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DOE/SC-ARM-21-016

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August 2021

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Work supported by the U.S. Department of Energy,
Office of Science, Office of Biological and Environmental Research

Acronyms and Abbreviations

AGL	above ground level
AMF	ARM mobile facility
ARM	Atmospheric Radiation Measurement
BCP	biphase communications processor
CDMS	cloud droplet measurement system
CDP	customer data platform
DOE	U.S. Department of Energy
NSA	North Slope of Alaska
PI	principal investigator
SGP	Southern Great Plains
SNL	Sandia National Laboratories
TBS	tethered balloon system

Contents

1.0 Summary

The Mesa Photonics' cloud droplet measurement system (CDMS) performs in situ measurement of droplet size distribution and droplet number density in clouds. These characteristics are important cloud microphysical properties that are critical input parameters for atmospheric models and are also useful for proper calibration and validation of performance of other atmospheric measurement instrumentation. This small campaign was the first project (out of two) that involved integration of the CDMS into the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) user facility's tethered balloon system (TBS) and its initial testing at the ARM Southern Great Plains (SGP) atmospheric observatory. The follow-up campaign (AFC07016) involved testing of the CDMS under relevant conditions at the third ARM Mobile Facility (AMF3) at Oliktok Point, Alaska and making in situ measurements in clouds.

The goal of this small field campaign was to deploy the CDMS on the ARM TBS, demonstrate its integrity and compatibility with the TBS, and test the wireless telecommunication system in preparation for subsequent in-cloud measurements at ARM's North Slope of Alaska (NSA) observatory at Utqiagvik (formerly Barrow). The specific technical objectives included: (1) Integration of the Mesa Photonics' CDMS into the ARM TBS, (2) testing of the wireless telecommunication system of the CDMS, (3) evaluating the data acquisition software and image processing algorithms especially under high-background-illumination conditions, and (4) testing the ruggedness of the instrument's optical alignment and other performance characteristics. All objectives have been successfully met.

The mounting hardware was designed and built mostly at Sandia National Laboratories (SNL), which allowed reliable mounting of the CDMS on the TBS and co-locating the CDMS with other instruments. The field tests were performed by the principal investigator (PI) in collaboration with the TBS operational crew led by D. Dexheimer. The field testing demonstrated good compatibility of the CDMS with the TBS. During the TBS flights, the crew did not experience any operational issues with the CDMS. The instrument demonstrated reliable operational characteristics, including sufficient battery life and good thermal management. The wireless telecommunication system has been successfully tested at TBS flight altitudes of up to 1000 m. During all flights, the CDMS raw data were wirelessly transmitted to the ground station and processed in real time. The ruggedness of the instrument's optical alignment was evaluated by performing calibration of the CDMS (using Mesa Photonics' fixed-size monodisperse droplet generator) before and after the campaign. The calibration was stable within the instrument's measurement precision.

In summary, the campaign demonstrated good compatibility of the Mesa Photonics' CDMS with the ARM TBS. The flight tests confirmed the mechanical integrity of the CDMS and stability of its optical layout, as well as reliability of the wireless telecommunication system. Successful completion of this campaign provided a solid basis for the next campaign (AFC07016, November 2020), that involved testing of the CDMS during in-cloud TBS flights at AMF3 at Oliktok Point.

2.0 Results

The Mesa Photonics' cloud droplet measurement system (CDMS) performs in situ measurement of droplet size distribution and droplet number density in clouds. These characteristics are important cloud microphysical properties that are critical input parameters for atmospheric models and are also useful for proper calibration and validation of performance of other atmospheric measurement instrumentation. This campaign was proposed in response to the ARM call for proposals of 8/8/2019 to fly guest instruments on TBS. This small campaign was the first project (out of two) that involved integration of the CDMS into the ARM TBS and its initial testing at SGP. The follow-up campaign (AFC07016) involved testing of the CDMS under relevant conditions at AMF3 and making in situ measurements in clouds.

The goal of this small field campaign was to deploy the CDMS on the ARM TBS, demonstrate its integrity and compatibility with the TBS, and test the wireless telecommunication system in preparation for subsequent in-cloud measurements at NSA. The specific technical objectives included: (1) Integration of the Mesa Photonics' CDMS into the ARM TBS, (2) testing of the wireless telecommunication system of the CDMS, (3) evaluating the data acquisition software and image processing algorithms, especially under high-background-illumination conditions and (4) testing the ruggedness of the instrument's optical alignment and other performance characteristics.

2.1 Integration of CDMS into ARM TBS

Most of the work on CDMS integration into TBS was performed at SNL. A mounting plate for the CDMS and battery compartment (attached to the bottom of the mounting plate) have been designed and constructed. In addition, a wireless transceiver mount that attaches the transceiver antenna to the TBS tether and aligns it along the tether has been built. A special mounting plate was designed to allow co-locating of the CDMS with other in situ cloud probes.

2.2 Flight Testing

The TBS flights were conducted at SGP on February 13–15, 2020. The field tests were performed by the PI in collaboration with the TBS operational crew led by D. Dexheimer. At SGP, in-cloud TBS flights are not allowed; therefore, all flights were conducted under clear-sky conditions or at least 150 m below the clouds or clouds base. The CDMS was operated in the wireless telecommunication mode, i.e., the raw data were broadcasted to the ground station and processed in real time and not stored on the CDMS local hard drive. Three TBS flights carrying the CDMS have been performed.

Flight 1. 2/13/2020, 11:55–14:40 MT

CDMS is mounted on the original mounting plate. The mounted instrument weight is 16.1 lbs (CDMS, four 6-cell batteries, original CDMS mounting plate). Initially, flying at low altitude (30-50 m), then getting to max elevation of 350 m AGL. The tether angle was 30–40°. Then loitering at 290 m AGL for 90 min.

No CDMS issues during the whole flight. The raw data are flawlessly broadcasted to the ground station. The wireless telecommunication system throughput is not monitored.

Flight 2. 2/14/2020, started 9:17 MT

CDMS is co-located with IFFExO (AFC07010) “Gondola” comprised of DMT customer data platform (CDP) and biphase communications processor (BCP) on a special mounting plate. Mounted CDMS and “Gondola” weight is 34.1 lbs (CDMS, four 6-cell batteries, special mounting plate and “Gondola”).

The maximum flight altitude is 350 m AGL (due to high wind). The wireless telecommunication system transceiver is at ~200 Mbps capacity at the maximum altitude. After about an hour, under lower wind conditions, reaching 450 m AGL. The transceiver is at ~280-450 Mbps capacity. To maximize the signal, the ground station antenna is manually aimed at the CDMS. The raw data are flawlessly broadcasted to the ground station during the whole flight.

After the flight, CDMS calibration was checked using the Mesa Photonics' fixed-size monodisperse droplet generator. The calibration was stable within the instrument's measurement precision.

Flight 3. 2/15/2020, 12:37–14:37 MT.

CDMS is mounted on the original mounting plate. The wind is low. Trying to get to the maximum altitude (150 m below the clouds is allowed). The main goal is testing the CDMS wireless telecommunication system.

CDMS transceiver performance:

Altitude	Data throughput
450 m	200-300 Mbps
600 m	100-200 Mbps
700 m	200-300 Mbps
800 m	100-150 Mbps, goes down to 50 Mbps at times, requires alignment of the antenna.
900 m	50-150 Mbps. By careful alignment of the antenna, 200-300 Mbps can be achieved.
1000 m	100 Mbps (150-250 Mbps after realignment). Loitering at 1000 m for 45 min. Collecting the raw image data at full rate (78 Mbps). Signal » -83–72 dBm; noise » -86 dBm; noise floor » -86 dBm.

2.3 Main Results

The field testing demonstrated good compatibility of the CDMS with the TBS. The mounting hardware allowed reliable mounting of the CDMS on the TBS, which included the possibility of co-locating of the CDMS with other instruments. During the TBS flights, the crew did not experience any operational issues with the CDMS. The instrument demonstrated reliable operational characteristics, including sufficient battery life and good thermal management. The stability of the CDMS calibration confirmed the ruggedness of the instrument's optical alignment.

Some raw data showed elevated image noise levels due to very high stray illumination background typical of sunny weather. These effects are especially noticeable when the imaging optics are directly illuminated by the sunlight. Although these conditions are not typical for in-cloud measurement, changes in the CDMS optical layout may be desirable.

Imaging artifacts were occasionally produced when the TBS ropes, operators' hands, and tools were in the field of view of the imaging optics, which, in some cases, overwhelmed the image processing algorithms. Implementing adaptive algorithms may be required to mitigate these issues.

The wireless telecommunication system was tested at altitudes of up to 1000 m AGL. The transceiver maintained good performance characteristics during all flights, the data throughput being higher than 100 Mbps even at the highest altitudes, which is sufficient to support the expected data rate (about 78 Mb/s) required to transmit the CDMS raw data.

In summary, all campaign objectives have been successfully met. The campaign demonstrated good compatibility of the Mesa Photonics' CDMS with the ARM TBS. The flight tests performed at altitudes up to 1000 m AGL confirmed mechanical integrity of the CDMS and stability of its optical layout, as well as reliability of the wireless telecommunication system. Some data processing issues have been revealed, which are currently being fixed. Successful completion of this campaign provided a solid basis for the next campaign (AFC07016, November 2020), that involved testing of the CDMS during in-cloud TBS flights at AMF3 at Oliktok Point.

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