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DOE/SC-ARM-17-012

EPIC Calibration/Validation Experiment Field Campaign Report

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ARM
CLIMATE RESEARCH FACILITY

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Additional team members engaged in this U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM)Climate Research Facility exercise at the Southern Great Plains (SGP) site include:

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Sherman Frederickson, National Oceanic and Atmospheric Administration (NOAA)/National Severe Storms Laboratory (NSSL)

Doug Kennedy, NOAA/NSSL

Dan Hasselius, Eric Frew, and Steve Borenstein, University of Colorado

A cadre of students supporting the Unmanned Aerial Systems operations.

Acronyms and Abbreviations

ABL	atmospheric boundary layer
AERI	atmospheric emitted radiance interferometer
AGL	above ground level
AMS	American Meteorological Society
ARM	Atmospheric Radiation Measurement
CLAMPS	Collaborative Lower Atmosphere Mobile Profiling System
COA	Certificate of Authority (FAA)
deg	degree
DOE	U.S. Department of Energy
EOL	Earth Observing Laboratory
EPIC	Environmental Profiling and Initiation of Convection
FAA	Federal Aviation Administration
ft	foot
km	kilometer
kts	knots
m	meter
NCAR	National Center for Atmospheric Research
NOAA	National Oceanic and Atmospheric Administration
NSSL	National Severe Storms Laboratory
NWS	National Weather Service
OU	University of Oklahoma
SGP	Southern Great Plains
UAS	Unmanned Aerial Systems

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1.0 Summary

A field exercise involving several different kinds of Unmanned Aerial Systems (UAS) and supporting instrumentation systems provided by DOE/ARM and NOAA/NSSL was conducted at the ARM SGP site in Lamont, Oklahoma on 29-30 October 2016. This campaign was part of a larger National Oceanic and Atmospheric Administration (NOAA) UAS Program Office program awarded to the National Severe Storms Laboratory (NSSL). named Environmental Profiling and Initiation of Convection (EPIC).

The EPIC Field Campaign (Test and Calibration/Validation) proposed to ARM was a test or "dry-run" for a follow-up campaign to be requested for spring/summer 2017.

The EPIC project addresses NOAA's objective to "evaluate options for UAS profiling of the lower atmosphere with applications for severe weather." The project goal is to demonstrate that fixed-wing and rotary-wing small UAS have the combined potential to provide a unique observing system capable of providing detailed profiles of temperature, moisture, and winds within the atmospheric boundary layer (ABL) to help determine the potential for severe weather development. Specific project objectives are: 1) to develop small UAS capable of acquiring needed wind and thermodynamic profiles and transects of the ABL using one fixed-wing UAS operating in tandem with two different fixed rotary-wing UAS pairs; 2) adapt and test miniaturized, high-precision, and fast-response atmospheric sensors with high accuracy in strong winds characteristic of the pre-convective ABL in Oklahoma; 3) conduct targeted short-duration experiments at the ARM Southern Great Plains site in northern Oklahoma concurrently with a second site to be chosen in "real-time" from the Oklahoma Mesonet in coordination with the (National Weather Service (NWS)-Norman Forecast Office; and 4) gain valuable experience in pursuit of NOAA's goals for determining the value of airborne, mobile observing systems for monitoring rapidly evolving high-impact severe weather conditions not observed with current operational systems.

OU operated three UAS at the Lamont SGP site – the OU CopterSonde, the OU Iris, and the Meteomatics Meteodrone – under a blanket Federal Aviation Administration (FAA) Certificate of Authorization (COA) allowing flights up to 400 feet above ground level (AGL). The mission for the rotary-wing UAS involved four aircraft, three from the ARM Lamont site and one from an Oklahoma Mesonet site located at Medford, involving a vertical ascent to an altitude of 400 ft (130 m) AGL at ~ 30 minute intervals for ~ 5 hours duration on each of the two experiment days. This operation was conducted in close coordination with NSSL-launched rawinsonde balloons at the two sites, and operation of a fixed-wing UAS from the University of Colorado called the TTwistor that flew mission flight legs between the Lamont site and Medford. The NSSL operation at Medford (outside of ARM) also involved use of their Collaborative Lower Atmosphere Mobile Profiling System (CLAMPS) ground-based remote-sensing system for measuring atmospheric profiles of temperature, moisture, and winds with atmospheric emitted radiance interferometer (AERI), microwave radiometer, and Doppler wind lidar systems. The ARM Facility supported the project by providing access to their instrumented tower data at Lamont (at three levels), as well as AERI and Doppler wind lidar data obtained from systems quite similar to those used by CLAMPS. These non-UAS data from both ARM and NSSL provided the observations used to validate the experimental UAS observations.

2.0 Results

Execution and coordination for this project was challenging, and some problems were encountered, as discussed below, but overall, the lessons learned and the excellent quality of the data collected by the various platforms made Phase 1 an unqualified success. The Meteodrones performed flawlessly in the project, and the quality of the data collected, in comparison to NSSL rawinsonde and ARM tower data, was very high, essentially matching or coming quite close to matching NOAA's requirements for observational accuracy and precision. The Meteodrone and the CopterSonde performed exceptionally well even under challenging conditions with wind gusts exceeding 40 knots (kts) – which was one of the secondary objectives of the experiment to evaluate.

TTwistor was flown on several legs in conditions that at times met or exceeded those wind speeds. The Phase 1 experiment allowed us to learn that we may need to fly this aircraft at an airspeed significantly greater than the minimum power speed with a higher throttle setting, which is likely to require a battery swap before the return leg.

Two 400-ft-level flights between Lamont and Medford (37 km straight distance) occurred successfully on the two days, and a total of four vertical profiles were made at the two sites in close coordination with the other UAS and ground-based systems. The NSSL balloon data showed some interesting problems, as the older Vaisala RS92 radiosonde produced much higher-frequency, and visually noisier, wind profiles than the new RS41 system that was not flown during the EPIC project.

The ARM data were all processed, including the AERI data used to retrieve temperature and humidity information from the radiances. These data were of critical importance to this UAS data validation project. Of particular utility was the 60-m tall instrumented tower with its sonic anemometers at Lamont. The CLAMPS and ARM Doppler wind lidar data observations were taken with the beam pointed at the default angle (the Doppler shift of the backscattered energy is measured every two minutes with a scanner at 70-deg elevation). This turned out to be far from optimum, as only 2-3 range gates were obtainable within the very shallow 400-ft layer near the ground where we could operate. In EPIC Phase 2, we want to use a lower elevation angle.

3.0 Publications and References

EPIC Phase 1 results were shared by Dr. Koch with the scientific community at the American Meteorological Society (AMS) Annual Meeting in Seattle, Washington in January 2017, including an oral presentation at the Special Symposium on Meteorological Observations and Instrumentation, and a NOAA display booth presentation.

EPIC results were shared by Koch, Chilson, and Argrow with the scientific community as a presentation at the National Center for Atmospheric Research/Earth Observing Laboratory (NCAR/EOL) Workshop on Applications of UAS to Atmospheric Science held 21-24 February, 2017.

The following paper provides some analysis that is being applied to EPIC data: Nichols, TW, B Argrow, and DB Kingston, "Error Sensitivity Analysis of Small UAS Wind-Sensing Systems," AIAA SciTech Conference, Dallas, Texas, 9-13 January, 2017.

Accepted for poster session at ISARRA 2017: Laurence, R, T Nichols, and B Argrow, "Flight Results for EPIC Phase 1," ISARRA 2017, 22-24 May, 2017.

A paper referencing NOAA UAS support titled "Abnormal optimal trajectory planning of multi-body systems in the presence of holonomic and nonholonomic constraints" has been submitted by EPIC team member Dr. Andrea L'Afflito to the *Journal of Intelligent and Robotic Systems*.

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