Environmental Controls on Aerosol-Induced Changes in Convective Cloud Updraft Velocities

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Introduction

Aerosols function as cloud condensation nuclei (CCN) and have been shown to invigorate convective cloud updraft velocities in prior studies.[1]

Environmental conditions (convective available potential energy (CAPE), wind shear, and entrainment) can modify vertical updraft velocities.

Aerosol influences on convective updraft velocities have been shown to be dependent on these environmental conditions.

Motivation and Goals

Aerosols influence cloud microstructure, precipitation formation, atmospheric circulation systems, and radiative energy budgets.[2]

Invigoration is crucial for climate because changes in convective intensity influence convective vertical transport, precipitation, and radiative effects.[3]

Previous work primarily used idealized simulations to understand aerosol interactions in deep convective clouds. Our work uses real case simulations, which realistically represent cloud and precipitation processes, to answer the following core science questions:

- How do cloud updraft velocities depend on aerosol concentrations for a range of environmental conditions?
- What is the dependence of aerosol-induced changes in convective cloud updraft velocities on environmental conditions?

Data and Methodology

Simulation Database:

- Over 400 real-case simulations are used to relate increasing aerosol concentration to changes in updraft velocity and relate these changes to CAPE, shear and entrainment
- 2 aerosol scenarios: "clean": 200 cm^{-3} and "polluted": 1000 cm^{-3}
- Simulations are made by combining models, cloud microphysics schemes, PBL schemes and an aerosol scenario over 10 days
  - Models for simulated initial/boundary conditions: GFS, NAM, HRRR
  - Cloud microphysics schemes: P3, Morrison, Thompson, Milbrandt
  - PBL schemes: MYNN-EDMF, YSU

Analysis Framework:

- Compute w_{max} in each column of the model domain for each simulation at 22Z and find 99.9th percentile w_{max} for each simulation
- Extract CAPE, shear and entrainment values at the location of the 99.9th percentile w_{max} value at 16Z
- Compute sensitivity of updraft velocity to aerosols: $\Delta w = w_P - w_C$ where w_P is updraft velocity in a polluted environment and w_C is updraft velocity in a clean environment
- Compute relative change in updraft velocity: $\frac{w_P - w_C}{w_C}$
- Use Pearson correlation coefficient (r) to assess strength of relationship of aerosols on updraft velocity
- Use fraction of variance explained (r^2) to assess how much of the variation in Δw can be explained by CAPE, shear or entrainment
- Use bias to assess difference between CAPE, shear, and entrainment produced in clean and polluted simulations

Results

1) Dependence of convective cloud updraft velocities on aerosol concentrations for a range of environmental conditions

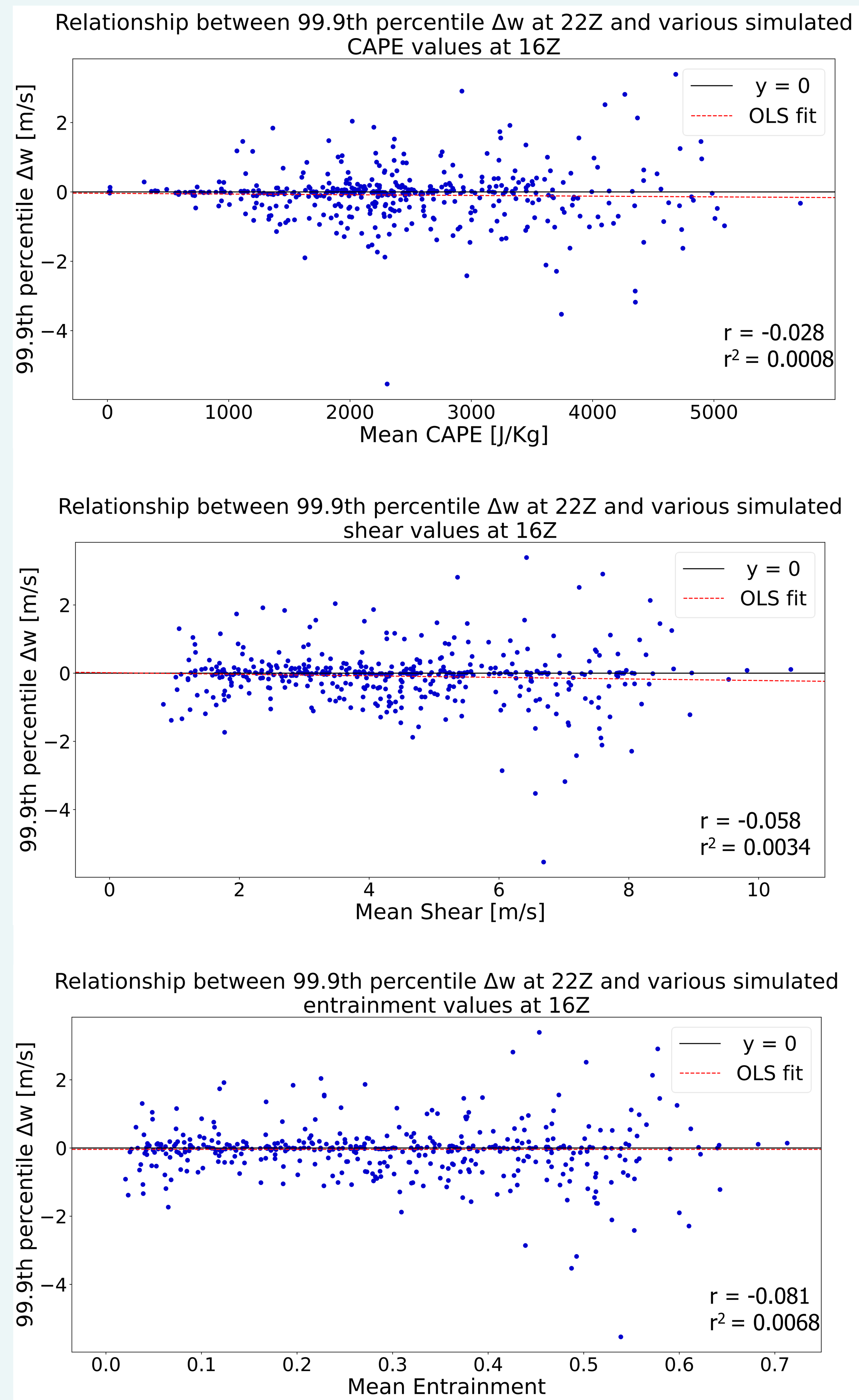
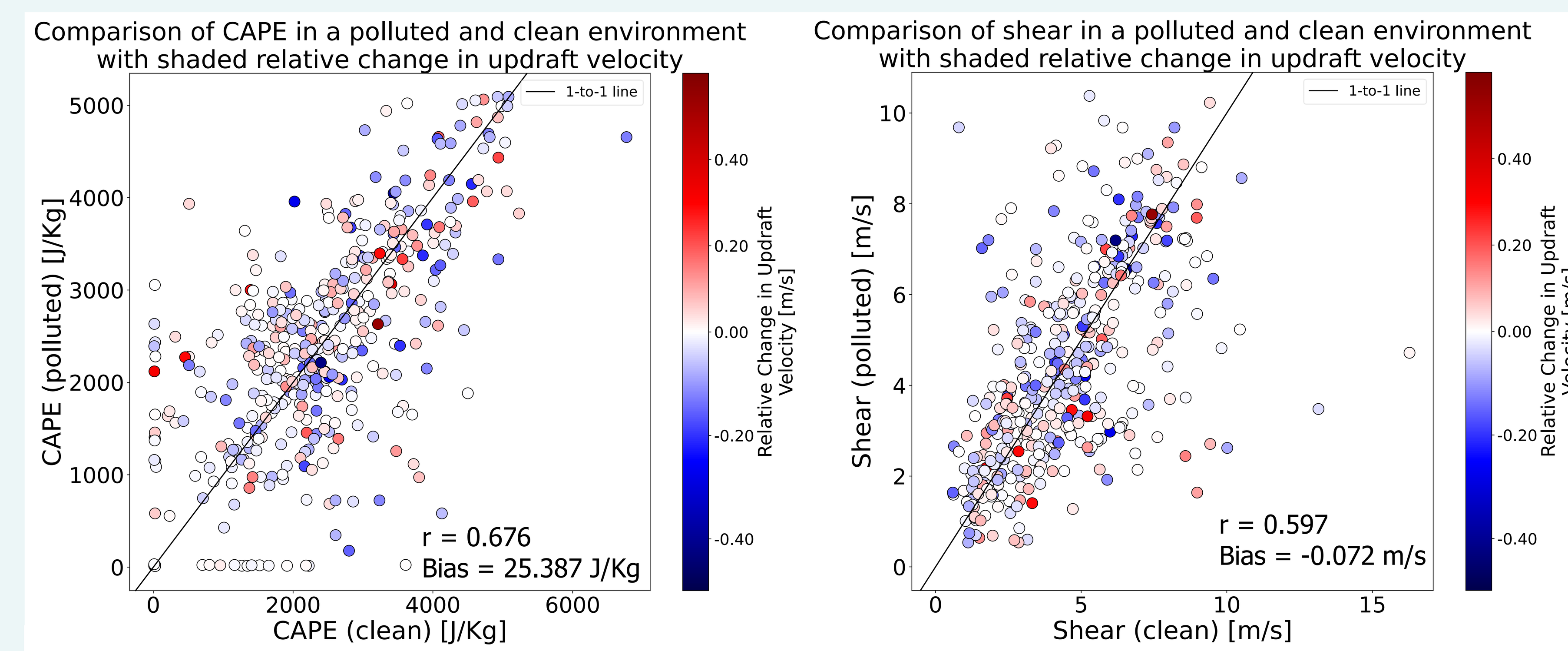
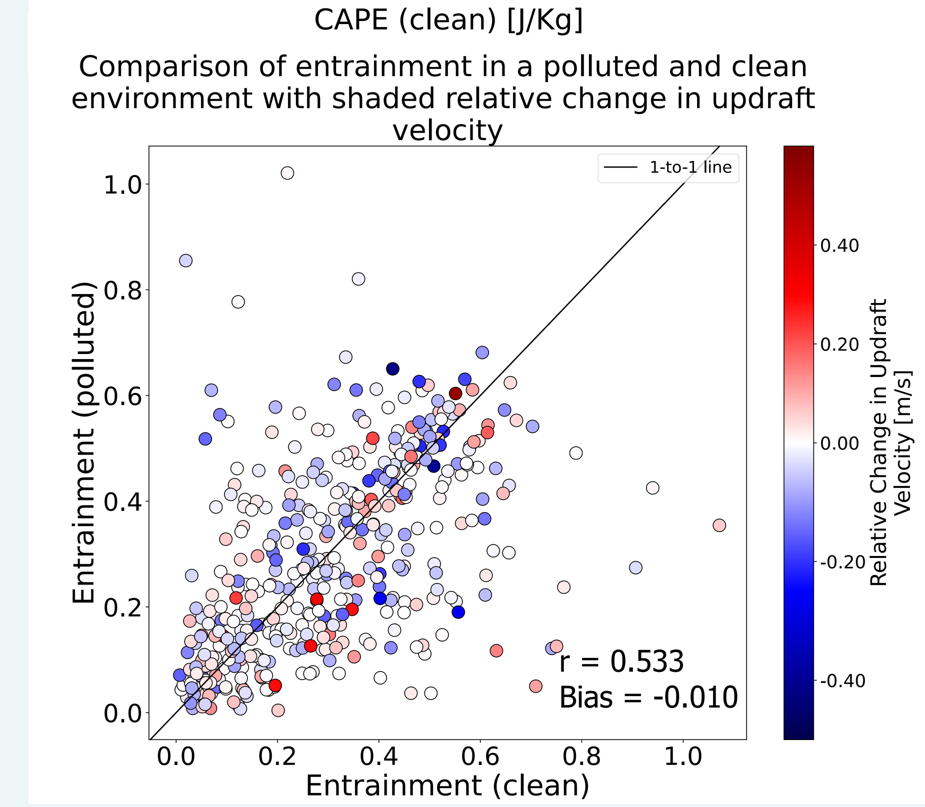


Figure 1: Correlation between sensitivity of updraft velocity to aerosols and CAPE (top), shear (middle) and entrainment (bottom).

No trend in updraft invigoration for smaller/larger CAPE, shear or entrainment.

2) Dependence of aerosol-induced changes in convective cloud updraft velocities on environmental conditions

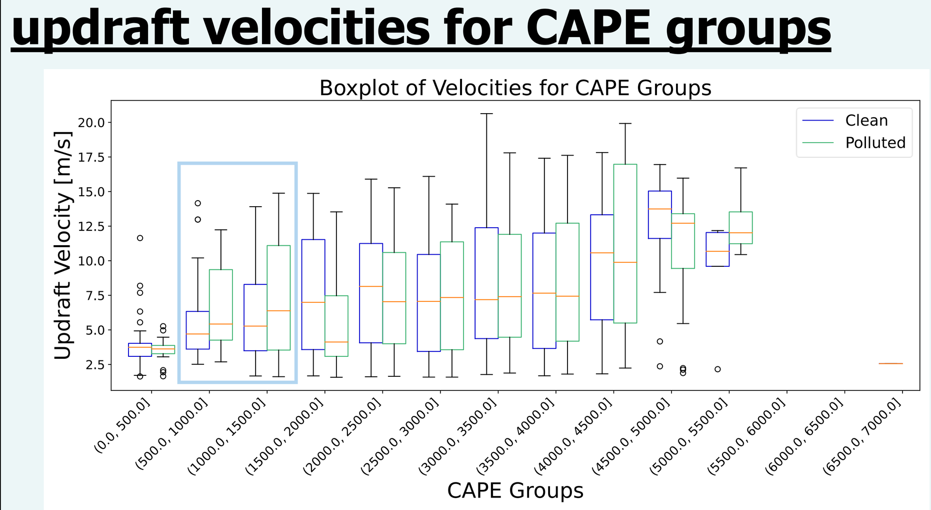




- ***Larger relative change in updraft velocity for larger CAPE and shear***
- ***No difference in the relative change in updraft velocity for entrainment***
- ***No trend in the sign of the relative change in updraft velocity for CAPE, shear or entrainment***

Figure 2: Scatterplot showing how relative changes in updraft velocity vary with CAPE (top left), shear (top right) and entrainment (bottom left) in clean and polluted scenarios.

3) Comparison of clean and polluted updraft velocities for CAPE groups



- ***On average, updrafts in the polluted simulations were higher than in the clean simulations for select CAPE groups***
- ***Equivalent comparisons for a range of shear and entrainment values were inconclusive***

Figure 3: Boxplot comparing the distribution of updrafts in clean and polluted simulations for a range of CAPE groups.

Conclusion

- Response of updraft velocity to a polluted environment is largely independent of the environmental conditions, except for low-CAPE conditions, in this study.
- Future work should investigate additional environmental conditions, analyze these across more times, and track individual storm cells.

Acknowledgements

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References

1. Igel, A. L., and S. C. Heever, 2021: Invigoration or Enervation of Convective Clouds by Aerosols? *Geophysical Research Letters*, 48, https://doi.org/10.1029/2021gl093804.
2. Rosenfeld, D., and Coauthors, 2014: Global observations of aerosol-cloud-precipitation-climate interactions. *Reviews of Geophysics*, 52, 750–808, https://doi.org/10.1002/2013rg000441.
3. Varble, A. C., A. L. Igel, H. Morrison, W. Grabowski, and Z. J. Lebo, 2023: Opinion: A critical evaluation of the evidence for aerosol invigoration of deep convection. *Atmospheric Chemistry and Physics*, **23**, 13791–13808, https://doi.org/10.5194/acp-23-13791-2023.

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