Spatial Video Street-Scale Damage Assessment of the Washington, Illinois Tornado of 2013

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ABSTRACT

This paper advances a growing body of mobile mapping work which captures building scale tornado damage in order to reveal vulnerabilities, or protections, within an otherwise apparently homogenous damage path. The hope is to find how micro geography, or built environment structure patterning might lead to policy advances with regards to rebuilding of critical infrastructure in tornado prone areas. This paper will use spatially encoded video to record damage patterns for the Washington, Illinois tornado of November 17, 2013. What makes this event notable is the location and time of year which can be considered outside the norm. Individual building damage data are coded using the Tornado Injury Scale (TIS) and then analyzed using two forms of local area spatial analysis - a Getis-Ord (Gi) z-score analysis to identify hotspots of damage, and a Local Moran's I to identify building outliers within hotspots.

Keywords

Tornado, spatial video, GIS, damage assessment.

INTRODUCTION

The Washington, Illinois tornado occurred on Sunday, November 17, 2013 at 11:06 am, and was part of a late-fall severe weather outbreak consisting of at least seventy tornadoes striking seven states (NOAA 2013a, 2013b, 2013c). The tornado that struck the town of Washington was arguably the most significant of this outbreak, with approximately 1,000 homes being impacted, and two fatalities and 125 injuries resulting (NOAA 2013c). The tornado was approximately a half mile wide when it struck Washington, with an overall damage path of approximately 46 miles in length (NOAA 2013c); towns that were impacted included East Peoria, Washington, and Dana, IL, although the town of Washington sustained the most damage (NOAA 2013a, 2013c). This tornado was ultimately rated as an upper-end EF4 on the Enhanced Fujita Scale with wind speeds estimated at approximately 85 ms^{-1}, or 190 mph (NOAA 2013c).

This paper focuses on a spatial video survey of building scale damage for this tornado, and incorporates a methodology which has been used to assess previous disasters (Mills et al., 2010). Although the Washington tornado had less impact than other notable recent tornadoes (e.g., the EF5 events of Moore-Newcastle, OK in 2013 and Joplin, MO in 2011), it still provides an interesting event for multiple reasons, not least because of the relatively unusual time-of-year and location. In addition, the purpose of conducting these spatial video surveys is to build an archive of spatial damage data to advance theories in increasing community resilience across geographies, urban scales, and for different size events. This paper adds to other spatial video post-tornado damage assessments previously applied to tornadoes in Tuscaloosa, Alabama (4/27/2011), Joplin, Missouri (5/22/2011), and Newcastle-Moore, Oklahoma (5/21/2013) (Curtis et al., 2013; Curtis and Fagan, 2013; Curtis and Mills 2011; Mills et al., 2008).

METHODS

Spatial Video Surveys

Two separate field surveys were conducted for portions of Washington impacted by the 17 November 2013 EF4 tornado; survey routes were constructed based on a preliminary map of the damage path acquired from the National Weather Service office branch in Lincoln, Illinois. On each side of the survey vehicle, a Contour + 2 camera with an inbuilt GPS recording functionality device was fixed to a window mount. Two additional Contour + 2 cameras pointed forward.

The first survey was conducted on Saturday, November 23, and was followed by a second on Friday, November 29. The reasons for the delayed dates of data collection stem both from heavy restrictions being placed on roadways accessing damaged neighborhoods coupled with recovery and clean-up efforts occurring over the Thanksgiving holiday. In the immediate days following the November 17 disaster, the damaged areas were only accessible to emergency management officials and for personnel responsible for clearing debris off roadways. On the following Friday, November 22, the town of Washington issued an ordinance allowing only residents to access their damaged homes until Sunday the 24th in order to collect personal belongings. It was during this period that the first survey attempt was conducted. For almost all damaged neighborhoods located throughout Washington, multiple law enforcement checkpoints strictly enforced the residents-only access ordinance. As a result, officers at the scene of heavily-damaged neighborhoods denied the survey team entry into these areas. Damaged neighborhoods located in southern sections of Washington did not feature law enforcement checkpoints, and ground imagery from the first survey consists mostly of these areas.

A second round of debris removal was conducted between Novembers 25-26, and restrictions for accessing the damaged neighborhoods again were enhanced (residents were not allowed to enter). The following Thursday coincided with the Thanksgiving holiday, and it was at this time when checkpoints were removed and restrictions were lifted to allow residents, insurers, maintenance crews, and other personnel to access the heavily damaged neighborhoods. The second and more comprehensive survey of the damaged areas was conducted by the survey team on the 29th (pathways are visible in Figure 1). Almost all building damage within the tornado path was collected, with the only notable exception being an apartment complex located in the southwestern portion of the damage path; this area had been sealed off to the public for access by the property owner. Driving speed in the heavily damaged neighborhoods was reduced to an estimated 10-20 mph, as insurers, residents, repair crews, and emergency vehicles were navigating on roads while large debris piles were mounted on curbsides of the hardest-hit areas.

Coding

Upon returning to the GIS Health & Hazards lab at Kent State University, video data was viewed using Contour Storyteller software. This software displays the spatial video on a main screen while an icon identifies the corresponding frame location on a map. While viewing Contour Storyteller, a second computer monitor displayed overhead satellite imagery of Washington, IL through Google Earth. Damage codes for each impacted building were subsequently digitized into Google Earth; this approach followed the same methods previously employed for Joplin, Missouri, and Moore, Oklahoma. Every surveyed building was assigned a damage rating on the basis of the Tornado Injury Scale (TIS), which was developed by Curtis and Fagan as a health risk evolution of the traditional EF scale (Curtis and Fagan 2013). The TIS Scale rates building damage magnitudes and injury likelihoods on a scale of 1-10, though ‘9’ and ‘10’ scores were combined due to each score being a variation of complete destruction (Figure 1 legend). Given that the more comprehensive of the two field surveys was conducted twelve days after the tornado event, it is assumed that some structural damage patterns captured on video on November 29 may not accurately represent damage initially sustained on November 17. In some instances, structures that had sustained light-to-moderate levels of damage but were not demolished (damage magnitudes of 1-6 on the TIS scale) were covered with tarp and other materials on November 29; these images were captured on camera during the second field survey, and it is on this primary basis that buildings were coded according to the TIS scale. Structures that had sustained more significant damage on November 17, however, such as the collapse of one or more exterior walls (damage magnitudes ranging from 7-10 on the TIS scale) were, in some instances, cleared from their respective foundations by the time of the November 29 survey date. In these instances, high resolution aerial photographic imagery (available through ArcGIS 10.1) was the primary resource referenced for assigning building damage. Altogether, 1,077 structures throughout Washington were geocoded (Figure 1 and Table 1). It should also be noted that variations in coding accuracy have been previously observed when simultaneously incorporating data sets from multispectral satellite imagery, ground survey work, and oblique photography (Gerke and Kerle 2011; Petrie 2009). For this paper, all coding was completed by the same coder, and a methodology was employed that has been previously utilized by the same research lab for other disaster case studies. The advantage of using the spatial video is that any suspicious code revealed by mapping or the outlier analysis employed in this paper can be validated by referencing the source video.

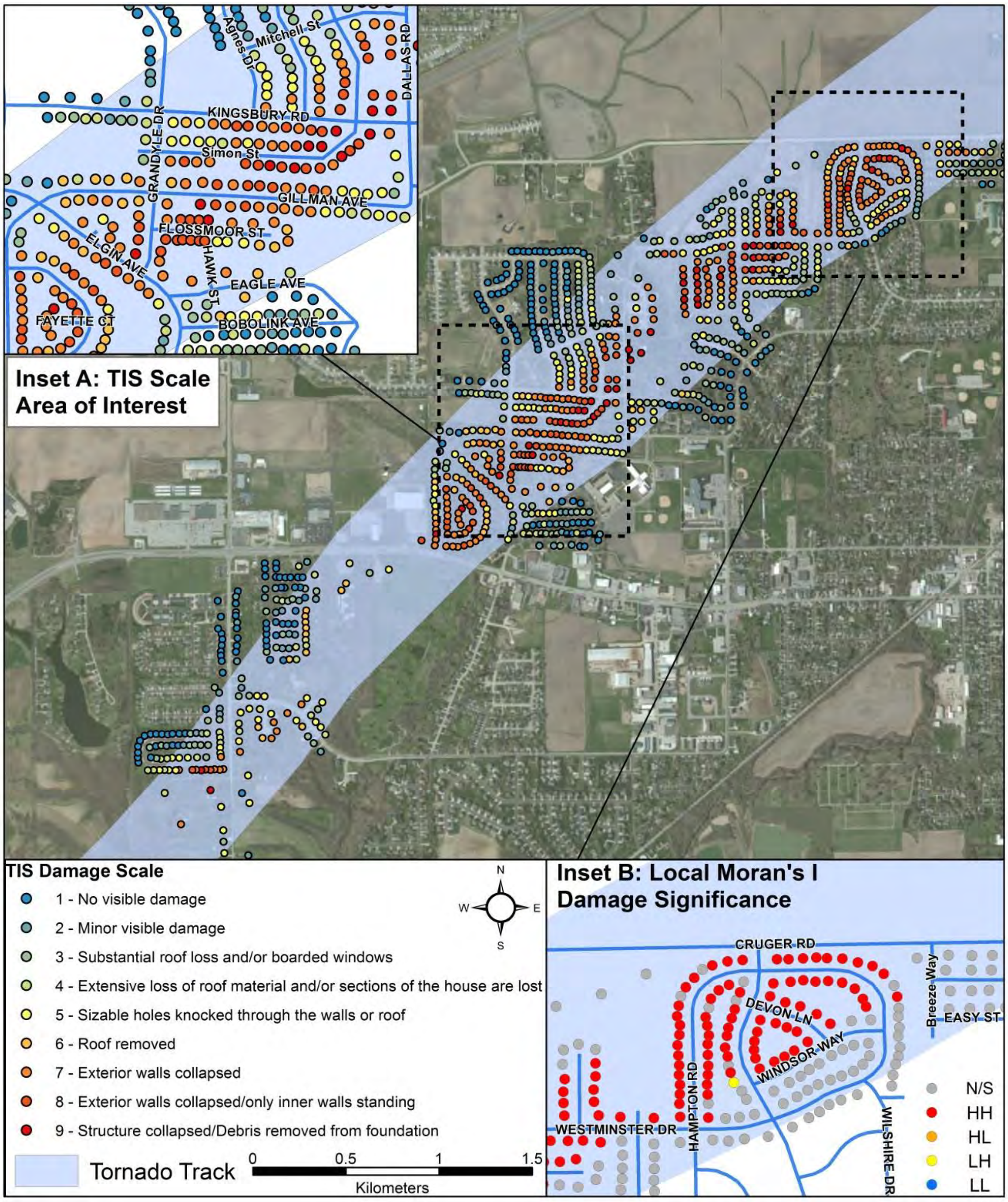

Figure 1: Spatial video assessment of Washington, IL with enhanced views of damaged streets and the Local Moran's I analysis

Fine Scale Spatial Analysis

To better understand damage patterns on the individual structural level that are in keeping with previous tornado research, two spatial tests were undertaken. First, a local area hotspot analysis featuring statistically significantly higher or lower degrees of damage relative to immediately surrounding structures was employed (Curtis et al., 2013; Curtis and Fagan 2013). A Getis-Ord (Gi) z-score analysis was conducted within ArcGIS 10.1 to identify structural damage magnitudes relative to three standard deviation thresholds (where p=0.01, p=0.05, and p=0.10). In addition, a Local Moran's I analysis was conducted in ArcGIS 10.1. This test determines whether statistically significant differences exist between damage magnitudes of individual structures relative to surrounding structures; statistical assessments are based on 'z' scores at the .05 p-value threshold.

RESULTS

In total, 1077 buildings were coded according to the TIS. The distribution of TIS codes can be seen in Table 1, with over 13% of surveyed homes sustaining damage that would probably have resulted in injury or worse for persons not seeking any protective action (TIS scores of 8 or above). The spatial pattern of the damage is shown in Figure 1, with Inset A displaying an enhanced view for several streets. The main map displays a typical pattern of damage extending evenly outwards from a center line. This pattern becomes less regular at a finer scale (as seen in Inset A), as TIS scores for homes along a street segment vary from '5' through '9'. In some places, damage also varies according to the side of the street (Simon St).

TIS Score	1	2	3	4	5	6	7	8	9	10	Total
Buildings Impacted	195	96	136	112	132	76	188	102	40	0	1,077

Table 1: Counts of buildings for every TIS class.

Results from the Getis-Ord (Gi) z-score analysis are not displayed here due to space limitations, but the maps mirror the damage patterns seen in Figure 1. This is as expected, given the traditionally concentrated nature of damage within the path. Of more interest is the Local Moran's I analysis which reveals homes either performing better than, or worse than, all surrounding structures. An example output from this approach can be seen in Inset B. 'HH' (high damage) and 'LL' (low damage) pertain to individual structures with high-end or low-end damage magnitudes that are surrounded by structures of similar damage magnitude values. 'HL' or 'LH' identify the presence of an outlier, or an individual structure consisting of either a high-end or low-end damage rating that is surrounded by structures with statistically significant differences in damage magnitude ratings. Grey dots indicate structures that were not significantly different or similar to their neighbors. In total, 335 structures comprise 'HH' clusters, 292 structures comprise 'LL' clusters, and only one 'LH' outlier is located near the northeastern portion of the damage path [there are no 'HL' outliers for this analysis] (Inset B). The structure in question is assigned a TIS damage score of '3,' and is located directly next to homes that have been assigned TIS damage values of '6' and '4.' The locations of these structures are all on the edge of the primary damage path where tornado wind speeds may vary, and these could be among the possible factors creating the 'LH' classification. Aside from this one outlier, results of the two statistical assessments suggest the overall damage patterns throughout Washington, IL are spatially well-defined and relatively consistent.

DISCUSSION

Spatial video provides a means to collect street scale damage data for different size disasters, and in so doing, records a neighborhood context that is often missing in a traditional damage assessment survey. This approach has been applied to three other killer tornado events in Tuscaloosa, Alabama (4/27/2011), Joplin, Missouri (5/22/2011), and Newcastle-Moore, Oklahoma (5/21/2013) (Curtis et al., 2013; Curtis and Fagan, 2013; Curtis and Mills 2011; Mills et al., 2008). Although the spatial patterns identified for these more destructive events have shown similar patterns to those identified here, greater damage nuances can be found along street segments upon a finer scale investigation. More damage outliers were identified in these other events, but this might be explained by the larger number of structures impacted in the path, which may have allowed for more variability. Further exploration is needed as to why such spatial damage nuances exist (not just the presence of outliers, but smaller differences in damage magnitudes located along one street). Although these differences may not be large (e.g., an '8' score compared to a '7' or '6'), a slight change in these TIS classes could be the difference between serious injuries or even the loss of life. For these reasons, and in following the suggestions of Simmons and Sutter, additional work is needed in developing new analytical approaches to reveal these damage nuances before potential causations can be suggested (Simmons and Sutter 2012).

This paper has again shown the benefit of spatial video as the data and analysis presented here are yet another entry in an archive of tornado-related damage, which can be reinvestigated at a later point with full spatially referenced street level imagery. From this approach, new theories can be advanced and then tested using multiple tornado events as source material.

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