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Spatial Analysis of Tornado Warning System Understanding and Relationship with Tornado Occurrence

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Tornadoes present a significant threat to life and property. The National Weather Service watch and warning system warns the public of tornadoes. If these warnings are not heeded by the public, the potential fatalities and destruction of property cannot be minimized. Thus, to prevent further loss of life and property, it is necessary to understand how the public understands the watch and warning system, as well as how they react. This paper aims to understand the correlation between understanding of watches and warnings and the occurrence of tornadoes, as well as how understanding varies spatially. Survey data were collected from 12 Tennessee counties on watch and warning understanding and compared with tornado GIS data from the NOAA Storm Prediction Center tornado database. Survey responses were coded into categories based on response correctness and percentages of "correct" and "incorrect" responses were organized by county, compared and mapped. There is a weak positive correlation between occurrence of tornadoes and poor watch and warning understanding, which p-values prove insignificant. Correlations are stronger when excluding outliers, but remain insignificant. The Memphis area appears to have the poorest watch understanding while the Knoxville area has the best understanding. Warning understanding seems to be the worst in the Knoxville area and best in the Nashville area. Poor watch and warning understanding cannot be predicted by tornado occurrence, so other factors must be affecting understanding. This paper highlights a need for future research and outreach.

1.1 Introduction

It is known that tornadoes present a significant threat to life[1] and property.[2] Over the past several decades there has been a continuous drive to understand tornadoes and related processes to prevent further property damage and fatalities. In recent years, there has been a push to establish an understanding of the human aspect of tornadoes, as current literature on public response to the warning system is very limited.[3] While the National Weather Service watch and warning system aims to warn the public of impending threats like tornadoes, the potential fatalities and destruction of property cannot be minimized if these warnings are not heeded by the public. In fact, response to warnings has shown to be very dependent on the public's understanding of warnings, their accuracy, and the trust of those who issue the warnings.[1] Thus, to prevent further loss of life and property, it is necessary to understand how the public understands the watch and warning system, as well as how they react.

This is one of the goals of VORTEX-SE (Verification of the Origins of Rotation in Tornadoes Experiment-SouthEast), with a focus being on the southeast United States.[4] Recently I assisted in research funded by NOAA through VORTEX-SE which aimed to understand tornadoes and the human response specifically in Tennessee. This is an important focus because Tennessee has the highest rate of nocturnal tornadoes[5], and one of the highest rates of tornado fatalities.[1] For the general southeast, including Tennessee, tornadoes can occur outside of the typical tornado season. Having tornadoes out of season and at night when they are hard to see or people are asleep can result in a lack of preparedness for incoming tornadoes.[6]

To better understand the human response to tornado watches and warnings in Tennessee, I used data from this research and supplemental tornado data to answer two questions: how does understanding of tornado watches and warnings vary spatially; and is there a correlation between understanding and tornado occurrence? For the purposes of this paper, understanding is defined as the ability to correctly define a watch or warning, or describe an appropriate behavioral response to a watch or warning. To answer these questions, I conducted statistical and spatial analysis using Geographic Information Science. My initial hypothesis was that understanding would be poorer in east Tennessee where tornadoes are less common, and relatively better in areas with higher tornado occurrence. Neither of these appear to be necessarily true.

1.2 Data

The data used to answer the research questions consisted of two data sets. The first data set is the survey data from the VORTEX-SE funded research project, which attained approval through the Institutional Review Board for research involving human subjects in February of 2016. Surveys were conducted over the phone through the Human Dimensions Research Laboratory at the University of Tennessee. Phone numbers were randomly sampled. The survey data consisted of survey responses from participants within 12 different Tennessee counties, which are listed in Table 1. The 12 counties are broken up into 3 clusters of 4 counties each; a western cluster (the Memphis area), a middle cluster (the Nashville area), and an eastern cluster (the Knoxville area). These specific regions were selected because tornado risk varies longitudinally across Tennessee, and the regions surround the three largest cities within the state, which are also located within three different areas of the state. Individual counties were selected based on their high variability of demographic characteristics. This research used answers from two questions from the larger survey completed for the VORTEX-SE funded project, providing a total of 3,630 responses. For these questions, participants were asked to describe in their own words what a tornado watch and warning meant respectively.

The second data set is the tornado database from the NOAA Storm Prediction Center,[7] which consisted of a tornado track shapefile in line form, with all tornadoes reported in the United States from 1950 to the present.

1.3 Methods

For the survey data set, responses were coded and then underwent statistical analysis. For the coding process, all 3,630 responses were placed into 8 different categories: incorrect, correct definition, correct behavior, correct definition and behavior, participant states “does not know”, participant refused to answer, other missing, and researcher unable to code. For watches, the correct definition was “a tornado was possible or conditions were favorable”, and the correct behavior was to be prepared to act. For warnings, the correct definition was “a tornado has been spotted or seen on radar”, and the correct behavior was to take shelter immediately. Since there were many responses, I created personal guidelines to ensure consistency. For example, if a participant stated in their watch response something along the lines of “be aware” or “watch out”, I placed it in the correct behavior category, since it implied preparedness. Similarly, if a participant stated in their warning response that a tornado was “coming”, “imminent” or “touched down” I considered it the correct definition since, even if it was not technically correct, if the participant believed a tornado had “touched down”, it implied the presence of a tornado and thus, for the purposes of the public, was correct understanding. The coding results were later combined with those of another researcher, and inconsistencies were analyzed and resolved by a Primary Investigator on the project. The finalized coding was in binary form, where 0’s indicated an incorrect response and 1’s indicated a correct response as determined by the researchers. Refusal to respond and statements of “does not know” were assigned different numbers to differentiate them from correct and incorrect responses. From there, responses were divided into their respective counties. Percentage of incorrect responses out of total responses were calculated. This was done for both watch and warning responses. The Pearson product-moment correlation coefficient was calculated for both the relationship between tornado count and incorrect watch percentage and incorrect warning percentage, with their respective p-values.

For the tornado shapefile data set, I conducted vector analysis in ArcMap. County shapefiles, provided by the U.S. Census Bureau, were used in tandem with the tornado data set. I identified all tornadoes intercepting all of the target counties, as well as tornadoes for each county individually. This resulted in a total tornado count of 243. Individual county tornado counts are shown in Table 1 in the Results section. It is important to note that tornado counts per county are not mutually exclusive as a single tornado track can pass from one county to another.

1.4 Results

The results of the spatial analysis are in Figures 1 and 2. The maps depict the understanding of watch or warning with graduated colors, where deeper red indicates less understanding. Tornado occurrence is mapped using graduated symbols, where the larger the circle, the more tornadoes occurred since 1950. As shown in the map, there are several counties with high tornado occurrence and poor understanding, and low tornado occurrence with relatively better understanding. As expected, tornado occurrence tends to decrease the farther east you go. The western cluster (Memphis area) appears to have the poorest watch understanding while the middle cluster has the best watch understanding. Warning understanding seems to be the worst in the Knoxville area and best in the Nashville area.

The results of statistical analysis are shown below in Table 1 in order of increasing tornado count. Again, as depicted in the maps, counties such as Davidson and Shelby had high tornado occurrence and poor understanding. Incorrect watch percentage had a mean of 19.92% with a standard deviation of 5.49%. Incorrect warning percentage had a mean of 26.45% with a standard deviation of 5.69%. Knox County had the highest percentage of incorrect understanding of warnings, while Williamson had the greatest understanding. Davidson County had the highest percentage of incorrect understanding of watches, while Williamson had the lowest and Knox was 3rd highest. Williamson County was a significant outlier with only 16.00% incorrect warning responses. Shelby County had the highest tornado count, 2nd highest incorrect warning percent and 2nd highest incorrect watch percent. Union county had the lowest tornado count and fell in the middle on both incorrect percentages. Overall, warnings were less understood than watches.

Counties	Tornado Count	Incorrect Watch %	Incorrect Warning %
Union	3	17.53	26.62
Anderson	7	18.42	29.61
Loudon	8	15.03	26.80
Knox	14	23.81	37.50
Haywood	16	22.83	18.89
Fayette	18	23.29	28.08
Robertson	21	18.18	25.76
Tipton	22	16.03	23.72
Williamson	24	8.00	16.00
Davidson	35	27.91	26.49
Rutherford	38	15.44	24.83
Shelby	52	25.14	33.14

Table 1

Figures 4 and 5 show tornado count alongside the incorrect watch and warning percentages, in order to understand the correlation between occurrence and perception. The Pearson correlation coefficient was calculated between the incorrect percentages and tornado count. For incorrect watch % and tornado count, there was a slight positive correlation with a coefficient of 0.27 and p-value of 0.19. For incorrect warning % and tornado count, there was a smaller positive correlation with a coefficient of 0.06 and a p-value of 0.43. If outliers such as Williamson and Knox are excluded, the correlation coefficient for warnings is 0.31 with a p-value of 0.19. This shows that any correlation between the understanding and tornado count variable is not significant at 5%.

1.5 Discussion and Conclusion

While it is apparent that there exists no significant correlation between tornado count and tornado watch and warning understanding, there are a few important things to note. First, there are counties with high tornado counts that also have poor understanding, such as Shelby and Davidson counties. Second, roughly a quarter of the participants surveyed could not correctly define a tornado warning or actions to take when one is in place. Similarly, roughly 19% could not correctly define a tornado watch. Additionally, it is critical for residents to understand warnings as much as they do watches, as knowing a tornado is imminent is essential for protecting life and property. Third, if poor watch and warning understanding cannot be predicted by tornado occurrence, other factors must be affecting understanding. Some potential factors could be income, education, or how warnings are received.

Limitations of the original VORTEX-SE funded project are the use of phone surveys and only having survey data at the county level. Since surveys were conducted over the phone, only people who had phones and were willing to answer could be participants. Phone surveys have been used historically to assess natural hazard knowledge and understanding. Some benefits of using phone surveys are cost effectiveness, the ability to clarify responses and an amount of anonymity not found in face-to-face interviews. Some known issues with using phone surveys are decreasing popularity of phone surveys over time, potential creation of class or gender bias, and the necessary simplicity of questions.[8] To allow participants to remain anonymous, geographic data of responses could only be done at the county level. While address or postal code information could have allowed a more in depth spatial analysis, this information would have made participants identifiable.

1.6 Future Research

Further research should be done to determine why there is a lack of understanding in some areas with relatively higher tornado occurrence. Action should be taken to better the understanding in these areas. While these results only examine one variable in relation to watch and warning understanding, they highlight a need for future research and outreach to understand how the public responds to the warning system and further prevent loss of life and property. Future research should examine the relationship between warning system understanding and education or income. Other potentially insightful examination of variables could include proximity to a city center, region of origin or how long one has lived in an area.

Later phases of the VORTEX-SE funded research intend on examining other factors such as poverty, complacency and communication networks. The final stage of the study includes workshops in the target counties to educate people on tornado safety.

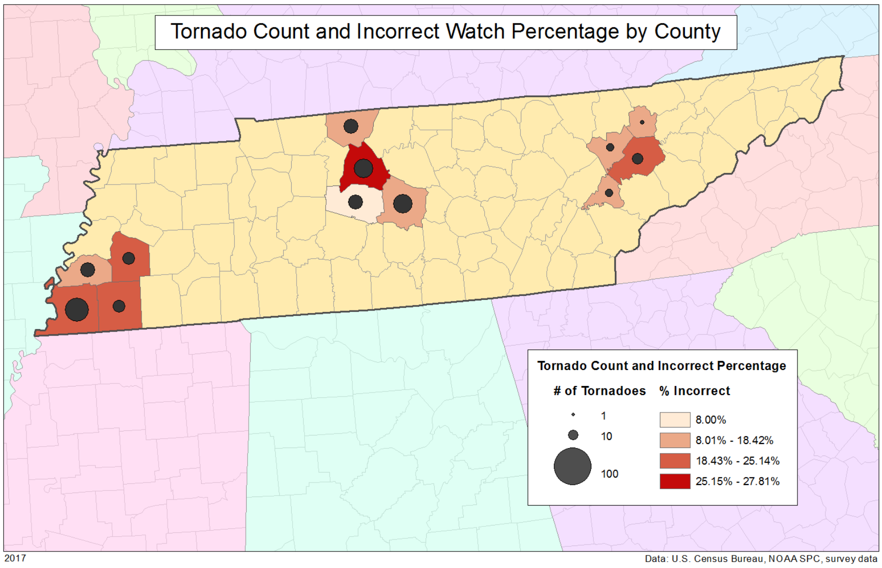

Figure 1

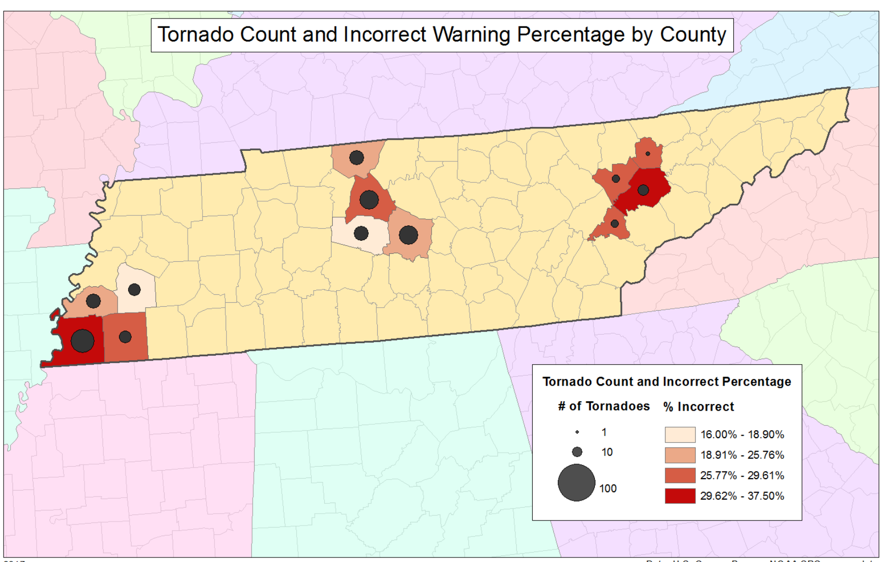

Figure 2

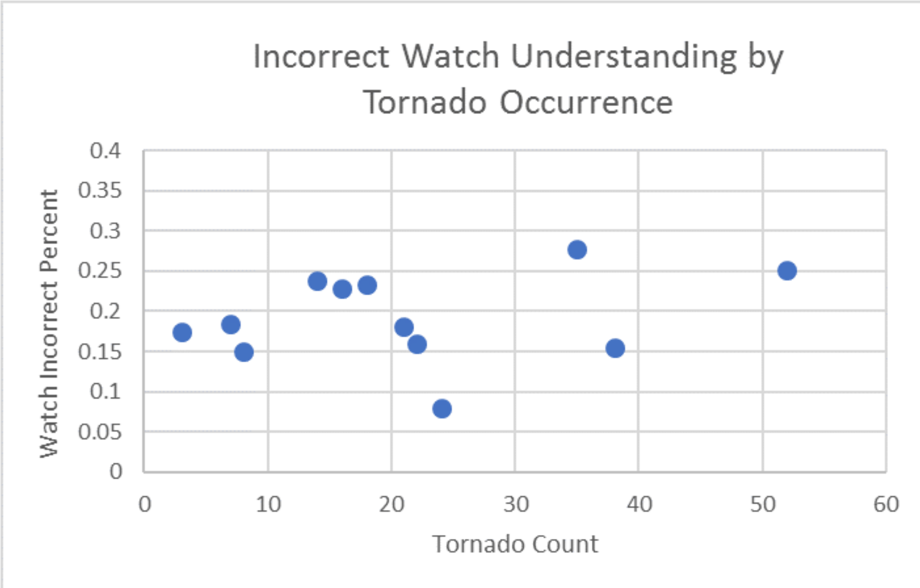

Figure 3

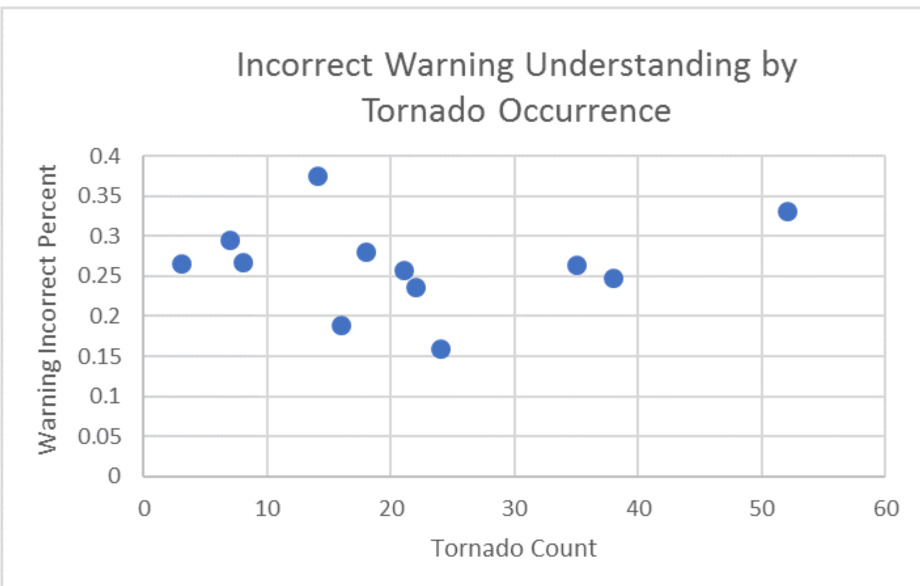

Figure 4

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