**Manuscript Review:**

**Time series of alpine snow surface radiative temperature maps from high precision thermal infrared imaging.**

**Arioli et al., 2024**

The manuscript presents a dataset comprised of a series of thermal maps/images and RGB images collected from a single observation station looking across a snow-covered mountain area in the French Alps. The paper presents perhaps the most rigorous and best example of calibration routines for thermal imaging over snow surfaces (and perhaps for any land surface thermal imaging) in the current literature. The authors address most of the major sensor limitations of microbolometer thermal sensors; including sensor drift, internal temperature, bias correction, emissivity, etc. This is a technically very challenging task and there are many valuable insights in the workflow presented that will be of great use to the research community. The datasets themselves are likely to provide a useful resource for snow studies and calibration of future satellite missions (if the dataset continues to be collected contemporaneously with these), alongside being a useful dataset in their own right for studies of snow surface energy balance, heterogeneity, etc. Furthermore, the manuscript is well written, and easy to follow.

However, I do have one major comment on the paper. While the authors account for most of the error sources of microbolometer sensors they do not address the potential impact of variable viewing angles and variable distance to target on their measurements/dataset. Studies have shown these can both potentially significantly impact thermal camera measurements. The impact of these on the datasets is likely not apparent in the error assessment against the more accurate IR sensors on the AWS because these are all located at roughly similar distances from the camera and have similar viewing angles. As a result, I believe the reported absolute error values of 0.67K (spring 2023) is probably only representative of areas with similar distance and viewing angle to the AWS stations and is likely worse in other areas of the study site, these limitations should ideally be investigated to confirm or negate their presence. If present the datasets could be improved by addressing these issues, however this is likely to be fairly labour intensive and the dataset and manuscript in their current form are still at the forefront of research in this field. To produce the most accurate and thus useful dataset I suggest the authors identify and address these error sources, however given the high quality of the paper and datasets already I would be satisfied if their potential impacts and consequent limitations were discussed within the paper, at a minimum.

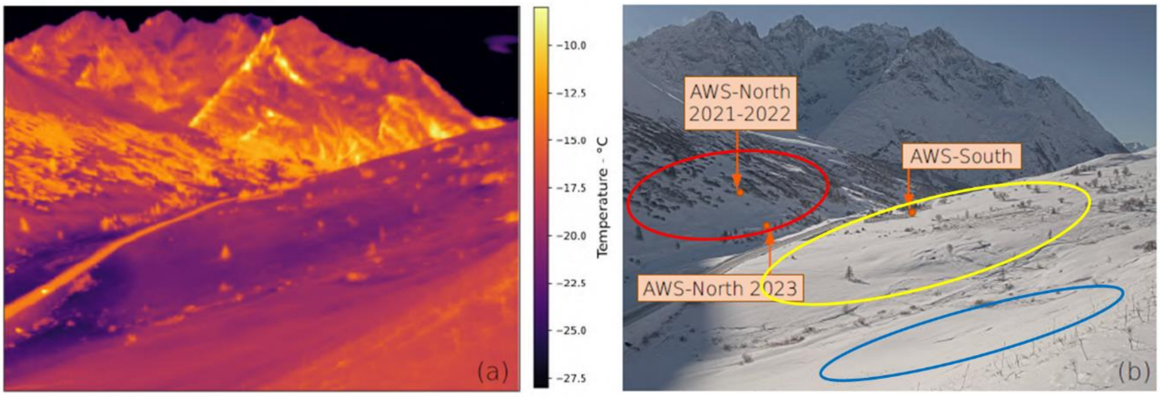
**Major comments:**

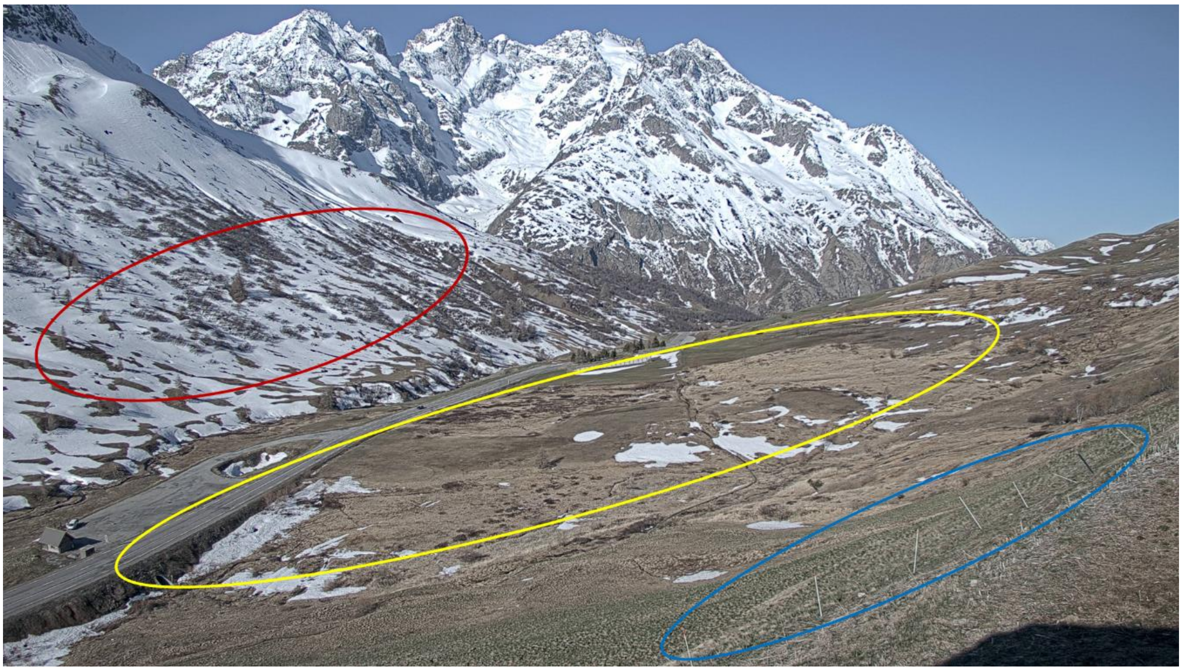
***Viewing Angle:***

Other studies have shown that microbolometer sensors suffer a significant reduction in measured temperatures when the viewing angle is greater than ~40° (Cheng et al., 2012; Jiao et al., 2016; Litwa, 2010). This is potentially what is visible in Figure 5 of the manuscript at the periphery of the black body where viewing angle increases, though this could also be temperature bleeding across the boundary of the calibration surface and the background. When shooting thermal imagery from a nadir position (e.g. from a drone/plane) the viewing angle is generally less than 40° (unless flying over very complex topography) and this effect is minimised. However, when shooting an oblique as is the case in this manuscript much of the image is taken from angles exceeding 40°, when the land is sloping away (blue ellipses) from the camera this effect is enhanced, while when the land faces towards (red ellipses) the camera the effect is minimised. These errors are likely not picked up in the bias correction to the AWS stations because they all appear to have a very similar viewing angle from the camera. I would suggest first testing the sensor to see if, and to what extent it suffers from viewing angle errors (which is likely). If this is confirmed then these errors could be corrected by calculating the impact of viewing angle on their sensor in a lab using a black body of known temperature (as shown in Figure 5 of the manuscript) e.g. following Alexander & Lunderman, (2021) and then applying this correction to the image temperature measurements after calculating each pixels view angle from the camera.

***Viewing Distance:***

The secondary issue is distance to sensor (Minkina & Klecha, 2016). Microbolometers are impacted by distance to the target for a number of reasons, and this also varies somewhat depending on atmospheric conditions at the time of imaging. When images are collected from a nadir position (e.g. drone/plane) this variability is minimal as height above ground can be kept relatively similar/constant (except with very complex topography). With oblique imagery this is not the case unless the target of interest is confined to a single location/distance to sensor. The manuscript presents data that is spread horizontally across ~1.2km of ground from the sensor/camera to the area beyond the AWS (but excluding the very distant mountains). There is likely a significant trend in the dataset because of this. The more accurate sensors on the AWS are all located at a roughly similar distance from the camera (~700m) and therefore are unlikely to pick up this effect/trend. To coarsely remedy this the authors could work out their sensors distance to target sensitivity in a lab by collecting images of a stable black body calibration plate from known distances (though extrapolating measurements from a few metres in the lab to many km in the field may be dubious and). Some cameras also provide this information within their software as a distance to target correction factor. The correction factor could then be applied to all the pixels dependent on their distance from the camera. This approach would ignore the impact of variations in atmospheric conditions between scenes and across the ~1.2km distance, however this is likely much too hard to correct for.





Blue areas slope steeply away from sensor, view angle likely >60. Approx. 0-200m away from sensor.

Yellow areas slope slightly towards sensor, view angle potentially >40°. Approx. 300-800m away from sensor.

Red areas slope towards sensor, view angle potentially <40°. Approx. 600-1200m away from sensor.

**Minor Comments:**

AWS coordinates are provided in the readme of the datafile in decimal degrees to 4 decimal places. This means >10-13m precision (latitude dependent). Given that the TIR map product is at 2m spatial resolution, it would be better to have the AWS coordinates to 5 or 6 decimal places (~1m to 0.1m precision) so that the field of view of the AWS IR sensors can be matched to the correct pixel within the scene. Ideally the actual centre point of what the IR sensor is looking at should also be provided as a coordinate in the readme file, not just the AWS/tower coordinates which I think are what is currently provided.

It would be useful for users to also have a georectified version of the RGB imagery made available so that users can directly link thermal maps to ground surface conditions at the pixel scale, but this is not 100% necessary and is likely to require more effort to produce.

Line 1 temperature of 'the' snow cover – delete 'the'

Line 26 improve – change to improving?

Line 56 cal/val change to calibration-validation as used elsewhere in the manuscript.

Line 111 'in a small volume'. Here and in later sentences I think the word volume is referring to the secondary external case that the camera was placed inside (and then temperature regulated). Change volume to case/box/enclosure or something to that effect for clarity.

Line 120/121 does this refer to the temperature setting of the volume/enclosure itself? How does raising the internal temperature by 7°C (15 raised to 22C) reduce overheating? Surely that would increase overheating? Check and revise if required.

141 A map showing the GCP locations could be useful, to assess the distribution and likely accuracy of this – some details on the accuracy of the georectification would also be beneficial here. I presume the GCPs were located in areas that were not snow covered during the winter and are constant and visible in every image? Also providing these GCP coordinates so that others can orthorectify the RGB imagery if it is not to be provided in a map format would be useful. I'm also wondering how well the 100x70cm GCPs were visible in the TIR imagery which is provided at a 2m spatial resolution. If the GCPs are well distributed across the survey area and can be assumed to accurately reflect sky temperature only (i.e. constant and stable for a given image) then perhaps they could be useful for identifying potential errors in Ts resulting from view angle and distance to target.

Table 2: lat long are presented to 6 sig fig precision (5dp longitude, 4dp latitude). These should be at least 5dp precision (ideally 6dp) in all cases so we are at ~metre scale accuracy at minimum.

Figure 11: a density scatterplot might better show the distribution of this many points. I think the black line is the 0/0 line and not the $R^2$ linear fit? Please add linear fit along with $R^2$ and RMSE. From the 2023 figure it looks like there is a warm bias in the camera measurement that increases with surface temperature (excluding the section circled in red), it might be worth discussing this too.

Line 346 – I have also noticed this warm temp in my own work of TIR imaging of melting snow/ice where I would expect 0°C. I wonder if it could be due to the camera actually measuring the temperature of a thin film of melt water sitting atop the snow/ice which could potentially exceed the 0°C of the snow/ice surface proper?

Alexander, Q. G., & Lunderman, C. V. (2021). *ERDC/ITL TN-21-1 "Thermal camera reliability study : FLIR One Pro."* Retrieved April 16, 2024, from https://erdc-library.erdc.dren.mil/jspui/handle/11681/42180

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Jiao, L., Dong, D., Zhao, X., & Han, P. (2016). Compensation method for the influence of angle of view on animal temperature measurement using thermal imaging camera combined with depth image. *Journal of Thermal Biology*, *62*, 15–19. https://doi.org/10.1016/J.JTHERBIO.2016.07.021

Litwa, M. (2010). Influence of angle of view on temperature measurements using thermovision camera. *IEEE Sensors Journal*, *10*(10), 1552–1554. https://doi.org/10.1109/JSEN.2010.2045651

Minkina, W., & Klecha, D. (2016). Atmospheric transmission coefficient modelling in the infrared for thermovision measurements. *J. Sens. Sens. Syst*, *5*, 17–23. https://doi.org/10.5194/jsss-5-17-2016