Response to Referee #2 for AMT-2020-515.

Dear Referee #2, thank you for your interest in our work and detailed review of our paper. On behalf of the co-authors, I am providing responses to your comments below. The line, page and figure numbers in {…} brackets correspond to the "latexdiff" version of the manuscript.

The authors present measurements of temperature profiles obtained with quadrocopters in the high Arctic in winter under challenging environmental conditions. The description of the methodology is sound and of interest to a broad range of scientists. In particular the technical challenges that were encountered can be very valuable for other drone operators.

There are a few minor comments. My only major point is the suggestion to correct the measured profiles for time lag and take this into account for the analysis of lapse rate, which might be strongly influenced by the correction.

The article is clearly structured and well written.

Detailed comments:

Major points:

- The authors derive the lapse rate/strength of near-surface temperature inversions. However, as they point out, they do not correct the time lag of sensors. This can be seen by the disagreement of temperature profiles around the top of the profiles. As the quadrocopter goes up to the maximum flight altitude and subsequently down again, there is only a short time between the two measurements, and the temperature should be comparable. This obvious artefact induced by the measurement method/sensor characteristics should be corrected before deriving parameters like lapse rate and inversion strength. It would be nice to have two sub-plots of Fig. 5, one with the raw data like shown already, one with the corrected data. The large differences of temperature profiles for ascent and descent are clearly artefacts and not features. This is further underlines by the dependence of the differences on sensor position.

Lines {402-420, 525-565}.

Done. We have applied a time lag correction to our raw temperature profiles from the flux tower flights and fjord flights following the approach reported by Cassano (2014). However, as it can be seen from updated figures in the manuscript, it does not always result in closely comparable temperature profiles measured on accent and descent. A discussion describing other sources that could contribute to the difference in the profiles has been included in the manuscript. For example, according to the data from NOAA Flux Tower, temperature variations on a scale of ~1C per minute occur nearly continuously during periods of extremely stable boundary conditions in Eureka (see Figure {6} in the updated version of the manuscript). Such fluctuations are natural and their effect could dominate over other factors in the calm or light wind conditions.

Figure {5} has been updated following the reviewer's suggestion.

Additionally, a discussion describing the reasons of the biases in the temperature readings from the sensors located at different places on the drone airframe has been included in the manuscript for clarification.

- You mention the influence on response time in l. 352. Please apply a correction, and compare also the correction to the literature.

Lines {402-420, 525-565, 693-697}

Done. We have applied a time lag correction to our raw temperature profiles from the flux tower and fjord flights following the approach reported by Cassano (2014). Our optimal time lag was found to be between 2 and 3.3 s. A comparison of our time lag with the literature values has been included in the manuscript.

- Further, it would be nice to embed the lapse rate observations more in the literature which describes such values.

Lines {62-73, 120-129}.

Done. The introduction has been updated with some extra references to the lapse rate measurements using radiosondes, drones and radiometers.

Minor comments:

- The lapse rate is provided in °C/m and °C per km. This seems an unusual parameter to me. Mostly known in atmospheric science is the temperature change within 100 m (usually roughly within the range of plusminus 1°C). Another method would be to describe the temperature change within the 10 m altitude interval. Values like 300°C/km are difficult to understand at a first glance, and appear throughout the text.

Done. The units in the manuscript have been updated. The lapse rate values have been given using both C/100 m and C/km dimensions.

- l. 18: is the heat flux through sea ice really called sensible heat flux? I would suggest to remove the “sensible”. The term sensible heat flux usually refers to turbulent transport of heat from the ground into the atmosphere

Done.

- l. 25: if you mention the remote sensing techniques for satellite-based temperature measurements, please explain in more detail. In particular satellite based surface temperature measurements are strongly hampered by clouds. In any case I’m not aware of a satellite based method for deriving surface temperature inversions.

Lines {68-73}.

We do not see many reasons to describe remote sensing techniques for satellite-based temperature measurements in details in this manuscript, since this is not the goal of the manuscript and the information can be found somewhere else. Main caveats affecting the quality of the surface air temperature datasets derived from the satellite-based measurements have been mentioned and references to some key publications have been included in the text.

In regards to characterisation of the surface temperature inversion derived from the satellite-based measurements please see Boylan, P., Wang, J., Cohn, S. A., Hultberg, T., and August, T. (2016), Identification and intercomparison of surface-based inversions over Antarctica from IASI, ERA-Interim, and Concordiasi dropsonde data, J. Geophys. Res. Atmos., 121, 9089– 9104, doi:10.1002/2015JD024724 and references.

- l. 70/l. 76: I do not agree that fixed-wing aircraft are able to transport more payload than multirotor aircraft. If they have the same mass, let's say 25 kg, usually fixed-wing systems have a payload in the range of 5 kg plus batteries for an endurance of around 45 min flight time. Multirotor systems can handle easily up to 10 kg of payload, but with a typical endurance of 20 min. Please specify what exactly you mean here.

Lines {98-119}.

We agree with the reviewer in this matter. This part of the manuscript has been rearranged to make our statements clearer.

- l. 85: please be more specific about the advantages of unmanned systems compared to manned aircraft. In remote regions it may be easier to do measurements with a manned aircraft with longer endurance and without the need of access to the site. Further, manned aircraft usually allow to include more payload, which is clearly an advantage.

Lines {110-119}.

Done. Specific clarification has been added to the beginning of the paragraph.

- please be specific about the usage of the terms "autonomous" and "automatic". Usually for drone operation, automatic refers to using an autopilot to fly along a given trajectory or way points. Autonomous means that you have a decision making instance on board, which can do tasks like detect and avoid. Not sure if you have this. In l. 309 it is mentioned that the "obstacle avoidance system" was disabled. This means that you were doing the flights in automatic mode.

Done.

We flew the drones using the autopilot along a set of preprogrammed way-points with the obstacle avoidance system being disabled, i.e. in automatic mode. The terminology in the manuscript has been fixed accordingly.

- l. 233: Why did you choose the maximum flight altitude of 90 m? Was this an arbitrary decision? Why not 100 m? Were there restrictions of air space?

Lines {326-339}.

More details have been added to the manuscript.

All drone operations reported in the manuscript were performed within the framework of the research activities conducted at PEARL and in accordance with Canadian Aviation Regulations for RPAS. Special procedures were established for operations in the vicinity of Eureka Aerodrome. The initial flight strategy consisted of several automatic (using an autopilot) or manual flights per day at various locations within FTS and RTS in the line-of-sight conditions with periodic ascents and descents.

Before June 1, 2019, the flights were conducted under Special Operation Flight Certificate, which restricted the maximum flight altitude for the drones to 91 m (300 ft) above the ground level, the minimum visibility - to 4.8 km (3 statute miles) and the minimum celling - to 305 m (1000 ft) above the ground level.

After June 1, 2019, the flights were conducted according to the updated Part IX of the Canadian Aviation Regulations, in which the maximum flight altitude for basic operations was extended to 122 m (400 ft) above the ground level.

To comply with the updated air space regulations and to increase the number of temperature profiles measured per flight before the drone batteries are drained, in 2020 our maximum flight altitude was 100 m above the ground level.

As can be seen from the manuscript, final maximum flight altitude did not exceed 60 m a.g.l. for the Flux Tower and Fjord flights and 100 m a.g.l. for the Gully flights.

- l. 235, 240: repetition of favourable flight conditions

Done.

- l. 240: contradiction: you say that the relative humidity was 70%, and the air was very dry. Maybe you refer to absolute humidity of water vapour mixing ratio? Please specify.

Lines {345-349}.

Done. This part has been modified as follows: “Potential challenges associated with propeller icing and darkness during the operations did not occur. At below -30C ambient temperature and at ~70% relative humidity (corresponds to 354~ppmv water vapour mixing ratio) the air was very dry and we did not observe any indications of icing on the propellers nor on the drone airframe during the flights (for comparison, 70% relative humidity at 0C corresponds to 4257~ppmv water vapour mixing ratio).”

- l. 248: add coordinates of measurement location

Done.

- l. 252: explain acronym GNSS when using it for the first time

Done.

- l. 268: refer to Fig. 4 for TS1

Done.

- l. 269/l. 324: explain FT earlier in the text

Done. Explained in the “2.3 Site description” section of the manuscript.

- l. 329: please explain more in detail how you investigate the influence of local topography

Lines {577-596}.

To investigate how local topography could influence the SBI a set of flights were conducted at the East side of the runway and in the gully near by. All the details and the results are discussed in section “3.2.3 Gully versus runway flights: SBI and local topography” of the manuscript.

- l. 341: is the bias reproducible and can therefore be corrected?

Lines {531-569}.

Yes, the bias is reproducible and can be corrected. However, we would like to avoid putting the temperature profiles from all 3 sensors in each temperature profile figure. Otherwise, the figures will be busy with data and hard to interpret. Since, the pole RTD was found to be the most accurate sensor onboard our drone, only the results from this sensor have been shown further in the paper. The manuscript has been updated with a discussion related to this.

- Fig.6/Fig 7: please use the same denominations for all flight legs and way points. What is “2-pass” (in the figure caption)? What is “–profile 2/3 passes” in the caption of Fig. 7? Does this correspond to waypoint p 3/5 in Fig. 6?

Done. Please, see updated Figures {7-11}.

- Fig. 13: why is the style so different to the other figures? There are many more pixels / different line style.

Done. The style has been updated to match the other figures. Please, see Figure {14}.

- l. 414: maybe use the term “laser altimeter”, if you only want to detect the ground return? Lidar may also refer to backscatter or wind lidar, which is not what you plan to use.

Done.

Suggestions for grammar/spelling:

- l. 17: above the sea ice

Done.

- l. 29: The WMO assesses global temperature

Done.

- l. 107: spent on a the development

Done.

- l. 132/137: same spelling: wheelbase or wheel base?

Done. Replaced with “wheelbase” everywhere in the manuscript.

- l. 155: housed a in 25 mm….. tubes

Lines {229-230}.

Changed as follows: “The modules with RTD elements are housed in a 25 mm diameter and 75 mm long PVC tubes for protection.”

- same style of date throughout the text, including year: 11 June 2019, also in tables, provide full date with year

Done.

- l. 232: The initial flight strategy

Done.

- l. 259: the drone performance

Done.

- l. 275: above the ground

Done.

- l. 334: wind speeds

Done.

- l. 370: maintain the drone's altitude

Done.

- l. 391: this suggests that the local …

Done.

- l. 394: "created" instead of "creating"?

Done.

- l. 404: unclear: "and with 19:00 UTC Eureka C temperature". Please rephrase.

Lines {633-635}.

Rephrased as follows: "Temperatures measured by the drone at 12 m above the sea ice ~210 and ~414 from the shoreline (pins #6 and #7 in Figure {3}) agree within ±0.5 C with the temperatures measured at Eureka C site at 18:00, 19:00 and 20:00 UTC."

- l. 413: field operations (not filed)?

Done.

- l. 424: conducted with the M100 drone

Done.

- l. 437: "suggested" instead of "suggesting"

Done. Used "suggest" instead to match present tense tone of the Conclusion section.

References:

Cassano, J.J.: Observations of atmospheric boundary layer temperature profiles with a small unmanned aerial vehicle. Antarctic Science, 26, 205-213, doi:10/1017/S0954102013000539, 2014