

Crowdsourcing Hazardous Weather Reports from Citizens via Twittersphere under the Short Warning Lead Times of EF5 Intensity Tornado Conditions

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Abstract

The May 20 2013 tornado in Oklahoma has demonstrated the short warning lead times of EF5 intensity tornadoes, even with the integrated Next Generation Weather Surveillance Doppler Radar network, remain a challenge both for governments responsible for early warnings and citizens who need to respond appropriately. Although research on government use of social media for adaptable disaster response is emerging, little is known about social media-mediated early tornado warnings and crowdsourcing in the e-government literature. This research, therefore, aims to reduce this gap in the literature through a case study of the National Weather Service's experimental use of Twitter for crowdsourcing hazardous weather reports from citizens during and in the immediate aftermath of the May 20 tornado. Our social network analysis and content analysis results found evidence for value of the #okwx Twittersphere to tie closely the government and volunteer citizen tornado watchers and enable multi-directional interactive conversations and crowdsourcing.

1. Introduction

At 2:56 pm on May 20, 2013 a very powerful EF5 scale tornado has struck Moore city, Oklahoma, causing 24 deaths, including 7 school children, more than 300 injured, and \$2 billion total damage cost [2, 15, 24]. The citizens of Moore and its nearby cities such as Oklahoma City had only 16 minutes of early tornado warning lead times, after the National Oceanic and Atmospheric Administration (NOAA)'s National Weather Service (NWS) in Norman, Oklahoma had issued its first official tornado warning at 2:40 pm.

Tornadoes very often develop with short warning lead times under favorable climate conditions, and hence continuing to be very difficult to detect and predict accurately even with the installation of the network of integrated NEXRAD (Next Generation Weather Radar) WSR-88D (Weather Surveillance Radar - 1988 Doppler) since 1993 in the US [4]. Given such short warning lead times, prior research on tornado warnings even argues that early warnings which do not reach the citizens and motivate their appropriate responses are not very valuable, even if they are accurate and timely [11]. However, prior survey research on citizen responses to tornado warnings in the US presents rather negative findings: while they understand the difference between tornado watch and tornado warning, they often fail to take appropriate actions despite the government warnings. This suggests the need for an innovative way to motivate more active manners of citizen engagement as well as the need for agile response by government agencies during the disaster management cycle, especially earlier phases of preparedness and response.

Prior research on social media-enabled early disaster warning has demonstrated that the effective use of Twitter in government which facilitates citizen co-production in public information services is very valuable in reaching a great number of citizens in a timely manner [7, 9]. Given the challenging conditions of the short warning lead times and EF4 or 5 scale powerful tornadoes, however, understanding government challenges and finding innovative ways to meet these challenges still remain relatively unknown, presenting critical gaps in the academic literatures both in the disaster informatics and e-government research fields. In this research, therefore, we will address the following two research questions:

(1) How governments responsible for tornado warnings have actually used social media for early tornado warnings during a rapidly unfolding tornado event?

(2) How governments responsible for tornado warnings have actually engaged net-savvy citizens via Twitter for crowdsourcing?

To answer these two research questions, we have investigated government Twitter use during and in the immediate aftermath of May 20 2013 EF5 Oklahoma Tornado as a case study.

The remainder of this paper is structured as follows: the next section presents a review of the relevant literature followed by research background on the May 20 2013 EF5 intensity Oklahoma tornado. Then, we present two research questions and describe the methodology used: the tweet data collection using #okwx, and the social network analysis method. Then, we present the results of the analyses followed by the discussion of citizens' Twitter-based information co-production during this EE.

We conclude that in the case studied the NOAA's National Weather Service Norman had introduced #hashtag symbol #okwx with geotagging for multi-directional interactive weather conversations between governments, ordinary citizens and citizen 'scientists' who wish to submit hazardous weather reports and tornado damages observed, which seems to transform the traditional government-to-citizen severe weather warning communication. Similar to prior research [9, 25], Twitter-literate citizens played a critical role in the timely diffusion of tornado-related EE information to their followers, and hence co-creating public information of high value by complementing and enhancing government's tornado detection, prediction and warning-related information management under the conditions of short warning lead times and EF scale intensity tornadoes. In the conclusion section, we discuss the contribution and the limitations of this study and future research directions.

2. Literature Review

2.1. Tornado warnings

While natural hazards cannot be prevented, governments aim to mitigate their impacts through a disaster early warning system. Disaster early warning systems provide timely and actionable information, through authorized government agencies, to enable citizens exposed to hazard to take effective action, avoid or reduce their risk, and prepare for effective response [31]. From an information perspective, early warning systems need to satisfy at least the following user information requirements:

- Speed of communication [8, 12, 16];
- Reach [7, 8, 16, 28];
- Information quality [12, 16].

In order to detect the likely occurrence of disasters, prior research has focused on advancing sensor technologies and implementing decision support systems (DSS) to predict the disaster's likely scale, time of occurrence, location, potential impacts, and the need for mass evacuations. On the other hand, government communication of the predicted hazard to the intended audience in a timely and actionable manner is also critically important. Citizens in the hazardous areas need to know about the looming extreme event (EE) so as to prepare for evacuations or other protective measures. In other words, public information services in providing citizens with timely and actionable information are of critical importance in mitigating the impacts of natural hazards and building a resilient society.

Conventional wisdom holds that improved early tornado warnings will reduce tornado casualties, because longer lead times on warnings provide extra opportunities to alert the local citizens who can respond appropriately. After the installation of Weather Surveillance Radar-1988 Doppler (WSR-88D) radars since 1993, early tornado warnings literature clearly shows the improvements in warning lead times and detection [4], the reduction of tornado casualties, and the increase of tornadoes warned from 35%, before WSR-88D installation, to 60% after installation, while the mean lead time on warnings increased from 5.3 to 9.5 min and the false alarm ratio fell slightly [26].

Against this, however, other study finds that the national false alarm rate (FAR) for tornado warnings in 2003 was 76%, indicating that only one in four tornado warnings was verified. Since FAR is one of the key performance metrics for verifying National Weather Service (NWS) weather warnings, the NWS's stated goal for 2010 is to reduce this value to 70% [3]. Conventional wisdom is that false alarms reduce the citizens' motivation to respond to future events. In the immediate aftermath of the May 20 2013 EF5 tornado that struck Moore city, Oklahoma, it was reported that tornado warnings that were false alarms remained high at 76% nationwide [32]. In a 5-year period of study from 2000 to 2004, it was also reported that during, more than 26% of all reported tornadoes across the United States occurred without an NWS warning being issued [6].

A study on the May 3 1999 tornado in the central Oklahoma found sixty-six tornadoes occurred during this outbreak, with 58 in the Norman, Oklahoma National Weather Service Weather Forecast Office (WFO) area of responsibility. It also found that the WFO issued 48 tornado warnings, with a median lead

time of 23 minutes and a FAR of 29% [1]. Another study on the same event underscored the challenges in obtaining accurate information about the existence, timing, location, and intensity of individual tornadoes [27].

Finally, despite the improvements in the integrated warning system in the United States, a study holds that volunteer citizen tornado watchers/spotters and the public forecasting services need to be closely tied. Furthermore, it concludes that government tornado warning dissemination is a major factor in an integrated warning service, and hence warnings and forecasts that do not reach the intended citizens and motivate appropriate responses are not very valuable, even if they are accurate and timely [11].

2.2. Twitter, #hashtags and geotagging

Twitter, a type of microblogging, was launched in 2006 and now has more than half a billion active account holders worldwide and more than 140 million users in the US alone. In its strategy to offset the 140-character limit of tweets, Twitter introduced the hashtag symbol (#) to direct the focus of tweets and categorize tweets by keyword, facilitating greater efficiency in Twitter search. While a tweet can contain several hashtags to show that it has many foci to highlight, Twitter suggests a tweet to have no more than 2 hashtags. Hashtags then have a link to a search result with the hashtag as the keyword.

The commonly accepted and frequently used hashtags in the same standard format, such as #txwx and #okwx (the latter will be discussed in detail later) which were introduced by National Weather Service (NWS) in the US, not only enable NWS to provide citizens with its weather service products (e.g. tornado warnings) in real time but also enable the government agency to promote “crowdsourcing” of hazardous weather reports submitted by citizens via Twitter [18]. So it seems that effective use of these #hashtags provides government with transforming potential in changing the traditional one-way government-to-citizen weather reporting into the new multi-directional interactive hazardous weather conversations and EE information sharing among governments, communities and citizens.

In the literature, tags in general refer to short textual annotations used to describe photos, in order to provide additional information to other users who are interested in those images. Tags are also essential in resolving user queries targeting shared photos [14]. More specifically, geotagging in the literature, for example, includes geotagged photographs which are photos whose metadata contain latitude/longitude

coordinates of the location where they were taken. The geotagging approach leverages the textual information of such photos published on the web which often include the name of the location [13].

2.3. Social media-mediated crowdsourcing

Social media technologies provide scale and ‘reach’ which can be defined as the capability to reach the intended audience. Social media technologies are by their very nature decentralized, distributed, and networked in form, with millions of users at multiple points of information production and consumption [5]. Consequently, social media’s speed of communication is fast, depending on the number of active users and followers who transmit the information without delay within their social media networks.

The use of social media channels in government for sharing time-critical information in disaster situations, especially via Twitter, has been emerging over the past five years [7, 8, 28]. Early social media-related research appeared in the context of the 2007 Southern California Wildfires [29]. So far empirical studies have focused on the use of social media for different disasters and different phases of the disaster management cycle, with the exception of the risk mitigation phase in which no prior research was found. While the type of social media use studied varies widely from Facebook, Twitter, blog, web forum, photo sharing, microblog and SharePoint, it appears that Twitter is the most frequently used social media channel in disaster situations.

Of the literature on disaster early warning systems, however, only Starbird & Palen (2010) and Chatfield & Brajawidagda (2012; 2013) focused on the use of social media technologies in government. Furthermore, of the social media-based disaster early warning systems, only Cheong & Cheong (2011) and Chatfield & Brajawidagda (2012) used social network analysis on Twitter data for in-depth understanding of information flows and exchanges within social networks.

While crowdsourcing practices have been pursued even before the advent of the Internet, our own research to date shows social media, particularly Twitter, provide an unprecedented ubiquitous public sphere, in which multi-directional interactive conversations and information sharing occur among government agencies, communities, businesses, and citizens in real time as a catastrophic extreme event is unfolding. However, these emerging phenomena have not been systematically studied [9, 25].

3. Background: May 20 EF5 Tornado

3.1. Tornado alley

90% of tornadoes occur in areas of the Central United States which are known as “tornado alley”, which is located between the Rocky Mountains and Appalachian Mountains. Tornadoes occur most frequently in this tornado alley where warm, moist air from the Gulf of Mexico and cold, dry air from the Rocky Mountains and Canada are conducive to creating intense, tornado-producing thunderstorms known as supercells [17, 23]. According to the storm events database of the National Climatic Data Center, Texas experiences more tornadoes than any other state. However, Kansas and Oklahoma rank first and second respectively in the number of tornadoes per square mile [33].

3.2. Deadly strike of May 20 EF5 tornadoes

At 2:56 pm CDT (Central Daylight Time) on May 20 2013, an EF5 (a most powerful) tornado struck the people of Moor city, 20 km south of Oklahoma City, Oklahoma. We use here the Enhanced Fujita scale (EF scale), which is a proxy for actual wind speeds by rating the strength of tornadoes in the United States and Canada based on the damage they cause. Figure 1 shows all EF scale tornadoes in Oklahoma, as of May 24 2013.

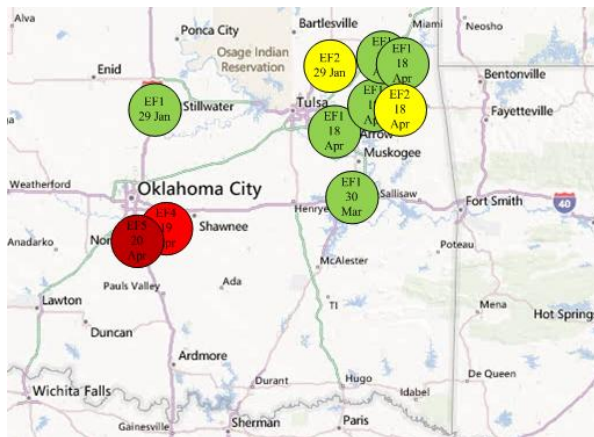


Figure 1. 2013 Tornadoes in Oklahoma

As Figure 1 above shows, there have been six EF1 tornadoes (green circles), two EF2 tornadoes (yellow circles), and one EF4 tornado on the previous day in East Norman (light red circle) leading up to the EF5 tornado in Moore on May 20 (dark red circle) [1]. Previously, on May 3 1999, Moore city was devastated by another EF5 scale tornado, with 36 people killed

and another 583 injured [20]. Another EF4 scale tornadoes also struck the city on May 8 2003 and May 10 2010. According to the NWS Norman, the May 20 2013 EF5 scale tornado made 17 miles path length with 1.3 mile wide.

4. Research Methodology

Given the short warning lead times of powerful tornadoes such as EF 4 or EF 5 scale tornadoes, however, there still are critical gaps in the academic literatures in the disaster informatics and e-government research fields. In this research, therefore, we have addressed the following two research questions:

(1) How governments responsible for tornado warnings have actually used social media for early tornado warnings during a rapidly unfolding tornado event?

(2) How governments responsible for tornado warnings have actually engaged net-savvy citizens via Twitter for crowdsourcing?

To answer these two research questions, we investigated government Twitter use during and in the immediate aftermath of May 20 2013 EF5 Oklahoma Tornado as a case study. Specifically, the first research question requires us to identify U.S government agencies responsible for storm disasters, especially tornadoes, at the federal, state and local levels. At the federal level, we found that the National Weather Service (NWS) is in charge to detect the tornado and release the warning to the citizens. We then analyzed NWS official website to identify whether a policy on social media exists. Then we collected the tweets from NWS Twitter account to analyze the use of the Twitter during the tornado event. We also identified the state and local government agencies Twitter account to analyze whether collaboration exists among those agencies. In this research we selected @NWSNorman, @okgov, @govmaryfallin, @CityofMoore and @MooreEOC for further analysis to represent federal, state and local government. @NWSNorman is an experimental Twitter account operated by NWS Norman (regional office). While @okgov is Oklahoma state Twitter account, @govmaryfallin is Governor of Oklahoma official Twitter account. @CityofMoore is the City of Moore official Twitter account and lastly @MooreEOC is the Emergency Management Department of City of Moore official Twitter account.

To answer the second research questions, we analyzed three hashtags #okwx, #oklahoma and #moore. The first hashtag, #okwx, was introduced by the National Weather Service (NWS) [18, 19] for citizens to submit hazardous weather reports assisting NWS, as well as for citizens to follow the NWS

weather warnings in real time via Twitter in NWS. Therefore, this hashtag differs from the other two hashtags which are intended more for general disaster-related conversations. We decided to focus on this #okwx hashtag to examine how this specific Twittersphere was used by the citizens during and in the immediate aftermath of the May 20 2013 EF5 intensity tornado that struck Moore city. However, we also analyzed the #oklahoma and #moore for comparison. The tweets were collected through Topsy.com [30] from the period May 19-May 23 2013. We chose Topsy.com mainly because Twitter.com limits access to direct data collection. The data collection resulted in 260 tweets for @NWSNorman, 175,615 tweets for #oklahoma, 68,046 tweets for #moore and 60,011 tweets for #okwx.

We then identified the active Twitter users involved in the #okwx during the most critical time on May 20, from 10.00 am when the severe weather increased the tornado possibility until 2.56 pm when finally the tornado touched down. We collected 313 Twitter users were active during that critical period, and based on that we identified their self-declared location and identity, and also the social ties among them through a social network analysis.

5. Findings

5.1. Twitter use in government

Federal government level: The National Weather Service (NWS) and its regional offices across the United States provide early tornado warnings under the National Oceanic and Atmospheric Administration (NOAA) which is managed by the U.S Department of Commerce. While NWS holds their social media accounts in Twitter, Facebook and YouTube, the focus of this research is its Twitter use. NWS uses @usNWSgov for its official Twitter account. NWS also operates several regional office Twitter accounts for Alaska, Western, Norman, Kansas City, Salt Lake, Charleston and Honolulu. In addition, the National Hurricane Centre (NHC) holds two Twitter accounts for North Atlantic and North East Pacific. While all the regional office Twitter account, including the two NHC Twitter accounts, still are an experiment [22], @usNWSgov is fully operational.

NWS Norman, the largest of the NWS regional offices, is located just 15 km south of the city of Moore in Oklahoma. NWS Norman is strategically located in the Tornado Alley for direct observations and predictions on when and where the tornado will likely occur. As mentioned earlier, NWS Norman operates an experimental Twitter account, @NWSNorman,

through which it has released 2,984 tweets to its 19,590 followers as of May 28, 2013.

At 2:40 pm on May 20, 2013, NWS Norman issued its first tornado warning for Oklahoma city metropolitan area citizens to take shelter from the moving tornado through (@NWSNorman) as shown in Figure 2 below.



Figure 2. @NWSNorman warning Tweet

Against the tornado warning, the predicted tornado did not strike Oklahoma City. However, exactly 16 minutes later an EF5 tornado struck and devastated Moore city at 2:56 pm.

During the severe weather lasting from May 19 to 23, there are 260 tweets released through @NWSNorman (or on average 52 tweets per day). Of those tweets, 226 tweets contained #okwx. There were also another hashtags used, for example, #txwx, #mowx, #kswx and #severe in a small number of tweets. Importantly, during the most critical period (between 2.00 pm and 4.00 pm) before and after issuing its first official tornado warning at 2:40 pm, 29 tweets were released through @NWSNorman.

In order to understand these tweets' content, we performed a content analysis and classified the content into five categories: safety tip, severe weather warning, tornado watch, tornado warning, and evacuation alert in the order of the increased level of tornado hazard risk to citizens' safety. We have adopted extant definitions for severe weather warning, tornado watch, and disaster/tornado warning found at NWS La Crosse website [21]. Severe weather warning refers to a thunderstorm which is producing or is expected to produce either wind gusts of 58 mph or higher or hail of 1" diameter size or larger. Tornado watch is an alert for the potential tornado hazard when severe thunderstorms can produce tornadoes, remaining in effect approximately for 6 hours and covering a region of a state. Finally, disaster/tornado warning means that either a tornado has been spotted or rotation is being detected within the thunderstorm on Doppler Radar, being typically in effect for 30 to 60 minutes. In addition to these official definitions, we define safety tip as general advisory for citizens to take safety measures for minimizing tornado hazard. In contrast, evacuation alert, in acknowledgement of the clear and

imminent danger of tornado in the region, is an unofficial “order” for citizens to evacuate themselves away from a predicted tornado path to a safe shelter.

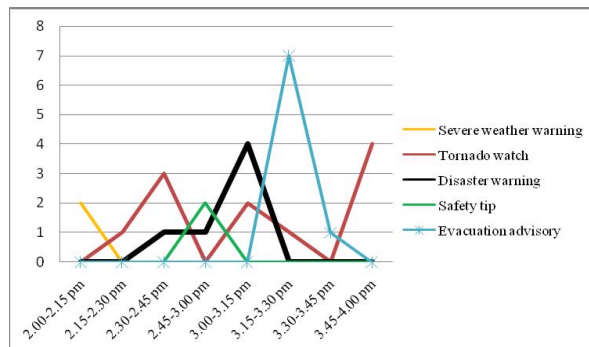


Figure 3. Tweet classifications

We then plotted the tweets’ content analysis results in a series of line graph, where x-axis is time in 15 minutes interval and y-axis shows the frequency of tweets. Figure 3 above shows this line graph. As we described earlier, the devastating EF5 tornado struck Moore city at 2:56 pm. The line graph shows that severe weather warnings (yellow) peaked earlier and on a decline, which were replaced by a sharp increase in tornado watches (red) till it reached its peak just prior to the first NWS tornado warning at 2:40 pm. During the 2:45-3:00 pm interval, when the EF5 tornado eventuated, tweets on tornado warnings have sharply increased. In the immediate aftermath of the EF5 tornado in Moore city, evacuation advisory tweets and new tornado watch tweets also increase sharply.

Using a sample of tweets drawn out of the 29 tweets, we show an event timeline in Figure 4. Figure 4’s x-axis has time interval of 5 minutes, whereas its y-axis shows the #okwx tweet traffic. The hashtag #okwx will be discussed in detail later in Section 5.2. The latter is measured by the number of tweets linked to #okwx per minute. This timeline shows that the 226 tweets released by @NWSNorman affects the overall #okwx tweet traffic. For example, while during May 19-23 2013 the average retweet of each tweet is 39 retweets from its direct followers, there are a significant increase during 2.00 PM – 4.00 PM May 20 2013 which reach 69 retweets. Though it is a significant increase, the number of retweets through this experimental Twitter use for crowdsourcing hazardous weather reports from citizens still is new and hence the number of users remains low.

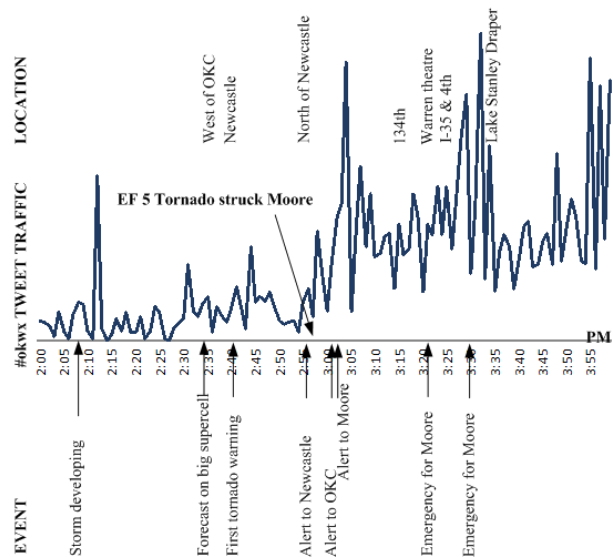


Figure 4. Event timeline

In the timeline above, we also show the location information contained in the tweets released through @NWSNorman. The tweets in the “tornado watch” category (see Figure 3) reported the location of the tornado funnel, for example, when the first supercell was first spotted on 2:39 PM in west of Oklahoma City (OKC). The timeline also presents several major events discovered from the tweets, for example the “first tornado warning” issued at 2:40 PM.

It seems that the tweets are not automatically generated by a twitterbot (computer program). In fact, a prime example of “tornado watch” tweets contains a picture of how the first tornado supercell was detected on a NWS staff’s computer screen as shown in Figure 5. A twitterbot cannot generate a photo image.



Figure 5. @NWSNorman operation center

State and local government levels: While the NWS as a federal government agency is responsible

for disaster preparedness especially through issuing tornado watches and tornado warnings to the citizens in a timely manner, state and local governments are responsible for all the activities related to the disaster management cycle: preparedness, response, recovery, and risk mitigation [10]. State of emergency can be declared by the Governor, which is a step to access federal resources. Local government responsible for disaster mitigation, including planning and preparing for, respond to, and recover from the various emergencies and disasters as reflected in their Emergency Management Department establishment.

The state of Oklahoma has its own Twitter account @okgov, separated from the official governor Twitter account. Governor of Oklahoma, Mary Fallin, released 78 tweets during the period of May 19-20 2013 (or 15 tweets per day in average) from @GovMaryFallin. In comparison, the official Oklahoma state Twitter account released 70 tweets during the same period. However, the 70 tweets were released on May 20 2013 5.57 PM or about 2 hours after the tornado strikes. Both @okgov and @GovMaryFallin sent no tweets during the tornado event (2.00 PM – 4.00 PM). While the tweets released by @okgov are mostly a retweet from news or other agencies, @GovMaryFallin creates her own tweets for expressing condolences for the disaster victims, informing official activities or retweeting other’s tweets. The governor released the state emergency on May 19 2013, and the tweet informing the emergency status was posted on the same day 10.05 PM. The tweet (as shown in Figure 6) has a link to the state emergency declaration in the state government website. The state emergency declaration tweet was released on time, but only retweeted 23 times.



Figure 6. Governor state of emergency tweet

In local government, as mentioned before, we observe @CityofMoore and @MooreEOC. According to the City of Moore’s website, all the disaster responder such as fire department and police department share their Twitter account with @CityofMoore. From May 19 to May 24, @CityofMoore posts 139 tweets. In the same period, @MooreEOC releases 18 tweets. Both @CityofMoore and @MooreEOC are active during 2 PM – 4 PM of May 20 2013 and release 12 and 8 tweets respectively. They use Twitter for situational awareness and retweeting alert during the critical period.

5.2. Crowdsourcing hazardous weather reports from the general public and tornado watchers

5.2.1. The crowd at #okwx, #oklahoma and #moore

To analyze the citizen engagement, we collected 60,011 tweets in the #okwx from May 19-23 2013. We also collected #oklahoma and #moore in the same period for comparison, with 176,792 and 68,048 tweets, respectively. Figure 7 below shows Twitter traffics via #oklahoma, #moore and #okwx, in which tweets’ traffics via the three hastags are captured: black line for #okwx, red line for #oklahoma and blue line for #moore. The lines (traffic) show the number of tweets in an hour that were plotted in a timeline from May 19-May 23 2013. This is different from Figure 3 which is measured by minute.

The black line graph shows that the traffic for #okwx tweets experienced an initial increase when the tornado struck Moore city at 2.56 pm on May 20, which was followed by a very sharp peak at 16.00-17.00 after the tornado touchdown. In comparison to #okwx, there are time lags for the #oklahoma and #moore tweets to reach their respective peaks. As discussed in section 5.1, the sharp and immediate increase in the #okwx tweets is caused because @NWSNorman fed lots of tweets into this hashtag. But, the number of #okwx tweets is much more than that of tweets released by #NWSNorman. This means that the #okwx is also fed by other agencies or citizens who reported hazardous weather situations in their area. Crowdsourcing of these hazardous weather reports from the grass roots can complement data from the integrated NWS radar network, enabling the NWS Norman to detect and analyze enfolding hazardous weather conditions to improve the current tornado false alarm rate of 76%.

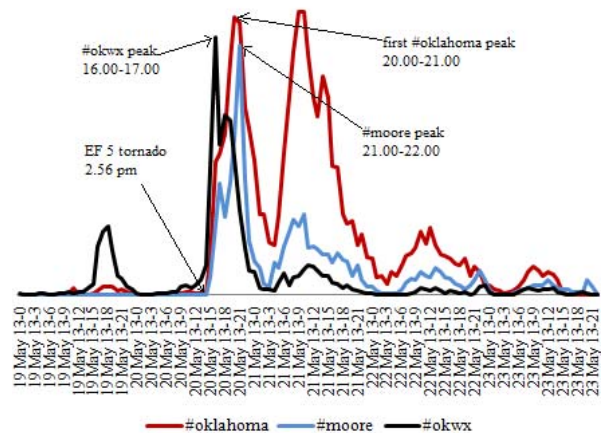


Figure 7. Tweet traffics

Next we categorized the top 50 Twitter followers who engaged in hazardous weather report conversations via #okwx and the other top 50 Twitter followers who engaged in more general weather-related conversations via #oklahoma and #moore into one of the following three categories: citizens, government agencies, and private-sector organizations or non-public organizations (NPOs) (see Figure 8). In the #okwx Twittersphere, citizens (50%) dominated, followed by either private organizations or NPOs (44%) and government agencies (only 6%). Similarly, in the #moore Twittersphere, citizens (72%) also dominated the conversations, followed by either private organizations or NPOs (28%), with no conversations contributed by government agencies. In contrast, however, in the #oklahoma Twittersphere, either private organizations or NPOs dominated (52%), with citizens (44%) and government agencies (4%). These findings seem to indicate that across the three different Twitterspheres, citizens have contributed actively to both the specific hazardous weather reports and more general weather-related conversations, whereas the presence of government agencies across the three hashtags is either low or missing. Nonetheless, their presence via the Twitterspheres seems to be important. We found that whenever the government presence is observed (the cases of #okwx and #oklahoma), the peaks of tweet traffics in Figure 7 reached sooner than when the government presence is not observed (the case of #moore).

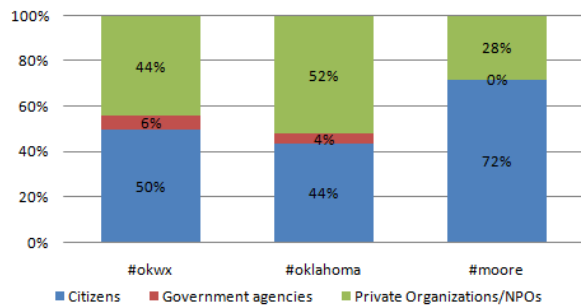


Figure 8. Contributors to conversations

As we discussed earlier, the tweets via the #okwx Twittersphere are designated to report enfolding hazardous weather conditions such as “Hail 1 1/2 inch in diameter at 6:25 p.m. #okwx” in the Twitter followers’ local areas. It was meant to attract citizens to participate in crowdsourcing through their ground sighting of thunder storms, hails, and tornadoes in their surrounding areas. Although NWS Norman provides other traditional information infrastructure for citizens to voluntarily report their direct observation through NWS website,

(<http://www.srh.noaa.gov/StormReport/SubmitReport.php?site=oun>), it seems that #okwx provides an innovative way for governments to promote active forms of citizen engagement with the NWS through Twitter-enabled crowdsourcing.

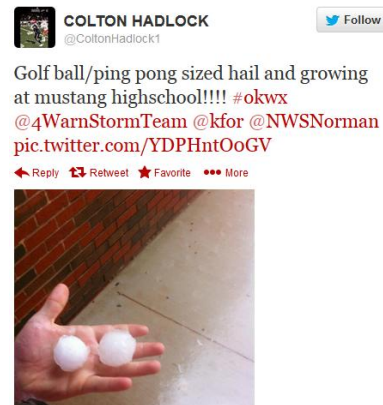


Figure 9. Citizens’ observation fed to #okwx and @NWSNorman

For example, when a hail storm started, some of the citizens in the affected area took a picture of a golf ball size hail that fell, which was loaded and shared via the #okwx Twittersphere. Other citizens also shared their direct visual observations. Samples of citizen reporting hazardous weather reports are shown in Figure 9.

5.2.2. Social network analysis on the active Twitter users in #okwx prior to the tornado

In this section we highlight the active involvement of the Twitter users in #okwx prior to the tornado, especially in the critical time from 10.00 am to 2.56 pm, in order to understand their social structures and relationships. During that span of time, we identified 313 distinct Twitter users involved in the #okwx hashtag. Figure 10 below shows the network build based on those 313 active users (nodes) and 5032 ties between the nodes. Only nodes with high *in degree centrality* are shown in the figure. The *in degree centrality* of a node refers to the number of nodes which point to the focal node. In other words, it describes the number of the followers who involve in the network. The network has its density 0.052, and it is quite high for a direct network. It means more social ties exist among the network member. The network diameter is 6 and this makes the information travels relatively faster among the network members.

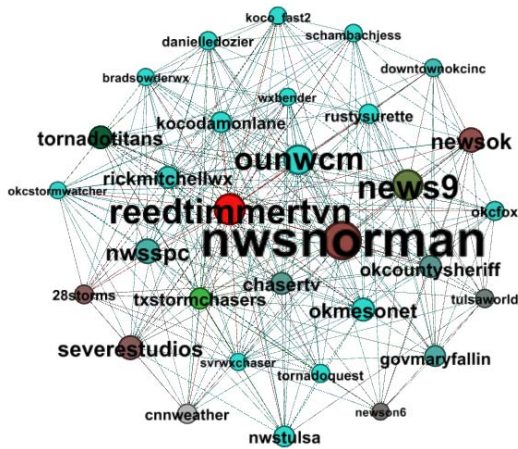


Figure 10. Active Twitter user in #okwx

Of the 313 active Twitter users, we identified their personal information declaration, as we can see in Figure 10, the network consists of government agencies (e.g., @nwsnorman, @ounwcm, @nwtulsa, @govmaryfallin), private organization and non public organization (e.g., @reeditimmertvn, @news9, @newsok, etc) and citizens (e.g., @tornadotitans, @txstormchasers, @rickmitchellwx, etc). After careful identification, we decided that 191 of them are citizens reside in the US, with the states distribution as presented in Table 1. Citizens of Oklahoma dominate #okwx by 66%, followed by Texas (8%), Arkansas (3%), Georgia (2%), Kansas (2%) and Ohio (2%). This domination is reasonable since the #okwx was introduced by NWS Norman and specifically used for Oklahoma area. In Table 1, we also can see that other states which familiar with tornadoes such as Texas, Kansas and Florida, also actively contribute in #okwx.

Table 1. Active citizens in #okwx in US, by states

States	Number of Active Citizens	Percentage
Oklahoma	127	66%
Texas	15	8%
Arkansas	5	3%
Georgia	4	2%
Kansas	4	2%
Ohio	4	2%
California	3	2%
Colorado	3	2%
Florida	2	1%
Indiana	2	1%

States	Number of Active Citizens	Percentage
Others	22	12%
Total	191	100%

Among those 191 citizens reside in the US, some of them has a huge number of follower (big nodes) as shown in Table 2. Most of them are people who are interested in meteorology, and specifically storm watchers and tornado catchers, such as @TornadoTitans, @TxStormChasers, @stormchasrbryce and @ChaserCentral. The rest are just common citizen such as @machstain81, @slackadjuster, @northlandfox and @CMV420, or specific profession such as @anchorman. In the previous research these big nodes number of follower is strategic to spread the information to the wider audience [7].

Table 2. Top 10 big nodes

Twitter Account	Followers	Personal Information
TornadoTitans	50,265	Stormwatcher
TxStormChasers	39,366	Stormwatcher
mchastain81	12,919	Citizen
stormchasrbryce	10,344	Stormwatcher
slackadjuster	9,659	Citizen
ChaserCentral	7,190	Stormwatcher
amanchor	7,080	Anchor man
OKCStormWatcher	7,043	Stormwatcher
northlandfox	7,009	Citizen, social media and emergency management volunteer
CMV420	5,843	Citizen

6. Discussion and Conclusion

Given the nature of EF intensity tornadoes - very short warning lead times and extant high-level warning false alarm rate (76%), citizens' direct observation and visual sighting of enfolding tornado development is an additional valuable information source for the NWS information infrastructure for detection and prediction of tornadoes. In this exploratory empirical study, we have presented some evidence for supporting the important role of citizens in the government crowdsourcing experiment.

In this research, the Twitter-mediated crowdsourcing was led by the NOAA's NWS in introducing a specific hashtag for the citizens to interactively engage with the government weather forecasting services. NWS Norman used #okwx actively to disseminate severe weather forecasts, tornado watches, tornado warnings and citizen evacuation alerts during EF 5 May 20 2013 Oklahoma tornadoes. It also used the same hashtag to promote the citizen tornado watchers to submit their hazardous weather reports and geotagged photos of hails and the formation of tornadoes. This hashtag consists of the combination of "ok" and "wx", representing the location, Oklahoma, and the keyword, Weather (in Morse code) respectively. It seems that #okwx provides an innovative way for the government agency to promote active forms of citizen engagement with NWS Norman through Twitter-enabled crowdsourcing. Our results show that this hashtag peaks quicker compared to other popular hashtags (#oklahoma and #moore), which suggest that this hashtag can mobilize the crowd timely who help the national weather services reach a wider range of the intended citizens with the critical tornado early warnings under the challenging conditions of short warning lead times of the EF5 intensity tornado that struck Moore city on May 20 2013.

As discussed in the literature review, prior tornado research has shown that while government tornado warnings dissemination is a key critical success factor in an integrated warning service in having reduced the rate of human casualty, tornado warnings and forecasts that do not reach the intended citizens and produce appropriate responses are not very valuable, even if they are accurate and timely. Therefore, they pointedly argue that volunteer citizen tornado watchers and the public weather forecasting services need to be closely tied for further improvement of detection and prediction of EF intensity tornadoes [11]. This exploratory empirical research has presented clear evidence for the value of the #okwx Twittersphere for bringing the volunteer citizen tornado waters and the NWS Norman weather forecasting services together for closer ties through the common Twitter-based public sphere for multi-directional severe weather conversations and crowdsourcing of hazardous weather reports from volunteer citizen tornado watchers.

However, although NWS Norman has demonstrated the effective use of Twitter during the May 20 EE, its #okwx still is an experiment, not fully adopted and diffused across all government agencies as our results also shown. This experimental use has some inherent limitations on our small data set. Our research also is limited by our focus on a single EE; the May 20 2013 EF5 intensity tornado event. Our

future research directions include further investigations on the government use of official hashtag effectiveness to promote citizen crowdsourcing and a longitudinal event study of the continuing use of #okwx, especially in the immediate aftermath of an EE.

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