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Experiment of Sea Breeze Convection, Aerosols, Precipitation, and Environment (ESCAPE) C-band Radar Deployment Field Campaign Report

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Acronyms and Abbreviations

AMF	ARM Mobile Facility
ARM	Atmospheric Radiation Measurement
CHIVO	C-band Hydrological Instrument for Volumetric Observation
CSAPR2	second-generation C-band Scanning ARM Precipitation Radar
CSU	Colorado State University
DOE	U.S. Department of Energy
ESCAPE	Experiment of Sea Breeze Convection, Aerosols, Precipitation, and Environment
IOP	intensive operational period
MAAS	Multisensor Agile Adaptive Sampling
NEXRAD	Next-Generation Weather Radar
NRC	National Research Council of Canada
NSF	National Science Foundation
PPI	plan position indicator
RHI	range height indicator
SPEC	Stratton Park Engineering Company
TRACVER	Tracking Aerosol Convection Interactions Experiment

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1.0 Summary

Convective clouds play a critical role in the Earth's climate system, acting as sinks of total water in the atmospheric column through precipitation, thereby contributing to the atmospheric energy balance. They serve as a primary mechanism for the transfer of heat, moisture, and momentum through the troposphere, significantly impacting the large-scale atmospheric circulation and local environment, and affecting the probability of subsequent cloud formation (e.g., Hartmann et al. 1984, Su et al. 2014, Sherwood et al. 2014). Convective characteristics including convective core size (reflectivity and updraft), cloud lifetime, precipitation intensity, total precipitation amount, precipitation efficiency, and lightning flash rates can be strongly related to environmental factors (e.g., wind shear, humidity). Since cumulus clouds evolve rapidly, their microphysical and dynamical properties and life cycles are challenging to resolve in models, and even in observations (e.g., Fridlind et al. 2017, Ladino et al. 2017).

To methodically advance observation-based understanding of fundamental convective cloud processes and aerosol impacts on these processes, the National Science Foundation (NSF) supported a large field experiment entitled: Experiment of Sea Breeze Convection, Aerosols, Precipitation and Environment (ESCAPE). The overarching scientific objective of ESCAPE is to collect and analyze observations of the fundamental process-level coupling between convective cloud vertical motions (kinematics), microphysics, and precipitation production across a full range of cloud environments (including background aerosol conditions) and meteorological regimes, throughout their life cycle.

ESCAPE took place between 30 May and 30 September, 2022 in Houston Texas. Houston was selected because it frequently experiences isolated deep convection that interacts with the region's mesoscale circulations and its range of aerosol conditions.

ESCAPE focused on collecting observations of isolated deep convection through innovative sampling and on developing novel analysis techniques. This included the deployment of two research aircraft, the National Research Council of Canada (NRC) Convair-580 and the Stratton Park Engineering Company (SPEC) Learjet, which conducted 24 research flights from 30 May to 17 June. On the ground, three mobile X-band radars, and one mobile Doppler lidar truck equipped with soundings, were deployed from 30 May to 28 June. From 1 August to 30 September 2022, a dual-polarization C-band radar system was deployed and operated using a novel, multisensor agile adaptive sampling strategy to track the entire life cycle of isolated convective clouds. Analysis of the observations collected by these platforms has already yielded preliminary findings on how aerosols and environmental conditions impact the convective life cycle.

The NSF-supported C-band radar was the Colorado State University (CSU) C-band Hydrological Instrument for Volumetric Observation (CHIVO), a commercial-grade, dual-polarization Doppler radar capable of collecting measurements of radar reflectivity, mean Doppler velocity, and spectrum width, as well as differential phase shift and differential reflectivity. In the ESCAPE C-band Radar Deployment field campaign proposal submitted to the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) user facility, we proposed to deploy the C-band radar at the first ARM Mobile Facility (AMF1) at the La Porte, Texas airport. The AMF 1 was deployed at the La Porte airport as part of the TRacking Aerosol Convection interactions ExpeRiment (TRACER) field campaign. The TRACER campaign began on 01 October 2021 and extended through 30 September 2022 with an intensive

operational period (IOP) during June-September 2022. During the IOP, the CSU C-band was used to track convective cells. It is only through tracking and measurement of individual convective cells that key processes controlling their properties can be inferred from kinematic and microphysical structures that may be time- and space-lagged with respect to the dynamical and microphysical interactions that act over time.

As part of the TRACER field experiment, the DOE/Atmospheric Radiation Measurement (ARM) user facility deployed the 2nd generation C-band Scanning ARM Precipitation Radar (CSAPR2; Kollias et al. 2020a). The CSAPR2 is a research-grade scanning polarimetric radar that can provide rapid sampling (via tracking) needed to observe the evolution of convective core properties under varying environmental conditions. During the TRACER IOP (06/01/2021-09/30/2021), the CSAPR2 was used to track convective cells. The deployment of the CSU C-band provided a second scanning precipitation radar. The work plan and experimental methods and nature of the measurements were like those of the CSAPR2. Both radars were guided by Multisensor Agile Adaptive Sampling (MAAS), an adaptive sampling algorithm developed by the principal investigator's research group.

Figure 1. The CHIVO radar deployed at the AMF1 site during ESCAPE.

During the IOP, the CHIVO was configured for a maximum unambiguous range of 125 km and a range gate spacing of 150 m. Note that during the TRACER and ESCAPE campaigns, the CHIVO radar was not allowed to transmit in the general direction of the CSAPR2 radar as mandated by local airport operations. The CHIVO's sampling sector is indicated by the red dashed pie depicted in Figure 2. Unlike the CSAPR2 radar, the CHIVO radar's native software by Vaisala does not require scan strategies to be predetermined. In other words, it can be given scan commands on the fly, thus offering great flexibility. That said, the access policy of the CHIVO radar's home institution required us to communicate commands and data through an intermediate server, which by its nature introduced timing latencies that prevented precise knowledge of radar state. This forced a more open-loop mode of operation than with the CSAPR2 and an inability to synchronize commands for new scans with the completion of prior scans. As a result, we found it most efficient to have the CHIVO radar mirror the scans of CSAPR2 rather than operating autonomously (Lamer et al. 2023).

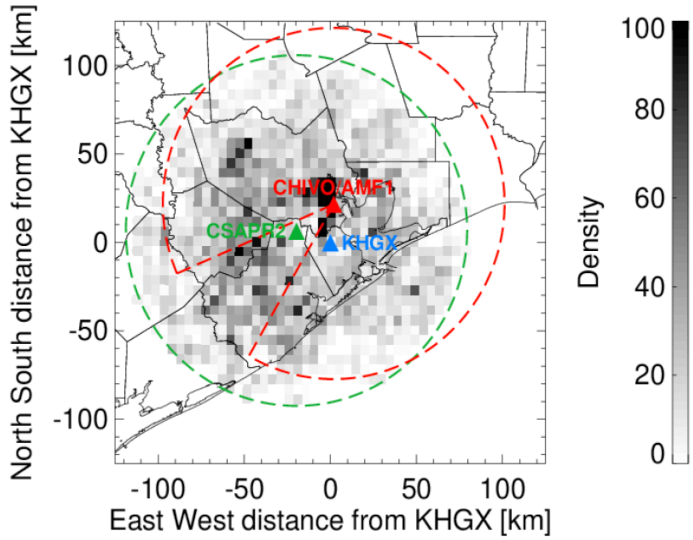

Figure 2. Map of the domain considered by MAAS with the location of the KHGX Next-Generation Weather Radar (NEXRAD) (blue marker), the CSAPR2 radar (green marker), and the CHIVO radar at the AMF1 site (red marker). Overlaid is the spatial distribution of the cells sampled by the CSAPR2 radar under MAAS guidance, noting that the CHIVO radar sampled only the subset of these cells that occurred after its installation in Houston. Adapted from Lamer et al. 2023.

2.0 Results

Kollias et al. (2020) introduced the MAAS methodology, which leverages observations external to the "dedicated" radar (e.g., satellite and cameras) to enable the tracking of features that are upwind or elevated beyond the sector of the "dedicated" radar and/or that are altogether not detectable by radar (e.g., lightning). MAAS also enables the tracking of fast-evolving processes and/or short-lived systems by eliminating the need for the "dedicated" radar to perform its own surveillance to gain situational awareness. During TRACER and ESCAPE, the two C-band radars were operated using a modified version of the MAAS framework (Lamer et al. 2023). This new iteration of MAAS includes the addition of a finessed cell tracking and advection module as well as of two edge computing client modules tailored to the CSAPR2 and the NSF-supported CHIVO radar.

During the IOP period of the TRACER and ESCAPE campaigns (June 01-September 30, 2022) scientist assessment of the daily forecast was used to decide if MAAS would be employed to guide the CSAPR2 to track isolated convective cells on any given day. In the 680 hours it operated, MAAS identified a total of 245,267 cells in the NEXRAD observations within a 250x250-km domain centered around the CSAPR2 location in Houston (the domain pictured in Figure 2). Most of the cells were identified and tracked in August and September and over 50% lasted less than 10 minutes (Figure 3 top panel; black bar).

Of those cells, 1,337 were selected for tracking by the CSAPR2 radar. 53% of the convective cells tracked by the CSAPR2 were tracked for more than 15 min and 25% of the cells were tracked for more than 30 min (Figure 3 top panel red bars). Tracking was performed automatically 80.19% of the time, leading to the collection of 17,708 CSAPR2 scan bundles, most of which were collected in the late afternoon (Figure 3 bottom panel; difference between the red and blue bar).

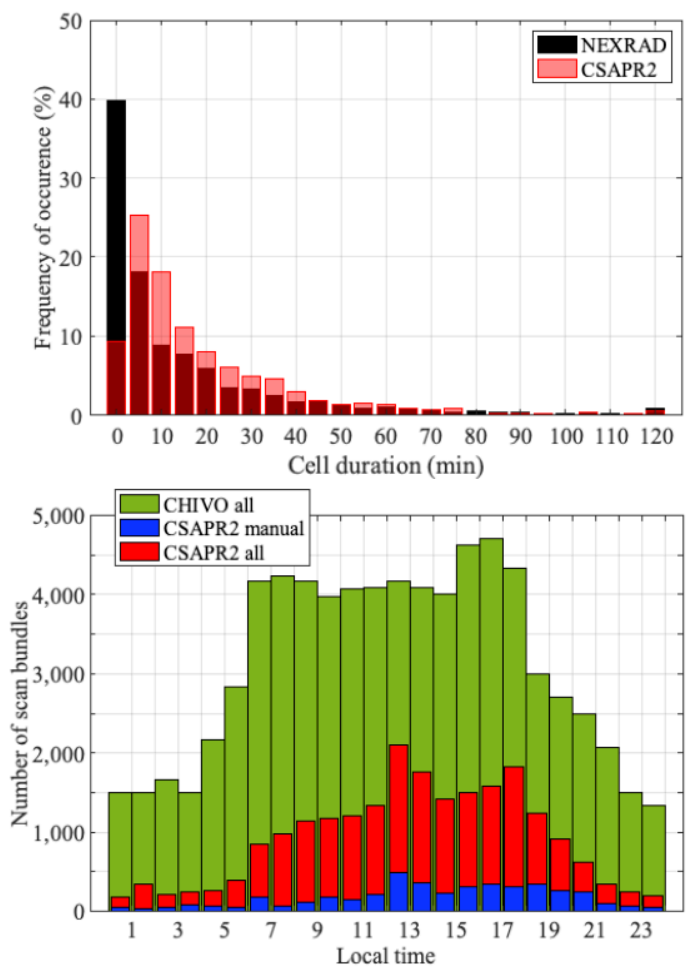

Figure 3. Top panel: Distribution of cell duration observed by the NEXRAD (black bars) and by the CSAPR2 (red bars) during the campaigns. Bottom panel: number of scan bundles collected by the CHIVO (green bars) and the CSAPR2 (red bars) during the entire campaign and the subset of CSAPR2 scan bundles acquired using super-user input to the MAAS framework.

The other 19.81% of the time, MAAS relied on super-user input to select cells for tracking, leading to the collection of 4,332 CSAPR2 scan bundles, most of them collected in the afternoon (Figure 3, bottom panel blue bars). Every CSAPR2 scan bundle includes three plan position indicators (PPIs) and four-six range height indicators (RHIs). The CHIVO came online on August 01, 2022 and operated through September 30, 2022. CHIVO mostly operated based on guidance from CSAPR2, thus sampling the same cells from a different viewing angle. Exceptions to that occurred when the “selected cells” were within the CHIVO blanking sector (then CHIVO operated under “lightning mode”) and when CSAPR2 was not under the guidance of MAAS, yet a super-user input was online to provide input. CHIVO collected a total of 75,730 scan bundles, most of them in the daytime (Figure 3 bottom panel green bars). Each CHIVO scan bundle includes 3-4 RHIs. This CSAPR2 and CHIVO data set constitutes the largest to-date database of radar observations of isolated convective cells.

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