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# TRACER-Coastal Urban Boundary-Layer Interactions with Convection (TRACER-CUBIC) Field Campaign Report

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June 2023

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# Acronyms and Abbreviations

| | |
|---|---|
| ABL | atmospheric boundary layer |
| AERI | atmospheric emitted radiance interferometer |
| AERIoe | Atmospheric Emitted Radiance Interferometer Optimal Estimation Value-Added Product |
| AMF | ARM Mobile Facility |
| ARM | Atmospheric Radiation Measurement |
| BB | bay breeze |
| CI | convective initiation |
| CLAMPS | Collaborative Lower Atmospheric Mobile Profiling System |
| CSAPR | C-Band Scanning ARM Precipitation Radar |
| CUBIC | Coastal Urban Boundary-Layer Interactions with Convection |
| DOE | U.S. Department of Energy |
| DOI | digital object identifier |
| IOP | intensive operational period |
| LLJ | low-level jet |
| MWR | microwave radiometer |
| NEXRAD | Next-Generation Weather Radar |
| NOAA | National Oceanic and Atmospheric Administration |
| PBL | planetary boundary layer |
| SB | sea breeze |
| SPARC | Space Science and Engineering Center Portable Atmospheric Research Center |
| SR | sunrise |
| SS | sunset |
| TBS | tethered balloon system |
| TRACER | Tracing Aerosol Convection Interactions Experiment |
| TROPoe | An algorithm that retrieves profiles of temperature and water vapor mixing ratio, together with cloud properties, for a single-layer cloud from AERI-observed infrared radiance spectrum. |
| UAV | uncrewed aerial vehicle |
| UH | University of Houston |
| UHCC | University of Houston Coastal Center |
| UO | University of Oklahoma |
| UTC | Coordinated Universal Time |

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# Figures



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# 1.0 Summary

To better understand the complicated web of processes governing convective cloud life cycle and aerosol-convection interactions, the U.S. Department of Energy (DOE)'s Atmospheric Radiation Measurement (ARM) user facility supported deployment of a variety of advanced atmospheric measurement systems to the greater Houston, Texas, area from 1 October 2021 to 30 September 2022 as part of the Tracking Aerosol Convection Interactions Experiment (TRACER). Houston was selected as a study area because isolated convection and a variety of aerosol conditions are common in this region (Wang et al. 2022). This one-year ARM Mobile Facility (AMF) deployment featured a four-month intensive operational period (IOP) during summer 2022 (1 June–30 September).

The ARM instrumentation was deployed at three sites along an east-west transect from La Porte, Texas to an ancillary site in a less-polluted rural region southwest of downtown Houston (Figure 1). At the La Porte Site, which is located near the Houston ship channel in an area that experiences significant pollution, the first ARM Mobile Facility (AMF1) was deployed. During the IOP, the ARM tethered balloon system (TBS) operated at the ancillary site. The second-generation C-Band Scanning ARM Precipitation Radar (CSAPR) operated near Pearland, Texas, roughly halfway between the Laporte and ancillary sites.

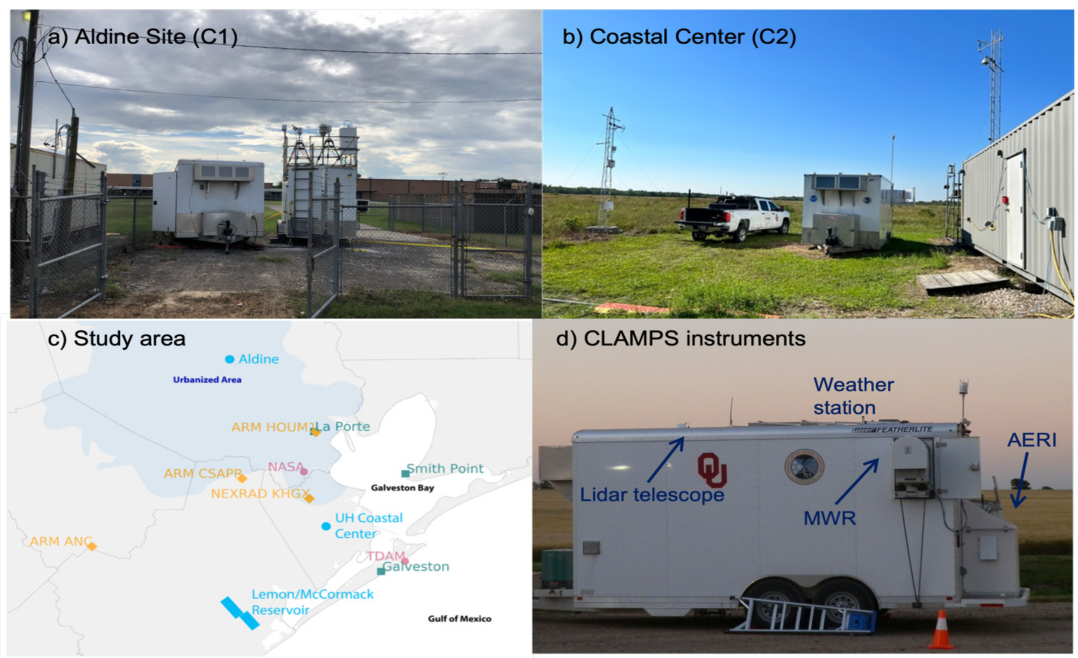


**Figure 1**. Photos of the Collaborative Lower Atmospheric Mobile Profiling System (CLAMPS) 1 (a) and 2 (b) trailers at their deployments sites and map of the instrumented sites during the IOP in the summer of the 2022 DOE TRACER campaign. The photos show the different ARM sites and the National Weather Service Next-Generation Weather Radar (NEXRAD) (orange diamonds), the two sites with deployments of the boundary-layer profiling systems CLAMPS (University of Houston [UH] Coastal Center and Aldine, blue circles) and Space Science and Engineering Center Portable Atmospheric Research Center (SPARC) (orange, collocated with ARM CSAPR), and sites with uncrewed aerial vehicle (UAV) operations (UH Coastal Center and Lemon/McCormack Reservoirs) (background map from Wang et al. 2022). Additionally, the instruments integrated in the CLAMPS trailers are highlighted (d).

As part of the TRACER- Coastal Urban Boundary-Layer Interactions with Convection (CUBIC) project, three boundary-layer profiling systems (Wagner et al. 2019) were deployed along a north-south transect spanning from the University of Houston Coastal Center (UHCC, blue dot in Figure 1) to the Aldine site north of downtown Houston (also blue dot in Figure 1) during the TRACER IOP. These systems included the National Oceanic and Atmospheric Administration (NOAA) National Severe Storms Laboratory CLAMPS2 (C2), which was deployed at the UHCC, the University of Wisconsin SPARC, which was deployed at the ARM CSAPR site near Pearland (orange diamond in middle of map in Figure 1), and the University of Oklahoma CLAMPS1 (C1), which was deployed at Aldine. These three systems have been successfully operated in various field campaigns, providing data sets that collectively offer new insights into atmospheric-boundary-layer (ABL) processes, sea-breeze (SB) circulations, and convection initiation (CI) (e.g., Geerts et al. 2017, Smith et al. 2019, Wagner et al. 2019, 2022). For the TRACER IOP window, these systems ran continuously between 1 June and 26 September, 2022. Due to commitments to NOAA projects, the Doppler lidar at the UHCC site was not available until 24 June 2022.

The CLAMPS and SPARC profiling systems are self-contained platforms that have benefited from several years of development and deployment. Instruments and data processing were maintained remotely, which made the 4-month deployment for the TRACER-CUBIC IOP period possible. The same basic instrument configuration comprises each system: a scanning Doppler wind lidar for flow characterization and passive profiler(s) for characterizing planetary-boundary-layer (PBL) thermodynamic properties. Each platform includes a Halo Streamline Doppler wind lidar, an Atmospheric Emitted Radiance Interferometer (AERI), and a surface meteorology station. CLAMPS1 and CLAMPS2 each also include a microwave radiometer (MWR, Figure 1d).

The TRACER-CUBIC hypotheses included (i) Interactions of SB and urban circulations and how they affect the PBL structure in the Houston environment, causing spatially (horizontally and vertically) and temporally highly variable flow patterns, (ii) heat, moisture, and aerosol transport and mixing depend on these flow dynamics, and (iii) an improved understanding of the flow patterns and PBL structure are critical for investigating the processes leading to CI. To test these hypotheses, the project aimed at (i) characterizing SB circulations and their impacts on the diurnal evolution of the structure of the ABL, (ii) studying the evolution of Houston's complex urban boundary layer, and (iii) identifying effects of urban-induced circulations on pre-convective environments.

TRACER-CUBIC observations generally provide good coverage during the summer IOP. Initial screening of the data indicates a good number of cases with bay-breeze (BB) and/or SB signatures, local CI, and interesting boundary-layer features such as strong nocturnal low-level jets (LLJs, Table 1). The numbers listed in rows 3-5 in this table will be further updated as part of ongoing in-depth analyses and systematic identification of local circulations and CI events.

More detailed information about the data availability and quality for each instrument is provided in the "readme" files that were submitted to the ARM Data Center along with each archived data sets (see DOI information in section 3). These "readme" files also provide instrument descriptions, information about the data collection and processing procedures, data formats, and any additional information relevant for further data analysis.

**Table 1**. Overview of TRACER-CUBIC data availability and observed weather conditions.

| Events | Number of cases observed |
|---|---|
| Days with good data coverage during 1 June–30 September, 2022 | 114<br>(C2 no lidar for 24.5 days) |
| Days with bay breeze (BB) and/or sea breeze (SB) circulations | 39<br>(plus 13 questionable SB days) |
| Cases with local convection initiation due to BB/SB | 16 |
| Nocturnal low-level jet with $U_{LLJ}$ > 10 m/s | 21 |
| Land/urban circulations | 14 |

# 2.0 Results

To illustrate the types of data available, we have selected two interesting cases. The first case, 18 July, 2022, was a clear-sky day. At the La Porte Site, a BB was detected at 18:33 UTC, followed by an SB at 20.54 UTC, with initially southwesterly surface winds (Wang et al. 2023). As illustrated in Figures 2-3, strong nocturnal LLJs were observed with the CLAMPS lidars at the UH Coastal Center and also at the Aldine site located north of downtown Houston (Figure 1).

At the CLAMPS2 lidar, data are missing in the morning hours from around 0930-1330 UTC due to fog forming on the lidar lens, an issue that frequently occurred due to the high humidity at this site (Figure 2). Following a sharp decline in the backscatter signal and drop in the depth of the layer with strong vertical mixing at around 1730 UTC, turning from southwesterly to southerly winds can be noted, indicative of a SB passage. At the Aldine site (Figure 3), winds start to turn much later (~2100 UTC) and this shift in wind direction does not cause drastic changes in vertical mixing and backscatter.

Clear differences can be noted in the daytime and nighttime boundary-layer dynamics between the two sites. While a nocturnal LLJ is observed at both sites, the nose of the jet is much more pronounced at the suburban Aldine site (Figure 3) than at the UH coastal site (Figure 2). Coinciding with the stronger shear below the jet nose, vertical mixing prevails throughout the night at the Aldine site while it is much weaker at the UH coastal site. In addition to roughness effects, thermal effects likely also contributed to the stronger nocturnal mixing at the suburban site. During the day, the convective boundary layer is deeper at the Aldine site, which can also be seen in the temperature plots, retrieved from the AERI and MWR data with TROPoe for the two sites (Figures 4-5). The TROPoe algorithm is a Python equivalent to the Atmospheric Emitted Radiance Interferometer Optimal Estimation Value-Added Product (AERIoe) algorithm (see Turner and Loehnert 2014, Turner and Blumberg 2019). The high precipitable water content at the deployment sites made it difficult to retrieve accurate water vapor profiles using TROPoe due to saturation of the spectral bands that are typically used to retrieve water vapor. To account for the lower information content in the water vapor band, a prior recentering technique that adjusts the prior mean profile based on the surface mixing ratio was added to TROPoe. By recentering the prior mean profile, the retrieval theoretically should be closer to the true water vapor profile. As a result, smaller observation-based adjustments are needed to retrieve profiles with improved accuracy. The data collection from this project has also spurred research into additional spectral bands that could be used for retrieving water vapor profiles at locations with high precipitable water.

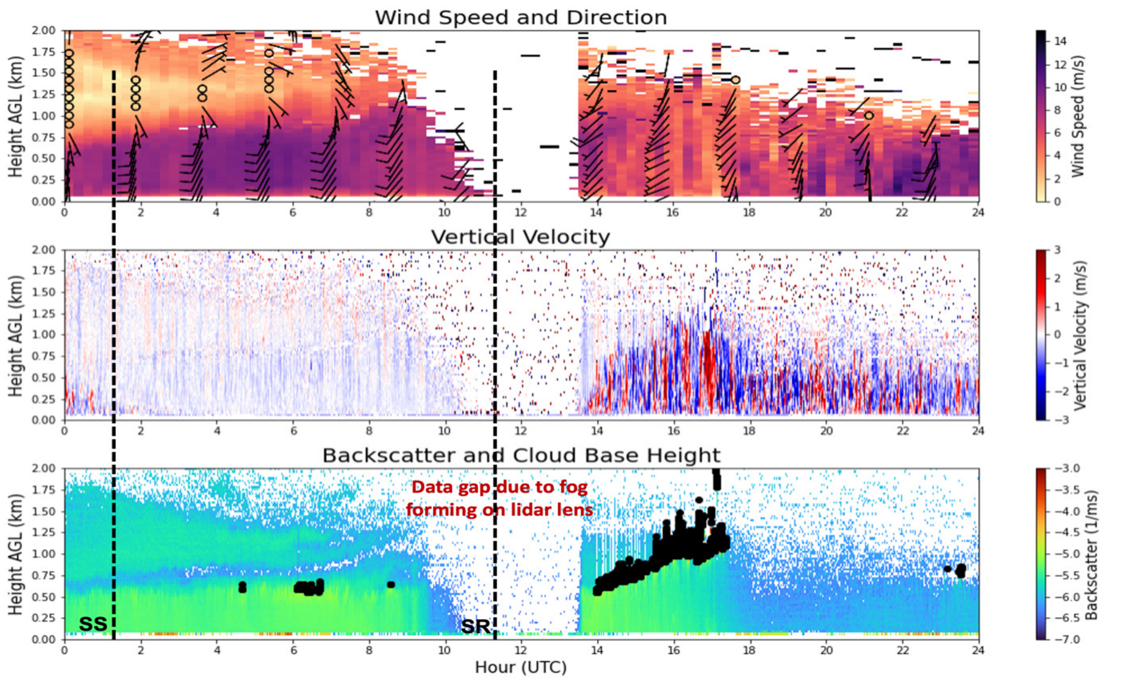


**Figure 2**. Mean wind speed and direction (top panel), 1-Hz vertical velocity (middle panel), and backscatter (bottom panel) collected with the CLAMPS 2 Doppler lidar at the UH coastal site on 07/18/2022. The black dots shown in the back scatter plots indicate cloud base height. The black dashed lines highlight the local sunset (SS) and sunrise (SR) times.

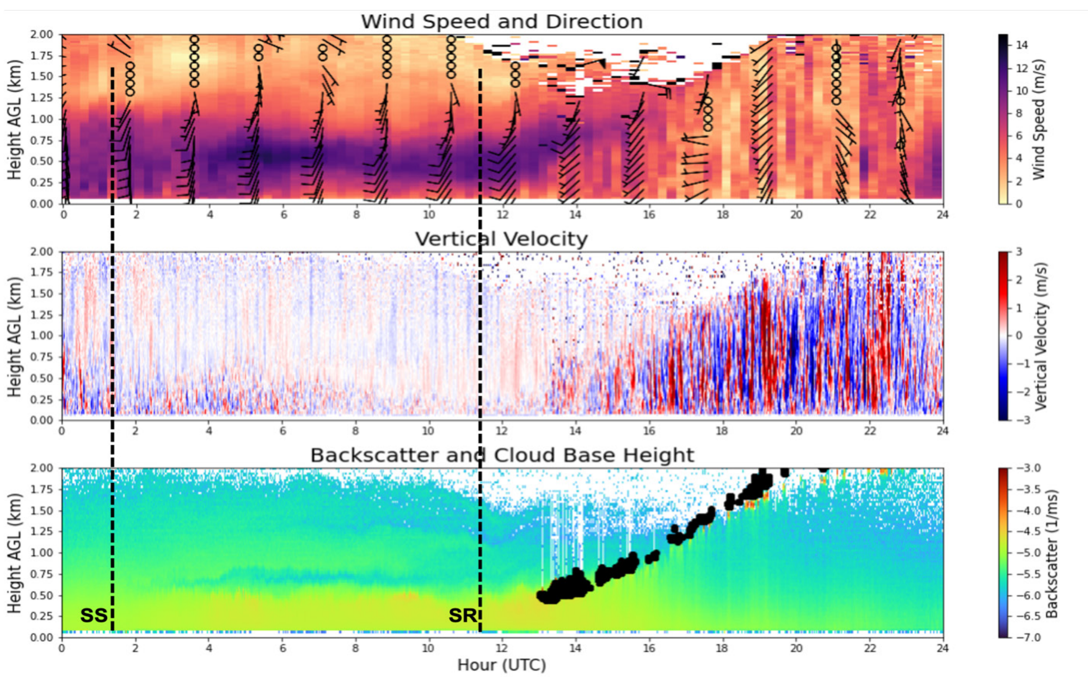


**Figure 3**. Same as Figure 2 but for the CLAMPS 1 Doppler lidar at the Aldine site on 07/18/2022.

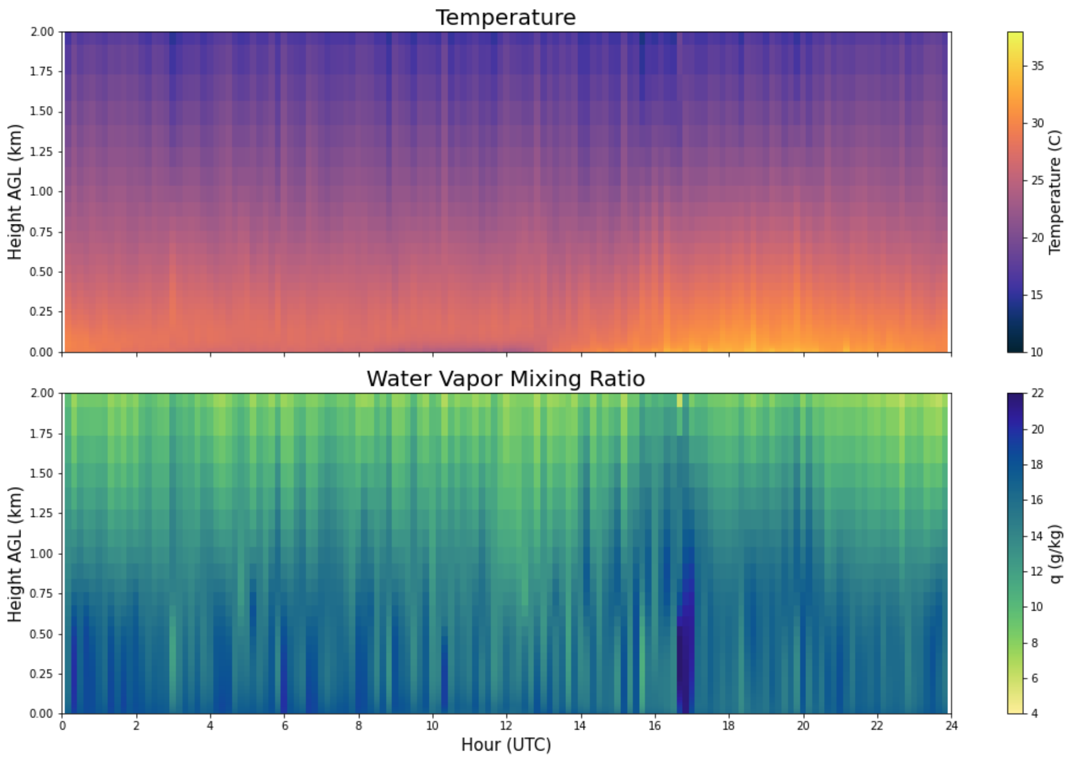


**Figure 4**. Temperature (top panel) and water vapor mixing ratio (bottom panel) retrieved from the CLAMPS 2 thermodynamic profiler data collected at the UH coastal site on 07/18/2022.

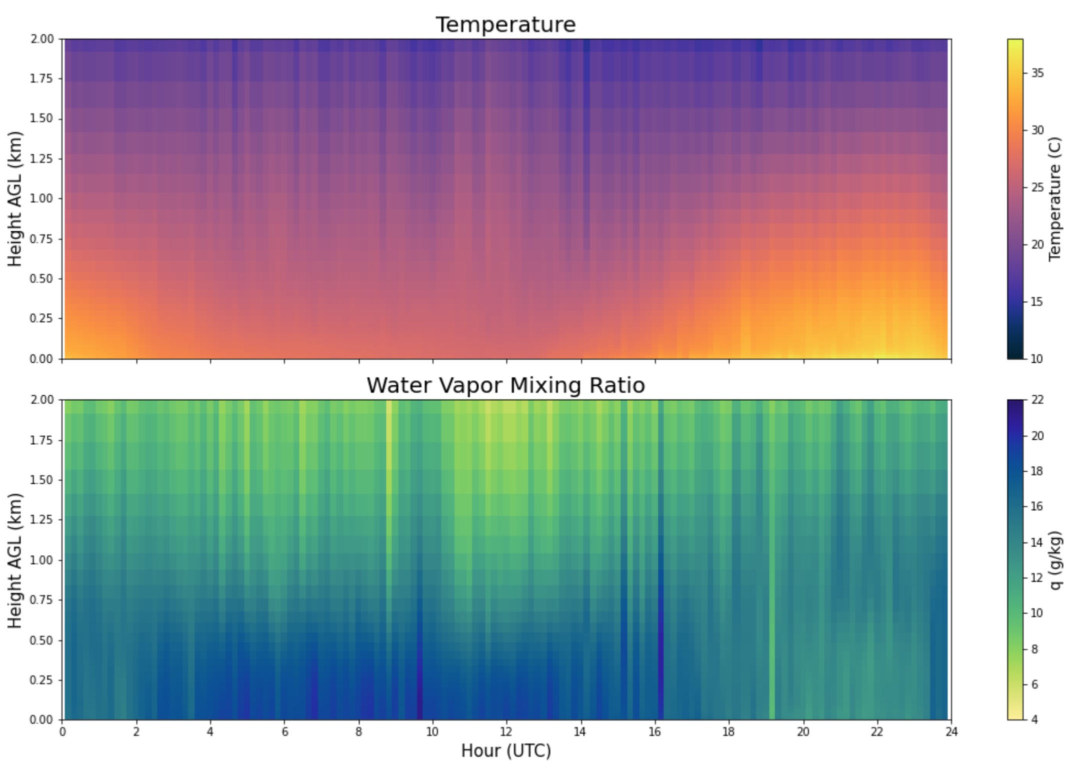


**Figure 5**. Same as Figure 4 but for the CLAMPS 1 data at the Aldine site on 07/18/2022.

The second case selected was another clear-sky day on 23 September, 2022. At the La Porte Site, surface winds were initially northeasterly; passage of a BB was detected at 17:30 UTC, followed by an SB at 22.54 UTC (Wang et al. 2023). At the Aldine (Figure 6) and Pearland sites (Figure 7), afternoon winds are initially easterly shifting to southeasterly at around 2230 UTC at Pearland and 2300 UTC at Aldine. The SPARC Doppler lidar lost data in the afternoon due to overheating of the lidar. During hot summer days this happens often, particularly at the Pearland site where the Doppler lidar was operated as a standalone instrument outside of the trailer. For the two CLAMPS systems, the Doppler lidar is integrated into the climate-controlled trailer, which mitigated some of the overheating issues of the Halo Doppler lidars.

For the 23 September, 2022 case, the nighttime winds are particularly interesting, showing strong directional shear with the wind below ~ 500 m turning from southwesterly to westerly after sunset at both sites while the upper-level winds are easterly. Land-breeze and/or urban circulations are possible reasons for this strong directional shear overnight and we are currently investigating this case further, incorporating data sets from the other TRACER sites into the analysis. We plan to submit a publication to a peer-reviewed journal later this summer. Additionally, we are applying a fuzzy-logic, boundary-layer-height-detection algorithm (Smith and Carlin 2023) to the Doppler lidar and thermodynamic profiler data collected at all sites to conduct a more systematic analysis of the boundary-layer evolution across the Houston domain, which will be described in a second journal paper to be submitted later this year.

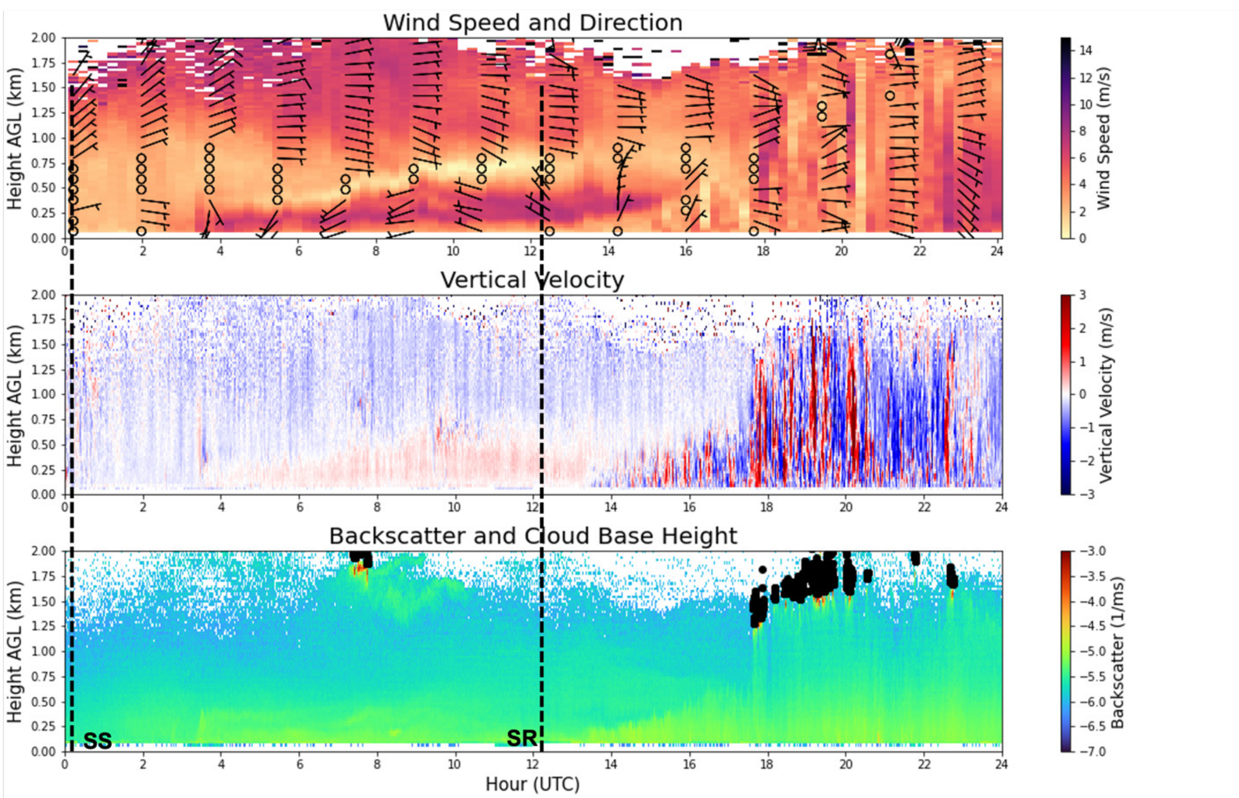


**Figure 6**. Same as Figure 2 but for the CLAMPS 1 Doppler lidar at the Aldine site on 09/23/2022.

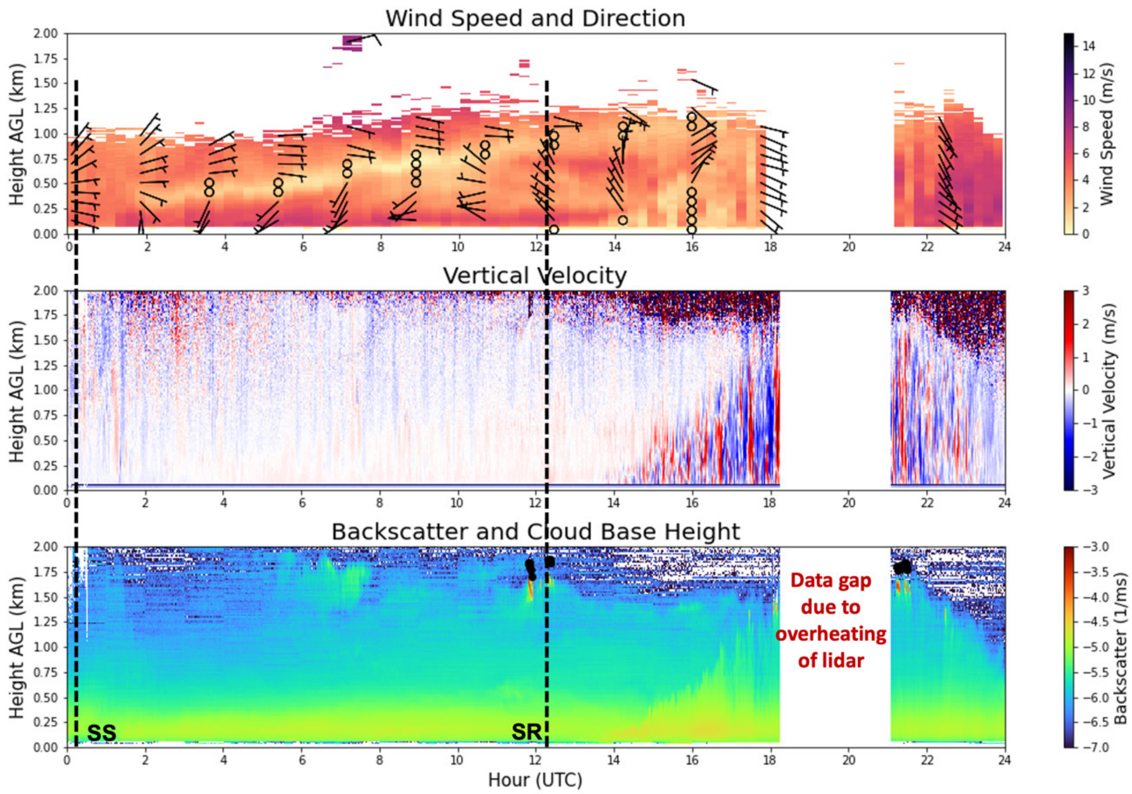


**Figure 7**. Same as Figure 2 but for the SPARC Doppler lidar at the Pearland site on 09/23/2022.

# 3.0 Publications and References

## 3.1 Project Data Sets to Date

**CLAMPS1(Aldine site):**

1. TRACER CLAMPS1 AERI TROPoe Retrievals - https://doi.org/10.5439/1973831
2. TRACER CLAMPS1 Doppler Lidar Vertical Stare Data - https://doi.org/10.5439/1971449
3. TRACER CLAMPS1 Doppler Lidar VAD Data - https://doi.org/10.5439/1971443

**CLAMPS2 (UH Coastal site):**

4. TRACER CLAMPS2 MWR TROPoe Retrievals - https://doi.org/10.5439/1973480
5. TRACER CLAMPS2 AERI MWR TROPoe Retrievals - https://doi.org/10.5439/1973833
6. TRACER CLAMPS2 Doppler Lidar VAD Data - https://doi.org/10.5439/1971453
7. TRACER CLAMPS2 Doppler Lidar Vertical Stare Data - https://doi.org/10.5439/1971456

**SPARC (Pearland site):**

8. TRACER SPARC Doppler Lidar VAD Data - https://doi.org/10.5439/1975084
9. TRACER SPARC AERI Data - https://doi.org/10.5439/1975083
10. TRACER SPARC Doppler Lidar Vertical Stare Data - https://doi.org/10.5439/1973242

## 3.2 Project Presentations to Date

Spencer, MR, PM Klein, EN Smith, T Wagner, FM Lappin, TM Bell, and JG Gebauer. 2022. "Boundary-layer profile observations during TRACER-CUBIC." Presented at the ARM/ASR Principal Investigators Meeting. Rockville, Maryland.

Klein, PM, EN Smith, T Wagner, MR Spencer, FM Lappin, TM Bell, and JG Gebauer. 2023. "Boundary-layer profile observations during the TRACER-CUBIC campaign in Houston." Presented at the 24th Conference on Boundary Layer and Turbulence. Denver, Colorado.

Klein, PM, EN Smith, and TM Bell. 2023. "Applications of ground-based remote sensing profiling systems for boundary-layer studies." Presented at the 24th Conference on Boundary Layer and Turbulence, Denver, Colorado.

Spencer, MR, EN Smith, PM Klein, T Wagner, FM Lappin, TM Bell, and JG Gebauer. 2023. "Sea-Breeze boundary layers across Houston during the TRACER-CUBIC campaign." Presented at the 24th Conference on Boundary Layer and Turbulence. Denver, Colorado.

Spencer, MR, PM Klein, EN Smith, T Wagner, FM Lappin, TM Bell, and JG Gebauer. 2023. "Boundary-layer profile observations, sea-breeze events, and implementation of PBL height algorithm during TRACER-CUBIC." Presented at the TRACER-ACPC Workshop. Houston, Texas.

## 3.3 Papers Cited in the Report

Geerts, B, D Parsons, C Ziegler, T Weckwerth, M Biggerstaff, RD Clark, M Coniglio, B Demoz, R Ferrare, W Gallus Jr., K Haghi, J Hanesiak, P Klein, K Knupp, K Kosiba, G McFarquhar, J Moore, A Nehrir, M Parker, J Pinto, R Rauber, R Schumacher, DD Turner, Q Wang, X Wang, Z Wang, and J Wurman. 2017. "The 2015 Plains Elevated Convection at Night field project." *Bulletin of the American Meteorological Society* 98(4): 767–786, https://doi.org/10.1175/BAMS-D-15-00257.1

Smith, EN, and JT Carlin. 2023. "A multi-instrument fuzzy logic boundary-layer top detection algorithm." To be submitted to *Atmospheric Measurement Techniques*.

Smith, EN, JG Gebauer, PM Klein, E Fedorovich, and JA Gibbs. 2019. "The Great Plains Low-Level Jet during PECAN: Observed and Simulated Characteristics." *Monthly Weather Review* 147(6): 1845–1869, https://doi.org/https://doi.org/10.1175/MWR-D-18-0293.1

Turner, DD, and U Loehnert. 2014. "Information content and uncertainties in thermodynamic profiles and liquid cloud properties retrieved from the ground-based Atmospheric Emitted Radiance Interferometer (AERI*)." Journal of Applied. Meteorology and Climatology* 53(3): 752−771, https://doi.org/10.1175/JAMC-D-13-0126.1

Turner, DD, and WG Blumberg. 2019. "Improvements to the AERIoe thermodynamic profile retrieval algorithm." *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sens*ing 12(5)**:** 1339−1354, https://doi.org/10.1109/JSTARS.2018.2874968

Wagner, TJ, PM Klein, and DD Turner. 2019. “A New Generation of Ground-Based Mobile Platforms for Active and Passive Profiling of the Boundary Layer.” *Bulletin of the American Meteorological Society* 100(1): 137–153, https://doi.org/10.1175/BAMS-D-17-0165.1

Wagner, TJ, AC Czarnetzki, M Christiansen, RB Pierce, CO Stanier, AF Dickens, and EW Eloranta. 2022. “Observations of the Development and Vertical Structure of the Lake-Breeze Circulation during the 2017 Lake Michigan Ozone Study.” *Journal of the Atmospheric Sciences* 79(4): 1005–1020, https://doi.org/10.1175/JAS-D-20-0297.1

Wang, D, E Melvin, N Smith, M Jensen, S Gupta, A Abdullah-Smoot, and N Pszeniczny. 2023. “Variability of sea-breeze characteristics during the TRACER field campaign.” *Monthly Weather Review*, in review.

Wang, D, MP Jensen, D Taylor, G Kowalski, M Hogan, BM Wittemann, A Rakotoarivony, SE Giangrande, and J Minnie Park. 2022. “Linking synoptic patterns to cloud properties and local circulations over southeastern Texas.” *Journal of Geophysical Research − Atmospheres* 127(5): e2021JD035920, https://doi.org/10.1029/2021JD035920

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