An LES Study of the Nonlocal Effect of Convective Buoyancy

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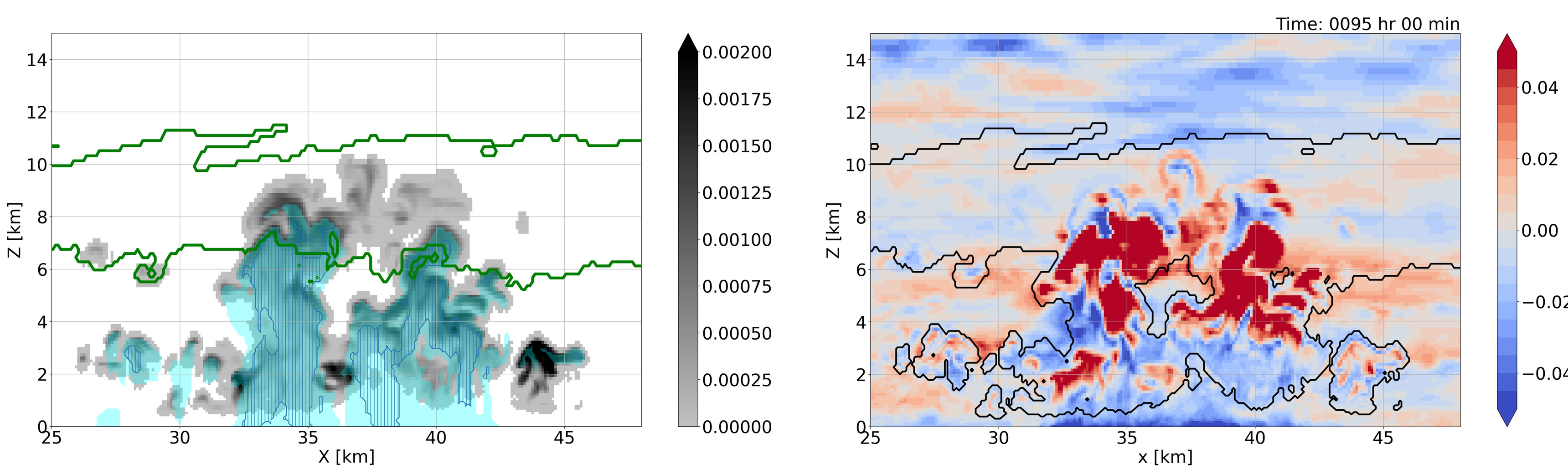
Abstract

The convective dynamics in cumulus clouds can be driven by the buoyancy structures, which can range from simple isolated thermal bubbles to organized thermal-chain systems. The dynamic response of convective updraft to the convective buoyancy could be quite complicated due to the strong local turbulence. Our research aims to identify a characteristic length scale for the nonlocal effect of convective buoyancy using a coarsening approach. To achieve this goal, we performed a large-eddy simulation (LES) using a VVM with a 100 m horizontal resolution. Gaussian convolution was applied in various scales to the buoyancy field as a coarsening method, smoothing high-frequency turbulence and preserving buoyant thermal structures in both shallow and deep convection. Quantifying these structures enables determination of the characteristic length for various convection types. Additionally, our research also focuses on uncovering the coherent structure of the convection in response to the buoyancy field, potentially yielding a universal characteristic governing dynamic inflow across different convection scales.

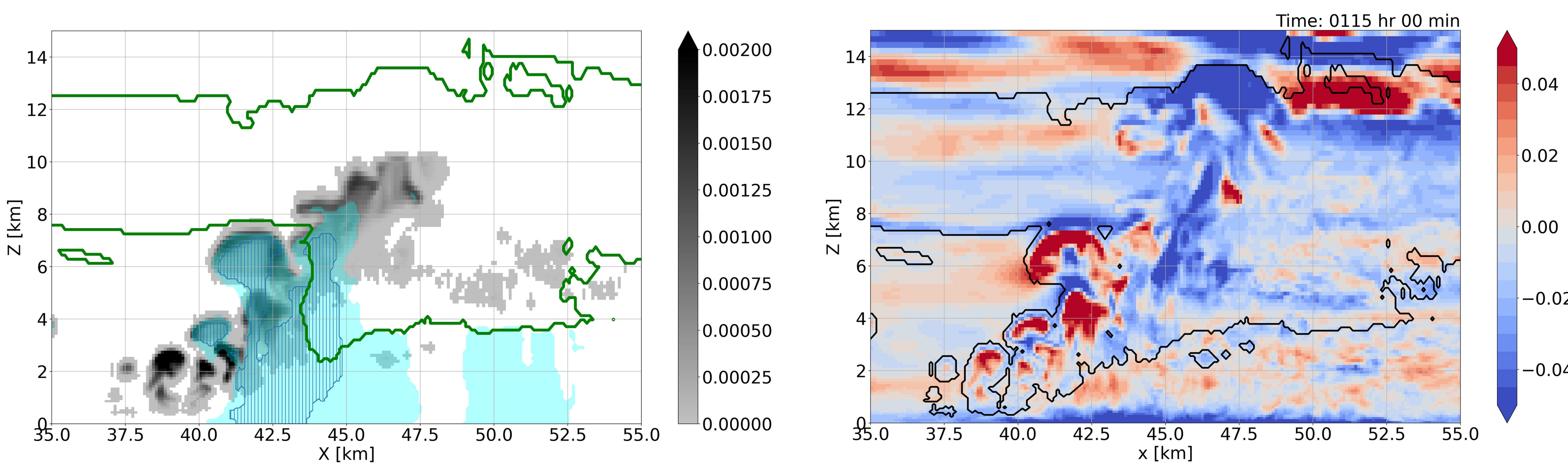
Diverse Convective Cloud Types

- Increasing the resolution of CRM transforms our understanding of convection from basic conceptual models like steady-state plumes and rising thermals to a more complex structure like a thermal chain-like structure [Morrison et al., 2020].

Plume



Thermal Chain-like

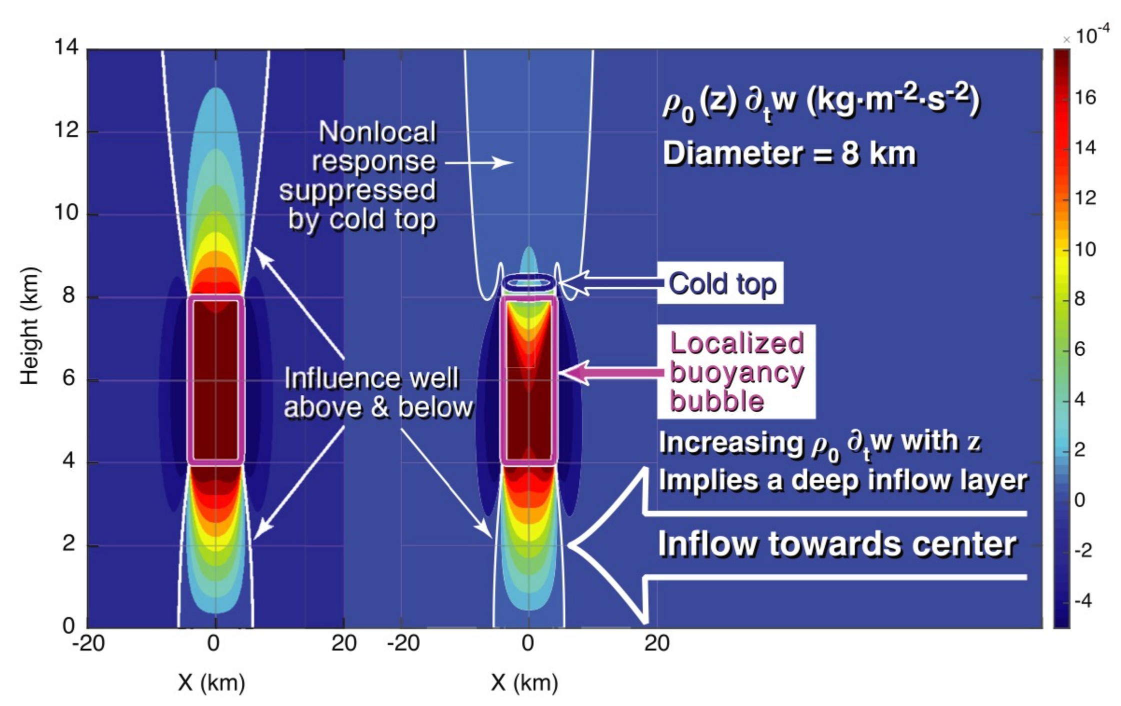


The Nonlocal Effect of Convective Buoyancy

- The dynamic response to buoyancy can be diagnosed:

$$\nabla_h^2 a + \frac{\partial}{\partial z}\left[\frac{1}{\rho_0}\frac{\partial}{\partial z}(\rho_0 a)\right] = \nabla_h^2 B + D$$

where a is the Eulerian vertical acceleration, B is the buoyancy, and D is a quadratic function of spatial derivatives of velocity (vanishes when u = 0) [Kuo and Neelin, 2022].



The nonlocal response of a thermal bubble [Kuo and Neelin, 2022]

Reference

Kuo, Y. H., & Neelin, J. D. (2022). Conditions for convective deep inflow. *Geophysical Research Letters*, *49*(20), e2022GL100552.

Morrison, H., Peters, J. M., Varble, A. C., Hannah, W. M., & Giangrande, S. E. (2020). Thermal Chains and Entrainment in Cumulus Updrafts. Part I: Theoretical Description. Journal of the Atmospheric Sciences, 77(11), 3637- 3660. https://doi.org/10.1175/Jas-D-19-0243.1

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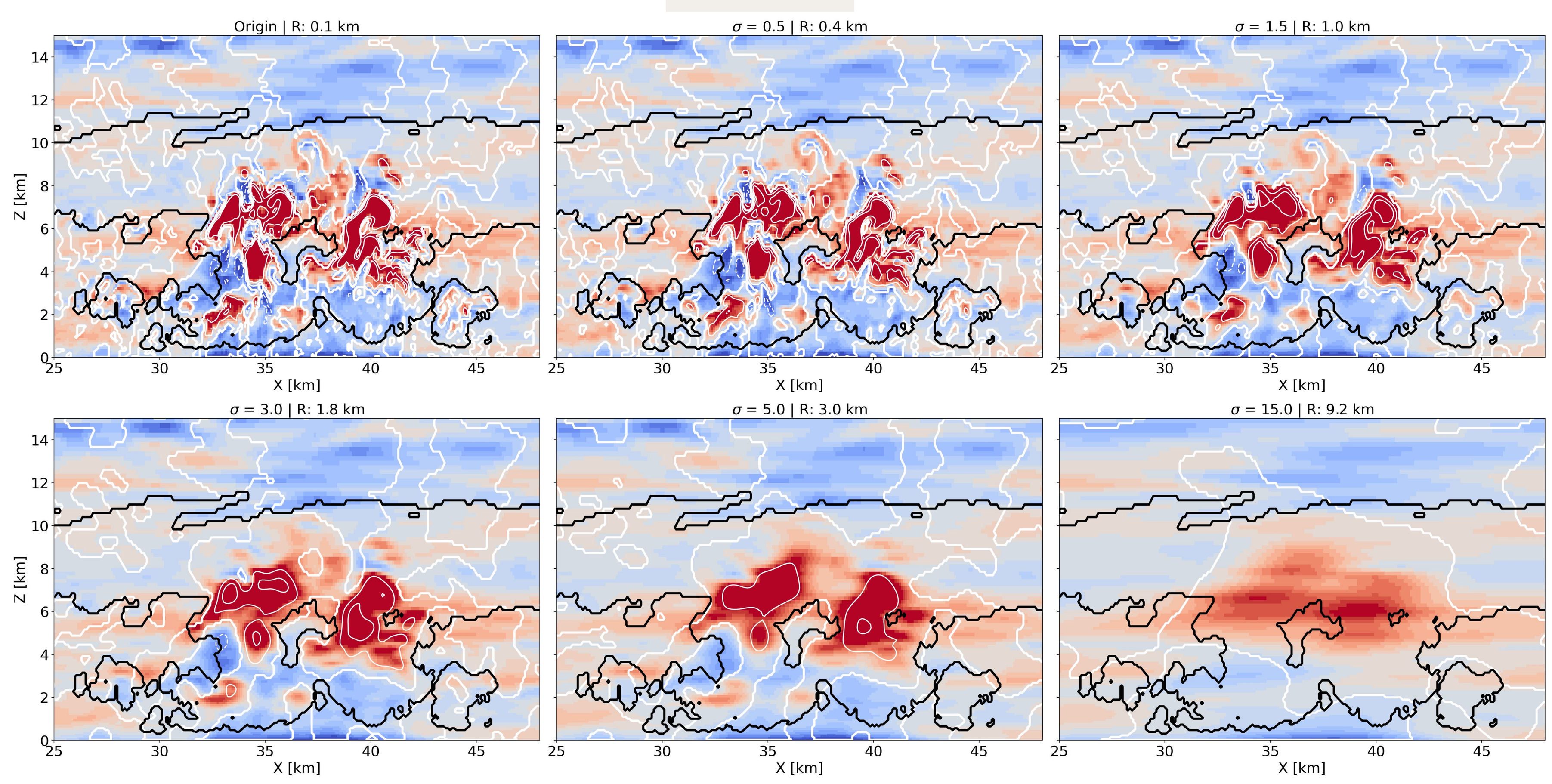
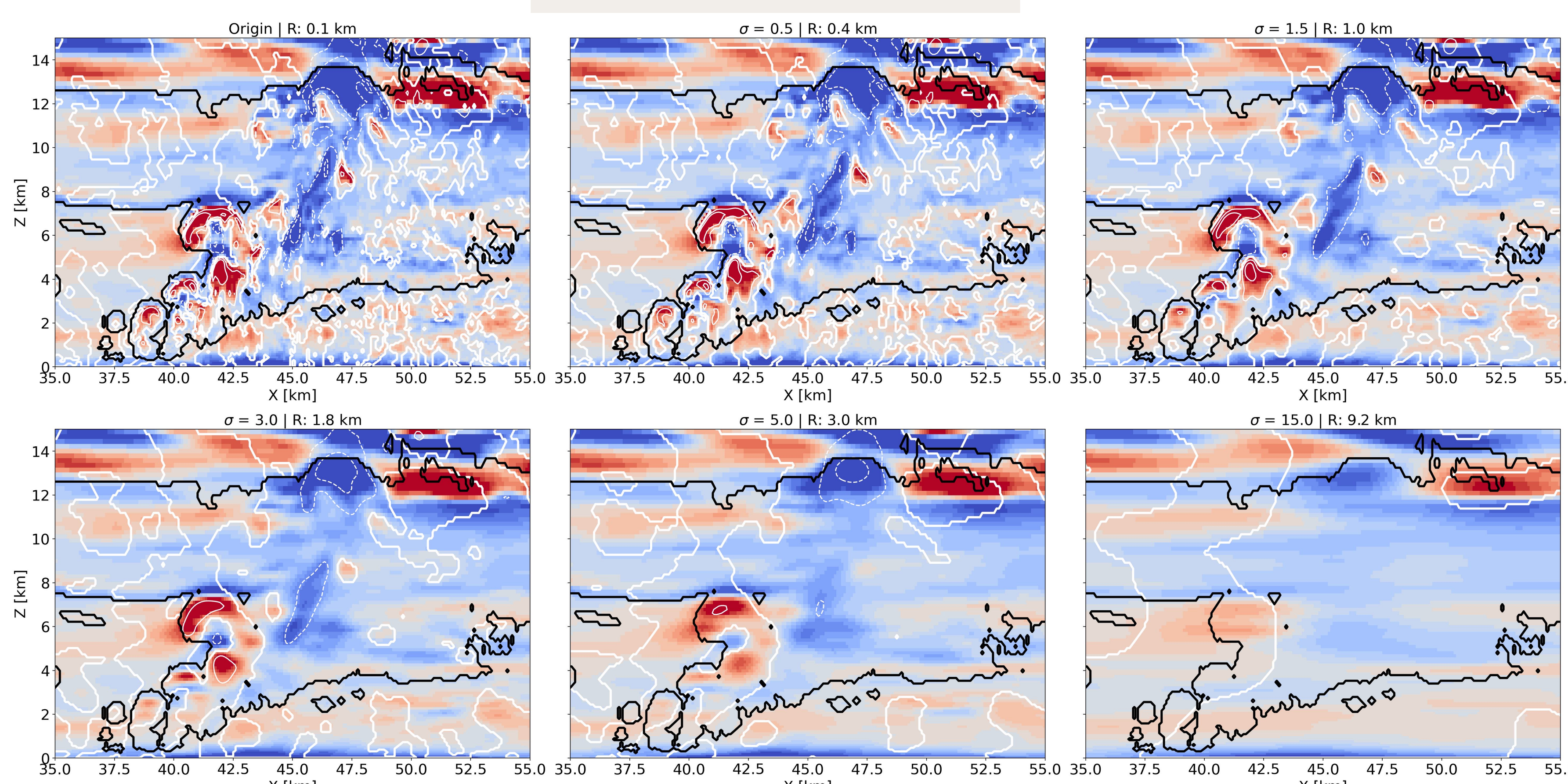
The Nonlocal Effect of Convective Buoyancy

- The convolution with different Gaussian kernels is applied to smooth out various scales of turbulence structure.
- Convective buoyancy and nonlocal response can be retained at a specific scale even after convolution, where turbulence within this range minimally affects the dynamic field.

Plume

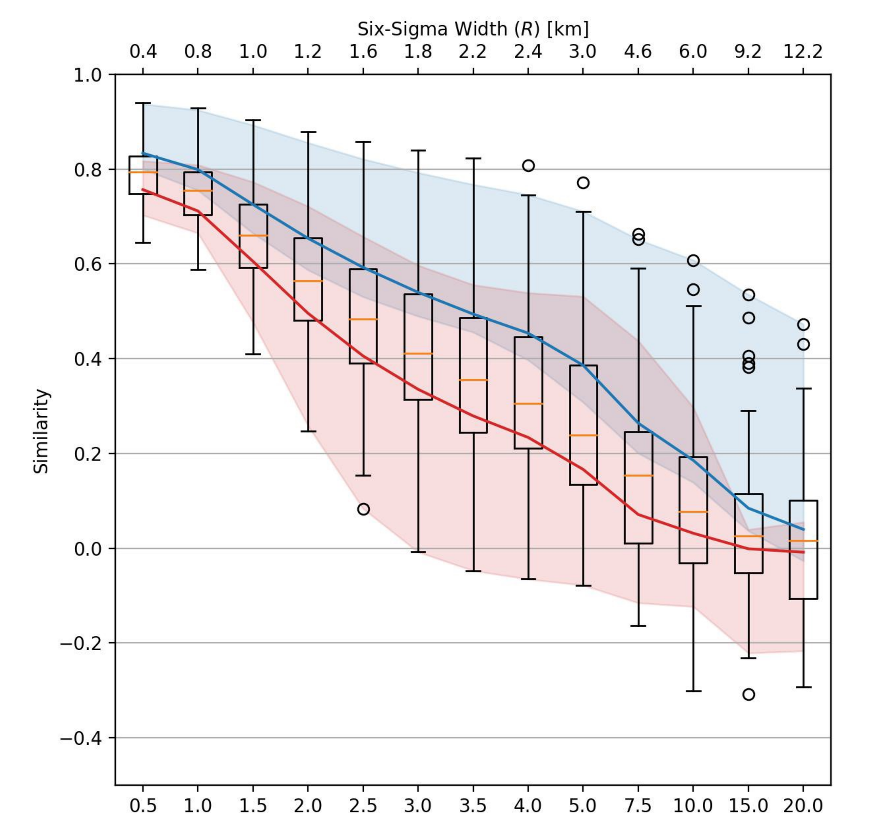


Thermal Chain-like



Discussion and Conclusion

- After coarsening, convection of different sizes or intensities exhibits distinct effects in preserving their dynamic fields.
- It largely depends on the strength and size of thermals within the convection.
- Our next steps are as follows:
  - Universal deep inflow structure resulted from the nonlocal effect.
  - The observable proxy for determining the characteristic length scale.



The similarity of a between original and coarsened buoyancy of cloud objects in different sizes.