The Impact of Large Cities on the Structure and Intensity of Deep Convective Storms

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Abstract

Although previous studies have shown that large cities can modify the regional distribution of convective precipitation, many questions remain regarding the physical processes most responsible for this modification. To date there has been relatively little emphasis on changes to cloud-scale processes within deep convective storms as they encounter large cities. This study uses an idealized atmospheric model to investigate changes in cloud-scale structure as convective storms interact with a simplified representation of a city. Two sets of simulations are shown for comparison. The first set uses the traditional approach of a horizontally homogeneous surface field while the second configuration approximates a large city via a circular area in the center of the model domain characterized by enhanced surface temperature, emissivity, and surface roughness compared to the surrounding region. Over several hours, an urban heat island feature evolves in the simulation containing the idealized city. In both model configurations, a continuous squall line is initiated in the western half of the model domain. As this line of storms propagates east and approaches the center of the domain, noticeable structural differences, particularly updraft strength and simulated radar reflectivity, are evident between simulations using the two different model configurations. Sensitivity tests are also conducted to show how the environmental wind profile impacts the magnitude and structure of convective storm modification by the idealized city.

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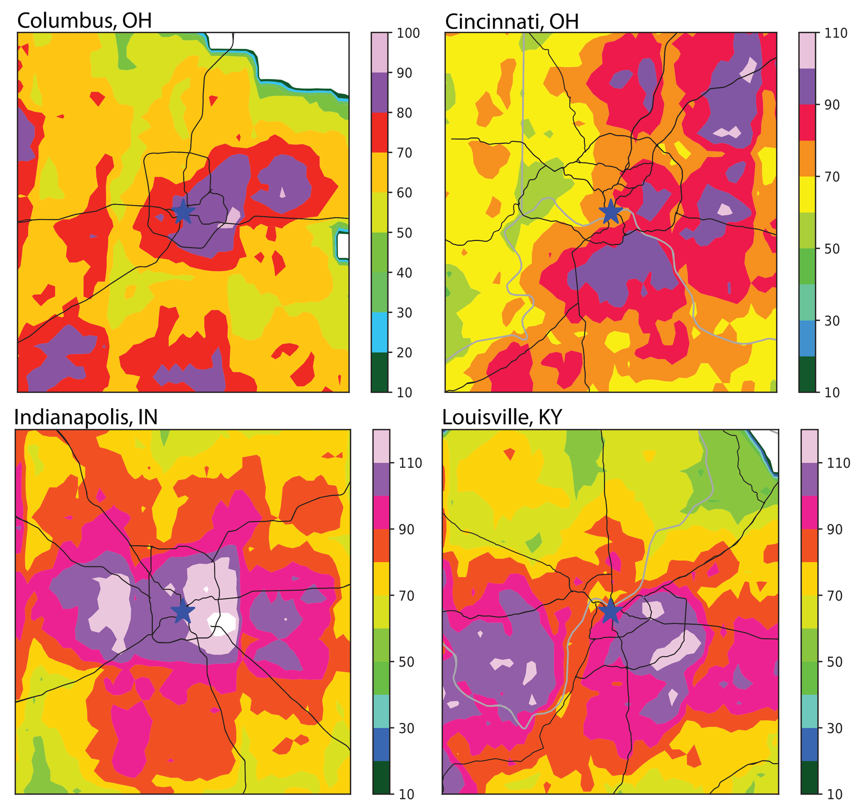
Background and Motivation

- Large cities have been shown to impact the regional distribution of precipitation. However, their impact on organized storms capable of producing severe weather has not been fully explored.
- There is evidence that severe weather warnings tend to be more frequent on the eastern side of major U.S. cities.



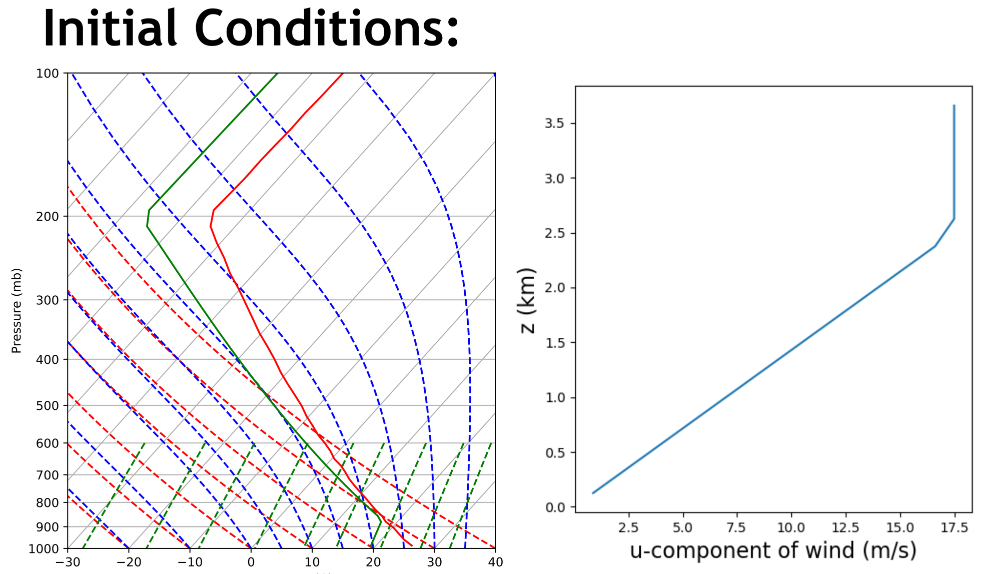
Total count of severe thunderstorm and tornado warnings issued by the National Weather Service between Oct 2008 and May 2018. Black lines denote interstate highways and blue stars indicate the downtown core of each city. From Naylor and Sexton 2018 (Weather and Forecasting).

The purpose of this study is to investigate physical changes to convective storms as they interact with an idealized 'city'

Methodology

Model: CM1 version 18
Configuration: Horizontal grid spacing of 500 m, stretched vertical grid, increasing from 250 m to 500 m above 9 km
Domain: 600 km x 60 km, Open boundary conditions in the x-direction, periodic boundary conditions in the y-direction
Parameterizations: double-moment microphysics, TKE turbulence, NASA Goddard radiation

Initial Conditions:



Westerly wind increases with height up to z=2.5 km. Wind is constant above this level. Vertical shear (Δu) is confined to lowest 2.5 km.

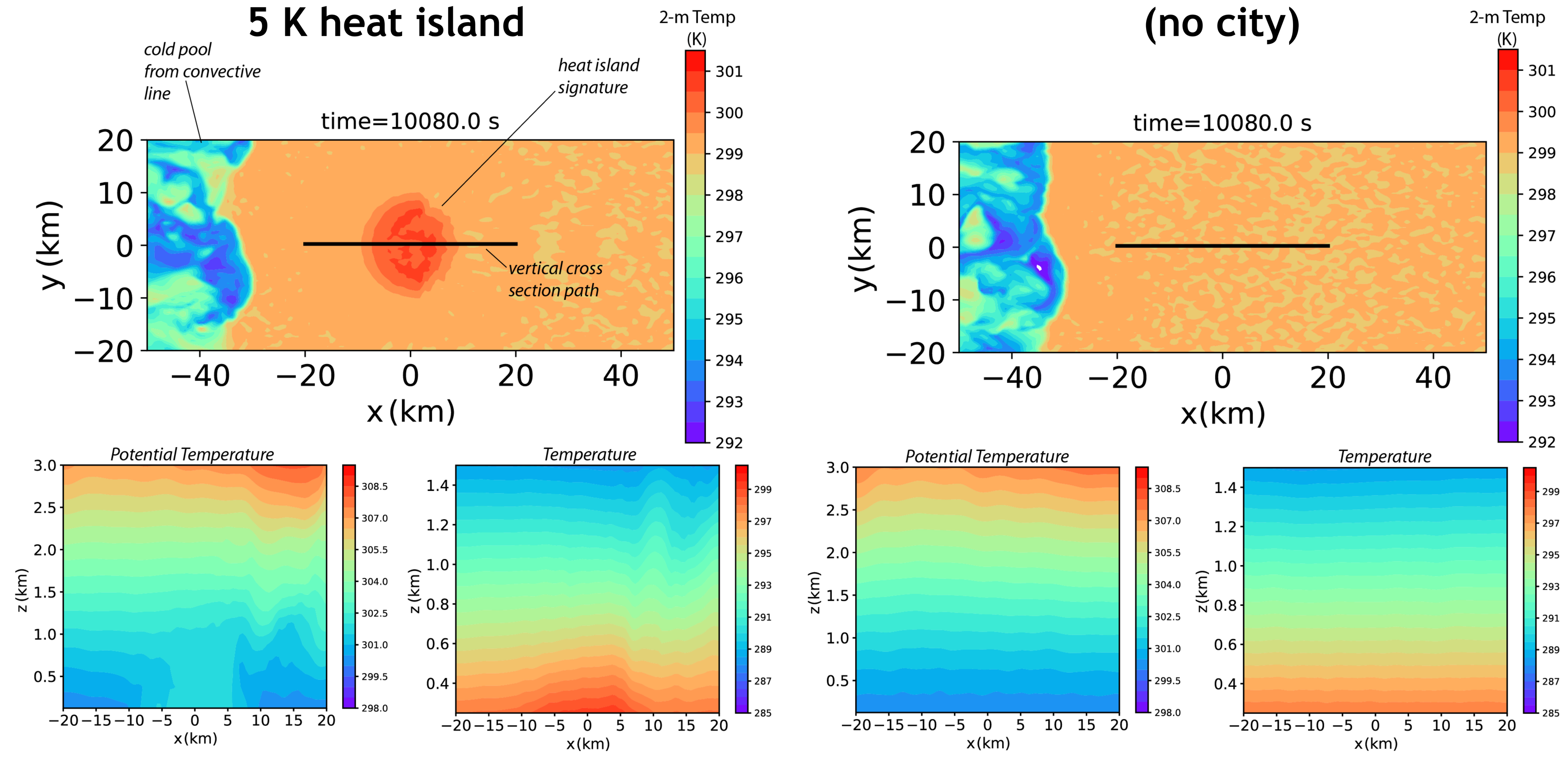
Four simulations:

control - no city and no heat island
idealized city with 0 K heat island
idealized city with 2 K heat island
idealized city with 5 K heat island

Idealized city was inserted by modifying the land usage category within 10 km radius disk in the center of the domain. Skin temperature within the disk was also increased by a specified amount.

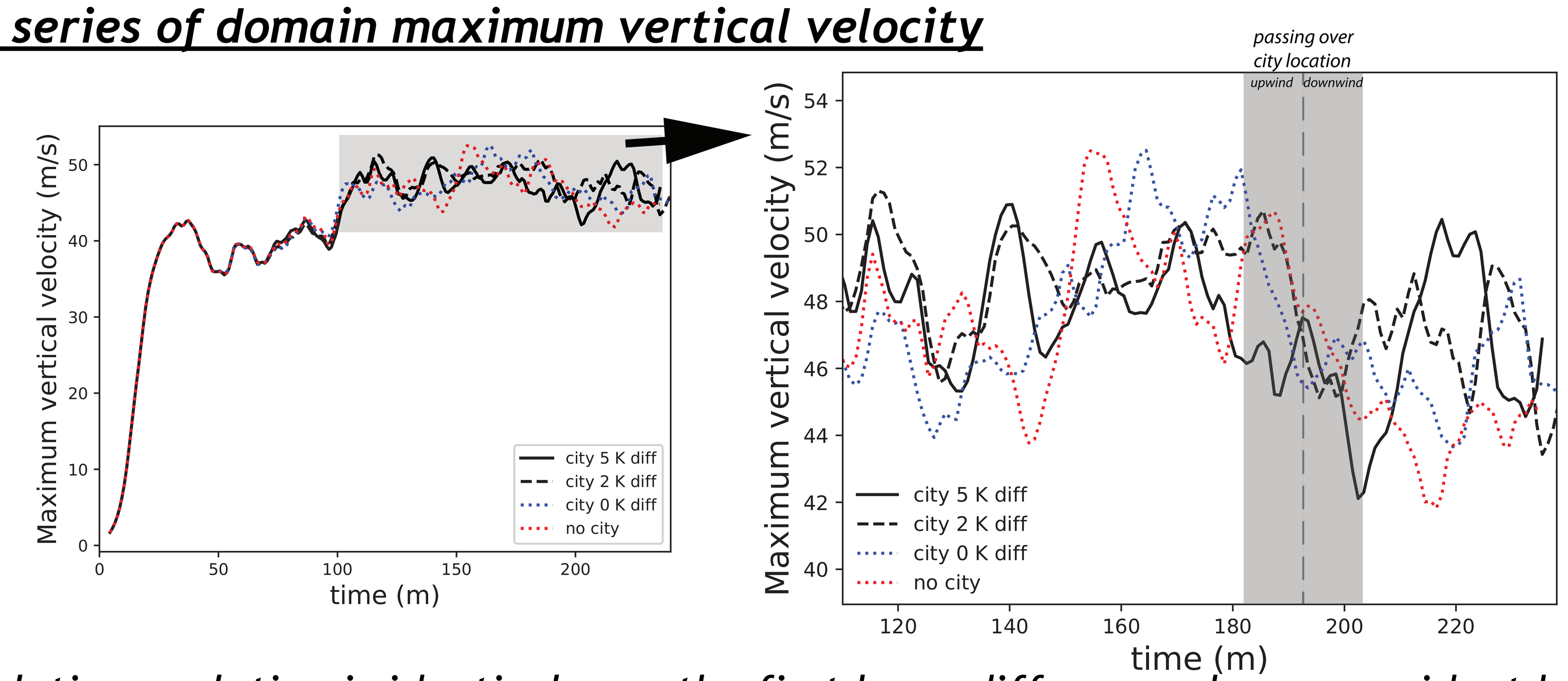
Results

Idealized city with 5 K heat island — **Control simulation (no city)**



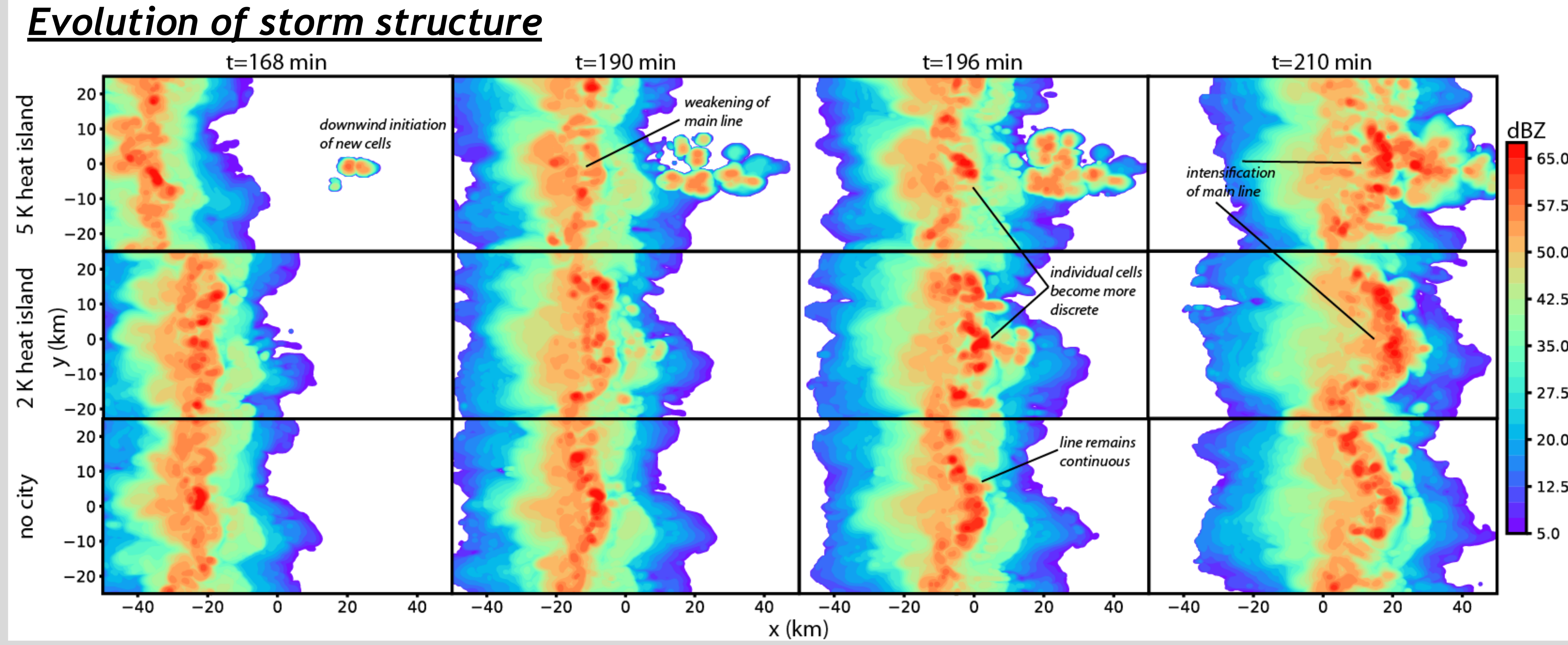
- *A well defined heat island forms in the idealized city simulation*
- *Reduction in stability (decreased potential temperature gradient) over the city*

Time series of domain maximum vertical velocity



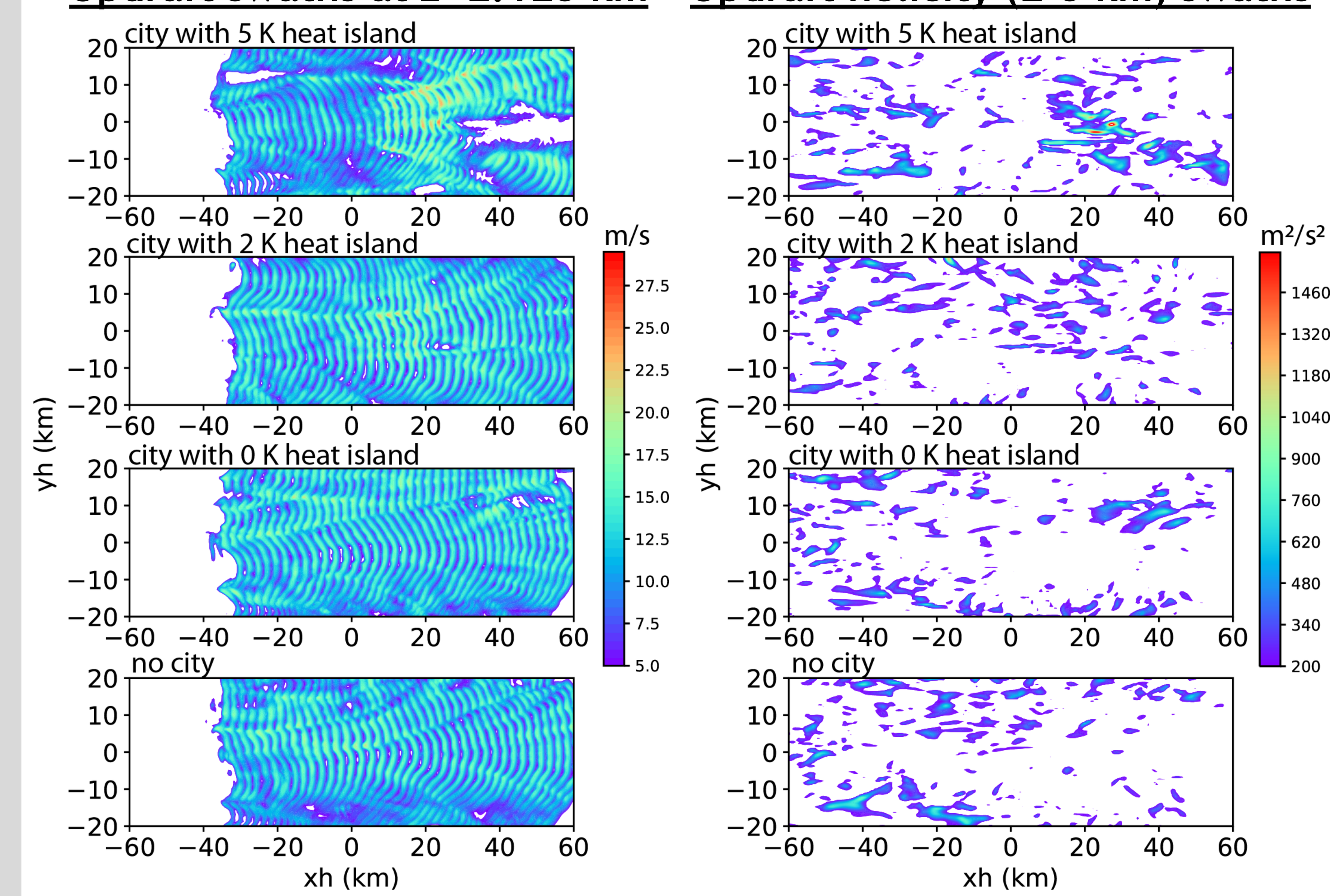
- *Simulation evolution is identical over the first hour, differences become evident by t=2 hr*
- *Largest differences occur as storms approach domain center and interact with city*

Evolution of storm structure



Results

Updraft swaths at z=2.125 km — **Updraft helicity (2-5 km) swaths**



Relative to the control (no city) simulation, storms in the city simulations
- experience a decrease in updraft intensity upwind of the city
- experience updraft intensification downwind of the city
- contain regions of larger updraft helicity downwind of the city

Conclusions and Future Work

Preliminary Conclusions

As the surface temperature of the city increases
- upwind decay of updraft becomes more noticeable
- downwind updraft enhancement becomes stronger
- initiation of discrete cells downwind of city

Continuing work
- Increased resolution, particularly near the surface
- Testing various shear profiles
- Trajectory analysis to determine dominate physical causes of updraft strengthening/weakening

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