Assessing Central Oklahoma's Tornado Risk: The May 24, 2011 Tornado Outbreak

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ABSTRACT

In this study, we looked at central Oklahoma's vulnerability, population exposure, and casualty estimates during a historical tornado outbreak. The event studied was the May 24, 2011 tornado outbreak that occurred over parts of central and western Oklahoma. GIS was used to perform an analysis of the outbreak. We found that we can use past tornado outbreaks to show potential severe weather risks. We also found that casualty statistics for counties can be estimated based on generated simulations and actual statistics calculated from the tornado outbreak. Lastly, We can have high confidence in these simulations effectively showing potential risk for an outbreak, with simulation population exposures showing numbers significantly higher than the actual exposure, as well as county confidence intervals showing the potential for some counties to be impacted multiple times by tornadoes.

I) Introduction

The city of Norman, Oklahoma has narrowly averted disaster from several violent tornadoes occurring on the periphery of the most densely populated areas of the city. In recent years, a series of mesocyclones associated with supercells traversed Norman, Oklahoma city limits that were primarily non-tornadic until they moved out of more densely parts of the city or out of the city limits entirely. During that same time frame, multiple significant

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tornadoes have struck nearby municipalities (EF4 in Shawnee, Oklahoma on May 19, 2013; EF5 in Moore, Oklahoma on May 20, 2013; EF2 in Moore, Oklahoma on March 20, 2015; EF4 in Little Axe, Oklahoma on May 10, 2010 to name a few). Climatologies of tornadoes suggest that Norman has a similar strong/violent tornado risk as these surrounding municipalities and, although the city of Norman has been fortunate with regard to the worst damage, this risk should not be ignored or marginalized.

Meanwhile, the proliferation of high-resolution tornado damage tracks has enabled for more detailed tornado risk assessments (Speheger 2002). Cannon et al. (2015), studied tornadoes in the historical April 27, 2011 tornado outbreak using high-resolution tornado damage information and county-based population tracks.

The current study has two main objectives: 1) to assess vulnerability from a past tornado outbreak in central Oklahoma and 2) to determine assess First, "Can we use previous tornadoes and tornado outbreaks to predict areas in Central Oklahoma most at risk for future events?". Secondly, "Can we determine the population exposure for the areas deemed most at risk for a catastrophic tornado outbreak?" Using detailed GIS-tornado information from the May 24, 2011 tornado outbreak, we have created a series of randomly generated impact scenarios to assess probabilities of impacts on populated areas in central Oklahoma. These scenarios will inform models of population exposure, casualty rates, and monetary damages to be used in subsequent studies. The goal of the current study is to look at a past tornado outbreak and use generated impact scenarios and GIS tornado information to determine potential population exposure for different risk scenarios.

Past studies have looked at past historical tornado outbreaks providing detailed aspects about them, as well as looking at tornado risk and vulnerabilities, incorporating factors such as urban sprawl and population growth. Speheger(2002) provides event verification and accuracy of individual tornadoes within the May 3, 1999 outbreak in central Oklahoma. The key interest of this study was to attain was proper documentation of this outbreak before damage and evidence of tornadoes was destroyed. Speheger was able to address individual tornadic data, including things such as existence, location and intensity, which can all shed light into areas that were at risk during that particular outbreak, but not for future tornadic events. This was one of the first in depth analysis of a tornado outbreak, and would lay the foundation for future tornado outbreak studies such as this one.

Ashley et al.(2014). performed an analysis of spatiotemporal changes in tornado hazard exposure. The study addresses how growing urban populations in Chicago increases the target area for tornadoes and increases the vulnerability of people and their possessions. Similarly using population census data to determine vulnerability, it was determined that increasing population densities in urban areas increases likeliness of a tornado disaster. We can apply aspects of this study for expanding metropolitan areas in central Oklahoma and how a growing population can increase risk of exposure for severe tornadic outbreaks. Hall and Ashley(2008) also studied the effects of urban sprawl on vulnerability to a significant tornado impact in Northeastern Illinois. Population tallies, housing unit tallies and housing values for 1990 and 2000 were examined in the study. It was determined that population increased significantly from the last severe tornado in the area, as well as an overall increase in wealth of the area, so there were also more expensive properties. The methods of this study can be useful to our current study in determining potential damage costs of a future tornado outbreak if a significant population is exposed to one. In certain counties in central Oklahoma with large populations, potential estimated population exposure rates, as well as damage rates, would be extremely beneficial to the state and the counties themselves, as our study will show. Cannon et al. (2011), studied tornadoes in the historical April 3, 1974 and April 27, 2011 tornado outbreaks using high-resolution tornado damage information and county-based population tracks. Similar to our study, they used GIS to analyze the outbreaks and evaluate tornado warning effectiveness between the outbreaks. This study was important in determining that one can have reasonably high confidence in using county level population data to compare recent and historical outbreaks, a method that is employed in our own study

II)Data and Methods

2.1 ***Population Data***

Census tracts acquired from the U.S. Census Bureau via American FactFinder (http://factfinder.census.gov/faces/nav/jsf/pages /index.xhtml) were the basis of population data used for this study. The census tract population data were spatially joined to unprojected shapefiles, projected to WGS 84, and then imported into Jupyter Notebook 5.5.0 software. This data formed the basis of population exposure and casualty modeling in Section 5.

2.2 ***Storm Data***

Detailed tornado track information utilized for this study were provided by the National Weather Service Forecast Office (NWSFO) in Norman, Oklahoma courtesy of Doug Speheger. Other tornado attributes (including F-scale ratings, injuries, and fatalities) were acquired from the NOAA/NWS Storm Prediction Center Severe Weather Database (Schaefer and Edwards 1999, https://www.spc.noaa.gov/wcm/#data).

2.3 ***Compilation of Data, Creation of Simulations, and Calculation of Population Exposure***

Anaconda Software Distribution and Jupyter Notebook 5.5.0 were used as an interpretation platform for python in creating the simulations and conducting the analysis. 5000 simulations were created by randomly translating each May 24, 2011 tornado track within 1° latitude and 1°

longitude of their initial positions (Figure 1). Then, tornado tracks from each simulation were intersected with county-level and census tract data to determine population exposure and potential casualty rates.

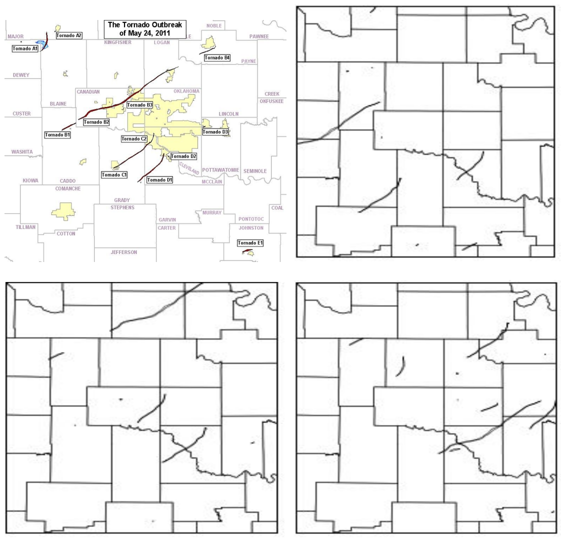

Figure 1: Top Left- May 24,2011 Tornado Outbreak. Top Right- Simulation 4897. Bottom Left- Simulation 4893. Bottom Right- Simulation 4848

Several steps were involved in estimating population exposure for tornado tracks in each of the simulations. The script would iterate through each track in each simulation and check for intersections between the tornado tracks and the census tracts. If there was an intersection, the script would clip the area of the intersection and calculate the area of that clipped section. Then it would calculate the ratio of the clipped area to the area of the census tract and multiply that ratio by the population density of census tract.

2.4 *Calculation of County Hits*

Once all of the simulations were created, a script was created to calculate how many times a county was hit by a tornado. In the script, the loop would iterate through each track in each simulation. Then it would check to see whether there was an intersection between a tornado track and a county. For each simulation, if there was an intersection, it would be counted as a hit and written out to a csv file. This file listed each county that got hit in that simulation, as well as how many times the county was hit. The resulting tally of county hits were then plotted onto box and whisker diagrams.

2.5 *Calculation of Fatality Rate, Injury Rate and Casualty Rate*

Casualty rates were derived by dividing the actual number of casualties in the tornado outbreak by the actual estimated population exposure of the outbreak (with estimated population exposure calculated via the above described method in Section 3.4). This casualty rate was applied to population exposure estimates from each of the simulations to estimate potential casualty totals(Equation 1).

$$Casualty\ Rate = \frac{\#\ of\ actual\ casualties\ in\ outbreak}{Estimated\ population\ exposure\ in\ outbreak}$$

Canadian, Cleveland, Grady, Logan, McClain, and Oklahoma Counties were depicted in this study due to being in or near the bulk of the May 24, 2011 tornado outbreak, total population, and number of times each county was hit both in our 5000 simulations and during the outbreak

III)Results

In the May 24 2011 tornado outbreak, some counties averted major disaster, especially in regards to the amount of times they were impacted by tornadoes. Oklahoma County in particular escaped the outbreak, not being hit by a single tornado, where as neighboring counties like Canadian Counties were hit twice. Counties like McClain County did not fare as well as Oklahoma County either, with McClain County being hit by four tornadoes. Figure 2 below shows the number of tornado hits in our simulations for six counties near the center of the outbreak. Some counties have outliers above the 90th percentile, meaning that a few simulations had counties like Oklahoma and Logan being hit up to 5 times in a single outbreak. This shows that counties like Oklahoma county were very fortunate with regard to the actual tornado outbreak.

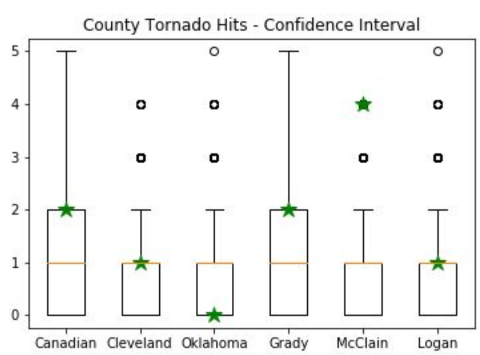

Figure 2: Confidence Interval of County Tornado Hits for Canadian, Cleveland, Oklahoma, Grady, McClain, and Logan Counties. Average number of hits for each county in the simulations is represented by orange line. Actual county hits in outbreak represented by green star.

For the outbreak in this study, the actual population exposure was above the average we determined in our simulations (Figure 2). The orange line represents the 50th percentile, or the average number of people exposed in the simulations(3,142 people). Although this confidence interval had an shown an average population exposure over the 5000 simulations that was lower than the actual population exposure, there are a number of simulations that had significantly larger population exposures due to simulated tracks traversing high-population areas. In some outlier simulations, population exposures are well above the 90th percentile, with a potentially as many as 50,000 people exposed to tornadic winds. This can probably be associated with simulations where more populated counties like Oklahoma and Cleveland got hit more than once or twice by tornadoes, potentially increasing the population exposure. On the lower scale of population exposure, there is a 10% chance of population exposures greater than 1,500 people to tornadic winds during this outbreak.

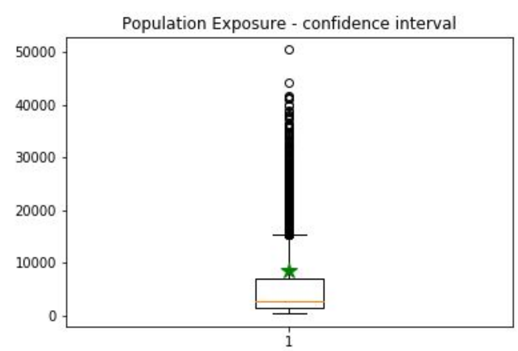

Figure 2: Confidence Interval of Population Exposure for 5000 tornado outbreak simulations. Average population exposure of simulations is represented by orange line. Actual population exposure of outbreak is represented by green star(8,658 people)

The counties of Canadian, Cleveland, Oklahoma Grady, McClain, and Logan counties were not only analyzed in simulations due to their overall proximity to the original outbreak, but their population and relation to the Oklahoma City metropolitan area as well.

Figure 3 shows the population exposure intervals for each of those counties, with the average exposure being zero as many simulations had the counties not being exposed to any tornadoes. Oklahoma County had the highest potential population exposure based on the simulations, with potentially up to 50,000 people exposed to tornadic winds in its highest-impact simulation. This result is not necessarily a surprise, however, given that Oklahoma County is the most populated county in the state. Similarly Cleveland county has a larger exposure number for its 75th percentile, and for both Oklahoma and Cleveland counties, this can be attributed to those counties being the 1st and 3rd most populated in Oklahoma respectively.

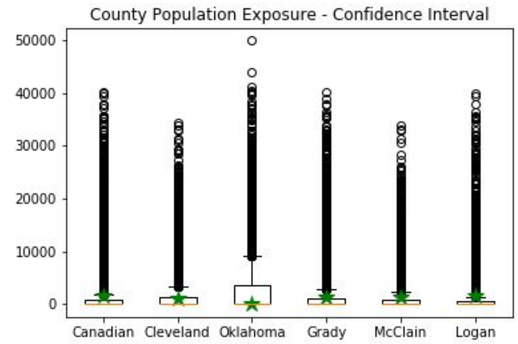

Figure 3: Confidence Interval of Population Exposure for Canadian, Cleveland, Oklahoma, Grady, McClain, and Logan Counties. Average population exposure of each county in the simulations is represented by orange line. Actual population exposure of each respective county is represented by green star.

Table 1 shows numerical results for fatality rate, injury rate, and casualty rates derived from this study. Looking at the results, the number of fatalities was pretty low and overall injuries and casualties were less than five percent, so a significant portion of the population escaped the outbreak relatively unharmed.

Tornado Outbreak Statistical Results
May 24, 2011
By Justin C. Bonds
7/20/2018

	Fatality Rate %	Injury Rate %	Casualty Rate %	Population Exposed to Outbreak
May 24, 2011 Outbreak	0.13 (11 deaths)	3.38 (293 injuries)	3.51 (304 total casualties)	8,658

Table 1: Numerical results derived from this study for the May 24, 2011 tornado outbreak. The first column shows the fatality rate percentage, the second column shows the injury rate percentage, the third column shows the casualty rate percentage, and the last column shows the actual population exposure for the entire outbreak.

Counties	Fatalities(Actual Pop.Exposure)	Fatalities(Max. Pop Exposure)	Fatalities(90th percentile)	Injuries(Actual Pop.Exposure	Injuries(Max. Pop Exposure)	Injuries(90th percentile)
Canadian	2	52	1	54	1,352	34
Cleveland	1	46	3	33	1,183	85
Oklahoma	0	65	6	0	1,690	152
Grady	2	52	2	43	1,352	51
McClain	2	46	1	43	1,183	34
Logan	2	52	<1	54	1,352	17

Table 2: Numerical results derived from this study for Canadian, Cleveland, Oklahoma, Grady McClain, and Logan Counties. The first and fourth columns show estimated fatalities and injuries based on actual population exposure, the second and fifth columns show estimated fatalities and injuries based on maximum population exposure, and the third column and sixth columns show the estimated fatalities and injuries based on the 90th percentile of population exposure.

Looking at Table 2, we can see estimates of casualties for the six counties looked at closely in this study. Interestingly, Oklahoma County had the highest potential fatalities and injuries for maximum population exposure and 90th percentile population exposure. Logan County had an interesting statistic of less than 1 death for its 90th percentile of fatalities, although it had higher potential deaths for its maximum population exposure than counties like Cleveland, which is more populated. The likelihood of a high-fatality event(such as 50 fatalities or greater) is very low, as a population exposure of 38,500 or greater would be needed in concurrence with fatality rate in Table 1. If we look at the maximum county population exposures in Figure 3, Cleveland and McClain Counties do not reach this level of exposure, and there is less than a 10% chance of this scenario occurring for Canadian, Oklahoma, Grady, and Logan Counties.

IV)Conclusion

This study has utilized high-resolution tornado track data to assess central Oklahoma's tornado risk during the 24 May 2011 tornado outbreak. We have shown that we can use past tornado outbreaks to show potential severe weather risks. In a tornado outbreak, even though some may be overshadowed by a larger number of weaker tornadoes while big tornadoes are threatening or occurring, it still remains relatively unlikely that one of those big tornadoes will actually impact a densely populated area, such as a town. We also can have high confidence in these simulations effectively showing potential risk for an outbreak, with simulation population exposures showing numbers significantly higher than the actual exposure, as well as county confidence intervals showing the potential for some counties to be impacted multiple times by tornadoes.

V)Future Work

This project was a pilot project to determine if we could use a past tornado outbreaks to assess potential risk for tornado outbreaks in central Oklahoma and assess potential population exposure. Since we believe we have done that, we would like to analyze other, larger outbreaks. We also would like to use this project to make potential risk assessments for other areas of the continental United States that are vulnerable to tornadoes. We would also like to separate county tornado hits by EF-Scale as well as population exposure to different strength tornadoes. Lastly, we would like to calculate dollar damage per person in simulated outbreaks to better assess monetary risks to outbreaks. This will be possible with proper verification of actual tornado monetary damage estimates and values.

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