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TRACER-Tethersonde Field Campaign Report

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ARM

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Acronyms and Abbreviations

3D	three-dimensional
AMF	ARM Mobile Facility
ARM	Atmospheric Radiation Measurement
ASR	Atmospheric System Research
BU	Baylor University
ECC	electrochemical cell
HGB	Houston-Galveston-Brazoria
IOP	intensive operational period
LT	local time
POPS	portable optical particle spectrometer
ppbv	parts per billion by volume
RH	relative humidity
TBS	tethered balloon system
TRACER	Tracking Aerosol Convection Interactions Experiment
TRACER-MAP	TRACER-Mapping Aerosol across Houston
VOC	volatile organic compound

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1.0 Summary

The U.S. Department of Energy Atmospheric Radiation Measurement (ARM) user facility's Tracking Aerosol Convection Interactions ExpeRiment (TRACER) in the greater Houston area from October 2021 to September 2022 investigated convective cloud life cycles and aerosol-convection interactions through a comprehensive data collection. TRACER-Tethersonde, a sub-campaign of TRACER, took place during the TRACER June-September 2022 intensive operational period (IOP) at the S3 Ancillary site (29.33°N, 95.74°W) near Guy, Texas (Figure 1). The tethered balloon system (TBS) operated during the first two weeks of each month during the TRACER IOP, making multiple (~4) up-and-down vertical profiles each day that could reach as high as ~1 km.

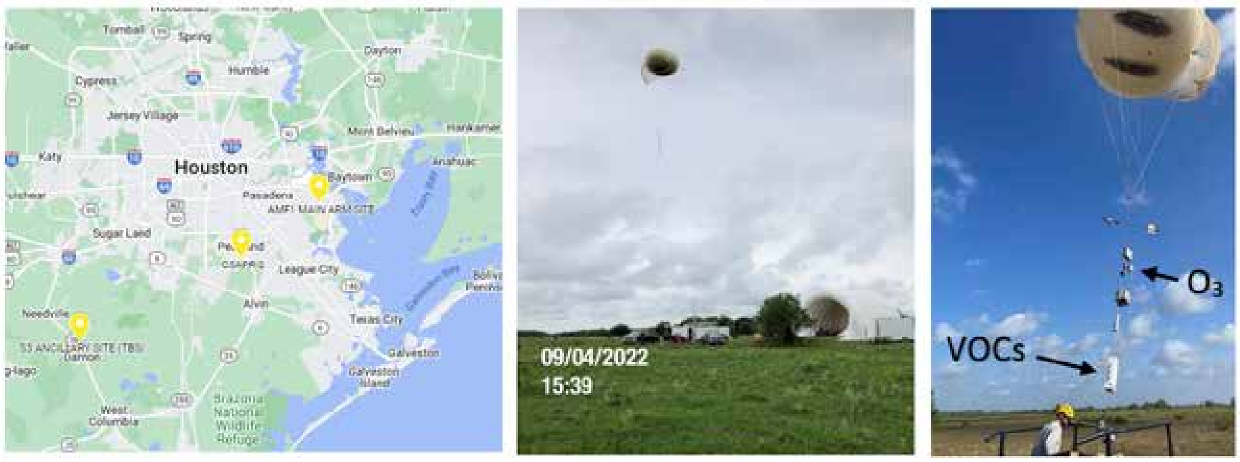

Figure 1. Left: The location of the tethered balloon system (TBS; S3 Ancillary site) relative to other ARM sites during TRACER. Middle and right: The TBS at the S3 Ancillary site near Guy, Texas, during the TRACER June-September 2022 IOP.

TRACER-Tethersonde included an En-Sci electrochemical cell (ECC) ozonesonde (Komhyr 1969, 1986) on the tether and, on occasion, included a volatile organic compound (VOC) resin tube sampler (Figures 1 and 2). ECC ozonesondes were included on the tether during 41 days in 2022: 10-14 June, 4-14 July, 2-14 August, 2-7 September, and 9-14 September. The ozonesonde was connected to an iMet-4RSB radiosonde, and the overall data collected included ozone, relative humidity, temperature, and altitude.

One objective of this campaign was to deploy a VOC sampler (Figure 2) on the TBS to create vertical profiles and characterize VOC composition. VOCs are highly reactive precursor species that undergo atmospheric processing to form secondary products, including aerosol (Pandis and Seinfeld 2016). VOC emissions are influenced by many factors that include but are not limited to temperature, time of day, local anthropogenic activities, and local vegetation, which result in large spatiotemporal variability (Gu et al. 2021, McKinney et al. 2019). The vertical distribution of volatile species is crucial for understanding gas-phase processing for particle production but challenging to accomplish using currently available sampling devices. The standalone sampler built during the campaign enabled the execution of robust experimental designs, including sample collection using resin tubes at multiple altitudes on subsequent flights. Following field sampling, resin tubes were transported back to Baylor University for chemical analysis using a Markes International thermal desorption unit coupled with a gas chromatograph-tandem mass spectrometer (Thermo Scientific). The target analyte list includes biogenic and anthropogenic VOCs; see the Results section for more information.

Figure 2. Modular VOC sampler with top and side access panels open. The unit is capable of collecting up to four samples per flight.

Prior to the TRACER IOP, VOC sampler test flights were conducted at ARM's Southern Great Plains atmospheric observatory. The flights highlighted a couple of necessary refinements to the sampler's housing (i.e., increasing the size and number of ports for operator access and additional hardware to provide in-flight stability) that bolstered the sampler's ability to maximize sample collection. A second version of the sampler was deployed to the TRACER ancillary site. However, extreme heat conditions during June and July flights challenged the electronics. Additional exhaust fans and vents were added to the housing to draw heat away from the internal computer and other electronics, which enabled successful flights during the August TBS deployment.

TRACER-Tethersonde allows for an extensive evaluation of the boundary-layer conditions at the S3 Ancillary site. Southerly winds transported relatively clean marine air from the Gulf of Mexico to the TBS site on most days and may provide an estimate of the background conditions to other areas in the Houston-Galveston-Brazoria (HGB) region on those days. In post-frontal conditions, northeasterly or easterly winds could bring more polluted air from the greater Houston area or other sources to the TBS site.

2.0 Results

The VOC sampler designed herein is an automated system to collect ambient air on up to four resin tubes per TBS flight using a time-delayed code. VOC observations were successfully made on 10 TBS flights (21 tubes total) over six days in the August deployment. Flights on 4 August are highlighted in Figure 3 and include meteorological, trace gas, aerosol, and VOC measurements. Our results show variations in the VOC chemical composition over the day. As expected, isoprene is present in all samples; however, the last sample of the day had a much different composition, possibly due to smoke moving through the area. In addition, the total VOC mixing ratio varied with time and decreased at higher altitudes. When paired with in situ gas, aerosol, and boundary-layer height measurements, a detailed analysis of VOC samples will provide insights into gas- and particle-phase interactions.

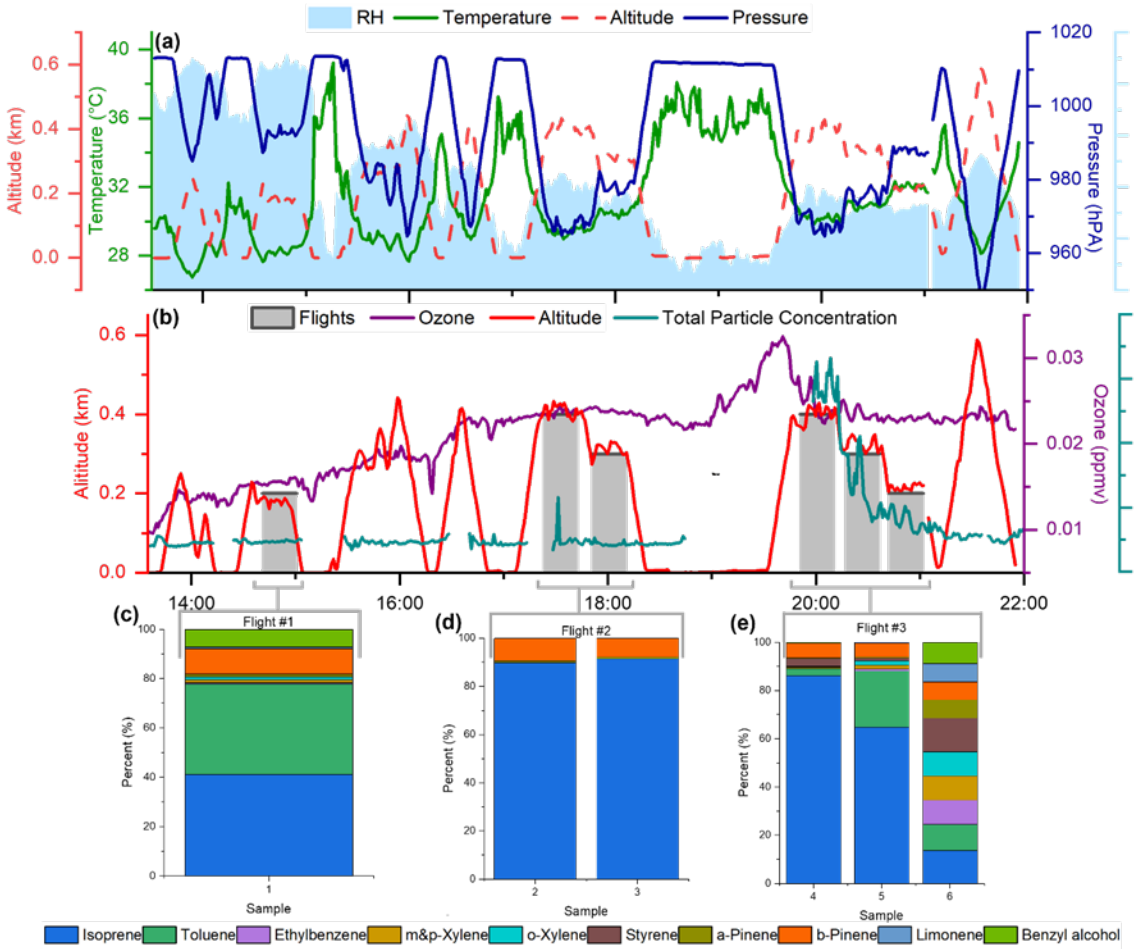

Figure 3. Time series of measured parameters on 4 August 2022. (a) Ambient relative humidity (RH), temperature, and pressure observations with corresponding flight heights from the iMet radiosonde (b) VOC flight times and heights, ozone, and total particle concentration from the portable optical particle spectrometer (POPs) with expanded panels showing observed VOCs on (c) flight #1, (d) flight #2, and (e) flight #3.

Potential future work includes comparing free-release balloon flights from LaPorte, Texas, or other locations in the region concurrent to the TRACER-Tethersonde flights. These data can contribute to our ability to (1) determine the vertical and temporal variability of pollution in the greater Houston area in pre- and post-storm scenarios in terms of exchange between the lower and upper atmosphere and (2) identify potential influences of convective transport using ozone as a tracer to complement meteorological measurements.

Other instrumentation was included on the tether; contact Dari Dexheimer (Sandia National Laboratory) for details (Dexheimer 2018). A portable optical particle spectrometer (POPS) provided counts of aerosols in different size ranges between 0.14-2.5 μm (Gao et al. 2016). An anemometer on the tether also provided wind data. Pairing ozone, aerosol, and, when available, VOC measurements can provide more context for influences in the boundary layer southwest of Houston at the S3 Ancillary site in relation to other measurements, such as those at the first ARM Mobile Facility (AMF1) site in La Porte (southeast of Houston) and TRACER-MAP.

For example, easterly winds transported smoke from fires on the eastern edge of the Bolivar peninsula on 2 September 2022. The POPS measured high aerosol concentrations (> 1500 particles/cc) from the ground to 500 m at around 10 am LT, likely at the top of the mixed layer. Ozone concentrations steadily increased throughout the morning and reached > 60 ppbv at 1 pm LT, well mixed from the surface to 1 km. Heavy precipitation that cleaned the boundary layer followed, as evidenced by a later profile in the early evening with lower ozone concentrations (< 45 ppbv).

3.0 Publications and References

3.1 Publications

A manuscript discussing VOC sampler development and integration into the TBS payload is currently in progress and will be circulated in the ARM/Atmospheric System Research (ASR) newsletter. Measurements from this campaign will also be included in a second planned manuscript discussing VOC observations made at ground sites, on mobile laboratories, and on marine vessels during the TRACER IOP.

3.2 Presentations

Preliminary VOC results were included in the following presentations:

Guagenti, M, S Usenko, R Sheesley, J Flynn, P Walter, D Dexheimer, and C Longbottom. 2022. "Preliminary results from TRACER-Tethersonde." ARM/ASR Principal Investigator meeting. Rockville, Maryland.

Guagenti, M, D Dexheimer, C Longbottom, A Ulinski, J Flynn, R Sheesley, and S Usenko. 2022. "Development of volatile organic compound samplers optimized for use on uncrewed aerial systems and marine vessels." American Geophysical Union Fall Meeting. Chicago, Illinois.

3.3 References

Dexheimer, D. 2018. Tethered Balloon System (TBS) Instrument Handbook . U.S. Department of Energy, Atmospheric Radiation Measurement user facility. DOE/SC-ARM-TR-206. https://doi.org/10.2172/1415858

Gao, RS, H Telg, RJ McLaughlin, SJ Ciciora, LA Watts, MS Richardson, JP Schwarz, AE Perring, TD Thornberry, AW Rollins, MZ Markovic, TS Bates, JE Johnson, and DW Fahey. 2016. "A light-weight, high-sensitivity particle spectrometer for PM2.5 aerosol measurements." *Aerosol Science and Technology* 50(1): 88–99, https://doi.org/10.1080/02786826.2015.1131809

Gu, S, A Guenther, and C Faiola. 2021. "Effects of Anthropogenic and Biogenic Volatile Organic Compounds on Los Angeles Air Quality." *Environmental Science & Technology* 55(18): 12191–12201, https://doi.org/10.1021/acs.est.1c01481

Komhyr, WD. 1969. "Electrical concentration cells for gas analysis." *Annals of Geophys*ics 25: 203–210.

Komhyr, WD. 1986. Operations handbook-ozone measurements to 40-km altitude with Model 4A Electrochemical Concentration Cell (ECC) ozonesondes (used with 1680-MHz radiosondes). National Oceanic and Atmospheric Administration Air Resources Laboratory Technical Memorandum ERL ARL-149.

McKinney, KA, D Wang, J Ye, J-B de Fouchier, PC Guimarães, CE Batista, RAF Souza, EG Alves, D Gu, AB Guenther, and ST Martin. 2019. "A sampler for atmospheric volatile organic compounds by copter unmanned aerial vehicles." *Atmospheric Measurement Techniques* 12(6): 3123–3135, https://doi.org/10.5194/amt-12-3123-2019

Pandis, SN, and JH Seinfeld. 2016. *Atmospheric Chemistry and Physics: From Air Pollution to Climate Change*. John Wiley & Sons, Hoboken, New Jersey.

4.0 Lessons Learned

There were two main challenges for deploying ECC ozonesondes on the TBS. The first was that the ECC ozonesonde must be suspended from the tether, regardless of the angle of the tether, to remain vertically oriented in a nearly upright position as if it were launched from a free-release balloon. Keeping the ECC ozonesonde oriented upright prevents the tipping of the ECC solutions in the cathode and anode cells of the ozonesonde. As shown in Figure 1, the ECC ozonesonde was allowed to hang freely from the tether. The main challenge for the ECC ozonesonde was preventing the instrument from overheating during the summer near Houston. An ECC ozonesonde has a motorized pump that draws ambient air into the cathode cell. To function properly, the pump temperature of an ECC ozonesonde should not exceed 40°C, which proved challenging near the surface in the afternoon. Any ozone data when the ozonesonde pump temperatures exceeded 40°C have been flagged. To assist with this issue, Casey Longbottom (Sandia National Laboratory) made a thin, vented 3D-printed plastic enclosure for the ozonesonde that also included a small fan. Future projects using ozonesondes on a TBS in similar hot environments could further investigate ways to improve this design to keep the instrument cool. Another minor issue is that for the ECC ozonesondes, the day-of-flight lab preparations took place in a trailer with a relative humidity similar to the ambient outside air, which was often much higher in the mornings than in a traditional lab setting. The high relative humidity during the preparation has a minor effect on the ozonesonde's flow rate correction measurement. Later in the campaign, the trailer had air conditioning and was climate controlled.

Many lessons were learned during this campaign, especially during the VOC sampler development. In preparation for TRACER deployment, several in-person meetings were conducted between TBS operators and Baylor University (BU) personnel to discuss 1) integrating the VOC sampler in the TBS payload and 2) creating experimental sampling designs for the campaign. As mentioned above, a preliminary deployment was conducted in April 2022 using an initial version of the VOC sampler. The lightweight housing and standalone power sources provided by Sandia guided BU personnel's sampler design to enable automatic sample collection during TBS flights. During the preliminary flights, BU personnel learned upgrades to the hardware were necessary to account for the tether's vibrations in flight, additional ports were required for operator access to the system for troubleshooting, and a larger battery was necessary to power the system. Therefore, the second version of the sampler was built and deployed during the TRACER IOP. Additional in-field upgrades were made to the unit to enable operation in the extreme heat conditions at the sampling site. Future updates to the VOC sampler on the TBS could build on the existing structure and include more sampling ports to collect more tubes per flight or extend flight time and use the computer in the VOC sampler to automate the sampling of additional species.

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