Idealized Simulations of Supercell Thunderstorm Interactions Near Stationary Boundaries

Jasen Greco and Dr. Casey Davenport

University of North Carolina at Charlotte

Department of Geography and Earth Sciences

Introduction

Supercell thunderstorms are characterized by a deep, persistently rotating mesocyclone, and are well-known for their production of severe weather, including large hail, gusty winds, and/or tornadoes. The structure, intensity, severe weather production, and longevity of a supercell thunderstorm is heavily influenced by its surrounding environment. Frontal boundaries are synonymous with strongly heterogeneous environments and have been demonstrated to augment severe weather production as a result of supercell-boundary interactions.

The primary goal of this research is to improve our understanding of supercell-boundary interactions by focusing on the role of spatial gradients in the environment and their contributions to supercell evolution independent of boundary circulation.

Data and Methods

A random set of 7 supercell thunderstorms interacting with stationary boundaries were selected from an established database of tornadic supercells interacting with stationary boundaries. A near-inflow sounding representing each side of the stationary boundary was selected based on the timing of the first tornado report for each case.

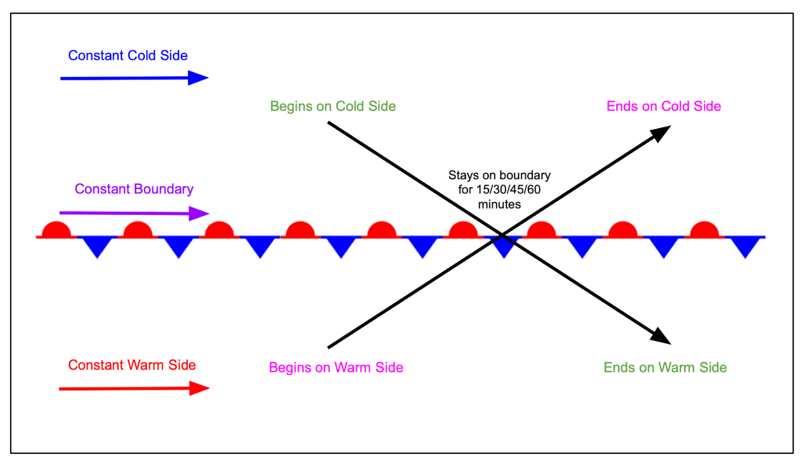
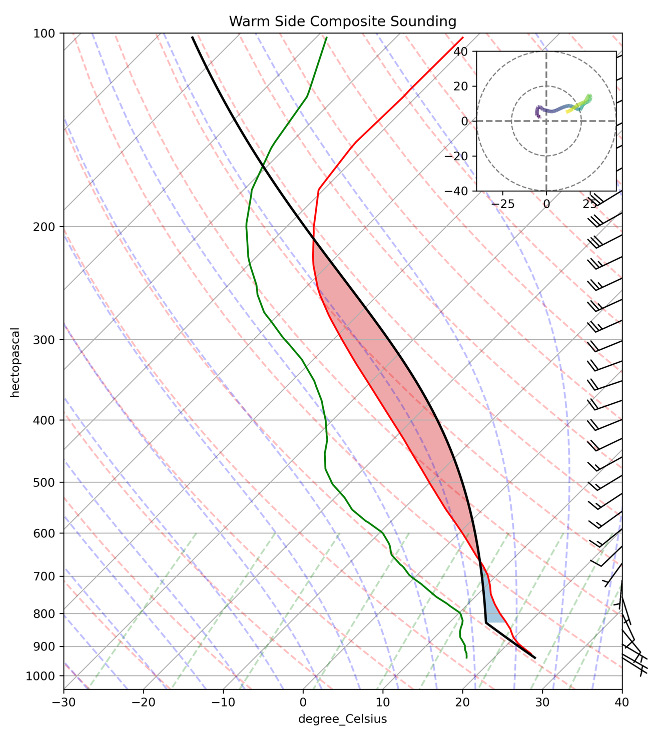


Fig. 1: Conceptual schematic showing how simulations are run in relation to their position near the stationary boundary

A series of idealized simulations were run to replicate environmental changes a supercell experiences when traveling near or across a stationary boundary (see Fig. 1). This was done using Base-State Substitution, where changes to the base-state environment (from warm to cold or cold to warm; see Fig. 2) were applied at different rates to reflect varying boundary interaction angles. These simulations were carried out with the following experimental set-up:

- The simulations begin in the warm-side (cold-side) environment to represent a supercell forming on a certain side of a boundary
- After 60 minutes, the boundary environment is introduced to represent the supercell moving onto the stationary boundary
- The boundary environment is maintained for 15, 30, 45, or 60 minutes to represent the supercell lingering on the boundary
- Once the boundary environment implementation is complete, the cold-side (warm-side) environment is introduced to represent the supercell moving off the stationary boundary

Results



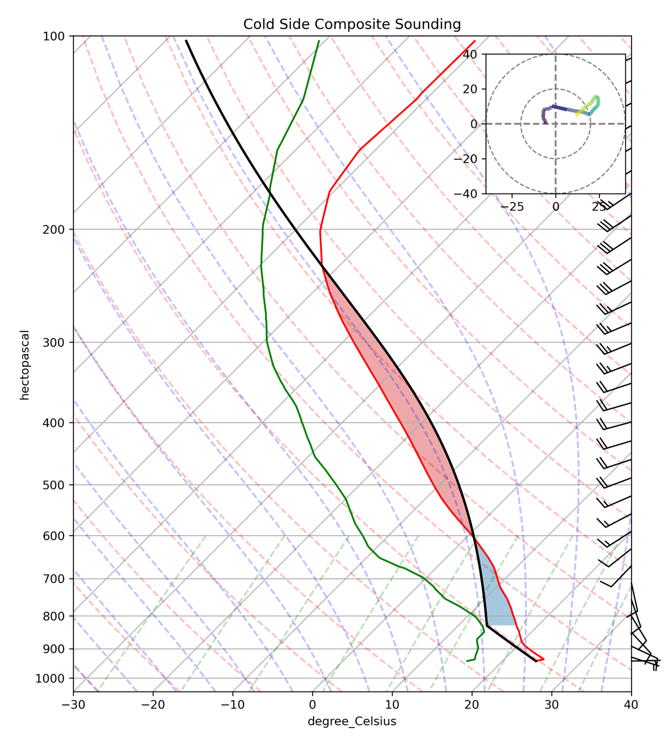
MUCAPE: 1619.0 J/kg

MUCIN: -68.2 J/kg

0-1 km Shear: 1.92 m/s

0-1 km SRH: 2.1 m^2/s^2

Fig. 2: Composite skew-T, log-p diagram of all warm-side inflow sounding points



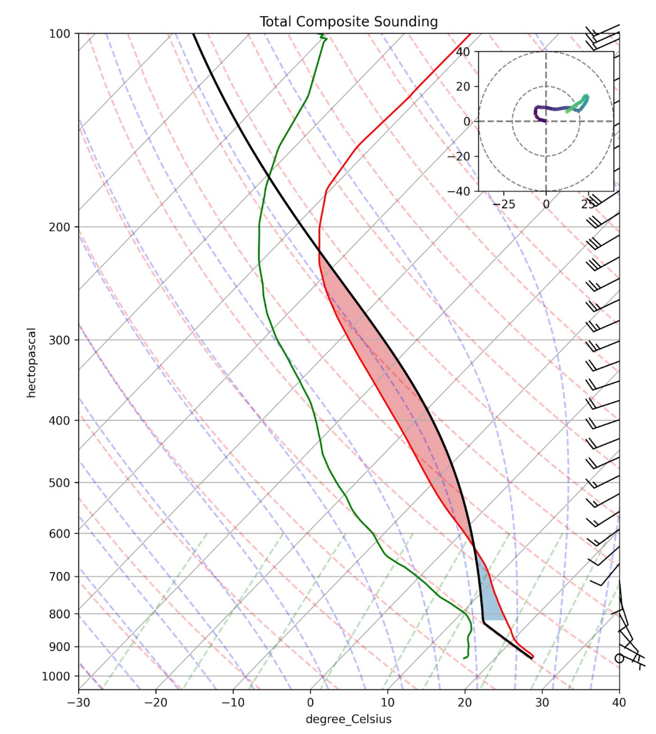
MUCAPE: 1639.7 J/kg

MUCIN: -55.7 J/kg

0-1 km Shear: 3.79 m/s

0-1 km SRH: 36.8 m^2/s^2

Fig. 3: Composite skew-T, log-p diagram of all cold-side inflow sounding points



MUCAPE: 1562.4 J/kg

MUCIN: -83.0 J/kg

0-1 km Shear: 2.40 m/s

0-1 km SRH: 14.8 m^2/s^2

Fig. 4: Composite skew-T, log-p diagram of all inflow sounding points to represent a boundary environment

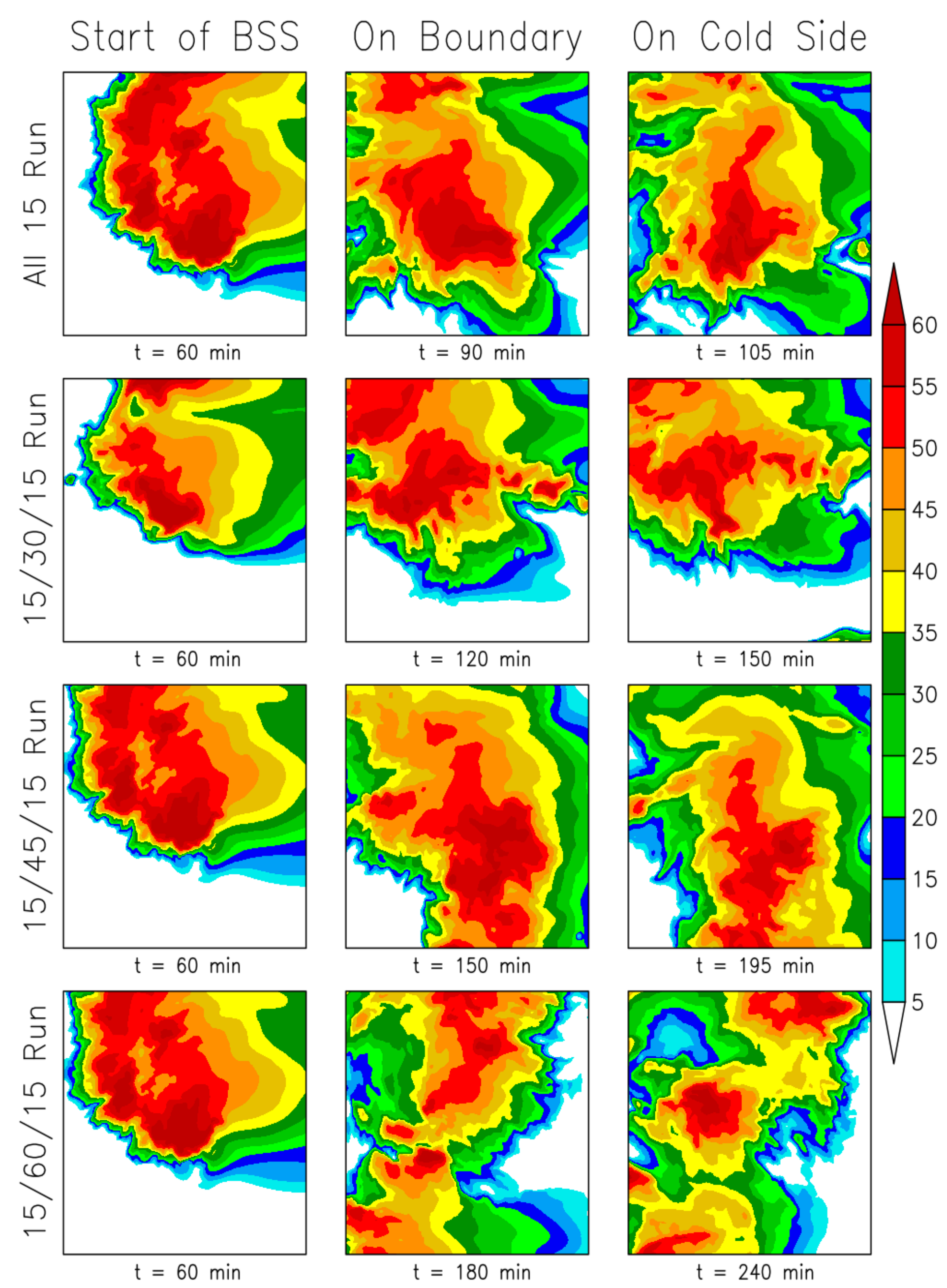


Fig. 5: Simulated radar reflectivity (shaded) of the warm-to-cold side simulations.

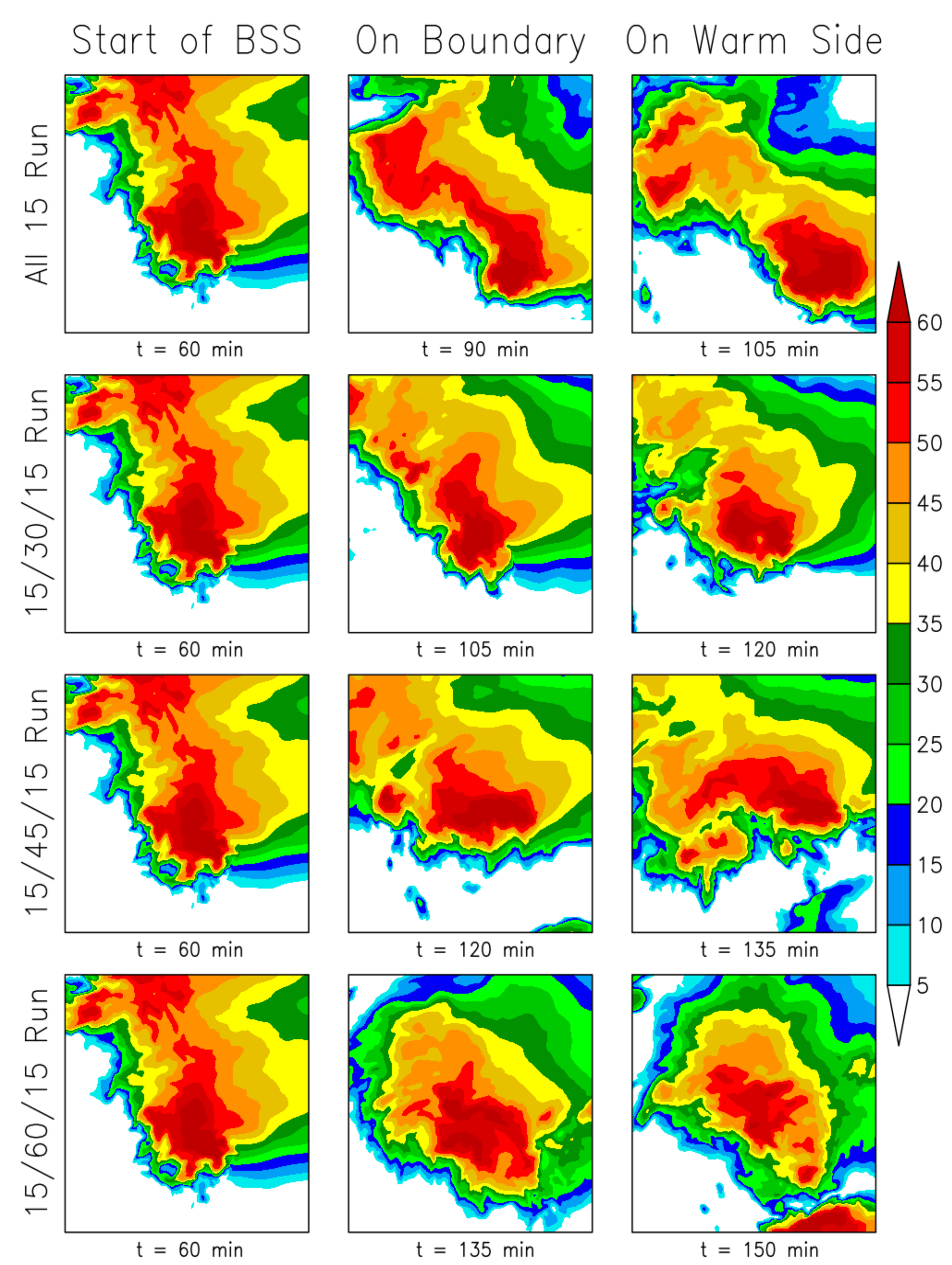


Fig. 6: Simulated radar reflectivity (shaded) of the cold-to-warm side simulations.

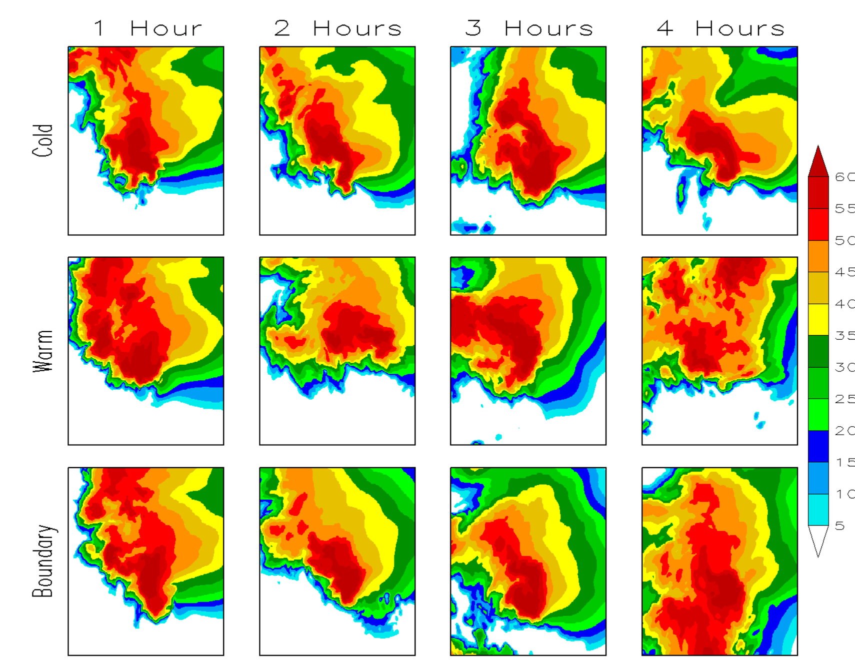


Fig. 7: Simulated radar reflectivity (shaded) shown at four different times in the constant cold-side, warm-side, and boundary simulations (see Fig. 1)

- Warm-to-Cold side simulations grew upscale regardless of boundary residence time
- Cold-to-Warm side simulations retained a more supercellular structure throughout their life cycle
- The constant cold-side simulation was the only control simulation to maintain a supercellular structure

Future Research

- Perform a deeper analysis to better understand the supercell evolutionary paths as well as other metrics of the mesocyclone, such as mesocyclone depth, volume, or updraft helicity areas
- Test different residence times in the warm, cold, and boundary environments
  - Keep the boundary environment residence time constant while changing the warm- and cold-side times

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