Winter UHI effect on Snowfall in St. Louis, Missouri

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Abstract

Urban Heat Islands (UHI) are localized meteorological phenomena characterized by urban areas featuring warmer temperatures than their surrounding areas. It is important to study the effects of UHI because over half the world's population currently resides in urban areas with 68% of the world's population being estimated to live in urban areas by 2050.The effects of UHI on summertime precipitation events are well documented. However, there is little to no research on their effects on wintertime precipitation events. This research investigates a wintertime UHI case-study of a synoptic snowfall event that occurred over the St. Louis, Missouri, metropolitan area February 4-5, 2014. The effects of the St. Louis UHI on this event were investigated by performing numerical simulations using the Weather Research and Forecasting (WRF) model. Two model simulations of the event, one with urban land cover and one without, were performed allowing for direct analysis of the influence of land cover on UHI processes.

Case Study

A snowfall event occurred February 4-5, 2014, in St. Louis produced 4-5 inches around the metropolitan area (Figure 1). As surface ridging moved out of the area an upper-level trough ejected from the northern plains producing a jet max of 120-130 knots (Figure 2). The onset of the snow occurred around 10Z on the 4th. The system was initially influenced by residual dry air aloft as warm air advection processes dominated the early snowfall in the area. As the system progressed, strong mid level frontogenesis pushed lingering dry air out of the area as the snowfall process became dominated by the deformation zone. As the system gained strength it also gained momentum and moved with haste to the northeast and out of the area. The last lingering precipitation ended by 17Z on the 5th.

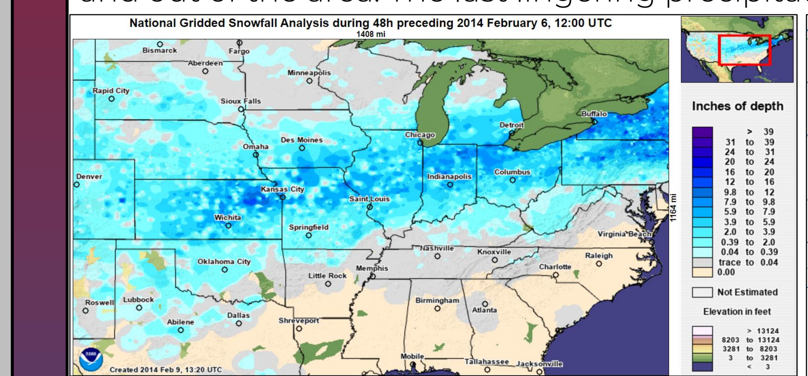

Figure 1: Observed 72-hour snow

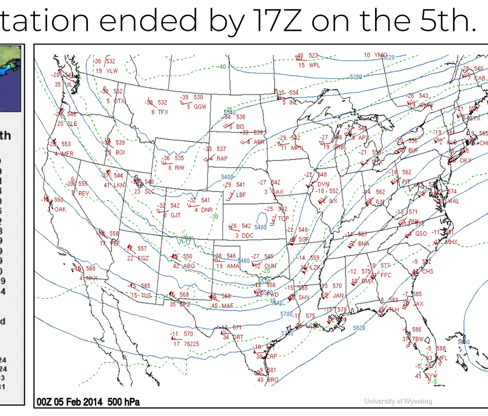

Figure 2: 00Z Feb 5th 500 hPa analysis

Model Verification

To verify the WRF simulation, model output of hourly temperature, wind speed, and wind direction data was compared against observed measurements from the ASOS station at St. Louis Lambert International Airport. Overall, the model accurately captured the evolution and magnitude of the event throughout the period of study when compared to real world data. The temperature proved the most variable with higher highs and lower lows. Comparison produced an RMSE of 1.42 °C and an MAE of 1.27 °C. The wind speed's trend was very similar but generally underperformed in magnitude throughout the study period. Comparison produced an RMSE of 3.50 knots and an MAE of 2.98 knots. The wind direction comparison produced an RMSE of 23.86 degrees and an MAE of 18.08 degrees.

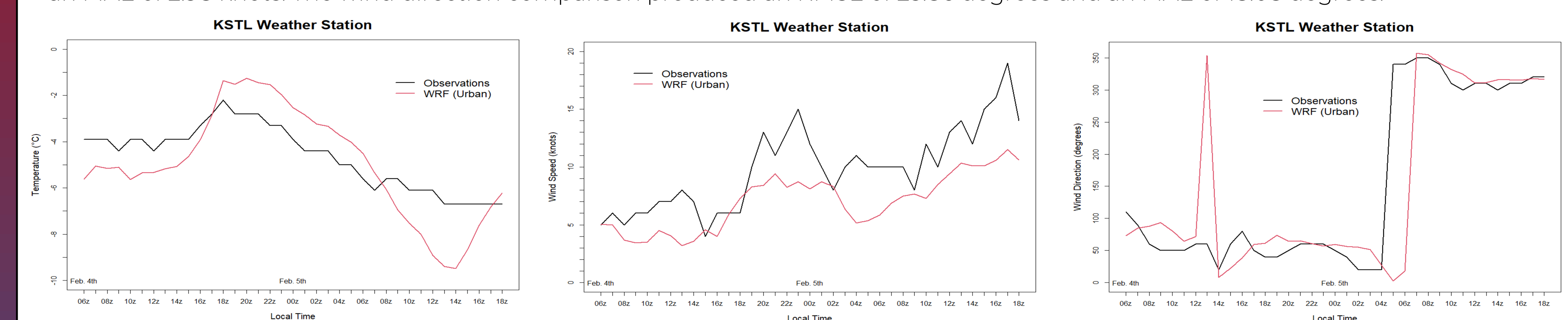

Figure 3: Time-series comparisons of observed and model values at Lambert International Airport for temperature (°C) (left), wind speed (kts) (middle), and wind direction (°) (right)

WRF Configuration

The Weather Research and Forecast (WRF) model was used to effectively capture the surface and boundary layer processes associated with UHIs. WRF was configured with three nested domains centered over St. Louis with 179 x 183, 211 x 205, and 133 x 136 grid points at 9, 3, and 1 km resolutions respectively along with 40 vertical levels (Figure 4). North American Regional Reanalysis (NARR) data was selected to initialize the model as it features a high enough spatial (32 km) and temporal (three hourly) resolution to accurately portray the overlying synoptic conditions during this event. To ensure the best representation of UHI characteristics and processes, the Noah-Multiparameterization Land Surface Model (NoahMP-LSM) coupled with an Urban Canopy Model (UCM) was selected to parameterize surface physics processes. All other WRF parameterizations (not shown) were selected based on their successful application in previous research to effectively capture UHI processes.

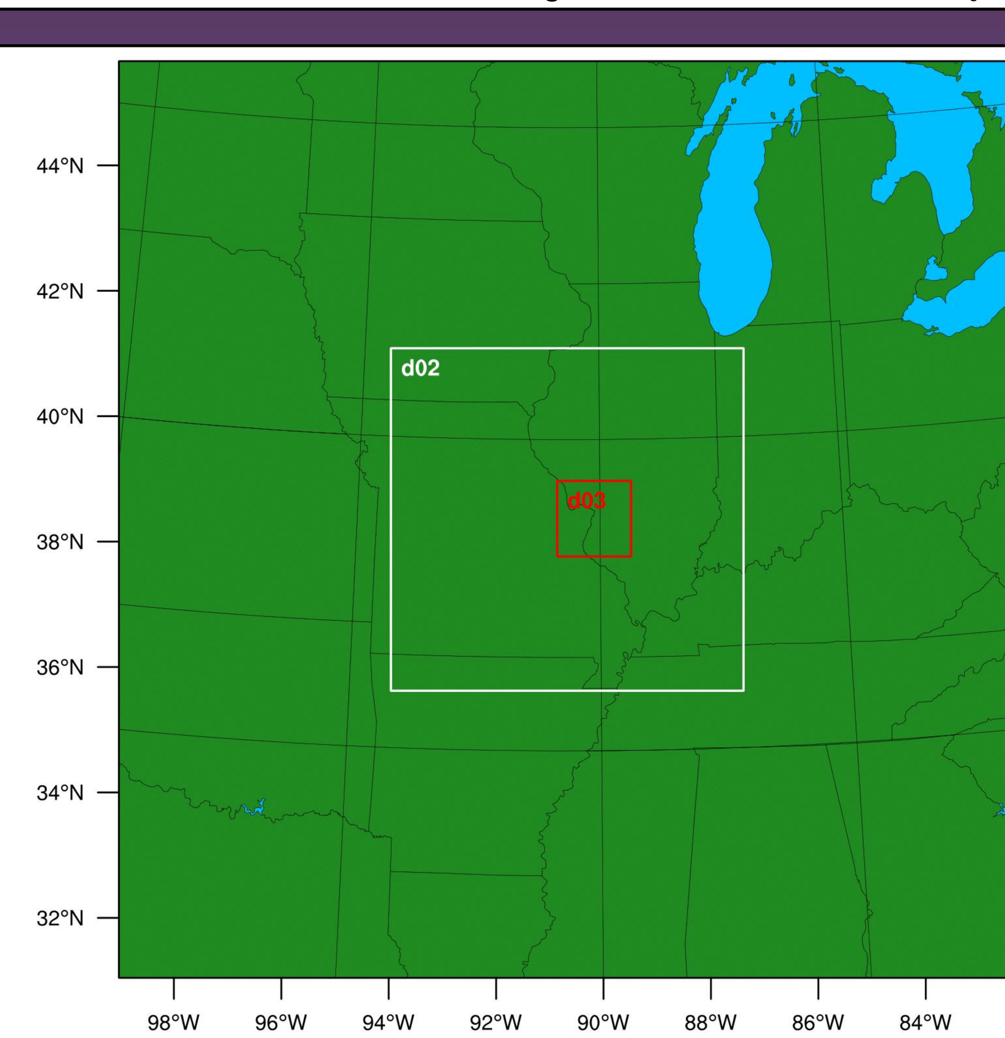

Figure 4: WRF domain configuration

Experiment Design

Two WRF simulations were conducted over a 36-hour period spanning from 06Z February 4th to 18Z February 5th. Each simulation only differed in the portraying of land cover type over St. Louis. The first simulation (hereby referred to as 'URBAN') featured all land cover data unaltered, precisely representing the St. Louis metropolitan area's urban features. The second simulation (hereby referred to as 'NOURBAN') was parameterized to replace all urban land cover with deciduous forest over the great St. Louis metropolitan area. Deciduous forest was decided to replace the urban land cover has historically been the primary land cover type replaced by St. Louis's urban expansion. The United States Geological Survey's (USGS) 2011 30-meter National Land Cover Database (NLCD) was selected to portray the heterogeneous land cover over the WRF domains (Figure 5). This dataset distinguishes four different types of urban land cover (referred to as 'developed') primarily based on the percentage of land covered by impervious surface. For the NOURBAN simulation, any urban land cover present in the third domain was changed to deciduous forest.

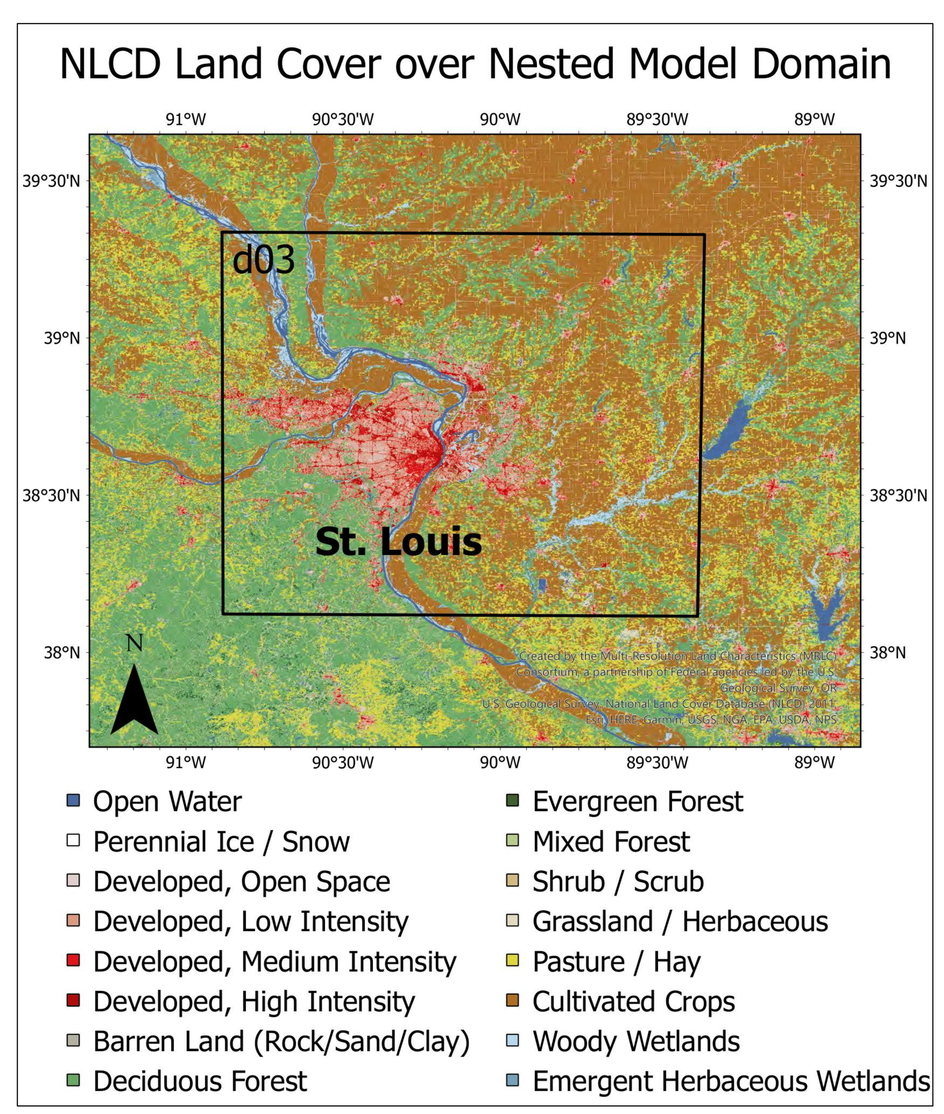

Figure 5: 2011 NLCD Land Cover over greater St. Louis metropolitan area

Results

Overall, the St. Louis UHI did not exert any meaningful influence during this synoptic scale wintertime snowfall event. The alteration from developed land cover (URBAN) to deciduous forest (NOURBAN) did not exhibit discernible differences in any main variables over the majority of the study period. All difference calculations consisted of subtracting the NOURBAN run from the URBAN run. Figure 6 shows the UHI produced a near zero change in precipitation accumulation between the two runs for this event. It is interesting to note that at the end of the study period, from 17Z to 18Z on the 5th when the system had moved out of the area, skin temperature difference rose from near zero to greater than 0.6 °C between runs (Figure 7). This difference directly led to a significant increase in sensible heat flux differences of around 50 to 70 W/m2 between runs at 18Z on the 5th compared to differences of less than 20 W/m2 at 18Z on the 4th. Comparing latent heat fluxes at the same timesteps, the differences of no more than 20 W/m2 only increase minimally in coverage at the later timestep. (Figure 8)

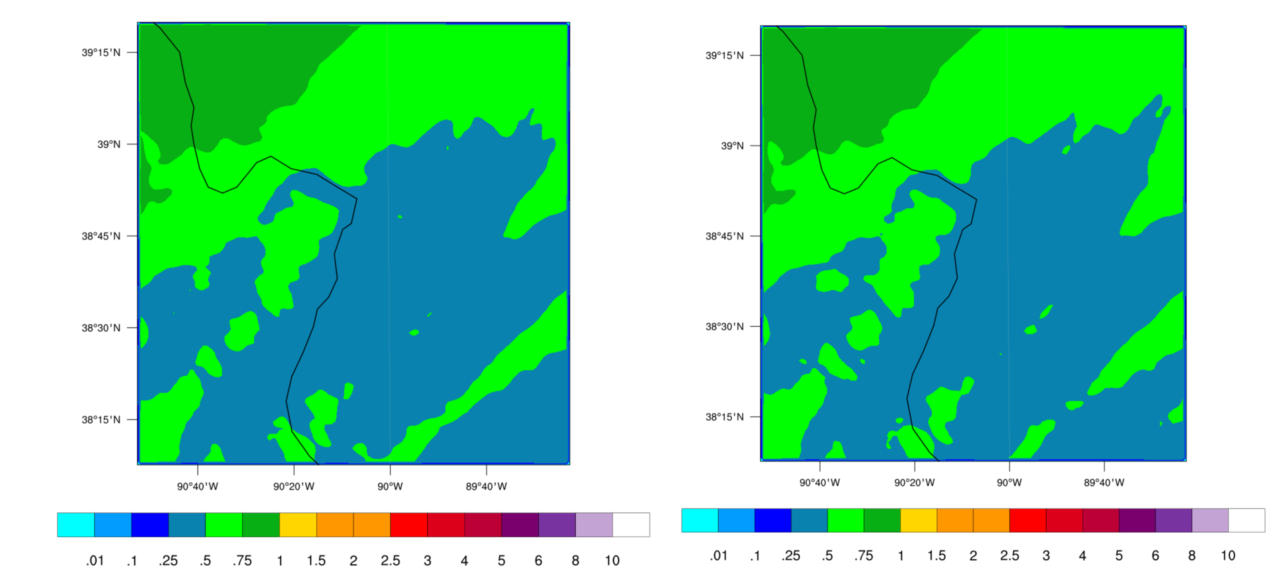

Figure 6: URBAN (left) and NOURBAN (right) total QPE (in)

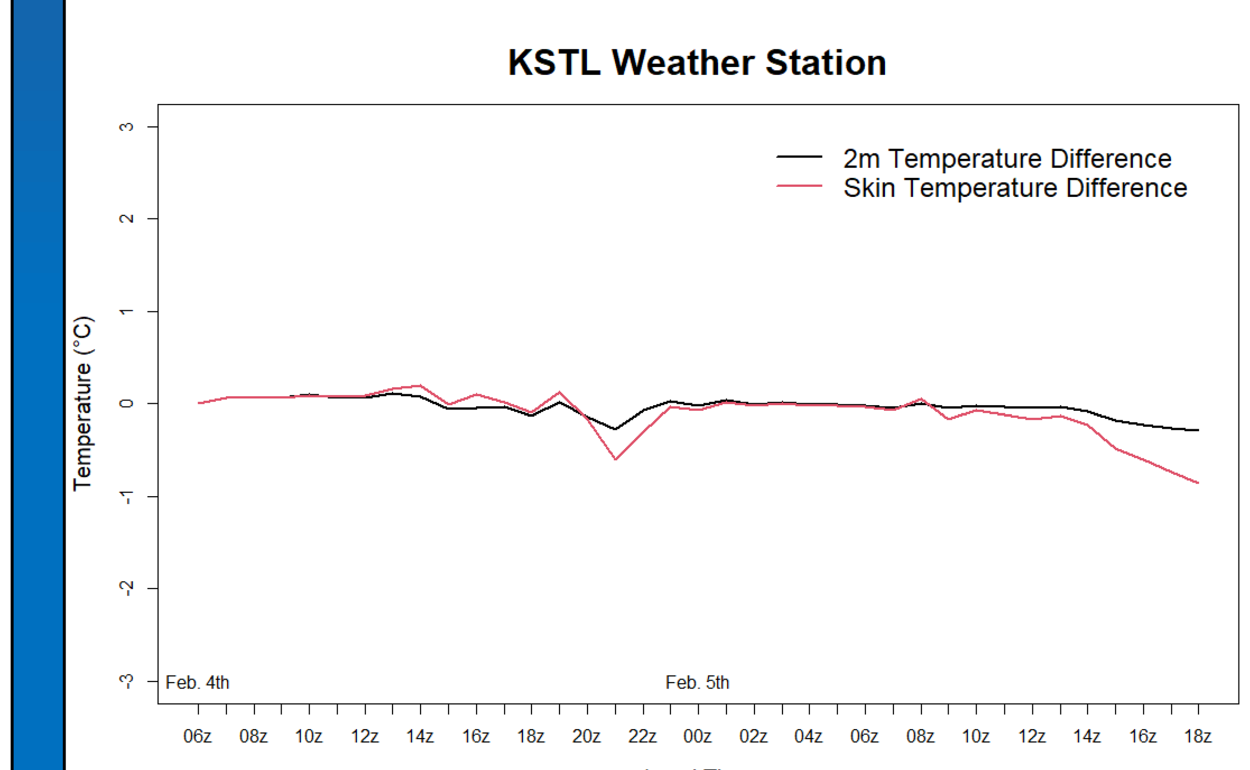

Figure 7: URBAN-NOURBAN time-series of skin temperature (°C) and 2m temperature (°C) differences

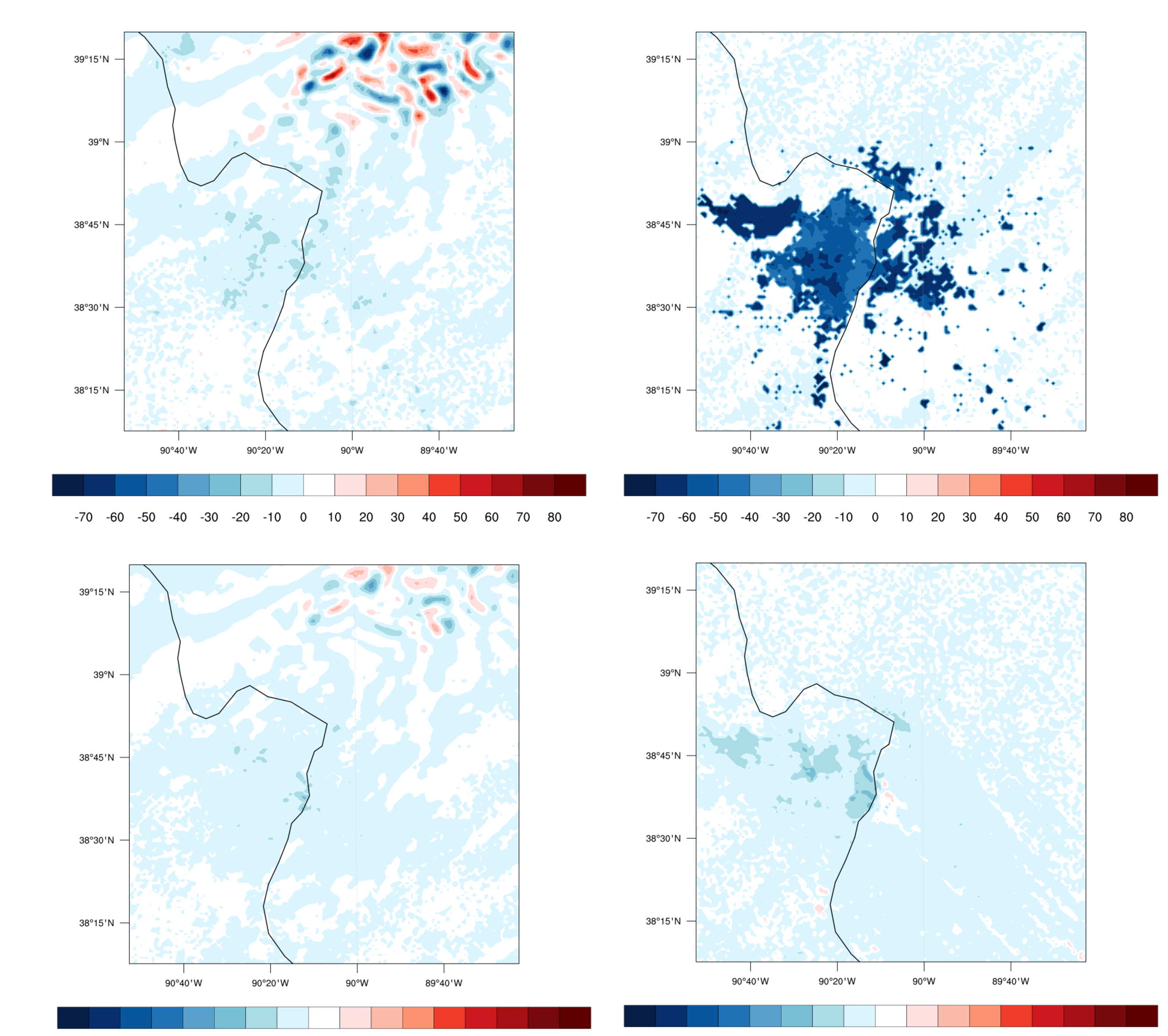

Figure 8: URBAN-NOURBAN heat flux differences (W/m2); sensible at 18z on the 4th (top left), sensible at 18z on the 5th (top right), latent at 18z on the 4th (bottom left), and latent at 18z on the 5th (bottom right)

Future Work

Future work should include performing a sensitivity analysis on the WRF for wintertime UHI in order to find the parameterization scheme that most effectively captures heat and moisture processes in these environments. With that should also be included a land cover sensitivity study to test which land cover is most suitable for this type of analysis. It would also be useful to conduct a very similar study on more of a "pop-up" snowfall event rather than a large synoptic event since that more closely mirrors how UHI most greatly affect summertime precipitation processes. Analyzing the UHI effect of many different urban areas for wintertime precipitation events could be very useful as well.