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The Analysis of Urban Effects on Winter Snowfall in the Saint Louis Metropolitan Area

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ABSTRACT

Studies were done to further analyze the effects of urbanization, specifically the urban heat island (UHI), on winter snowfall in the Saint Louis Metropolitan area using station data from a climatologically significant year in Saint Louis snowfall. Two sets of data were collected and analyzed. Raw snowfall data over the course of 4 months in 2013 were gathered as well as isolated snowfall data from 4 significant events in 2013. Radar data was also collected and analyzed in order to create a model to use when collecting the raw snowfall data. Both station data and radar data were broken into a downwind and upwind sector and the information was processed to identify the effects of urbanization on systems bringing snowfall to the region. A series of averages and totals was analyzed to provide a better understanding of how the urban heat island affects the raw snowfall . Results show that while the downwind sector has increased precipitation overall in the monthly analysis, the 4 significant events (in which the most snowfall was experienced) favored higher snow amounts in the upwind sector. This shows that the effects of the urban heat island are minimal in cases of strong winter storms with the capability to precipitate up to eight inches of snow or more. However, it can also be inferred that for overall snowfall totals, the urban heat island effects do play a significant role and are responsible for an urban enhanced precipitation.

1. Introduction

This study aims to understand more about the effects of the urban heat island and specifically related to winter precipitation. The urban heat island is a well-studied phenomenon that has been analyzed for various reasons and purposes including its warming features, mitigation techniques, “greening” urban landscapes, and its impact on precipitation.

These past studies have reasonable evidence to support the hypothesis that the urban heat island does play a role in changing the climatology and weather on a synoptic level. Warming within the city limits as a result of man-made devices and landscape is no surprise and has been in the forefront for recent academic journals. However, while most of the studies have looked into these effects in warm seasons with rain as the main precipitation, few have been done regarding winter storms. The focus of this study is to fill that void and provide sound analysis in order to justify or denounce that the urban heat island does in fact enhance winter snowfall.

2. Literature Review

While it is well known that the urban heat island effect is a producer of anthropogenic warming, it’s important to look at previous studies and analyze their findings. Perhaps one of the most iconic studies on this subject was done in 1972 by scientists Huff and Changnon (1972) in which they formulated a model to best analyze the urban effects on precipitation, specifically thunderstorms and rainstorms, and ended with some very interesting conclusions. The scientists found that the urbanization increased average rainfall during the summer by up to 15% downwind of the city. This study focused primarily on summer precipitation, but showed conclusive evidence of the urban effects and their impact. Further modeling years later by Changnon was done to analyze trajectory and incorporate it into his urban-induced severe weather analysis (1978).

Another study by Changnon in 2003 focused on freezing rain. Results show that urbanization decreases freezing rain in the urban environment due to the warming which prevents surface freezing. The study analyzed various urban centers and still displayed decreases in freezing rain for both large cities (New York City, Chicago) and small cities (St. Louis, Washington D.C) compared to their surrounding rural areas (Changnon, 2003).

The study on freezing rain is the closest study to winter storms so far. Still, there remains a gap in winter precipitation analysis with respect to urban effects. In 2003, a study done in Atlanta used synoptic and air mass data to find correlations in UHI related effects. Results show that although the heat island plays a significant role in the increased precipitation, another likely component is moisture at low levels (Dixon, 2003).

Many cities have been individually studied and tested. All seem to have similar results. This can hopefully allow us as scientists to conclude that the urban effects

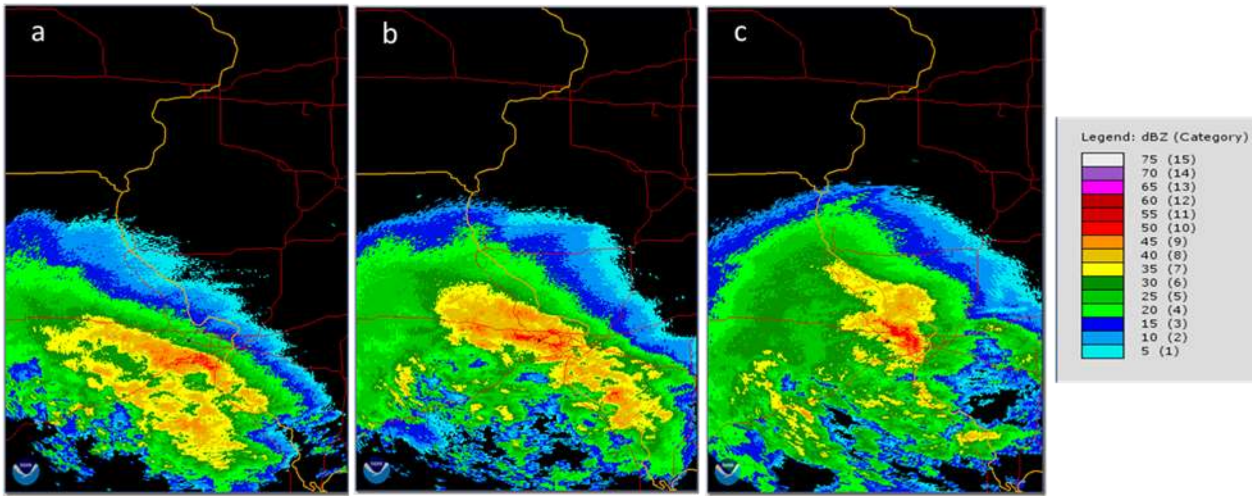

Fig 1. Three radar images over the Saint Louis metropolitan area of winter precipitation during a February snowstorm in 2013. Depicted in the figure are three different frames of time: 15:08GMT (a), 16:09 GMT (b), and 17:09 GMT (c). All were approximately one hour apart over a three hour period on 21 February 2013. Radar imagery was provided by the National Climatic Data Center. https://www.ncdc.noaa.gov/

are not dependent only on geographical location, but instead on size, population, and proximity to rural surroundings. Temperature studies were done in New York dating back to 1968 which looked into temperature inversions compared to the non-urban surroundings (Bornstein, 1968).

More recent studies have been done in the twin cities to focus on diurnal modulations of rainfall (Smoliak, 2015). This has certainly been something to look into as we delve further into the topic. Even social tendencies have come into play with UHI studies. One in particular came to a conclusion that more research should be done on urban analysis with regards to weather prediction and improved forecasting (Dabberdt et al., 2000). Possibly the most inventive research right now is an article that focuses on urban induced rainfall and mitigations for the future (Shepherd, 2005). This second-stage thinking is perhaps what is most important as we look further into UHI effects.

3. Methods

The first decision when conducting this study was deciding on a city. Saint Louis was a perfect fit. The metropolitan area provides a balanced city diagram among local cities and surrounding areas. Recent census totals, in 2013, by the United States Census Bureau claim that Saint Louis has around 320,000 residents within the city alone and upwards of close to three million residents within the surrounding area. This urban environment makes for a perfect case study when analyzing urban effects on precipitation and synoptic scale events.

The second decision was to create a timeline to work with. Research was done by looking into climate records in order to

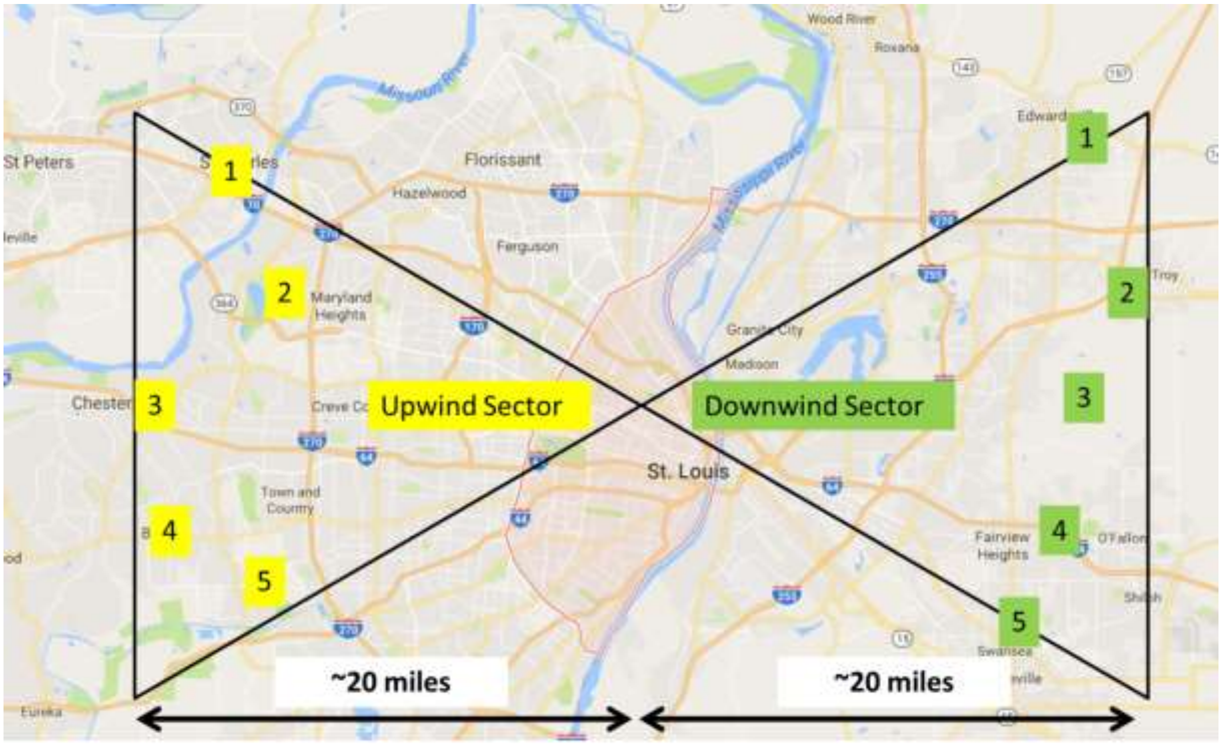

Fig 2. The map above depicts two sectors in the Saint Louis metropolitan area. Upwind (left) and downwind (right) are used as sectors in the study to provide a field of play for station data analysis and overall urbanization. Five station points in each sector are identified above with individual enumeration. There are approximately 20 miles from each station to the city center. Upwind sector stations (in Missouri) are enumerated at the following locations: St. Charles (1), Maryland Heights (2), Chesterfield (3), Ballwin (4), and Kirkwood (5). Directly across from the city to the east (in Illinois) are the following enumerated downwind sector stations: Edwardsville (1), Troy (2), Collinsville (3), Fairview Heights (4), and Belleville (5). https://www.google.com/maps/place/St.+Louis,+MO

find concrete data to analyze and look into. According to the National Weather Service (NWS), 2013 was classified as a heavy snowfall year for the Saint Louis region. For this reason, I used this year as a starting point for obtaining my data. Once the region and date were selected, it was necessary to create a model or template in order to carry out the study.

Some modeling in this experiment was adapted from previous studies from Changnon in order to best diagram the results of urban-induced precipitation. First, in order to decide on a model template, radar imagery was analyzed over the course of the winter months in 2013 for Saint Louis provided by the National Climatic Data Center (NCDC). This radar imagery was used to find a best frame of study by looking at the general trajectory experienced with winter storms. From the imagery, it was evident that the standard flow followed an eastward pattern. Snapshots of the radar images show just one sample of the commonly occurring trajectory experienced and analyzed over the Saint Louis metropolitan area (Fig 1).

Modeled from this easterly flow, two sectors were created. These sectors, upwind and downwind, were overlayed onto the city to divide the precipitation totals and averages into two different regions (Fig 2). Upwind (depicted on the left of the city) and downwind (on the right) sectors both had five station points which were each approximately 20 miles away from the city center.

Data was collected from each station point (each day with 24 hour duration period) by the National Operational Hydrologic Remote Sensing Center (NOHRSC) and are represented in the imagery, tables and figures. Each enumerated station in the figure is mirrored with another enumerated station of the opposite sector (Fig 2). Analysis through comparison/contrast was used in the graphs below. The study used two different methods of timing in order to better understand the UHI effects on winter storm precipitation for snowfall in the Saint Louis metropolitan region.

a. *Significant Events*

Like mentioned earlier, the NWS classified 2013 as a heavy snowfall year for Saint Louis. They also came up with four significant events in 2013 that resulted in large amounts of raw snowfall in the region. This study looked at the station data results for each event and plotted the snowfall data (in inches) for both upwind and downwind sectors.

b. *Monthly Analysis*

In addition, overall monthly measurements were made for four winter months in 2013 (January, February, March, and December). Similarly, the data was plotted and used to compare upwind/downwind results and the relation to the overall study of urban-affected winter precipitation in the Saint Louis metro.

Additional imagery provided by NOHRSC was also used to best look at snowfall melt and overall snowfall precipitation in the Midwest region. This imagery was analyzed in order to research any visual findings on such a large scale.

4. Data and Results

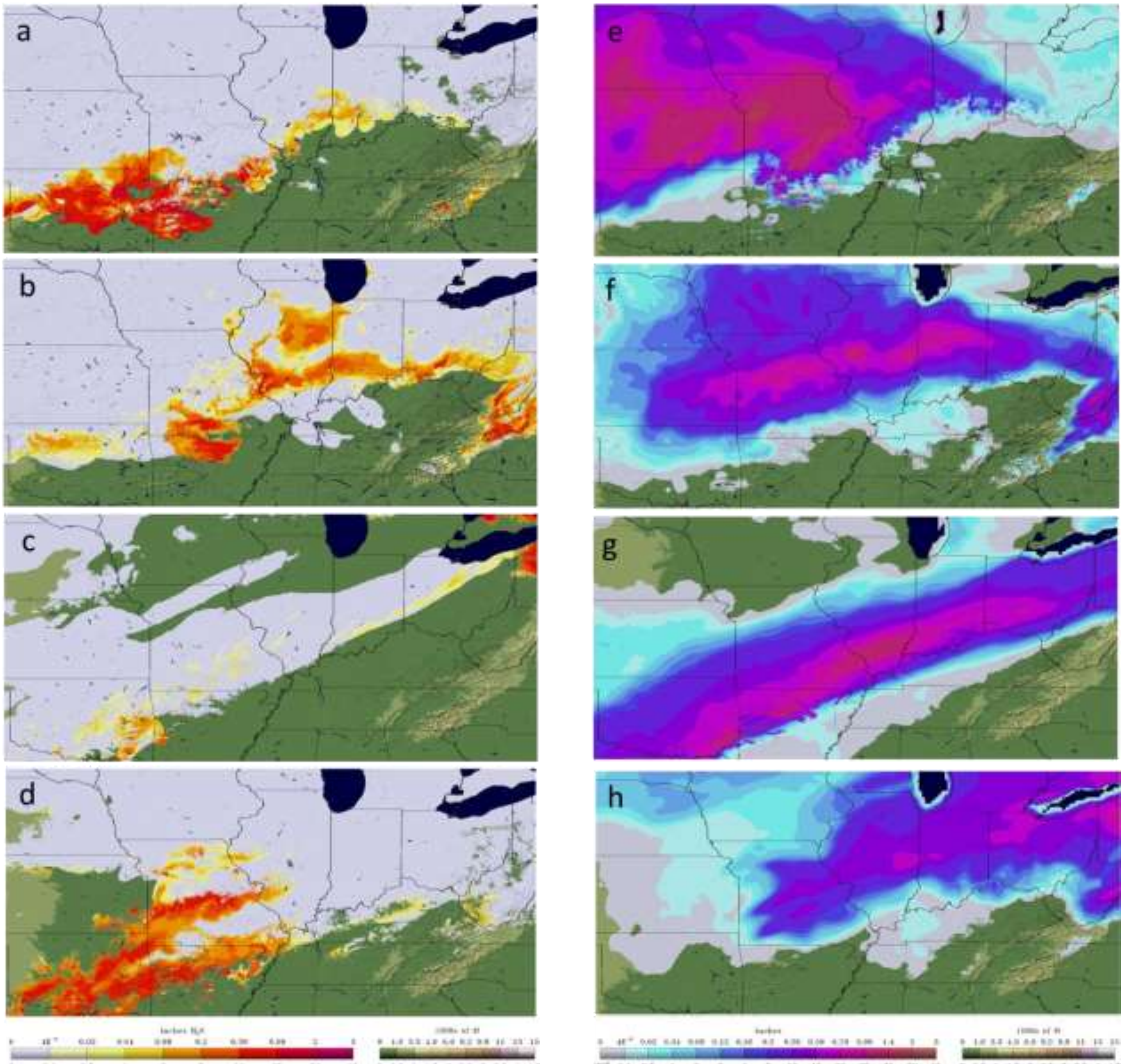

Fig 3. Two sets of data were plotted to show snowfall melt and overall snowfall precipitation. Each alphabetized image corresponds to a set of data and a winter storm event in 2013. Images “a-d” are of snowfall melt measured in inches and images “e-h” are of snowfall precipitation also measured in inches. The following events have been depicted in each image: 22 February 2013 (a, e), 25 March 2013 (b, f), 6 December 2013 (c, g), and 13 December 2013 (d, h). Measurements were taken over the course of 24 hours and all images were provided by the National Operational Hydrologic Remote Sensing Center (NOHRSC). http://www.nohrsc.noaa.gov/

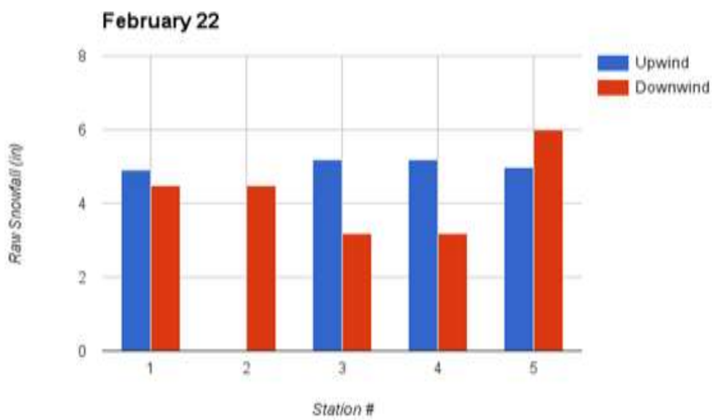

Fig 4a. Raw snowfall data in inches at individual upwind and downwind stations for the event of February 22, 2013. Each station point number corresponds to the enumerated station within each sector depicted in Fig 3.

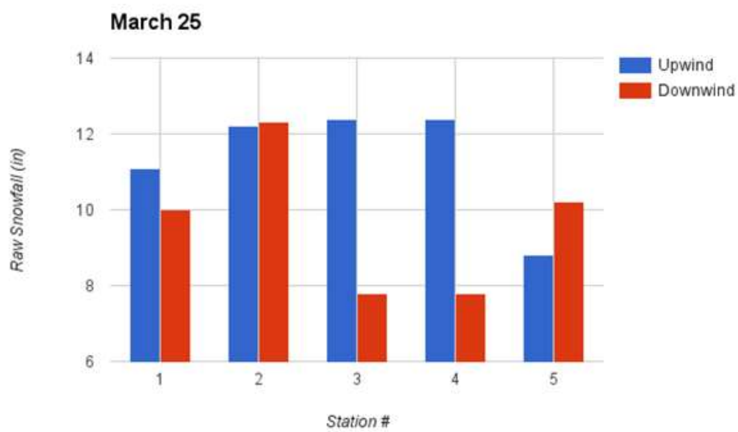

Fig 4b. Raw snowfall data in inches at individual upwind and downwind stations for the event of March 25, 2013. Each station point number corresponds to the enumerated station within each sector depicted in Fig 3.

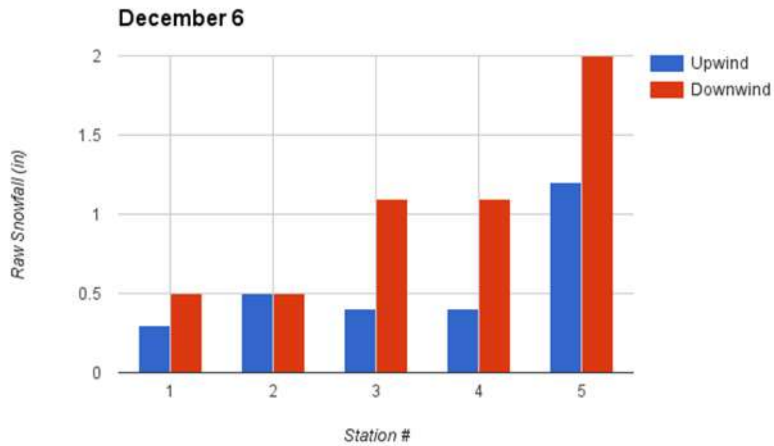

Fig 4c. Raw snowfall data in inches at individual upwind and downwind stations for the event of December 6, 2013. Each station point number corresponds to the enumerated station within each sector depicted in Fig 3.

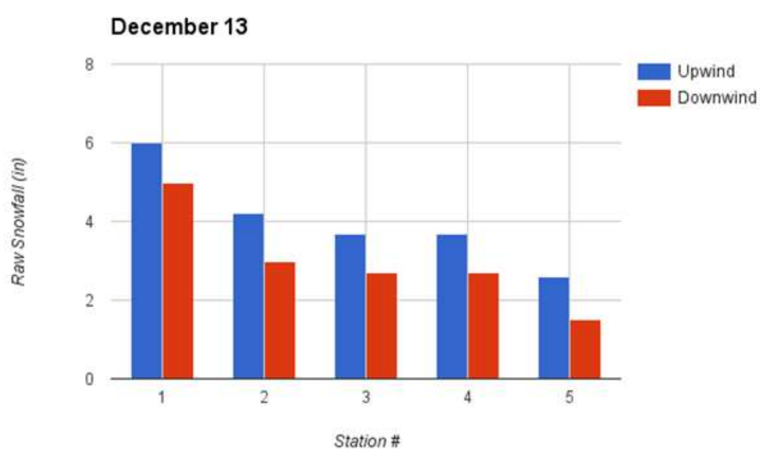

Fig 4d. Raw snowfall data in inches at individual upwind and downwind stations for the event of December 13, 2013. Each station point number corresponds to the enumerated station within each sector depicted in Fig 3.

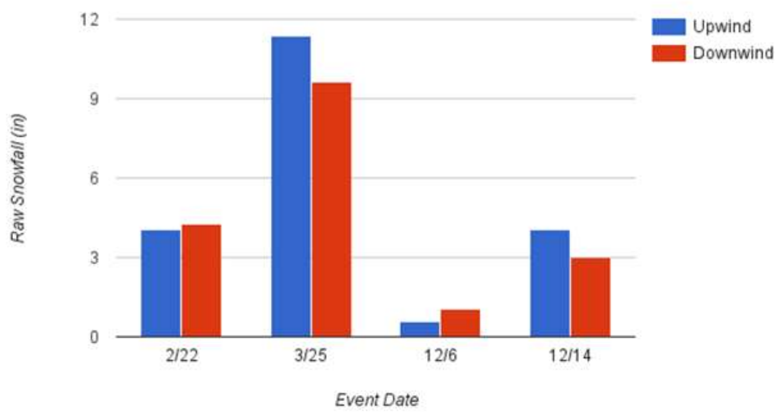

Fig 4e. Raw snowfall averages in inches depicted from both upwind and downwind sectors for all four significant snow total events.

Month	Upwind	Downwind
January	1.4	1.8
February	9.02	9.9
March	12.08	10.7
December	4.8	5.56

Table 1. Raw snowfall averages in inches over the course of 4 winter months in 2013 overs Saint Louis metropolitan area.

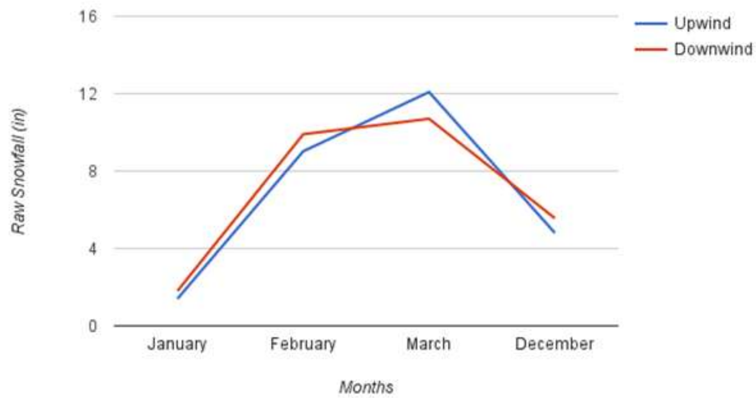

Fig 5a. Line graph depiction of raw snowfall averages over the course of 4 winter months in 2013 overs Saint Louis metropolitan area.

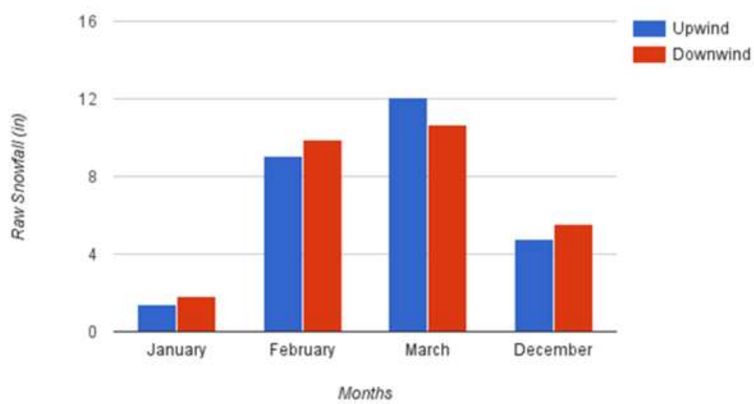

Fig 5b. Bar graph depiction of raw snowfall averages over the course of 4 winter months in 2013 overs Saint Louis metropolitan area.

First, by analyzing the imagery from NOHRSC, it is clear that for all significant events studied in this experiment, the trajectory of overall mesoscale movement similarly matches that of the radar imagery provided above. Just by a naked eye observation, it's evident that the urban environment in the Saint Louis region seems to attract snowfall totals and more importantly snowfall melt. The increased snowfall melt "downwind" of the city seems to prove once again the existence of warming over the city and its close urban surroundings (Fig 3).

With regards to the data obtained in the study, it is more worthwhile discussing the significant event results first. On February 22, 2013, the first event of the year for this study, snowfall totals showed no direct correlation for the upwind/downwind comparison (Fig 4a). Similar results in March for the March 25, 2013 event show no trend but a decisive contrast in large upwind snowfall values in corresponding stations three and four (Fig 4b). On this event the city center recorded 8 inches of snowfall. Upwind values show a 55% increase on that amount for stations three and four and up to 58% larger than the downwind stations. For both events, (February 22 and March 25) stations three and four in each sector showed the largest difference. This makes sense since they are both classified as the most "parallel" stations to the assumed trajectory and flow of the winter storms.

For the other two significant events, there is a definitive pattern associated with each figure. December 6, 2013, was significant, but by far the weakest performing (in terms of snowfall totals) winter storm in this study. This characteristic of lower snowfall totals certainly could be a factor in its results. Contrary to the previous dates, stations three and four were dominated by the downwind sector. A very linear trend is clear in the figure and provides reason to examine the synoptic reasoning behind it (Fig 4c). December 13, 2013 shows the same linear relationship, but has two important things opposite. On this event, the upwind led the downwind sector in totals for each station with a negative trend with respect to station number (Fig 4d). Important to the study is the fact that December 13 was an event in which the surrounding region saw as much as six inches in snow whereas the December 6 event saw as much as two inches. This disparity is one of the most important findings in the study. All four significant events were plotted with each other and there is a clear relationship present, but before jumping to a conclusion, it's important to look at the results of the monthly analysis as well (Fig 4e).

Two graphs depict the raw snowfall averages over the course of four winter months in 2013 (Fig 5a/5b). These graphs show a clear relationship between upwind/downwind snowfall totals and the role that significant snowfall event totals can have on an overall monthly amount. For the months January, February, and December, downwind sector totals are greater than that for the upwind sector. Although including the significant events studied above, they were not enough to alter the overall trend that for "non-significant" or "light" snow storms, the urban heat island effect plays a major role in providing an enhancement in snowfall totals. Clearly, the month of March (which has the event of highest snowfall totals with as much as 12.4 inches in stations three and four within the upwind sector) was affected by the largest snowfall event of the year. If you omit the event itself, the overall trend of urban-enhanced snowfall totals in the downwind sector still holds.

5. Discussion

a. What we did know

It’s important to look at what was already known before the study. It was known that the urban heat island does exist. It was known that it plays a role in certain synoptic level events and has been well-studied for many rainstorm events. However, it’s also known that there have not been many (if any at all) major studies that concern the winter storm snowfall rates and their impact from the urban heat island effect.

b. What we know now

After the results of this study, it’s clear that there is a role of urbanization in winter snow storms. This role can be classified as an enhancement of winter storm snowfall rates due to the presence of the urban heat island and other urbanization factors. With the exception of acute and isolated events, there is a significant factor of UHI effects that will enhance snowstorm totals in the downwind sector. However, it is just as equally important to conclude that these isolated, significant events provide the reasoning to assume that in cases of snowfall totals that reach eight or more inches, the urban heat island effects are insignificant and no longer a major contributor to downwind precipitation.

c. What we want to find out

A lot has been found out during this study, but this has only opened the door into winter weather studies within this subject. Looking into possible future works, it’s crucial that studies are done to focus more on the synoptic behaviors present during winter storms in the Saint Louis metro and in all urban environments. Some examples could be to analyze dew points, freezing points, and further looking into vertical trajectory changes that occur over the city.

6. Conclusion

The data in this study can be concluded to prove that the urban-enhanced precipitation effects do play a role in winter snowstorms and in overall snowfall totals within an urban environment. The effects are greater and more pronounced during periods where large snowfall is not present in one isolated instance.

In the long term, it is clear that the urbanization factors affect the snowfall totals, but in the isolated cases in which eight or more inches of snowfall is precipitated out over the course of 24 hours, the effects of the urban heat island no longer play a role in the distribution of snowfall totals within an urban environment and its surrounding area.

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REFERENCES

Bornstein, R.D., 1968: Observations of the urban heat island effect in New York City. *Journal of Applied Meteorology*., **7**, 575-582

Changnon, S.A., 2003: Urban modification of freezing-rain events. *Journal of Applied Meteorology*., **42**., 863-870.

Changnon Jr, S.A., F.A. Huff, R. G. Semonin, 1978: Metromex: an investigation of inadvertent weather modification. *Bulletin American Meteorological Society*., **52**, 958-968

Dabberdt, W. F., and Coauthors, 2000: Forecast issues in the urban zone: report of the 10th prospectus development team of the U.S.Weather Research Program. *Bulletin American Meteorological Society.*, **81**, 2047– 2064.

Dixon, P.G., T.L. Mote, 2003: Patterns and causes of Atlanta's urban heat island-initiated precipitation. *Journal of Applied Meteorology*., **42**, 1273-1284

Huff, F.A., S.A. Changnon Jr., 1972: Climatological assessment of urban effects on precipitation at St. Louis. *Journal of Applied Meteorology*., **11**, 823-842

NOHRSC National Operational Hydrologic Remote Sensing Center, cited 2016: Data Access. [Available online at http://www.nohrsc.noaa.gov/]

Shepherd, J. M., 2005: A review of current investigations of urban-induced rainfall and recommendations for the future. *Earth Interactions*., **9**, 1-27

Smoliak, B., P. Snyder, T. Twine, P. Mykleby, and W. Hertel, 2015: Dense network observations of the twin cities canopy-layer urban heat island. *Journal of Applied Meteorology and Climatology*., **54**, 1899-1917