Response to Referee #4 for AMT-2020-515.

Dear Referee #4, 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. Corrections are marked in blue color in the “latexdiff” version of the manuscript.

General comments:

This is a useful research article within the scope of the journal. The potential for using drones to measure the characteristics of temperature inversion in challenging conditions has been demonstrated, and the critical points of this task have been discussed in detail. A very good review of the references is given.

However, the wrong choice of drone and temperature measurement system limited the quality of this research. Also, the altitude of all flights was below 60 meters, and some even less than 30 meters, which is a very limited altitude range for drone measurements.

Specific comments:

1. Line 13: Why did you limit the flight altitude to less than 60 meters? You had the ability to measure a much wider range of altitudes above ground level.

Please, see lines {13, 167, 311-317, 319, 582, 590-599, 604, 607} and Figures {12 and 13}.

We realized that our statement about 60 m maximum flight altitude requires a correction.

For the flux tower flights, drone altitudes did not exceed a maximum of 60 m above the ground. For the gully versus runway flights, they did not exceed 75 m and 70 m above the gully and runway surface levels correspondingly. For the fjord flights, drone altitudes did not exceed a maximum of 55 m above the ice surface.

There are three reasons such altitudes were used:

1. In our SBI measurements we focused our interest on 0-100m layer where strong temperature gradients were observed.
2. Since the flights were conducted at low ascent/descent speeds (0.1-0.7 m/s) our priority was to measure as many temperature profiles per flight as possible before the drone batteries were drained. Due to this, in most of the flux tower flights, drone altitudes did not exceed a maximum of 40 m above the ground.
3. As we mentioned in the manuscript (see lines {311-317}), to comply with the Canadian Aviation Regulations, during our 2017 and 2020 flight campaigns drone maximum altitudes were kept within 91 m (300 ft) and 122 m (400 ft) above the ground level, correspondingly.

The numbers in the manuscript as well as Figures {12 and 13} have been corrected accordingly. Also, a clarification has been added to the conclusion of the manuscript.

2. Line 185: Why did you choose a commercial drone over an open-source solution? Such closed product does not allow adjustments of the drone for this purpose. You could solve the barometer problems by using a laser altimeter, which is very easy to implement in the case of an open-source platform. You could also try different magnetic field sensors and GNSS receivers with interchangeable antennas, etc. Bad drone selection has made solving the problems arising from challenging atmospheric conditions impossible.

Please, see lines {163-168, 566-589}.

Among the goals of the paper was to demonstrate and evaluate the feasibility of drone operations at 80N. We were driven by the idea of using a commercial "turn-key" drone solution for our application. Keeping this in mind, the plan was to evaluate and learn whether an "off-the-shelf" rotary-wing drone can be economic, robust, and reliable in the High Arctic environment, so the time and efforts spent on the development of a custom system can be saved. This has been clearly stated in the Introduction.

While we had issues with our M100 drone, the M210 RTK drone equipped with RTK navigation system allowed us to conduct automatic flights in RTK mode.

As we stated in section “3.2.5 Lessons learned and future prospects”, in the future, our payload will be improved by an installation of a laser altimeter which would provide information about drone’s altitude above the ground with a precision better than barometric altimeter. The altimeter also can be used to track fine scale topography of the surface during the flight.

3. Line 216: The declared accuracy of the temperature measurement system is poor for this purpose. You did not calibrate the temperature measurement system before the measurement campaign, but in the last phase of the research you did the validation and stated that the temperature measurement system has shortcomings.

Please, see lines {423-426}.

Unfortunately, during our studies we did not have access to a test chamber to calibrate our sensors.

The most significant uncertainty in our temperature measurements is associated with the tolerance class of Omega 1PT100KN1510 RTDs (Class B, W0.3, total accuracy $\Delta T = \pm(0.30 + 0.0050 |T|)$, where T is temperature in [C]). For 0, -40 and -50 C temperatures this results in ±0.30, ±0.50 and ±0.55C measurement accuracy, correspondingly. High linearity and stability of platinum RTDs together with the results of validation of the sensors in the melting ice and application of bias correction (biases did not exceed -0.003±0.013, 0.25±0.02 and 0.30±0.02 for the pole, top and rotor 3 RTDs) allow us to conclude that the accuracy of our temperature measurements is ~0.3 C for -50 to -40C temperature range.

This value is equal to the required instrument measurement uncertainty recommended by WMO for below -40 air temperatures (Guide to Instruments and Methods of Observation, Volume I – Measurement of Meteorological Variables, 2018 edition, page 24: https://library.wmo.int/doc_num.php?explnum_id=10616).

The manuscript has been updated accordingly.

4. Line 217: placing the sensor in a protective PVC tube has an effect on the response time of the sensor. You should have measured the sensor response time, at least in the laboratory.

Please, see lines {412-414}

We understand that. For this reason, in 2020 the pole PVC tube was equipped a with fan, which provided aspiration for the pole RTD element to improve the response time.

5. Line 367: You state the response time of the sensor from the manufacturer's specification, and you said earlier that you protected the sensor with a PVC tube. Based on Figure 5 showing the thick hysteresis in the temperature graphs, I suspect that the actual response time of your sensor is much longer than the value from the specifications.

Please, see lines {412-414, 445-447, 615-619} and Figures {5, 9-11}

Figure {5} represents the results of the measurements conducted in 2017. At that time neither of the sensors were forcibly aspirated.

In 2020 we introduced aspiration of the pole RTD element by a fan. Additionally, we decreased the drone’s speed of ascent/descent from 1-2.8 m/s down to 0.1-0.7 m/s. This allowed us to decrease the effect of the response time on the measurements and, hence, minimize the hysteresis (please, see Figures {9-11}.

6. Line 410: You had to do laboratory tests and calibration of the temperature measurement system before the field measurement campaign, not at this stage of the research.

Please, see lines {415-426}.

Please, also see our response to the comment #3 above.

During our studies we did not have access to a test chamber to calibrate our temperature sensors. Due to that, we conducted pre- and post-flight validation of the sensors.

7. Line 423: You (correctly) state here that a closed commercial drone, a “black box”, prevents you to solve technical problems.

Please, see our response to the comment #2 above.

8. In Chapter 3.2.5, the authors realize that poor equipment selection has limited their research.

Please, see our response to the comment #2 above.

9. Nevertheless, despite these shortcomings, this paper contains useful information and results and complements previous research of the phenomenon of temperature inversion using drones.

We appreciate the feedback provided by the referee very much.

We would like to include the following additional references to the manuscript:

1. Kral, S.T.; Reuder, J.; Vihma, T.; Suomi, I.; O'Connor, E.; Kouznetsov, R.; Wrenger, B.; Rautenberg, A.; Urbancic, G.; Jonassen, M.O.; Båserud, L.; Maronga, B.; Mayer, S.; Lorenz, T.; Holtslag, A.A.M.; Steeneveld, G.-J.; Seidl, A.; Müller, M.; Lindenberg, C.; Langohr, C.; Voss, H.; Bange, J.; Hundhausen, M.; Hilsheimer, P.; Schygulla, M. Innovative Strategies for Observations in the Arctic Atmospheric Boundary Layer (ISOBAR)—The Hailuoto 2017 Campaign. Atmosphere 2018, 9, 268. https://doi.org/10.3390/atmos9070268

2. Varentsov, M.; Stepanenko, V.; Repina, I.; Artamonov, A.; Bogomolov, V.; Kuksova, N.; Marchuk, E.; Pashkin, A.; Varentsov, A. Balloons and Quadcopters: Intercomparison of Two Low-Cost Wind Profiling Methods. Atmosphere 2021, 12, 380. https://doi.org/10.3390/atmos12030380

3. Wenta, M., Brus, D., Doulgeris, K., Vakkari, V., and Herman, A.: Winter atmospheric boundary layer observations over sea ice in the coastal zone of the Bay of Bothnia (Baltic Sea), Earth Syst. Sci. Data, 13, 33–42, https://doi.org/10.5194/essd-13-33-2021, 2021.

4. Barbieri, L.; Kral, S.T.; Bailey, S.C.C.; Frazier, A.E.; Jacob, J.D.; Reuder, J.; Brus, D.; Chilson, P.B.; Crick, C.; Detweiler, C.; Doddi, A.; Elston, J.; Foroutan, H.; González-Rocha, J.; Greene, B.R.; Guzman, M.I.; Houston, A.L.; Islam, A.; Kemppinen, O.; Lawrence, D.; Pillar-Little, E.A.; Ross, S.D.; Sama, M.P.; Schmale, D.G.; Schuyler, T.J.; Shankar, A.; Smith, S.W.; Waugh, S.; Dixon, C.; Borenstein, S.; de Boer, G. Intercomparison of Small Unmanned Aircraft System (sUAS) Measurements for Atmospheric Science during the LAPSE-RATE Campaign. Sensors 2019, 19, 2179. https://doi.org/10.3390/s19092179

5. Segales, A. R., Greene, B. R., Bell, T. M., Doyle, W., Martin, J. J., Pillar-Little, E. A., and Chilson, P. B.: The CopterSonde: an insight into the development of a smart unmanned aircraft system for atmospheric boundary layer research, Atmos. Meas. Tech., 13, 2833–2848, https://doi.org/10.5194/amt-13-2833-2020, 2020.

The following figures have been also updated:

Figures {6, 12, 13, 14}