Review of manuscript egusphere-2024-2984

Title: Shallow cloud variability in Houston, Texas during the ESCAPE and TRACER field experiments

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Summary:

The authors use a multi-sensor data fusion approach to analyze the partition the cloud coverage and precipitation fraction from shallow and deep convective clouds observed over the Houston region during the TRACER and ESCAPE field campaigns between June and September 2022. The authors adopt a novel and creative methodology to differentiate between shallow and deep convective clouds while making use of NEXRAD and KAZR reflectivity data to estimate the diurnal variability in spatial coverage, cloud top height, and precipitation fraction of shallow and deep convective clouds. Using a clustering method, the authors identify four dominant modes of shallow convection wherein each cluster contains far more non-precipitating clouds, with a larger number of these nonprecipitating shallow clouds occurring over water. The manuscript is well-organized, and the results are generally presented coherently. However, the results and discussion sections rely heavily on exact percentages, which could disrupt the reading flow. The authors omit certain technical details and inherent assumptions of the scientific methods described in the methodology section that could be clarified in a revised version of the manuscript. A major assumption in this study is that meteorological characteristics—such as relative humidity, wind speed and direction, and cloud top temperature at AMF1—are inherently mapped to shallow and deep convective clouds across the entire 250 km x 250 km domain. This "critical" assumption should be explicitly acknowledged in the methodology and addressed in the discussion of the results, especially when other studies from the TRACER field campaign have explicitly quantified the mesoscale environmental variability across the sea breezes. Otherwise, the manuscript is in a good shape and within the scope of ACP, except for a few sections where more details or clarifications can be added to improve the quality of the manuscript. My recommendation is for major revision, and I encourage the authors to consider my feedback to address the concerns in the comments provided below:

<u>Major comments:</u>

1. **Lines 50-52**: This discussion is completely irrelevant for the purposes of this study. Please consider removing this.
2. **Lines 54-67:** The authors seem to overlook a key point regarding Houston's suitability as a site for the TRACER and ESCAPE field campaigns. This discussion becomes muddled with unnecessary details on mechanisms affecting cloud properties in the following paragraph since none of those are the focus of this study. I suggest reorganizing the paragraph to highlight the main points outlined in Fridlind et al. (2019), emphasizing Houston's unique advantages in the context of a relatively strong aerosol perturbation driven by mesoscale shallow circulations from the Gulf of Mexico sea breeze and Houston-Galveston Bay breeze. Additionally, the summer-time 500-hPa ridge pattern

leads to synoptically weak large-scale forcing that increases the likelihood of a diurnal convective cycle associated with the onshore flow. You may also want to refer other studies relevant to the TRACER field campaign, such as Wang et al. (2024) and Sharma et al. (2024).

References:

1. Fridlind, Ann M., et al. "Use of polarimetric radar measurements to constrain simulated convective cell evolution: A pilot study with Lagrangian tracking." Atmospheric Measurement Techniques 12.6 (2019): 2979-3000.
2. Wang, Dié, et al. "TRACER Perspectives on Gulf-Breeze and Bay-Breeze Circulations and Coastal Convection." *Monthly Weather Review* 152.10 (2024): 2207-2228.
3. Sharma, Milind, et al. "Observed Variability in Convective Cell Characteristics and Near-Storm Environments across the Sea-and Bay-Breeze Fronts in Southeast Texas." *Monthly Weather Review* 152.11 (2024): 2419-2441.

3. **Lines 69-87:** I recommend removing the discussion on aerosols, convective initiation, rainfall anomalies, urban dynamics, and the urban heat island effect, as these topics are outside the study's primary focus. Instead, consolidate this paragraph by integrating the relevant discussion on sea breeze circulations and shallow convection with the previous paragraph.
4. **Lines 101-103:** The italicized text summarizing the main objective of this study is a bit misleading. The authors do not characterize the control of aerosols (and to some extent even meteorology) in this study. The only meteorological variables analyzed include the relative humidity, and wind speed and direction. There is no discussion on convective instability (CAPE), inhibition (CIN), large-scale vertical velocity, among others, e.g., refer Marquis et al. (2023). I suggest rephrasing this sentence to make it more aligned with the main goals of this study.

References:

1. Marquis, James N., et al. "Near-cloud atmospheric ingredients for deep convection initiation." *Monthly Weather Review* 151.5 (2023): 1247-1267.

5. **Lines 109-110:** I am not quite sure what the authors mean by 'Days with deep clouds are identified and ignored…' Aren't Figs. 4,5,6,8,9, and 10 comparing the deep convective cloud activity over the domain? Additionally, do the authors not account for precipitation from deep convection to arrive at the frequency of occurrence of precipitation at AMF1(2.2%)? Please clarify or revise as needed.

6. **Lines 123-128:** If the variables mentioned here were primarily used as part of the INTERPSONDE VAP, then please revise and cite the correct product documentation reference.

7. **Lines 130-135:** Please mention the gate spacing and temporal resolution of KAZR radar reflectivity data.

8. **Lines 141-154:** Please mention the gate spacing, VCP mode, and average temporal resolution of the KHGX observations.

9. **Lines 150-154:** Sudden transition to 'three-dimensional gridded KHGX radar data' and without prior context and lack of details regarding the quality control steps. Additionally, the purpose of two different types of radar data, i.e., polar coordinate (native) and gridded radar data is not specified. Please revise.

10. **Lines 155-170:** Please include the temporal resolution of GOES-R ABI data products.

11. **Line 178:** Please include the spatial extent of the analysis domain in terms of the latitude and longitude of the lower left and upper right corners of the encompassing box.

12. **Lines 180-181:** How are categorical data such ACM classification of cloudy or non-cloudy pixel gridded onto a 500 m grid?

13. **Line 223:** Which precipitation type categories were included in this calculation? Both drizzle and raindrops?

14. **Line 227:** I am assuming that the KHGX CAPPI was chosen to be at 1.5 km ARL to ensure greater spatial coverage, but using the same argument as provided in lines 239-242, reflectivity at 1.5 km could be an inflated when some droplets evaporate between surface and 1.5 km. I am wondering how this might affect the KHGX reflectivity threshold and subsequent analysis.

15. **Line 228:** Why were the reflectivity values confined to the -10 to 60 dBZ range? Additionally, line 262 mentions that the 10 dBZ threshold still contains a considerable amount of nonmeteorological scatterers. Why use the -10 to 10 dBZ range then? Why not, just 10 to 60 dBZ range?

16. **Lines 245-247:** I am not sure why the histogram for KAZR reflectivity values matters for the analysis. Was it being used to inform the KHGX reflectivity threshold?

17. **Lines 271-287:** It is not obvious to me how the authors avoided mislabeling or misclassification of shallow and deep clouds using the cloud mask and cloud-top temperature products. In a hypothetical scenario, a cloudy pixel may be assigned to a cirrus cloud which is high enough in the troposphere to meet the cloud-top temperature threshold of < -5 deg C. Will that be classified as a deep cloud then? A similar misclassification can be imagined for a shallow cloud case. How were such cases avoided during this analysis. This information needs to be included in the methodology section.

18. **Lines 280-282:** Since the analysis domain is 250 km x 250 km, I am wondering how representative is the AMF1 sounding for clouds hundreds of kilometers away from the AMF1 site.

19. **Line 339:** Which high-resolution data are being talked about here? Similarly, what does all data in line 344 mean?

20. **Lines 356-359:** I disagree that cluster 1 and 4 have a similar evolution of shallow cloud fraction. While cluster 1 has a steady growth through early through and peaks around mid-afternoon before it declines, cluster 4 has a much more rapid growth right before the peak mid-afternoon and then becomes steady for the rest of the day.

21. **Lines 409-410:** It is difficult to figure out the peaks in Fig. 10g (over water) since the absolute magnitude is very small and there are multiple peaks.

22. **Line 421:** I would argue that the subsequent analysis presented in this section is not adequate to comment on what controls the shallow-to-deep transition. Please consider removing or rephrasing this sentence.

23. **Lines 435-437:** This sentence sounds quite vague, especially because there is no supporting analysis to back it up. Please consider removing or rephrasing it.

24. **Lines 439-461:** As pointed out in the summary above, assuming uniform meteorological conditions for convective clouds across the entire domain (and all four clusters) is problematic. Studies by Wang et al. (2024) and Sharma et al. (2024) demonstrate significant mesoscale variability around Houston—variability that motivated the TRACER and ESCAPE field campaigns. Additionally, the authors base this study's motivation on Houston's role as a natural laboratory for examining environmental and aerosol perturbation effects on shallow cloud evolution. I recommend incorporating additional TRACER radiosonde and profiling observations to assess meteorological variability across the four clusters.

25. **Lines 460-461:** As with the effects of humidity profile discussed above, can the authors offer some physically reasonable explanation for the wind effects on the characteristic differences across the clusters?

26. **Line 477:** Can the authors support their statement regarding 'stable marine boundary layer' using observed profiling/radiosonde data?

27. **Lines 491-492:** Same comment as above. Is the boundary layer stability a guess or a finding supported by observations?

28. **Line 500:** Why was the analysis changed from pixel-level data to a 10 km x 10 km box?

29. **Lines 528-532:** This discussion is irrelevant to the analysis, results, and prior discussion. Please consider removing it to avoid potential confusion.

30. **Lines 546-547:** This motivation should have been provided while introducing the cluster analysis in the results section as well.

31. **Lines 549-550:** Same comment as comment 29 above. This sentence is vague since none of the analysis presented in this study can help isolate the role of sea breeze circulation on shallow cloud properties. Please consider removing or rephrasing it.

32. **Lines 553-554:** How are the authors sure that stronger updrafts are driven by surface and aerosol properties? Is it possible that the terrain is higher in that region? Is it possible that the clouds over that region were part of a synoptic-scale system over the Gulf of Mexico that were often advected over land during the day?

33. **Lines 560-567:** Is this paragraph meant to serve as a direction for future work? If not, it sounds quite vague. Either way, I suggest rephrasing it to make the intention clear or remove it altogether.

34. **Lines 643-645:** It would be helpful to add URLs to the specific GOES-R ABI products used in this study. Also, are the authors planning to share the quality controlled KHGX data generated during MAAS cell tracking?

Minor comments:

1. **Line 94:** favors the subsequent development…

2. **Line 132:** Suggest replacing 'radar Doppler moments' with 'moment of the Doppler spectrum.'

3. **Line 137:** Suggest replacing 'counteracts' with 'complements.'

4. **Line 149:** This sentence has insufficient details about which 'two mechanically scanning radars' are being talked about.

5. **Line 151:** 'MAAS activities' sounds odd. Please revise to something like 'MAAS cell tracking analysis' or something similar.

6. **Line 164:** Is IGFOV different from IFOV. Please expand or revise this acronym.

7. **Lines 166-167:** Please specify the purpose for using reflectance and brightness temperature data here as well.

8. **Line 192:** Does that mean that the KHGX analysis region is a circle with diameter 225 km?

9. **Line 203:** Please use a consistent terminology to describe the data products. Either use 'cloud boundaries' or 'hydrometeor layer boundaries' if both these terms are being used interchangeably. If not, then please define them separately.

10. **Line 207:** Suggest using a specific time range instead of 'Early on…'

11. **Line 213:** May want to specify that two radars being discussed are KHGX and KAZR.

12. **Line 215:** Suggest rephrasing '…usage as surveillance' as '…usage for surveillance.'

13. **Line 217:** '…that can be~~en~~ used…'

14. **Line 245:** '… KAZR radar reflectivity values at 160 m AGL…'

15. **Line 255:** Please specify the furthest range.

16. **Line 260:** Please cite the relevant source for the Z-R relationship.

17. **Line 281:** Please specify the reflectivity threshold used to define the echo-top height.

18. **Lines 373-376:** Suggest moving this sentence to line 372 before 'C1 and C4…' to maintain continuity of discussion regarding clusters 2 and 3.

19. **Line 385:** 'C4 ~~even~~ has this feature…'

20. **Line 420:** 'Given these two clusters feature…'

21. **Line 445:** What does 'these afternoon hours' refer to?

22. **Line 518:** Typo error: 'figure 11d' should be 'figure 13d' instead.

23. **Lines 521-522:** This is a standalone sentence with no prior context. Please add more context or consider removing it.

24. **Line 548:** Suggest replacing 'healthy' with 'robust' or something similar.

25. **Line 614:** Please specify the highest precision value.

26. **Line 940:** '…grid point over ~~the~~ TRACER AMF1.'

Figures:

1. **Figures 1,4,13,14,15:** A negative sign in front of longitude values indicates locations east of the Prime Meridian. I suggest either removing the negative sign from longitude values or omitting [°W] from the x-axis labels to avoid redundancy.

2. **Figure 1:** Suggest specifying that the KHGX pixels are confined to a 112.5 km range for the KHGX radar in the figure caption. The locations/sites depicted through markers should also be specified either directly in the plots or specified in the caption.

3. **Figure 2:** It may be helpful to add information regarding the set of elevation angles used in panel plot (a). Suggest replacing 'radar' with 'KAZR' in line 937.

4. **Figure 4:** The reflectivity data in panel plot (f) shows some convective cells in the region close to the coast which was masked out for analysis. Can the authors clarify what's going on here?

5. **Figure A1:** In the panel plot (a), does MPL CBH mean the same thing as AMF1 ARSCL product? If so, then use one term to be consistent.