To the editor: We appreciate the reviewer's comments on all fronts. To address the reviewers request for a description of the installation of the temperature sensor, we have added the full part number for the sensor which details the package as well as a clarification to where the sensor package is mounted in section 2.4.2. We also include the data sheet as a citation for readers curious about the mechanical design of the sensor package. While we don't believe that top-down solar radiation significantly affects our temperature measurement, we neglected to consider the upwards-pointing surface albedo effect over the ice sheet. We now mention this in the text. To address to impact of angle of attack of our aircraft on sensor hysteresis, we tied our existing discussion about reducing bank angle to new discussion about the impact of the angle of attack. We include mention of our plan to test ascension rates in our future field campaigns to reduce the hysteresis effect. Changes to the text are shown by yellow highlights below:

New text in first paragraph in 2.4.2

Environmental sensing is also fed into the BST SwiftCore™ and down to the ground station. The temperature and humidity is determined by an E+E Elektronik EE03-FT9 sensor (±0.3°C and ±3%RH), and the pressure is determined by a high resolution (±1.5mbar) MEMS sensor (TE Connectivity MS5611). Both sensors are included as part of the forward pointing package to assist in autopilot flight on the underside of the right wing of the aircraft to minimize solar radiation, a well-known issue with UAV applications (*Green et al.,* 2019). A detailed physical description of the sensor can be found in *E+E Elektronik*, 2021. While underwing sensor placement may protect against top-down solar radiation, surface albedo is high over the Greenlandic ice sheet and may contribute to an unknown positive bias in measurement (*Box et al.,* 2012). We suggest for future drone research over Greenland or other high-albedo areas that the sensor be protected from radiation from all angles, if possible.

New text in 3.2

The CHCI was calculated post-flight for comparison with 1) the self-similarity of Euclidean distance (used during the 2019 field campaign, but later updated to the CHCI approach) and 2) operator determination of the PBL. The results are shown in Appendix A. The CHCI had a direct match with Euclidean distance for half of the flights. In the other half, the CHCI predicted altitudes significantly higher than the other determinations. The results of our comparison reveal that our original PBL-detection algorithm using Euclidian distance needs improvement (Figure 9). Specifically, we have determined that Euclidean distance can under or overestimate the height of the PBL due to sensor (temperature and humidity) hysteresis. This hysteresis exceeded the stated manufacturer response time for the atmospheric temperatures we encountered, discussed in Appendix B. The hysteresis could be the result of either errors introduced from the changing rate of ascent during flight or from inconsistent airflow over the sensor package resulting from a varying angle of attack of the aircraft (*Stickney et al.,* 1994). Before a flight, the UAV is static at ground level, thus temperature and humidity measurements will be stable, varying only slightly with small changes in surface conditions. The energetic pneumatically-driven launch of the aircraft (a 12 G force) results in a rapid increase in altitude that can introduce a bias into the sensor output due largely to the thermal mass of the sensor and slow response to rapidly changing conditions. A similar effect occurs anytime the rate of ascent is not constant, such as when the UAV transitions between different orbitals (i.e. a sampling orbital and landing orbital).

A case study in Figure 9 illustrates a shift in orbitals from the June 21st mission. The operator moved from the initial launch orbital to a lower altitude to begin an ascension profile. During the transition

between the two orbitals, the aircraft moved from about 110m to 60m in altitude in ~1 minute. During the transition and immediately during the ascent, multiple temperature and humidity values were generated for the same altitude creating a region of varying hysteresis effects that can bias PBL prediction by Euclidean distance, ultimately causing the operator to misidentify the altitude of the PBL. More concisely, the algorithm detected this data anomaly as atmospheric structure, when in fact it was due to hysteresis. While removing this skewed data could be an easy fix, the stabilization of temperature and humidity to that new starting altitude biases the beginning of the climb just as it does at the surface before launch.

The hysteresis effect is also noticeable in the CHCI (Figure 10, green circles). Relaxing the *a priori* assumption of a single PBL that separates the surface atmosphere from the free troposphere, additional transition regions can be identified. As CHCI uses Euclidean distance to establish variances, it is also subject to potentially poor predictions in situations of significant hysteresis. However, its ability to establish regions of similarity, such as the case of the transition region between launch orbital and the ascension orbital during the June 21th mission provides an objective method of informing the operator of potential false positives for the boundary layer altitude. In this specific case, three of the top five PBL altitudes predicted by the Euclidean distance algorithm can be flagged as incorrect. However, even with sensor hysteresis, we determine the CHCI to be an effective tool to assist in fast mid-flight evaluation of the boundary layer by the drone operator.

Overall, there are two options for overcoming the effects of hysteresis: 1) better sensors and 2) changes to flight mission plans. We have identified the Vaisala RSS-421 sonde sensor to meet the first requirement. The RSS-421 includes a low thermal mass fine-wire thermocouple and heated humidity sensor with bakeout unit, which will allow for faster response in arctic conditions. This sensor has already shown to be capable of producing accurate temperatures in challenging UAV fixed-wing missions (*Frew et al.* 2020). For flight planning, relocating launch sites to be as close to the ascension orbital as possible will reduce hysteresis during horizontal transitions between orbitals. The ascension rate can also be slowed to less than 2 m/s allowing the maximum time for sensors to equilibrate with the surrounding atmospheric conditions. The tradeoff is that this may require reducing the maximum flight altitude to conserve battery life and reduce the bank angle. A sharp bank angle decreases the lift coefficient (*Williamson* 1979), and a higher angle of attack is needed to maintain ascension rate in tailwind situations (*Blakelock* 1991). Larger angles of attack could be detrimental as they are known to introduce temperature errors, favoring the use of slower ascension rates (*Stickney et al.,* 1994). Slower ascension rates may be required regardless when the pitch angle needed is too high and outside the flight envelope, causing the Black Swift Technologies autopilot to slow ascension to protect the aircraft. It is assumed that variability in temperature, pressure, and humidity is small in the x and y plane, allowing for a large increase in orbital diameter to reduce bank angle significantly. In future field campaigns, we will test the effect that ascension rate has on hysteresis both with the new RSS-421 sonde along with the current sensor which will remain on the aircraft. We don't expect to eliminate hysteresis entirely but we do expect to reach precisions appropriate to model PBL-free troposphere atmospheric isotopic exchange.

New citations:

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Greene, B. R., Segales, A. R., Bell, T. M., Pillar-Little, E. A., and Chilson, P. B. (2019). Environmental and sensor integration influences on temperature measurements by rotary-wing unmanned aircraft systems. *Sensors*, *19*(6), 1470.

Stickney, T. M., M. W. Shedlov, and D. I. Thompson. "Goodrich total temperature sensors. Technical report 5755." *Rosemount Aerospace Inc* (1994).