 2012.

Line 108 and 109: Remove “The” in phrase “The Steps,” also “Steps” is not capitalized - Done
Figure 2: Please add a more informative caption. - Done
Line 129: Rewrite 129 to not begin with “Because” - Done
Line 141: Remove “To do that” - Done
Line 161: What is a deviation from a space-time average? This doesn’t make sense to me. – this is the overall mean temperature of the entire flight, obtained by first averaging the temperatures within each image, and then averaging those over the whole recorded sequence. Each images is essentially adjusted so that to make its average equal to that “space-time average”. As explained in the text, this is done to alleviate the calibration drift of the sensor.
Line 162: Replace “so” with “such” - Done
Line 165: No need for “e.g.” - Done
Line 169: This is confusing to me. A forward finite difference already implies it was divided the time. Was dT/dt multiplied by the sampling frequency after this? – I apologize for the inconsistency – this quantity is actually not used in the current version of the manuscript. This sentence is now removed.
Line 173: Remove “now” - Done
Line 181: Rewrite to “A 2D wavelet...” - Done
Line 181: Remove “then” - Done
Line 186: Incomplete sentence “The positive...” – What do you mean? I think the sentence is complete, “The positive and negative regions remaining after that filtering operation represent, in essence, the smoothed boundaries of the larger coherent structure thermal traces”
Line 194: Please spell out wind direction or define WD - Done
Lines 205-210: Here you are calling the methodology PIV. While it is true you are borrowing methodology from PIV, the community has adopted the terminology Thermal
Image Velocimetry (TIV) when using “thermal” particles. – we agree with that, PIV changed to TIV throughout the document.
Line 215: Replace “that is” with “as” - Done
Line 216: (WS) - Done

Line 218: u star, z_0 and L should all be in parentheses. - Done
Line 220: I think partitioned should be replaced with temporally averaged. - Done
Line 224: Informal sentence, please rewrite - Done
Line 225: Here you abbreviate August. Please spell it out like you did earlier in the document. - Done
Line 227: "3-m" - Done
Table 2: Is z L0 suppose to be z/L0? – that is correct, this is z/Lo written in exponential notation. Perhaps it wasn't correctly presented in the document for you.
Caption Figure 4: Here you use a percentage for the emissivity. Earlier in the document you use a factional number. Please be consistent. - Done
Line 258: Remove "probably" and please hedge this sentence more formally. - Done
Line 271: Super interesting about the heat capacity of the needles! – thank You for mentioning this - indeed a factor to be accounted for. The forest canopy temperature does fluctuate much more than the moss (or any other sparsely vegetated surface) due to the vast difference in heat capacity and atmospheric coupling (the latter has been added to the text, as it is an equally important aspect controlling the heat exchange with the air.)
Line 279: Spell out north and south - Done
Line 281: Please define sigma. I assume you are talking about the standard deviation. - Done
Line 286: When was this spectrum taken? Using which data? Can you commenthere on the difference between the signals at the larger frequencies. I think this is ainteresting result.- added "The generally lower spectral energy of the UAS T_s data is due to the fact that the high heat capacity of the ground leads to much lower surface temperature fluctuations than those observed in the airflow. The flattening of the UAS spectrum at higher frequencies results from noise contributed mainly by the thermal measurement and the image registration error."
Line 305: Please spell out temperature - Done
Line 342: Please change "power" to "spectral power density" - Done
Line 349: Remove "However" - Done
Line 350: Change the colon to a comma - Done
Line 358: Please change "additionally explored by inquiry" to "studied by dividing the signal" - Done
Line 369: Remove ",too," - Done
Figure 10: Please add a legend for the red lines - Done
Line 371: Please correct for informalities. – Done
Figure 10: It is interesting to see the larger variability in the ratio of the 128-cross and along wind structures peak for flight 3. I understand this to be the flight with the fanning pattern observed. – Actually, this was the flight with elongated linear structures. I can interpret the high peaks in the ratio of the 128m along:cross spectral powers as the periods when such structures were at their peak development. It is a little counter-intuitive, but it seems that the highest power occurs when the entire field of view is occupied by a burst of structures approaching the extent of FOV in the given direction (ca. 300-400m long). Thus, a packet of long, intense linear structure creates a greater spectral 128m power in the along-wind direction than a packet of shorter structures would.
Line 395: Can you rewrite, I don't understand what you mean "flights 1-2 group closetogether..." and so forth - Done

Figure 11: What's the major and minor axis? – Added the explanation: Major axis is the greater dimension of the coherent structure's thermal trace, which is always oriented in streamwise direction; correspondingly, the minor axis is the "width".
Line 423: What do you mean by "associated"? - Done
Line 424: Please use consistent nomenclature for "R2" - Done
Figure 13: It would be easier to interpret this one to one if the limits of the axes werethe same. – This is maybe unnecessary as different quantities are presented in (a-c).
Figure 13: Which footprint methodology did you use? Please cite. – it was Kormann and Meixner (2001). Citation added.
Line 434: Change from "Such,.." to "The" - Done
Line 436: Please use a comma instead of the colon - Done
Line 440: These are indeed "large" structures but are not the "largest structures." I would be more specific here and say structures ranging from 1-420 m. - Done
Line 443: Again, be careful here about how you talk about turbulent length scales. The smallest scales of turbulence are order 1 mm. - Done
Lines 440-452: While I agree this method is very advantageous and progressive, some of the previous works mentioned were looking at smaller scale turbulence. For the goal of looking at TOS I agree a larger field of view from a UAV is perfect, but the tradeoffs were looking resolution for smaller scale processes and sensitivity from using a thermal imager with a microbolometer. – We quite agree with this. Hopefully, future research will succeed in minimizing the artefacts of the thermal camera data and the processing methods, and improve the quality of the derived turbulence characteristics!

Line 464: Plethora is informal - Done

Line 470: Add citations here about wind speed and TOS. Such papers as "Surface Thermal Heterogeneities and the Atmospheric Boundary Layer: The Relevance of Dis-persive Fluxes" by Margairaz et al and "Buoyancy effects on the integral length scales and mean velocity profile in atmospheric surface layer flows" by Salesky et al. – Thank You so much for the suggestions, they have been added. Our findings find support in this literature, indeed.

Lines 434-500: I do not feel like this discussion is anything more than a conclusion of the presented work. – Perhaps, but these are the points we felt can be raised based on the proof-of-concept study that had been conducted. A larger dataset (some tens of flights spanning the range of stabilities) would allow for a deeper analysis. We hope to undertake such an effort in the future.

Lines 490-495: Several methods exist to exact SHF from thermal imaging products.Morrison et al 2012 as well as other remote sensing papers should be discussed here. – Thank You for the suggestion, this is added. However, in this approach the sensible heat flux is a residual of the energy budget, and typically the smallest component of it in boreal peatlands. In such ecosystems, the surface distribution of LE would be an important factor controlling the local-scale (ca. 1 m) energy budget, and thus introduce a strong uncertainty. This can be avoided by measuring over fallow agricultural fields during drought. However, if the turbulence over a given ecosystem at given conditions must be addressed, these uncertainties inevitably have to be dealt with.