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Spatial video data collection in a post-disaster landscape: The Tuscaloosa Tornado of April 27th 2011

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A B S T R A C T

Fine scale disaster response and recovery data suitable for spatial analysis are still relatively rare. This is unfortunate as insight into spatial patterns of recovery could be invaluable in predicting the reestablishment of homes, streets and neighborhoods. The purpose of this paper is to show how fine scale geographic data can be collected in near real-time for the intermediate phase between response and recovery. These data will initially be used to assess the degree of damage (with relation to the Enhanced F scale) while also establishing a baseline for subsequent recovery monitoring. A spatial video system is used to collect data from the post-disaster landscape of Tuscaloosa which was hit by a large tornado in April 2011. This video, once processed, can be viewed within a Geographic Information System which combines street-level images with exact location. These data can be used to support ongoing recovery efforts, while also archiving a dataset suitable for the spatial analysis of the changing post-disaster landscape.

Introduction

In the emergency management cycle, fine scale data collection can provide invaluable inputs for spatial analyses of the different disaster phases (planning/preparedness, mitigation, response, and recovery). Such data is imperative if we are to advance our understanding of how a post-disaster landscape returns to normalcy which is important as "recovery" remains the least understood phase (Cutter, 2003; Mileti, 1999; Mills, 2008, 2010; Rubin, 2009; Smith & Wenger, 2006). Though "place" is noted as having an influence on the process of recovery and spatial patterns are acknowledged to exist, they have not received much attention (Miles & Chang, 2006) especially from a spatial analytical perspective. To date, the work on this subject has been primarily descriptive, at coarse aggregated units (Green, Bates, & Smyth, 2007; Liu & Plyer, 2008), and generally is only suggestive of the need for improved spatial study (Cutter & Emrich, 2006). Effectively, the geography of this process has remained an afterthought.

From a geographer's perspective, potentially one of our more valuable contributions is predicting the spatial recovery process in terms of reestablishing homes, streets and neighborhoods. With an understanding of how this process unfolds, in particular knowing what acts as facilitators or inhibitors, emergency managers and other government officials can plan for an efficient, equitable, and sustainable post-disaster recovery. Many questions still need to be answered. For example, how do individual actions, even within the frame of various externalities such as insurance payout, disaster relief and non-profit aid lead to identifiable rebuilding patterns that can either stimulate further recovery or impede growth? Furthermore, how can these patterns be combined with other data to gain insight into associated recovery problems such as post-disaster health disparities? Only a few studies have performed fine spatial scale recovery analysis (Curtis, Duval-Diop, & Novak, 2010; Stevenson, Emrich, Mitchell, & Cutter, 2010). Finally, how might these data be disseminated to facilitate decision support for government and non-profit agencies, as well as for the public through such tools as web-based mapping services and cloud-based GIS? The lingering aftermath of Katrina over five years after the hurricane is a compelling case for the need to understand the geography of recovery. As this process begins shortly after the disaster event, data collection must commence early. The current study is set in this beginning point of recovery. Future field data collection will focus on these study areas and will use the data as the baseline upon which to measure recovery. Therefore, the purpose of this paper is to show

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how fine scale geographic data can be collected in near real-time using a spatial video approach to assess degree of damage while also establishing a baseline for subsequent recovery monitoring.

This paper will present the initial data collection results of the mobile mapping performed approximately three weeks after the Tuscaloosa tornado of April 27th 2011. The goal of this paper is to a) present the utility of this data collection approach for near real-time analysis and decision-making in disasters, and b) demonstrate how data collected early in the aftermath of a disaster can serve as a baseline for future fine scale recovery analysis. In addition, six spatial video samples are made available allowing the reader to investigate these types of data.

The Tuscaloosa Tornado of 2011

> "*Did I see the tornado? Absolutely. Horrifying. Had tornadoes my whole life, maybe one or two a year. Tornados of that size usually in Kansas or on the Great Plains. This one seemed to fuel more on people. At first I heard a train. I've lived by railroad tracks my whole life so I'm used to hearing trains. I said that train was going to come in the middle of the storm well it wasn't a train. It was the tornado coming and then it got so loud it was like the backend of a jet plane – like so loud you can't hear what someone is saying. That is how loud it was.*"
>
> Local resident paraphrased comments during spatial video collection.

On April 27th, 2011 at least 53 tornadoes occurred in Alabama, with 4 in Tuscaloosa County[2] alone. The worst was at least an Enhanced F-4 which cut a 0.5 mile wide swath through the city in a south west to north east direction.[3] As of the writing of this paper, there are 41 confirmed fatalities while approximately 950 people were treated for injuries in local area hospitals. FEMA has received 11,665 requests for assistance from individuals or families from the county, with 7371 homes being damaged, 2349 being severely damaged and 2375 destroyed (Jones, 2011).

During Hurricane Katrina in 2005 emphasis was placed on the need for spatial data to be collected in an available warehouse format (Mills, Curtis, Pine et al., 2008) primarily directed to non-public consumption. Changes in Internet based technology (especially Web 2.0), more available data from government sources, the public's appreciation of spatial data, and the growth of neogeography (Goodchild, 2009) have led to a renaissance in disaster mapping, with arguably the California Wildfires of 2007 being the first US disaster to benefit from these new cartographies (see Liu & Palen, 2010; Zook, Graham, Shelton, & Gorman, 2010). To this end, online versions of newspapers should be commended for both providing important information and adopting novel interactive geographic visualization approaches. Indeed, within the first month of the Tuscaloosa disaster several such static and dynamic maps have been produced. One of the more interesting, "A panoramic experience of area tornado damage" links interactive photography with 360° views of pre-determined locations on a map (Sutton & Rattey, 2011). This combination of map with imagery allows users to interrogate the map for particular areas of interest while also seeing pictures that can help visualize (and therefore appreciate) the damage. There have been several other examples of media based fine scale visualization of post-disaster landscapes (for another example of Hurricane Katrina see Levitz & Esterl, 2010) though usually the street-level imagery is temporally limited and restricted to pre-determined locations. In this regard these visualizations enhance our spatial appreciation but are limited as research data sources. An obvious advance is to have more spatially and temporally interactive data which requires more fine scale data collection.

Data collection technology

Fine scale disaster related data collection using a spatial video has been previously used by the authors of this paper in multiple post-disaster environments (Curtis, Mills, & Leitner, 2007; Curtis, Mills, Kennedy, Fotheringham, & McCarthy, 2007; Mills, Curtis, Fagan, & Core, 2008). Although the spatially encoded video can be used to make maps of all stages in the disaster process (Mills, Curtis, Kennedy, Kennedy, & Edwards, 2010), it is especially useful in capturing fine scale recovery across multiple time periods, for example being used to monitor blight in post-Katrina neighborhoods (Curtis, Duval-Diop, and Novak, 2010; Curtis, Mills, et al., 2010), as cartographic support for community groups (Duval-Diop, Curtis, & Clark, 2010) and even as a spatial analysis input linking recovery to other social processes evident in the built environment (Curtis & Mills, 2011). Crossover to the public can also occur through media as the same video data of street-level change in recovery were effectively visualized by the New York Times which mapped two streets and four time periods in the Lower 9th Ward (New York Times, 2010). The data used as input for that visualization are the same type as presented here.

Though georeferenced photographs are a standard form of post-disaster field data collection, the spatial video system offers several advantages. In particular, it is efficient, easy to replicate, and extensible. With still photography, the amount of area that can be reasonably covered is limited by the design of the data collection team: the number of people, the number of cameras, and the mode of transport (walking, use of vehicle). However, acquiring extensive spatial video coverage requires few people (from 2 to 3 per team is ideal), only one unit per team, and one vehicle per team. Furthermore, driving with a spatial video system is more efficient than windshield surveys which make stops in front of each structure in order to take a photograph, and even more so than data collection achieved by walking impacted places. In the context of monitoring recovery, with spatial video, acquiring the same image at each time interval is easier than with still photography. In urban environments, the vehicle stays on the road and captures video from the same location at each pass removing individual variability in photos and therefore improving standardization. Finally, the video system can include additional data, such as audio commentary that can also be geocoded to place. Such sources can be valuable for providing context for the visual image.

In order to record a spatial video, multiple cameras are connected to a central global positioning system. Each camera is linked through a cable into the microphone input jack. This transmits an audio signal coding onto the tape of a coordinate from a roof based magnetic GPS receiver. Each camera (usually left and right, sometimes with a third forward facing camera) is secured to a vehicle window using a clamp. The entire spatial video capture kit easily fits into a medium size camera backpack. After collection, each tape

[2] Tuscaloosa County has a population of 194,696 and is 1324.27 square miles in area. The population density is 147 per square mile (http://quickfacts.census.gov/qfd/states/01/01125.html).

[3] "The National Oceanic and Atmospheric Administration (NOAA) reported that the tornado was spawned by a supercell thunderstorm that lasted more than 7 h. The supercell started in Newton County, Mississippi, at 2:54 p.m. Central Daylight Time (CDT), and finally ended in Macon County, North Carolina, at 10:18 p.m. CDT. The trail of damage stretched 80.3 miles (129.2 km) long and as much as 1.5 miles (2.4 km) wide. Between 7:00 a.m. CDT on April 25 and 7:00 a.m. on April 28, a total of 305 tornadoes struck the southeastern and central United States, according to a preliminary estimate from NOAA released May 4. The tornado that passed through Tuscaloosa caused more than 1000 injuries and at least 65 deaths across several towns and cities, the highest number of fatalities from a single tornado in the United States since May 25, 1955." (http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=50434).

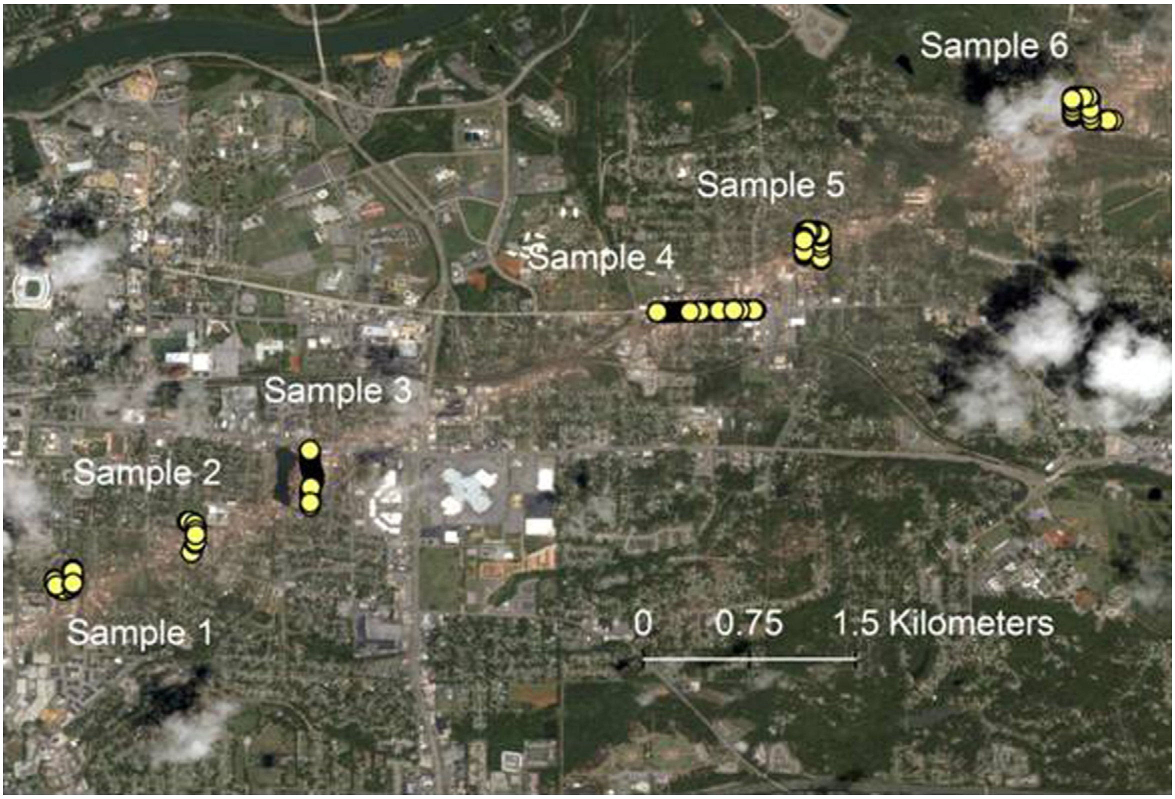

Fig. 1. The location of six sample street segments and the path of the Tuscaloosa Tornado. Source imagery: GeoEye IKONOS-2 imagery acquired April 28th, 2011 in response to tornados in the Southeastern United States of America available through ArcGIS Services (http://rasterevents.arcgisonline.com/ArcGIS/rest/services/GeoEye_IKONOS2_TornadoResponse/ImageServer).

is digitized (and then archived) with the digital version being processed using GoVideo toolbar for ArcGIS (ESRI 2011; Red Hen Systems, 2011). This allows for each camera's video feed to be displayed as a GIS path of coordinates, with a cursor moving on the map as the video progresses. The video feed can be manipulated in terms of starting location, speed, forward/backward movements with the option of still or video segments being extracted. The images in this paper are all examples of such still captures from within ArcMap. Although this spatially encoded video can be shared using a ArcGIS server environment, a free Google Earth extension (MediaMapper IsWhere Video) is also available through Red Hen that allows for ubiquitous access. A further benefit of collecting spatial video, and one of particular interest to researchers, is that audio commentary can be collected simultaneously and merged with the video. Although there are different approaches to achieve this, the authors prefer to use video editing software (Corel VideoStudio) to paste digital commentary from an additional internal vehicle video camera into the spare audio channel of the digitized video capture (the other channel containing the GPS signal). In this way comments by experts can be located exactly to where they are collected. This is invaluable when the commentary directly refers to the landscape being captured.

Methods

Using aerial photography of the tornado path a route was planned from a starting point in the south west leading to the north east. As this data collection occurred shortly after the tornado, the routes driven were determined in part by accessibility, though these sites were also chosen for the variety of structures (homes of various sizes, businesses) and interest of local collaborators. In total, 8 h of data collection covered approximately 50% of the streets within the tornado path. Although three weeks had passed since the disaster, the city had barely begun to recover, with many streets being closed because of debris clearance or utility reestablishment. A three camera system was utilized for day one, and a two camera system used for day two.[4]

Within two days of returning from Tuscaloosa, all tapes had been digitized, processed and routes and video loaded into ArcMap 9.3. From these video routes, six segments were extracted for the purpose of this paper as examples from different sections of the tornado path (Fig. 1). Four sample segments were linear, while two covered a single neighborhood block to show concentrated damage.

In order to establish a baseline of damage for each sample segment a commonly used degree of damage estimate was utilized. The Enhanced F scale (EF) was developed as an update to the traditional Fujita Tornado Damage Scale and is used to estimate 3-s wind gusts from the degree of damage to different types of structures or trees (see http://www.spc.noaa.gov/faq/tornado/ef-scale.html). The EF scale is estimated by assessing the observed degree of damage for a type of structure such as a one or two family residence (defined by several material conditions). Lower and upper wind speed bounds are also presented that could result in the same amount of damage. For example, if a one or two family residence lost all walls, then the expected wind speed would be

[4] Although a forward facing camera does provide additional perspective on the damaged landscape, it was found that it was more advantageous to rely only on two cameras fixed to the back windows if a two-person data collection team is used. This is because the passenger needs to navigate, continually check cord connections and generally facilitate data collection, which is easier to perform from the back seat between both cameras, and next to the central GPS. After video processing, the decision to rely on a left and right facing camera with a wide-angle lens was found to be justified.

170 mph, with a lower bound of 142 mph, and an upper bound of 198 mph. These speeds can be compared to an operational EF or traditional F scale to give the “size” of tornado. For each of the six segments, the EF was determined by the worst observable damage.

Results

The following brief descriptions of each spatial video sample should be read as a precursor or while watching the video associated with this paper. Each Sample Area is described with 1) a characterization of the area (types of structures), 2) the level of visible damage, and 3) the Enhanced F Scale assessment of the tornado based on the visible damage. Table 1 also summarizes the EF scores for each segment along with potential future recovery research topics.

Sample Area 1. This middle income neighborhood of large detached homes bordered the path of severe damage. There is variation in damage along the street with some homes having extensive areas covered with blue tarps while others appear largely untouched. Although this video collection was twenty three days after the tornado, the city was still in a response/post-response phase as evidenced by the American Red Cross disaster relief van. Continuing around the crescent, the damage to trees increases, and there are large piles of debris at the curb side. Although the majority of homes suffered some damage, this video surveillance suggests that this was superficial to moderate with mostly roof damage. It is unlikely any home was damaged to the point of having to be rebuilt, which given the income level of this community suggests that recovery will occur quickly and “normalcy” should reflect the pre-disaster environment (Fig. 2).

If we refer to Table 1 then the highest degree of damage scores “4” for a single or double family residence, suggesting a tornado of EF 1 to 2 though it should be remembered this section was not directly on the scoured path as seen in Fig. 1.

Sample Area 2 is further along the tornado’s path and cuts directly across the center of the worst damage. The neighborhood is again middle income with moderately sized detached homes. At the beginning of the sample are a cluster of disaster support facilities which provide food, water, comfort and even insurance information for returnees. Next to these facilities are extensive piles of debris showing that this neighborhood was hit far harder than Sample Area 1 and that at its height the tornado caused complete building destruction. Interestingly, one home is already being rebuilt (Fig. 3). The rest of the homes show decreasing amounts of damage, mainly roof related, until the last home appears untouched. In this street, the level of damage runs from complete destruction to apparent habitability.

Using Google Street View as a pre-disaster reference, the single-family homes in the section with the greatest damage have been completely destroyed and leveled to the ground. If we refer to Table 1, the degree of destruction ranges between 9 and 10, suggesting a tornado of size EF4 or EF5.

Table 1
A summary of degree of damage and EF scores for each spatial video segment.

Sample Segment	Structure Type	Degree of Damage	Expected Wind Seed	EF	Recovery
1	Single	4	97	1–2	Speed
2	Single	9–10	170–200	4–5	Patterns/social networks
3	Single	9	170	4	Patterns/social networks
4	Small professional building	10	170	4	Economic
5	Single	9–10	170–200	4–5	Patterns/health/ comparisons
6	Single	9–10	170–200	4–5	Patterns/health/ comparisons

Sample Area 3. The next transect of the tornado’s path captures a wider swath of destruction. Although the area was characterized by single family homes, they are smaller and indicate a lower income status than the two previous neighborhoods. The first home has been cut in two by a fallen tree. The next few homes are either completely destroyed or display catastrophic structural failure with only a few walls remaining. It is also interesting to note how the trees have been sheared off. The last home also displays one of the telltale signs of wind damage; the roof has been completely lifted from the house though the walls remain untouched. The wind enters through broken windows and doors and causes failures along the weakest structural surfaces, which in this case is from below the roof pushing upwards (Fig. 4).

Again using Google Street View as a pre-disaster reference, the degree of damage scores a 9 suggesting wind speeds in the range of 170–198 mph, and an EF4 tornado.

Sample Area 4 again crosses the path of the tornado, though this section has been chosen to capture the conditions of local businesses. During conversations with a resident during data collection he explained that this area had only recently been improved through investments.

The degree of damage is variable, from buildings which appear to have suffered mainly glass breakages to those that have been totally destroyed. It is also possible to see along some of the side streets to the homes beyond which also display considerable damage. The majority of structures along this segment has been completely destroyed and will have to be cleared before being rebuilt (Fig. 5).

This section also benefits from reference to pre-disaster imagery found in Google Street View. Most of the buildings were single story simple construction commercial units typical of strip malls. The hardest hit section, toward the beginning of this sample, was completely destroyed and reduced to rubble. There are several building types along this segment that could be used to suggest the EF. For “small professional building” then “total destruction of the entire building” would place wind speeds at between 157 and 200 mph. For “strip mall” then “complete destruction” would again place wind speeds at between 171 and 198 mph. In other words, for commercial sections such as this, it is hard to suggest a tornado of EF5 as an EF4 would cause complete destruction of typical small commercial buildings.

Sample Area 5 is the first of the two horseshoe collection routes which show the condition of an entire block. At this point the tornado had intensified and the path becoming wider. The destruction of this block is total with all structures needing to be rebuilt. The relatively small homes have all been reduced to either piles of debris or massively compromised structures. It is worth watching this video segment to appreciate the destructive capability of the tornado. There are several images to look for: a) the “home” which is now just a concrete slab with debris on top and a house number painted on a board in the front; b) the cars which lie upside down and inside where a house had previously stood; c) the corner home where both outside walls have been blown out but the front remains intact; d) the classic search and rescue “X” (the search and rescue team is to the top, the date to the right, and any mortalities below); e) and the uprooted trees and other trunks that have been splintered. Comments from a resident who accompanied us during data collection were telling (Fig. 6)

> “*That was another scary thing. When I came out in the night just after the tornado hit, all the screaming and people hollering for other people. Dead bodies being pulled out and put on the ground over there… Horrifying. People crying for help under rubble.*”

Fig. 2. A damaged home from Sample Area 1, the windows have been blown out, the roof damaged (and covered with a blue tarp), and the tree in front broken in two. (For interpretation of the colour reference in this figure caption, kindly refer to the online version of this article.)

Just as with Sample Area 2, the degree of destruction is between 9 and 10 suggesting a tornado of EF4 or EF5. However, there are differences between these neighborhoods, as the quality of construction is less robust in Sample Area 5 with fewer larger brick buildings.

Sample Area 6 captures data from where the tornado path widens further, and the extent of severe damage covers large tracts of homes. This neighborhood is on the outskirts of the city and could almost be classed as rural in nature. Just as with Sample Area 5, a horseshoe route captures a block where none of the buildings appear salvageable (Fig. 7).

Although there is some variation in the degree of damage for this video segment, the highest score is 10, suggesting a tornado of EF4 or EF5.

Discussion

This paper has shown how a mobile mapping (spatial video) approach can be used to collect fine scale damage data shortly after a disaster. These data are collected with the intent that they will act as a baseline upon which to monitor the recovery phase that will follow over the subsequent months, and even years. These data are an improvement of typical windshield survey damage assessment as used by the American Red Cross in that data are more accurate (because visual records are captured and these can be validated), are stored in a digital format that is both transferable and easily archived, and can be used to investigate other questions such as categorizing the strength of tornado winds across the samples presented. It should be remembered that approximately only

Fig. 3. Rebuilding in Sample Area 2 next to a completely destroyed home.

Fig. 4. A home from Sample Area 3 showing severe upper deck damage, with a flag waving from within the roof, and a message from the owner spray painted on the building side.

10 min of video is available here from a total video collection numbering multiple hours. By using the same degree of damage estimates, a fine scale estimate of tornado strength can be developed throughout the whole path. In addition, the video evidence is useful in capturing other tornado characteristics, such as how different structures respond to these winds. The visual capturing of post-earthquake damage to help determine different structural integrities is not new, but the use of a spatial video to capture immediate post-tornado, post-hurricane and even post-wildfire landscapes should become more of a standard approach.

However, the primary purpose of collecting these spatial video data is that these layers can now be used as a benchmark against which to compare subsequent recovery-focused data collection. The authors have been collecting similar data for post-Katrina neighborhoods for five years, and now Tuscaloosa will provide another case on which to analyze patterns in recovery. Currently, no spatial theory exists that guides understanding of how and why some places recover, while others do not, especially at fine spatial scales. The spatial video system enables systematic data collection over extended time periods which will yield the observations upon which to build such a theory. The selection of the six sample areas were chosen to illustrate the types of question that these data may support; for example how different neighborhoods of similar damage but different socioeconomic background recover; how quickly economic interests return; how similar neighborhoods vary in recovery according to their political representation; and in

Fig. 5. A light commercial building from Sample Area 4 leveled to the ground.

Fig. 6. Complete destruction in Sample Area 5 with a search and rescue "X" visible on the wall that remains standing.

neighborhoods of total devastation, is there a pattern of recovery that either stimulates or impedes return? These data can also be combined with secondary data, such as crime or health information to investigate how the loss of neighborhood can cause long-term problems.

Even without coding and analysis in a GIS, the spatially referenced video is a standalone resource for decision support. One finding from prior work in the response and recovery phases of Hurricane Katrina is that any one geospatial data product is useful in a variety of ways to a variety of stakeholders, from government officials to displaced residents (Mills & Curtis, 2008; Mills, Curtis, Pine et al., 2008). Government officials may use repeat video routes of an area they represent to assess whether policies enacted to stimulate recovery are having the desired result, such as policies on debris removal and blight. In addition, when the same path is collected at set time intervals, quarterly, for example, the rebuilding process is visible, including the materials being used and the mitigation measures being employed (e.g., installation of hurricane shutters). For members of the public, however, such videos can be a way to assess conditions at home. It can help answer questions such as, are the streets navigable, have my neighbors returned, what are the general conditions surrounding my home? Indeed, video (not geocoded) has been used to assist displaced residents of New Orleans with achieving such situation awareness (Mills, 2009; Mills et al., 2010).

In addition, given the archival character of video, these data are easily stored so future investigations can return to the images. For example, Hagen and Ender (1999) wrote a paper regarding the use of graffiti in post-disaster landscapes focusing on the Red River Valley flood of 1999. Their work could be replicated by other

Fig. 7. The home has been shifted off its foundation and there is considerable roof damage.

researchers using the spatial video data presented here. Imagine if all disasters had archives such as this – what other questions could we ask? With archived spatial video, these data can also serve a role for the disaster-impacted community, either being used directly as a data source by neighborhood associations, or as visual histories of recovery. By including commentaries recorded by community members during data collection these data can become an important part of the physical, social and cultural record of what has been lost, and how recovery occurs.

Conclusion

Prior to 2005, much of the existing research on post-disaster recovery was focused on developing countries. However, Hurricane Katrina, the subsequent flooding of New Orleans, and the ongoing problems with recovery in the city raised awareness that even developed countries are in need of understanding how this process occurs. With concerns about the future of coastal cities due to sea level rise and global climate change, attention is being directed on these places in regards to planning for future disasters.

As a result of the April 27, 2011 tornado, Tuscaloosa, Alabama experienced widespread destruction on a scale more commonly seen from hurricanes. However, this tragedy can also provide benefit to those places faced with destruction in the future. Tuscaloosa, like New Orleans before it, can serve as a field laboratory to examine how the recovery process occurs. From existing work on Katrina, recovery is known to operate at a fine scale (house, street segment, block) and, in some cases, take years to accomplish. Furthermore, recovery is not a linear process. Some places may decline and become blighted, others may begin to recover, but then regress due to exogenous forces. Some places, however, return to "normalcy" in a matter of months. These patterns are spatially and temporally variable and are visible, though the data are ephemeral. With the advance of spatial video technology, however, these visible aspects of recovery can be captured, georeferenced, mapped, and analyzed. The results of such analysis will hopefully lead to an understanding of the geography of recovery such that scholars and practitioners can collaborate to plan for more efficient, equitable and sustainable recovery from the inevitable disasters to come.

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Appendix. Supplementary material

The sample segment column in Table 1 links to the associated supplemental video found at doi:10.1016/j.apgeog.2011.06.002.

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