

Atmos. Meas. Tech. Discuss., author comment AC2
<https://doi.org/10.5194/amt-2021-335-AC2>, 2022
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Reply on RC2

Benjamin Schumacher et al.

Author comment on "Adaptive thermal image velocimetry of spatial wind movement on landscapes using near-target infrared cameras" by Benjamin Schumacher et al., Atmos. Meas. Tech. Discuss., <https://doi.org/10.5194/amt-2021-335-AC2>, 2022

Review: Adaptive Thermal Image Velocimetry of spatial wind movement on landscapes using near target infrared cameras

The authors present a modification of the thermal image velocimetry (TIV) method called adaptive TIV (A-TIV). They use fluctuations in surface brightness temperature derived from time series of UAS-based thermal imagery for estimating two-dimensional near surface wind velocities.

With my background (I use UAS-based thermal imagery for assessing turbulent energy fluxes), parts of the manuscript remain unclear. The description of the method is not detailed enough in my opinion and the structure of the methods part is also a bit unclear to me (some sections would probably better fit into the results part?). The results part lacks important information, e.g. it does not provide any comparison of the presented A-TIV algorithm with the existing TIV algorithm, which would be essential for assessing the benefit of the new method.

Since I am not a native myself, I do not comment on language in general. But long sequences of nouns (e.g. multiple surface brightness temperature perturbation filter sizes) make the text hard to read, which might be avoided by rearranging sentences.

In my opinion this manuscript needs a thorough revision before publication.

I list some more specific comments below:

Answer:

Thank you for your detailed suggestions and comments. We have updated the manuscript according to your concerns. We agree with the reviewer that more details of the method need to be provided. To address this issue, we have added an Appendix providing detailed information about the areal footprint of the sonic anemometer that, we now realized, are essential to include based on the reviewer's feedback. We also added a new table to compare TIV and A-TIV as well as new clarifications to questions raised about the

methods. The discussion section was also expanded by several paragraphs to meet the reviewer's suggestions and discuss the newly added results.

Reviewer 2:

P4: I would rephrase the objective imagerys since in the current form it is clear that the objectives were defined after conducting the experimimageryents as they already provide information about the outcomes.

Answer:

We have rephrased the objectives and provided new and concise information about the outcomes (line 98).

Reviewer 2:

P5, line 118: I have no experience with the HHT, but what would happen if you chose the second highest frequency? The highest frequency is obviously the noisiest and might include camera noise effects?

Answer:

The highest frequency includes camera noise effects as well as usable signal. From experience with other (lower quality) IR cameras we have seen that the highest frequency contains camera noise and this approach may help (we have added this possible solution in the discussion section on line 354 - 355). However, with the equipment we used in the TURF experiments the HHT frequency decomposition helps in selecting the minimum time interval required for perturbation calculations that are used for the estimation of velocities from thermal imagery. This is the optimal approach because any other picked frequency would potentially miss higher frequencies. The second highest frequency may also be successfully used, however the A-TIV output may display more vacant grid cells.

Reviewer 2:

P 5, line 126: Add the weights here.

Answer:

We have added the weights according to your suggestion (line 130).

Reviewer 2:

P5, line 136: This sentence belongs to 2.1

Answer:

Thank you for the suggestion. We couldn't find line 136 on page 5. The lines around 136 also doesn't fit the reviewer's comments. We would kindly ask the reviewer to update us

on the correct line number if this remains unresolved and requires further attention.

Reviewer 2:

P6: In part C the colors are not correct, it depicts twice the same 3x3 window. To me it is not clear why the correlation map has numbers in all pixels. A sentence on what the numbers in the correlation map mean would make it much easier to understand for people not familiar with the method.

Answer:

Thank you for pointing this out. We have corrected the figure with it's colours and added a sentence about the numbers in the correlation matrix. This correlation technique is also described in Schumacher et al. (2019), Inagaki et al. (2013) and Kaga et al. (1992). (line 139 - 141)

Reviewer 2:

P7, line 144: This sentence is totally unclear to me: *The weather station data is used to contextualize the A-TIV output in respect to the other experiments.*

Answer:

We have rephrased the sentence to clarify the use of the weather station data (line 151 - 152) It now reads: The weather station data was used to monitor the atmospheric conditions during the experiment and evaluate the A-TIV results in comparison with the TURF-T1 experiment and TURF-T2 experiment.

Reviewer 2:

P 10, line 178: Did the scattered clouds have any effect on surface temperature perturbations?

Answer:

The scattered high clouds did not occur during the experimental period. Therefore, there were no effects on the surface temperature perturbations during the experiments. We have added this clarification to the manuscript (line 185)

Reviewer 2:

P10, table 1: what is the height of the grass? Grass can easily reach the same height as the wheat stubble. What is the ground resolution of the imagery? Why did flying altitude vary between the experiments?

Answer:

The grass was mowed and about 3-5 cm in height. We have added the information to table 1. The altitude varied to better resolve the small-scale turbulent structures in the grass and the turf area in TURF-T2 and the possible differences between them. Furthermore, the extent of the turf was smaller compared to TURF-T1 which limited the field of view of the camera and hence the flight altitude.

Reviewer 2:

P11, line 186: I do not see the cold spots. What is the emissivity of the high emissivity targets? Grass itself has a high emissivity. What is the approximate emissivity of turf? I am wondering why high emissivity targets are cold spots and not the low emissivity targets? If I understand it correctly, this means that the air (the reflected part of the signal) is warmer than the surface, which drives a negative sensible heat flux? Could you explain this in more detail?

Answer:

Thank you very much for catching this important detail. The targets were polished aluminium plates (60 cm x 60 cm). Therefore, these targets had a lower emissivity compared to the surrounding turf and grass. We have corrected this mistake (line 195). In the figure caption of figure 4 the reference to the target is correct as "low emissivity targets".

In the previous text the high emissivity value for turf is mentioned as a requirement for TIV to work.

Reviewer 2:

P11, figure 4: Why is the peak in the standard deviation spatially shifted between a) and b)? It would make the interpretation of the images easier if also RGB images of the same scene were provided.

Answer:

Due to the shaking of the imagery the low emissivity target will shift from one video frame to the next. The Blender software tracking algorithm tracks this movement from frame to frame. Therefore, the spatial continuity is referenced to the first tracked frame not to the entire video sequence. This means, that the software will always try to match any new frame in the sequence spatially to the first frame of the video. A spatial continuity from unstable to stable imagery is based on the very first frame of the video not the entire video sequence. Hence the peak of standard deviation for the stabilized video will be at the first position of the detected low emissivity target. We have added the RGB imagery and the above explanation to the figure caption.

Reviewer 2:

P12, line 200: it is not clear to me how error vectors are assessed here?

Answer:

An error vector in this image is a vector which implies unrealistic effects such as localized large advection speeds. Most vectors in Figure 6 A) express 6-8 m/s in a very small area whereas the average wind speed during the day was 2.6 m/s. It is very unlikely that the A-TIV would cover such local wind speeds. We have added a clearer specification to the paragraph (line 256-257).

Reviewer 2:

P13 & 14, figure 6 & 7: I do not understand why these figures are part of the methods section? It would be more interesting to have something similar in the results section including a comparison of the different wind speed estimates with the reference data.

Answer:

We have moved the respective sections 2.5 and 2.6 to the results section becoming section 3.2.2 and 3.2.3. Furthermore, we have added an additional comparison table to section 3.2.2 which compares TIV to A-TIV in terms of vacant grid cells and added velocity information. This clarifies the advantage of A-TIV over TIV. The following sections show the comparison of A-TIV with the reference data.

Reviewer 2:

P15, line 223: Can you explain why you used a spatial shift of 9 m?

Answer:

The spatial shift of 9m was introduced to separate the virtual array completely from the physical array which has a 6m diagonal extent. Therefore, it was necessary to move the entire virtual array by 9m to the southwest/northeast to ensure no thermal signature is captured from the physical devices and wires.

Reviewer 2:

P15, line 233: how was the location of these 15x15 m windows selected?

Answer:

The reviewer 1 also asked the same question. Please see our answer to Reviewer 1 question 3. We have also added a section with the footprint calculation to a section in the amendments.

Answer to Reviewer 1:

"We have added new material (Appendix) for the estimation of the footprint of the sonic anemometer using the UMEP plugin for QGIS which allowed us to pick a suitable area for the averaging (Lindberg 2018). We have now prepared a more detailed view in the appendix. We have also referenced the Appendix in the text where needed."

Reviewer 2:

P16, line 249: I am confused concerning the p value. Is the null hypothesis that both data sets stem from the same distribution? Then this would be rejected for TURF-T1?

Answer:

Please see Reviewer 1 Question 6). We have adjusted the analysis to report a higher p-value as per common practice.

Answer to Reviewer 1:

"Your statement is correct. This analysis used the null hypothesis (H0) that the means of the two distributions do not match. Hence the low p-value. We have adjusted H0 and

report now a higher p-value as per common practice (line 263 - 265)."

Reviewer 2:

P16, figure 8: In general, legends are missing in the figures. I would further encourage the authors to make their plots a bit more black/white friendly.

Answer:

Thank you for bringing up the concern. We strongly agree with the reviewer that the plots should be easy to distinguish and colorblind-friendly. To be compliant with the journals' regulations we have checked each individual figure with the colorblindness simulator Coblis and the screen tool color oracle. All figures comply with the most frequent dispositions of colorblindness. The diverging colormaps in figure 5, 6 and 7 are compliant with the diverging colorblind colorbars from matplotlib python. See: <https://github.com/matplotlib/matplotlib/issues/7081/>

All figures except for Figure 8 expose legend items that help to understand the figures. Figure 8 does not necessarily need this legend item to express that there is no significant difference between the thermocouple and the brightness temperature measurement.

Reviewer 2:

P17 line 262: maybe I missed it but I think it was never stated before that the TC wind speed is limited to ≥ 0.25 m/s.

Answer:

We have added a corresponding sentence to the Methods section (line 212 - 213)

Reviewer 2:

P18 figure 9: this plot is a bit hard to read

Answer:

We have separated the line plot into two separate plots.

Reviewer 2:

P22, figure 13: which ratio is used for the dashed expected line?

Answer:

We have clarified the ratio in the figure caption.

Reviewer 2:

P22 line 291: this sentence is not clear to me

Answer:

We have restructured the sentence and split it into two separate sentences and added some additional information (line 309 - 314).

Reviewer 2:

P23 line 295: what would happen if the resetting mechanism is set to a longer interval? What would be the effect on the thermal patterns and on the absolute values? It is not clear to me how these data gaps were accounted for in the analysis.

Answer:

The thermal sensor in the camera is very sensitive to external heating. Specifically one-sided solar heating creates a thermal imbalance from one side of the image to the other. The resetting mechanism ensures that the sensor can adjust to this imbalance of external heating. Therefore, this resetting mechanism is necessary otherwise the thermal imbalance of the image would increase over time.

When the data was resampled to 2 Hz, the two NA-frames caused by the resetting mechanism were replaced with the last available image. Before the calculation of the A-TIV the corresponding frames were removed from the perturbation time series to ensure for a continuous velocimetry estimation. This shortened the signal by 26 seconds and caused the shorter time coverage of the A-TIV signal visible in figure 9.

Reviewer 2:

P23 line 305: this sentence is not clear to me

Answer:

A-TIV estimates velocity based on changes in the spatiotemporal patterns of the brightness temperature. Surface brightness temperature changes in response to rapid heat exchange occurring between the surface and near-surface turbulent air that tends to have a coherency associated with it. However, we know from eddy covariance measurements that turbulent coherent structures are 3D structures and as a result the 2D thermal patterns detected by the a TIV method will be a convolution of these 3D dynamics. Hence, A-TIV is not necessarily capturing the exact movement of the coherent structure due to the lack of any explicit vertical measurements via infrared.

Reviewer 2:

P23, line 312: If I am correct then EC measurements are missing mostly the lower frequencies (larger eddies). Can you put this sentence a bit more into context with your experiment?

Answer:

With this paragraph we wanted to point out the advantage of combining the traditional point measurement methods with the newly proposed A-TIV / infrared camera measurements. We have rephrased the paragraph accordingly (330 - 336)

Reviewer 2:

P23, line 323: A very general question: can you describe why one would expect that the air and surface temperature perturbations show similar magnitudes given differences in thermal properties?

Answer:

This depends entirely on the surface type and its water content. As seen in the wheat stubble experiment the canopy decreases the effect of the thermal interaction of atmosphere and surface. It is expected that short cut grass and turf react well and immediately to temperature changes by the atmosphere adjacent to the surface. Additionally, other factors such as cloud cover, surface and soil moisture creating latent heat play a major role in the surface temperature perturbation magnitudes.

Reviewer 2:

P24 line 344: It would be helpful if you could link these statements to the single figures that support these claims?

Answer:

We have linked each statement to the figures from the results section (line 392 - 400).

Reviewer 2:

P24 line 356: this sentence is a bit unclear to me

Answer:

We have added a subordinate clause to clarify the sentence (line 403).