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S0 Uncrewed Aircraft System Measurement Characterization Field Campaign Report

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ARM

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Acronyms and Abbreviations

ARM	Atmospheric Radiation Measurement
CoMeT	Combined Mesonet and Tracker
DOE	U.S. Department of Energy
SGP	Southern Great Plains
sUAS	smaller UAS
TRACER	Tracking Aerosol Convection Interactions Experiment
UAS	uncrewed aircraft system
UNL	University of Nebraska-Lincoln

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1.0 Summary

The lower atmosphere contributes directly to the modulation of weather and climate. Understanding the importance of this part of the atmosphere, scientists have worked to improve the representation of the atmospheric boundary layer in numerical prediction tools. Such work depends upon information from observing systems, including remote sensors, weather balloons, and research aircraft. Recent years have seen significant advances in uncrewed aircraft systems (UAS) for atmospheric research. Those efforts have provided new perspectives on atmospheric and surface conditions, particularly from smaller UAS (sUAS) platforms.

This field campaign included collection of data using several sUAS, and comparing the sUAS data to those from different observing facilities at the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) user facility's Southern Great Plains (SGP) observatory in Oklahoma. Over the course of one week, the Black Swift Technologies and University of Nebraska teams conducted flights for the sole purpose of system evaluation and intercomparison. In addition, these teams conducted joint flight operations at the Marshall, Oklahoma Mesonet site alongside teams from the University of Colorado, University of Oklahoma, and Oklahoma State University to collect additional data for side-by-side comparison.

Platforms operated by Black Swift Technologies and the University of Nebraska under this project included one fixed-wing and two rotary-wing platforms, as well as an instrumented surface vehicle. These include the Black Swift Technologies S0 UAS, the University of Nebraska M600 UAS, a University of Nebraska-operated Meteomatics Meteodrone UAS, and the University of Nebraska CoMeT (Combined Mesonet and Tracker) vehicle. Additional details on all of these platforms can be found in de Boer et al. (in prep).

In total, 95 sUAS flights were conducted for a combined total of 18.6 flight hours. The S0 was operated both to the south and north of the SGP 60 m tower, while the M600 and Meteodrone were operated directly to the east of the tower (see Figure 2). Weather conditions were generally good, with moderate winds. Flights were conducted both to follow the extra radiosondes that were launched as part of this campaign, as well as to conduct extended statistical sampling at tower instrument heights. The later flights also provided data for statistical platform intercomparison.

Figure 1. Black Swift Technologies (left) and University of Nebraska (right) teams at the SGP facility.

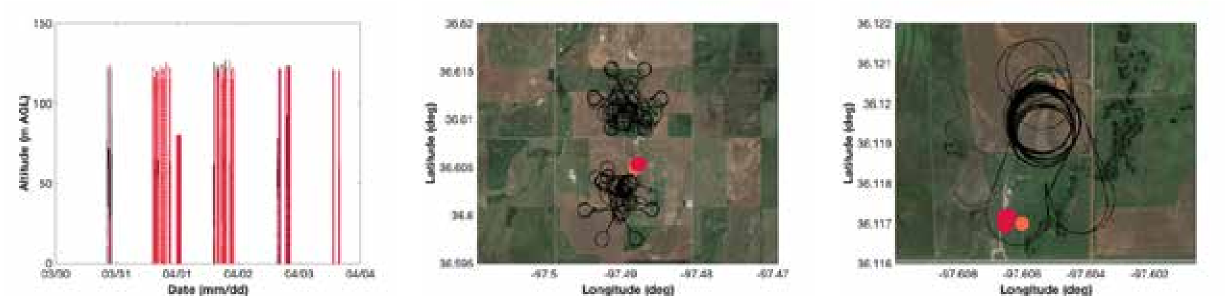

Figure 2. Flights conducted as part of this campaign. Black markers illustrate the flights conducted by the S0, and red markers illustrate the flights conducted by the UNL Meteodrone and M600. The left figure shows the altitudes covered by the different platforms and the maps show the spatial extent of flights completed at SGP (center) and Marshall (right).

2.0 Results

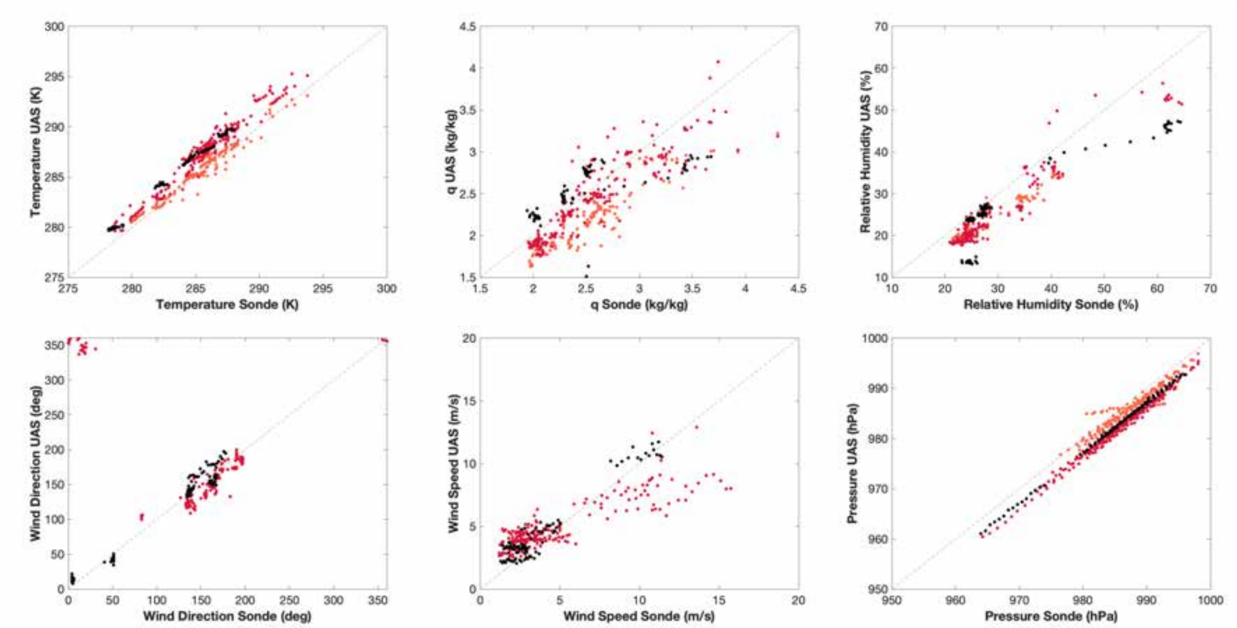

Figure 3. A comparison of measured quantities from the S0 (black), Meteodrone (light red), and M600 (dark red) against those from radiosondes launched from the SGP facility.

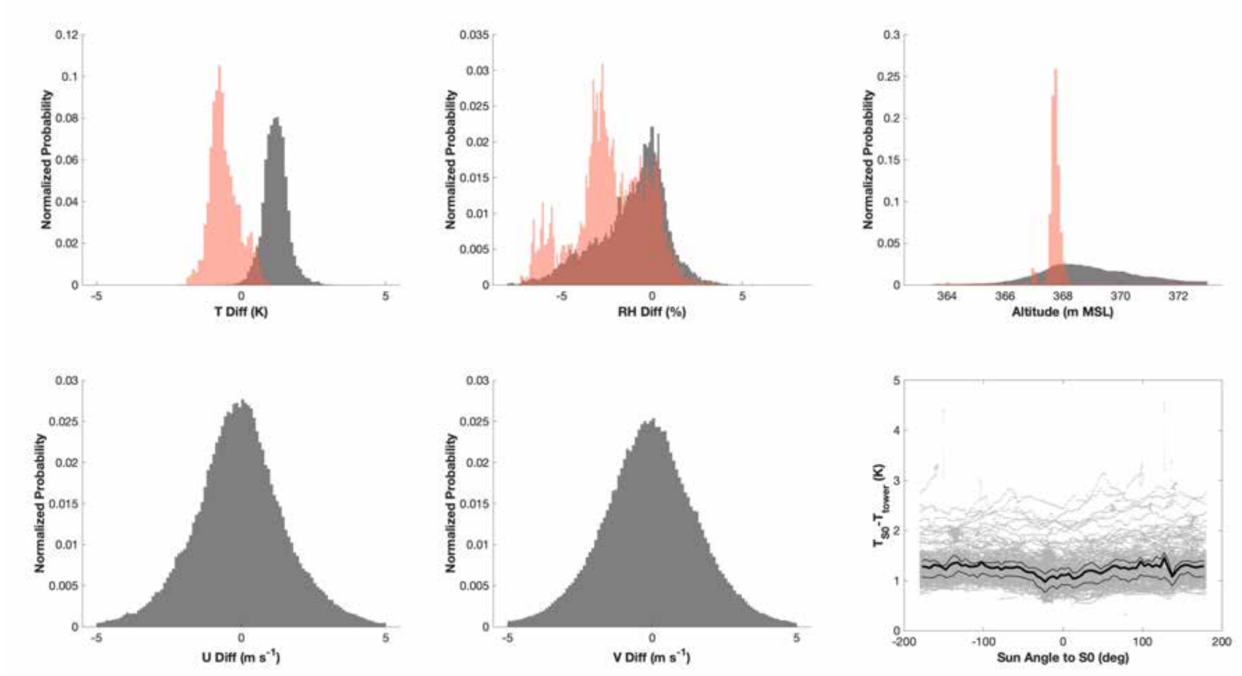

Figure 4. Histograms showing differences between the UAS-measured quantities and those measured at 60 m on the SGP tower. Differences from the M600 are shown in red, and the S0 in black. The bottom right-hand figure shows temperature differences between the S0 and tower as a function of sun angle on the aircraft.

The flight data collected during these flights has resulted in a rich data set that can be used to evaluate the quality of UAS-based data. Figure 3 shows some initial comparisons of the data collected by the S0 and two UNL multi-rotors against radiosondes launched by the ARM facility. As discussed above, spatial differences are going to be present and are difficult to account for in this comparison. However, these figures generally show agreement between the UAS-measured values and those from the radiosonde. Over the course of several radiosonde launches we expect the data to straddle the one-to-one line, as any spatial differences would be equally likely to fall on the positive and negative side of the line. While we do not provide many details here, one obvious result from this comparison is that the S0 appears to have a slight (~1-1.5 C) warm bias relative to the radiosondes and to the other platforms. This is informative for continued advancement of this platform, in that the design team will leverage this information and revisit the housing that is currently used to protect the temperature sensor on the aircraft. Also of interest is the fact that both the Meteodrone and S0 appear to generally capture the wind speeds and directions that were measured by the radiosondes. This is encouraging because wind measurements from UAS platforms are always deemed to be uncertain.

Additional detailed evaluation of the platforms was done relative to the SGP tower. Figure 4 illustrates some of the results of that comparison in the form of histograms of differences of key quantities of interest for all flights. Again, these histograms are derived for periods when the aircraft was located at the same altitude as the sensors, and because the Meteodrone does not support a hover flight configuration, results from that platform are not included here. The S0's temperature bias is again evident. Interestingly, for the M600, there appears to be significant variability in the relative humidity. It is challenging to say for sure whether this difference results from measurement biases, or whether this is the result of small changes in the aircraft's pressure-based altitude sensing from one flight to the next. Again, as with the radiosonde measurements, the tower-based comparison shows that the mean wind errors are close to zero, with spread to +/- 5 m s^{-1} likely being the result of spatial variability in boundary-layer winds, since these are being evaluated on a time-specific basis. Finally, the last frame of Figure 4 shows the S0 temperature bias as a function of solar incidence angle to the aircraft. This was done to evaluate whether there was any sensitivity to solar orientation that could be detected as far as temperature sampling biases go. Perhaps there is a slight tendency for the bias to be smaller when the aircraft is heading directly into the sun (sun angle of 0 degrees), though that difference is only 0.2 C or so.

Finally, some ground testing was conducted to compare UAS sensors against those on ARM's eddy correlation flux measurement system. Results from this testing have not been finalized and are therefore not shown here. Future work will support evaluation of the mean quantities and the variability around that mean for all quantities from the tower-based intercomparison flights. This and other analyses are underway, and a publication summarizing the results and outcomes is to be submitted for publication in *Atmospheric and Oceanic Technology* in the coming months. This publication will additionally include comparisons between these platforms and those deployed by the University of Colorado and the University of Oklahoma as part of the Tracking Aerosol Convection Interactions Experiment (TRACER) UAS field campaign. We encourage anyone interested in the final outcomes of these evaluations to seek out the *Journal of Atmospheric and Oceanic Technology* publication, and/or contact the authors of this report for additional details.

3.0 Publications and References

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4.0 Lessons Learned

The SGP team were great to work with in development and planning of UAS operations. They were very welcoming of our teams and we appreciate the work that they put in to support this project! One minor suggestion is to add some pressure sensors to the tower to make it easier to confirm that the aircraft was at exactly the right height, and also to allow for the calculation of additional variables such as potential temperature.

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