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Stereo Camera Deployment in Support of TRACER Field Campaign Report

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ARM

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Acronyms and Abbreviations

AMF	ARM Mobile Facility
ARM	Atmospheric Radiation Measurement
LES	large-eddy simulation
PCCP	Point Cloud of Cloud Points
PI	principal investigator
STEREOCAM	stereo cameras for clouds
TRACER	Tracking Aerosol Convection Interactions Experiment
UTC	Coordinated Universal Time
VAP	value-added product

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1.0 Summary

An improved understanding of the salient environmental controls on cloud formation, evolution, and eventual dissipation is critical to address ongoing challenges with cloud process and parameterization representations in global climate and Earth system models. One goal for the recent U.S. Department of Energy Atmospheric Radiation Measurement (ARM) user facility's Tracking Aerosol Convection Interactions Experiment (TRACER) campaign was to collect a comprehensive data set that enabled such convective cloud process studies and key demonstrations for those controls that influenced cloud life cycle (i.e., aerosols, thermodynamics) in the Houston, Texas region. To help accomplish this, ARM instrumentation during TRACER was tasked with tracking a large number of individual, isolated convective cells – and to follow the evolution of these cells at high spatiotemporal resolution to characterize changes in cloud dynamic and microphysical properties. Since Houston experiences a range of convective clouds, it was known that the standard ARM Mobile Facility (AMF) instruments may not be sufficient to completely document initiating, transient, or dissipating low- or shallow-cloud behaviors that were also expected during this campaign (in terms of sensitivity, resolution, and/or operational availability). As one partial solution, a supplemental stereo camera deployment (this sub-campaign) was requested to augment the ARM AMF instrumentation to better address shallow and shallow-to-deep transitional types of cloud process drivers during TRACER (ARM stereo cameras for clouds [STEREOCAM]; Romps and Öktem 2018). The primary scientific focus was the relationships between cloud properties and the ambient conditions, which points to several key TRACER science questions including: '*What is the relationship between cloud size or updraft intensity to the environmental wind shear and/or humidity?*'

Overall, the ARM TRACER stereo camera deployment demonstrated unique effectiveness in observing a wide range of critical shallow, congestus, and transitioning or time-evolving cloud characteristics. The data sets from these cameras include information on the clouds' horizontal dimensions, elevations, and depths, while also enabling potential products for cloud initiation and dissipation rates, and vertical velocities. Stereo cameras simultaneously inform on cloud life cycle stage and spatial properties such as cloud fractional coverage, which should provide complementary information for ARM users when combined with TRACER cloud radars, lidar, and/or other profiling sensors. Moreover, camera products offer large-eddy simulation (LES),-scale-appropriate cloud coverage, depth, and spatial variability estimates, while opening additional avenues to challenge difficult process questions on cloud updrafts/entrainment and their covariability with environmental controls such as wind shear and humidity.

1.1 The TRACER Stereo Camera Deployment

The TRACER stereo camera setup comprised two cameras, with a single camera installed at two locations: 29º 41' 38.1" N, 94º 56' 11.87' 'W and 29º 41' 1.1" N, 94º 56' 8.13" W. These locations are identified in Figure 1. The complete installation and adjustment of the cameras' orientations were completed by August 25, 2021. The stereo camera data are available for general use, with value-added products (VAPs) also available throughout TRACER, starting August 26, 2021, with reasonable coverage/uptime to September 30, 2022.

Figure 1. Stereo camera positions with respect to the AMF M1 LaPorte Airport site. The blue/red lines identify the field of view of the cameras "Hou-A" and "Hou-B", respectively. Clouds > 10 km in depth fit in the field of view of the cameras starting at the yellow line.

In Figure 2, we provide examples of camera images captured at 19:30 UTC (Coordinated Universal Time) from a 25 July, 2022 event. For the campaign, cameras recorded synchronous shots at 20-second intervals during daytime hours. Nighttime images were also captured during TRACER, with images collected at six-minute intervals for stellar stereo calibration purposes.

Figure 2. Sample shots from (right) Hou-A and (left) Hou-B cameras at 19:30 UTC on July 25, 2022.

With synchronized shots from the two cameras, it is possible to execute stereo reconstruction of feature points, i.e., three-dimensional coordinates of distinctive cloud pixels (i.e., point distance to east, distance to west, height above the ground with respect to a base location). In ARM parlance, the associated VAP for this procedure is named "PCCP" (i.e., "Point Cloud of Cloud Points"). In practical terms, the crisper the cloud boundaries in these camera images, the better the reconstruction and/or availability of the VAP. For example, in Figure 3 we plot a camera image and the associated output from the PCCP VAP processes (reconstructions aimed at the AMF M1 location at LaPorte Airport). The image and resulting VAP correspond to the cloud field at 20:10 UTC on 25 July, 2022. For this scene, more than 11,000 cloud points were extracted. Throughout this campaign, the number of extracted cloud points (and thus, VAP availability) is contingent on several factors: i) the visual quality (i.e., haze, rain lower availability), ii) if clouds are obstructed by other clouds, iii) clouds that are not in the clear view of both cameras, and iv) the distance of the clouds from the cameras.

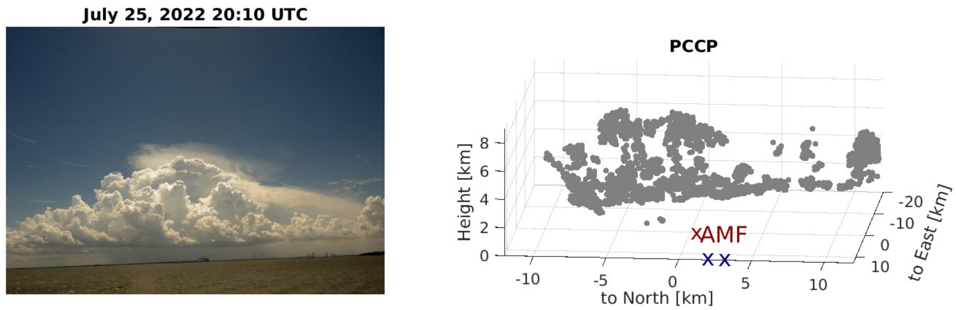

Figure 3. (Left panel) A sample shot from Hou-A camera from 20:10 UTC on 25 July, 2022. (Right panel) Reconstructed cloud points at the corresponding time. Red/blue crosses mark the AMF and camera locations, respectively. PCCP data indicate cloud base heights around 1.2 km and cloud tops up to 6.7 km at this time.

1.2 Notable Events and TRACER Notes

Owing to the lengthy deployment and instrument robustness, an extensive record of cloudy events was captured by the cameras during TRACER. Early months into TRACER provided copious low-cloud observation days (i.e., Figure 4), including events that transitioned into deeper convective cloud modes. Overall, Houston typically experienced 10 or more cloudy days each month having clouds well observed within the stereo camera field of view. As such, the stereo cameras also provide a valuable resource for comprehensive or summary campaign cloud properties, given strong instrument uptime compared to other cloud sensors.

Figure 4. Snapshot from "Hou B" on 24 October, 2021 at 18:56 UTC. The congestus to the left of the center forms at ~3 km south of the AMF site with cloud top height reaching above 3 km. The cloud base heights are ~700 m.

While the post-campaign stereo camera analysis is ongoing, the principal investigators (PIs) anticipate that select "shallow-to-deep" convective events during the intensive operational period will potentially garner immediate attention for TRACER cloud studies. A scientific emphasis we anticipate from TRACER will focus on the role of sea breeze or bay breeze features on shallow-cloud formation and evolution, noting that these efforts may also benefit from the spatiotemporal properties and overall uptime/availability of the stereo camera data sets. At the intersection of these themes, the following "shallow-to-deep" events have been identified by the PIs as notable in having high-quality camera performance and known sea or bay breeze passages at the AMF M1 location:

- 17 June, 2022
- 22 June, 2022
- 11 July, 2022
- 24-26 July, 2022
- 16 August, 2022.

Finally, camera observations may provide the ARM community guidance for how to interpret profiling observations collected at the AMF M1 site at the LaPorte Airport (the classical ARM "soda straw" challenge). As one emerging extension of this, discussions following TRACER have centered on the role of local (within a few km) power plants on cloud formation and life cycle. The influence of the power plants on the interpretation of ARM M1 site observations is of interest for previous control studies, and stereo camera cloud properties and products shown above are spatiotemporally well suited to inform on the potential initiation and modification of clouds in the vicinity of the ARM site associated with known plant locations.

2.0 Results

Although post-TRACER scientific efforts (for notable events identified in the previous section) are at their early stages, the PIs are confident that this stereo camera deployment has added significant value to the overall TRACER deployment, and will help TRACER PIs better achieve their stated science goals. The PIs anticipate several publications to benefit from these unique camera observations in a complicated Houston setting, including possibilities for higher-impact studies that benefit from the comprehensive nature of the stereo camera record, the camera sensitivity to shallower/low clouds, and the tracking of time-evolving cloud properties that the cameras enable. Initial deployment results are summarized as follows:

- The stereo camera deployment was successfully sited, deployed on time, and demonstrated an exceptional operational uptime consistent or exceeding the high standards of the ARM infrastructure team (availability of in-demand cloud properties).
- Stereo cameras during TRACER observed > 100 cloudy events throughout the campaign, each associated with high-quality images, quick-look movies, and VAPs (PCCP) from these events available at the ARM Data Center in a timely fashion. The record represents one of the most comprehensive cloud property data sets from TRACER for campaign summaries and process studies.
- Stereo cameras observed multiple "golden" events. These events included several high-quality daytime low-cloud events, shallow-to-congestus cloud transitioning days, deeper convective cloud overpasses, and power-plant-influenced cloud scenes.
- The long-term data sets and overall availability of cloud properties afforded by the stereo cameras should facilitate cloud regime-influence or sensitivity studies aimed at different scales. These may include topics on the role of larger-scale frontal intrusions, regional/local sea or bay breeze passage, and other environmental controls on cloud formation and life cycle.

3.0 Publications and References

Romps, D, and R Öktem. 2018. "Observing clouds in 4D with multi-view stereo photogrammetry." *Bulletin of the American Meteorological Society* 99(12):2575−2586, https://doi.org/10.1175/BAMS-D-18-0029.1

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