



Misinformation debunking and cross-platform information sharing through Twitter during Hurricanes Harvey and Irma: a case study on shelters and ID checks

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Abstract

As the internet and social media continue to become increasingly used for sharing breaking news and important updates, it is with great motivation to study the behaviors of online users during crisis events. One of the biggest issues with obtaining information online is the veracity of such content. Given this vulnerability, misinformation becomes a very dangerous and real threat when spread online. This study investigates misinformation debunking efforts and fills the research gap on cross-platform information sharing when misinformation is spread during disasters. The false rumor “immigration status is checked at shelters” spread in both Hurricane Harvey and Hurricane Irma in 2017 and was analyzed in this paper based on a collection of 12,900 tweets. By studying the rumor control efforts made by thousands of accounts, we found that Twitter users respond and interact the most with tweets from verified Twitter accounts, and especially government organizations. Results on sourcing analysis show that the majority of Twitter users who utilize URLs in their postings are employing the information in the URLs to help debunk the false rumor. The most frequently cited information comes from news agencies when analyzing both URLs and domains. This paper provides novel insights into rumor control efforts made through social media during natural disasters and also the information sourcing and sharing behaviors that users exhibit during the debunking of false rumors.

Keywords Rumor · Twitter · Information sharing · Social media · Hurricane Harvey · Hurricane Irma

1 Introduction

Traditionally, information is spread within social networks by personal communication such as word of mouth. With the advent of Web 2.0, the forming of social networks is no longer limited to offline contacts between individual human beings. A variety of contemporary platforms, such as Twitter, Facebook, and YouTube, provide users a great way to

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communicate and share information with each other across networks at extreme speeds (Wang and Zhuang 2017). Without information validity being monitored on postings, online social networks have been criticized as a rumor mill (Leberecht 2010; Friggeri et al. 2014), given the significantly increased diffusion scale when rumors, misinformation, and fake news spread online. One example of such misinformation can be taken from the 2017 Manchester Arena bombing in England. Following this disaster, a false rumor spread on Facebook and Twitter which stated that unaccompanied children were being taken to a local Holiday Inn for shelter. This false rumor caused unneeded chaos and confusion, as parents and guardians traveled to the Holiday Inn in search for their children who were not there.

The variety of online social network services makes it possible to share information among different networking sites such as Twitter and Facebook. In addition, people cite other information sources, such as news sites, to diffuse interesting news, support their views, and comment on topics. Therefore, it is with great potential that social media users will cite information from different platforms when posting their statuses. Cross-platform sourcing occurs when sources within posts come from social media and/or Web site platforms other than the one used to make the post (e.g., a Twitter user cites a Facebook post or news story in their tweet). In review of this, we are motivated to investigate the cross-platform sourcing behaviors of Twitter users in disseminating misinformation-related content during natural disasters, an area which has been unexplored to the best of our knowledge. Throughout this paper, misinformation propagation is studied in the context of a false rumor that is spread during both Hurricane Harvey and Hurricane Irma.

Two research questions will be answered in this study, including: (1) To what extent are misinformation debunking posts, which are posted by official government organizations (GOs) and other organizations (news agencies, non-government organizations, and normal Twitter users), utilized by Twitter users to help end the dissemination of misinformation during natural disasters? and (2) What platforms will Twitter users cite as information sources when debunking false information? Results of this study contribute in extending the existing research on rumor-related information diffusion within social media, and bridge the literature gap on cross-platform information diffusion; specifically relating to false rumors and rumor control efforts during natural disasters.

The rest of the paper is organized as follows: Sect. 2 introduces the related literature and the gap this study bridges; Sect. 3 presents the research methods and data collection for the analysis; Sect. 4 presents the analysis results; and Sect. 5 concludes and presents future research directions.

2 Literature review

The coming of social media has changed the way people generate and share information during disasters (Alexander 2014), and people rely on social media for the latest developments in breaking news stories (Phuvipadawat and Murata 2010). It outperforms the traditional mass media given its timely updates of events and interactive two-way communications (Fraustino et al. 2012). As a result, a great amount of work has been conducted to investigate the use of social media during disasters (Houston et al. 2015; Abedin et al. 2014; Lundgren and McMakin 2013), including crisis communication (Bruns and Burgess 2014), information credibility (Gupta and Kumaraguru 2012; Spence et al. 2015), situation awareness (Vieweg et al. 2010; Yuan et al. 2013), and information system design (Okada

and Ogura 2014; di Tada and Large 2010). These works contribute to a better social media application in disaster management, where a larger demand for updated information is produced with the diminished communication capacity and increased threats.

Unmoderated postings on Twitter allow for rumors, misinformation, and fake news to spread (Procter et al. 2013; Castillo et al. 2011). This proves to be a substantial threat, as false news spreads faster than the truth on Twitter (Vosoughi et al. 2018). Rumors, defined as unverified statements about an event during circulation (Peterson and Gist 1951; Allport and Postman 1947), propagate widely on online social networks during disasters (Wang and Zhuang 2018; Oh et al. 2013; Hunt et al. 2019b). Starbird et al. (2014) studied three different rumors during the 2013 Boston Bombing and found that Twitter users did not do well in distinguishing truth and hoax. Research from Kwon et al. (2013) investigates the determinant features of online rumor spreading from temporal, structural, and linguistic aspects and tests the determinant features with five different classification algorithms, achieving a good classification performance. Shin et al. (2018) unfold spreading factors in terms of temporal pattern, message, and source for political rumors during the 2012 presidential election and find that rumor information will travel back and forth between platforms, while verified information usually does not. More research on rumor spreading features could be found in (Miyabe et al. 2014; Chierichetti et al. 2011; Del Vicario et al. 2016; Mendoza et al. 2010). Results of these studies improve the performance of rumor detection on social media during disasters.

Compared with the rumor spreading studies, rumor correction and debunking research is gaining in popularity and attention (Hunt et al. 2019a, 2020; Chua et al. 2017). Besides the physical supports needed in disaster relief, timely and accurate information is also vitally important during disasters. Therefore, the official response agents are expected to update public users with correct information to combat rumors. Though issuing official anti-rumor statements serves as an efficient method for rumor combating on Twitter (Andrews et al. 2016), it has not been well studied in the literature, especially in the case of natural disasters. Takayasu et al. (2015) fail to investigate the collective effect of all rumor correcting statements following the Great East Japan Earthquake, and only study the impact of one official rumor correction tweet. A gap in the literature exists in studying rumor debunking messages from verified Twitter accounts compared to unverified Twitter accounts to find the differences in dissemination and interaction. In review of this, we are motivated to acquire insights on official debunking messages by conducting a case study of Hurricane Harvey and Irma in 2017. Although research in the detection and correction of rumors has seen substantial progress since the rapid growth of social media (Zubiaga et al. 2018), there is still a lot of work to be done to offer emergency responders, governments, and everyday Twitter users knowledge on how to best use their platform in times of misinformation spreading and crisis situations. Results of this study provide more valuable insights to rumor control and crisis management during disasters.

Uniform resource locators (URLs) are often cited and used in social networks to provide additional details on an event (Boyd et al. 2010; Poblete et al. 2011), especially in the micro-blog service provider Twitter, which imposes the 280-character limit to each message (Honey and Herring 2009). URLs cited by Twitter users could come from a variety of Web sites, such as YouTube, Facebook, and news sites. As a result of these citation behaviors, information flows among different networks. In terms of rumor debunking, we are interested to know what platforms and Web sites are most cited in tweets. Besides external sources, internal source citation (citing another tweet) will also be analyzed in this study to compare external and internal information source frequency. To the best of our knowledge, no research has studied any of these features. Analysis on the sources that Twitter users

cited in their posts during these rumors and natural disasters serves as the primary research gap that will be filled in this study.

3 Research methodology

To answer the two research questions listed in Sect. 1, the rumor “immigration status is checked at shelters” is analyzed from both Hurricane Harvey and Hurricane Irma. The false rumor was identified on the Federal Emergency Management Agency’s (FEMA’s) rumor control pages for both Hurricane Harvey and Hurricane Irma (Federal Emergency 2017a, b) and was listed under the title “Shelters and ID Checks.” On these rumor control pages, there are many additional false rumor cases which had negative impacts during the hurricanes, such as a rumor which stated that flood waters were carrying a plague, and another rumor which stated that there was a fuel shortage in Texas and Florida. For this study, we choose to analyze “Shelters and ID Checks” due to its extensive coverage in the news, and widespread presence on Twitter. This false rumor case is appropriate for this research for three reasons. First, the rumor spread in both hurricanes, which will be used for comparing the debunking responses and cross-platform information sharing of the Twitter users when the same false rumor occurs. Second, this rumor case can be used to study if people get immune to a false rumor as it re-occurs in a different geography, and therefore reduces the spread. Third, the false rumor-related news was broadcast both online and offline, which makes it possible for cross-platform information sourcing and sharing. Both latent and manifest content analysis (CA) are used throughout this paper to code the data, analyze the retweets/likes on postings, and analyze the content of the false rumor debunking posts (Kimberly 2002; Wang and Zhuang 2017). Latent CA refers to the analysis of the underlying meaning of content, whereas manifest CA refers to directly observable words or objects within content. For example, when tweets are coded into different categories, latent CA must be used in order to identify the meaning of the messages. When the tweets are coded, manifest CA can be used to identify accounts in specific categories by simply looking at the account names. Tableau software and R programming language are used for all data visualizations and data handling.

3.1 Background of false rumors and hurricanes

Immigration Rumor in Hurricane Harvey On August 25, 2017, Hurricane Harvey made landfall in Texas as the strongest hurricane to hit US mainland in the previous decade. During Hurricane Harvey, there was legislation due to be passed in Texas that was set to greatly increase anti-immigration laws. This legislation, known as Senate Bill 4 (SB4), caused fear among many undocumented immigrants in Texas and was the catalyst for the false rumor to begin on Twitter. An example of SB4 being used in a tweet to spread the misinformation is given in Table 1. As some people began to inquire about identification checks at evacuation shelters, rumors began swirling throughout social media and Texas that stated shelters were indeed checking IDs. This misinformation could have led to thousands of undocumented immigrants not seeking the shelter they needed, as they were in fear of deportation due to their lack of citizenship (Aguilar 2017). Starting with a tweet from @HoustonTX in both English and Spanish, as provided in Table 1, it took multiple debunking attempts to quell the false rumor.

Table 1 Tweets related to the false rumor during Hurricane Harvey: (a) is a tweet which used SB4 to spread the misinformation; (b) is a post from @HoustonTX debunking the false rumor; (c) is the same post from @HoustonTX which they translated to Spanish; (d) is another debunking post from @HoustonTX which has both English and Spanish texts

	Timestamp	Retweets	Likes	Message
(a)	08/27/2017 09:43	47	35	On Friday, #SB4 will require TX officers to detain and ask immigration status. #SB4 will magnify the damage from #HurricaneHarvey
(b)	08/28/2017 20:22	71,567	143,743	We will not ask for immigration status or papers from anyone at any shelter. This rumor is FALSE!
(c)	08/28/2017 20:24	7810	9513	No vamos a pedir documentos ni estatus migratorio en ningun albergue este rumor es FALSO!
(d)	08/29/2017 12:08	102,886	241,719	WE WILL NOT ASK FOR IMMIGRATION STATUS OR PAPERS AT ANY SHELTER. No vamos a pedir documentos ni estatus migratorio en ningun albergue

Immigration Rumor in Hurricane Irma On the heels of Hurricane Harvey, Hurricane Irma was wreaking havoc across the Caribbean on its path toward Florida. On September 10, 2017, Hurricane Irma made landfall in Cudjoe Key, Florida, bringing along deadly storm surges and rainfall (Jansen 2017). Before landfall, on September 6, 2017, a Polk County Sheriff tweeted saying that he would be checking identifications at all evacuation centers in the county, as provided in Table 2. This tweet led to anger and fear among citizens and undocumented immigrants. Although the sheriff did not spread any false information, and his tweets were factual in their content, many citizens and undocumented immigrants inferred that he was checking IDs to primarily scare undocumented immigrants from seeking safety in those shelters. This sheriff had to later clarify his tweet, as provided in Table 2, and many debunking efforts were made in order to help comfort the population. The City of Miami, FEMA, DHS-ICE, DHS-CBP, and other organizations posted information to let the undocumented population know that it was safe for them to seek shelter. Examples of these tweets are given in Table 3.

3.2 Data collection

Twitter's REST Application Programming Interface (<https://dev.twitter.com/rest/public>) and Python programming were used for collecting all of the tweets and their retweets. The standard Twitter search API returns tweets that have been published in the last 7 days and does not return an exhaustive list of tweets; therefore, our data do not contain every tweet related to the misinformation cases based on our search criteria. To counter this problem and retrieve a more complete dataset, the collection took place over a 28-day window, with collection done every 3 days using the same search criteria every time. This method allowed for collection to be done at least twice for every day in the 28-day window (excluding the last 3 days before collection ended). Although this method still does not supply every related tweet and is computationally expensive, it gives us a less limited dataset and allows us to capture many tweets which may have been deleted after any of our given collections (Maddock et al. 2015). The searching period for Hurricane Harvey started on August 28, 2017, and collection continued through September 24, 2017. The search criteria used were case-insensitive keywords, hashtags, and their combinations (e.g., "immigration status," "immigration enforcement," "immigration check," "#harvey," "#hurricaneharvey"). The search results in 2,032 unique tweets and 7,721 retweets, after removing non-related tweets. The searching period for Hurricane Irma started on September 9, 2017, and collection continued through October 6, 2017. The search criteria used were case-insensitive keywords, hashtags, and their combinations (e.g., "immigration status," "immigration enforcement," "immigration check," "#irma," "#hurricaneirma"). The search results in 601 unique tweets and 2,539 retweets, after removing non-related tweets. In total between the two cases, we analyzed 2,633 related unique tweets and 10,260 related retweets. The amount of data collected for both rumor cases is very similar to the samples collected in Wang and Zhuang (2018), where the authors also studied false rumors that were spread during disasters. The exact search criteria used for both cases are found in Appendix 1, Table 6. The search criteria were chosen via an extensive Twitter Advanced Search to find major keywords and hashtags that identified tweets related to the false rumor in both hurricanes. The criteria were searched in English.

Table 2 Tweets related to the false rumor in Hurricane Irma: (a) is the first tweet from the Polk County Sheriff; (b) is the second tweet from the Polk County Sheriff; (c) is a follow-up tweet which clarifies the false rumor.

	Timestamp	Retweets	Likes	Message
(a)	09/06/2017 7:30	4247	8850	If you go to a shelter for #Irma, be advised: sworn LEOs will be at every shelter, checking IDs. Sex offenders/predators will not be allowed
(b)	09/06/2017 7:31	7075	10,484	If you go to a shelter for #Irma and you have a warrant, we'll gladly escort you to the safe and secure shelter called the Polk County Jail
(c)	09/08/2017 12:35	14	41	We aren't turning away folks who don't have ID, or illegals. That's a rumor that has spun off all this. But thanks for the tag! Be safe!

Table 3 False rumor debunking tweets from Hurricane Irma: (a) is from @CityofMiami; (b) is from @fema; (c) is from @ICEgov; (d) is from @CBP

	Timestamp	Retweets	Likes	Message
(a)	09/07/2017 09:43	248	297	ATTENTION—@MiamiDadeCounty will NOT inquire about anyone's immigration status at its shelters. #Miami
(b)	09/08/2017 16:06	13,919	12,861	We created an #Irma rumor control page to help you verify what's true and what's not. Visit it here: fema.gov/hurricane-irma-rumor-control
(c)	09/06/2017 21:46	157	283	When it comes to rescuing people in the wake of #Hurricane #Irma, immigration status is not & will not be a factor ice.gov/news/releases/dhs-statement-regarding-safety-and-enforcement-during-hurricane-irma
(d)	09/06/2017 17:37	87	111	When it comes to rescuing people in the wake of Hurricane Irma, immigration status is not and will not be a factor. bit.ly/2wHQw3Z

3.3 Coding scheme

Utilizing latent CA, the text of each unique tweet and retweet was coded to categorize the information within it. Based on the rules suggested by Krippendorff (2013) and Richard and Koch (1997) for message coding and analysis, two students, one graduate and one undergraduate, joined in the coding process for tweets. Both coders were required to become familiar with these two hurricanes and the false rumor case in this study before coding. All of the tweets were coded into the following five categories: false rumor debunking, false rumor spreading, false rumor questioning, other, and not related to rumor (Andrews et al. 2016; Mendoza et al. 2010; Starbird et al. 2014; Zeng et al. 2016; Wang and Zhuang 2018). A rubric for the coding scheme is provided in Appendix 2, Table 7. If a tweet contained any information that was spreading the false rumor, then it was labeled as false rumor spreading. Likewise, if a tweet contained any information that debunked the false rumor, then it was labeled as false rumor debunking. Therefore, the remaining two categories (false rumor questioning and other) did not contain any tweets where rumor spreading or debunking occurred. A total of 270 tweets were used for an inter-coder reliability test. The kappa value reached 0.93, which was reliable enough for the independent coding which followed (Richard and Koch 1997). After both coders completed the datasets independently, they then worked together to cross-validate any of the data points in which they disagreed on the labels. During cross-validation, for any tweets which had two different labels, the coders decided which label was more prominent in the content of the tweet. There were a total of 208 tweets which required cross-validation, and a few examples of such tweets are provided in Table 4. After cross-validation was completed, all non-related tweets and non-related retweets were discarded, leaving us with the final samples reported in Sect. 3.2. Figure 1 shows the number of tweets (original and retweets) from each label in hour unit for Hurricane Harvey and Hurricane Irma. The origin of the false rumor debunking and spreading tweets within the USA is provided in Fig. 2, where debunking tweets are indicated by orange dots and spreading tweets are indicated by blue dots. The geographical locations of the users are very similar between the two hurricanes. One possible cause for such patterns may be explained by common interests in disaster-related news in these areas (e.g., users in disaster prone areas may have more interest in disaster-related news). The distribution of tweets also appears to closely follow the population density.

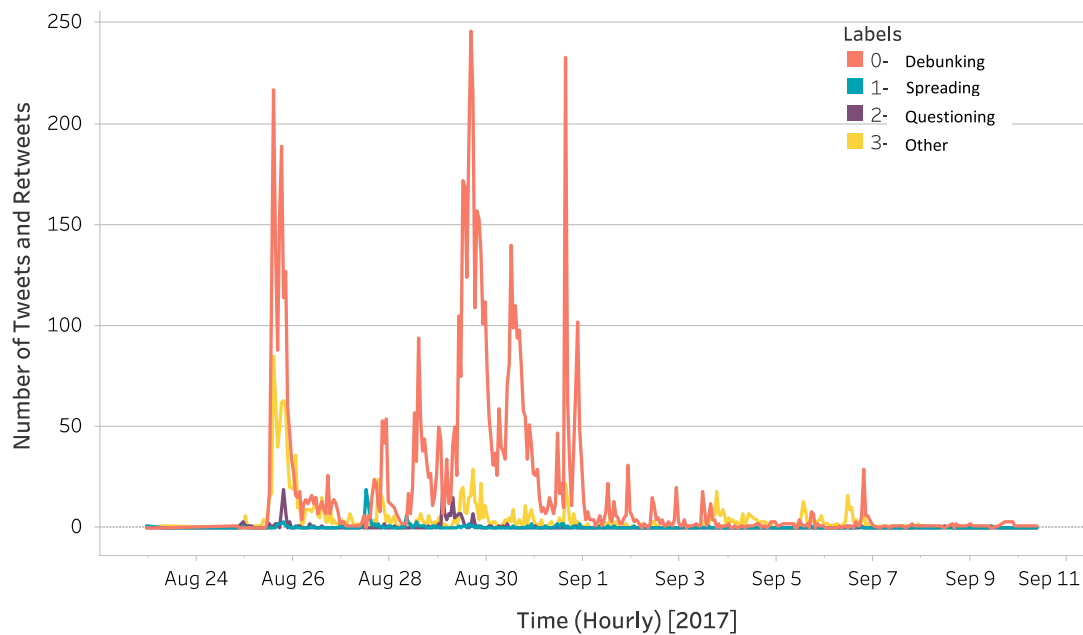
4 Data analysis

4.1 Lifespan

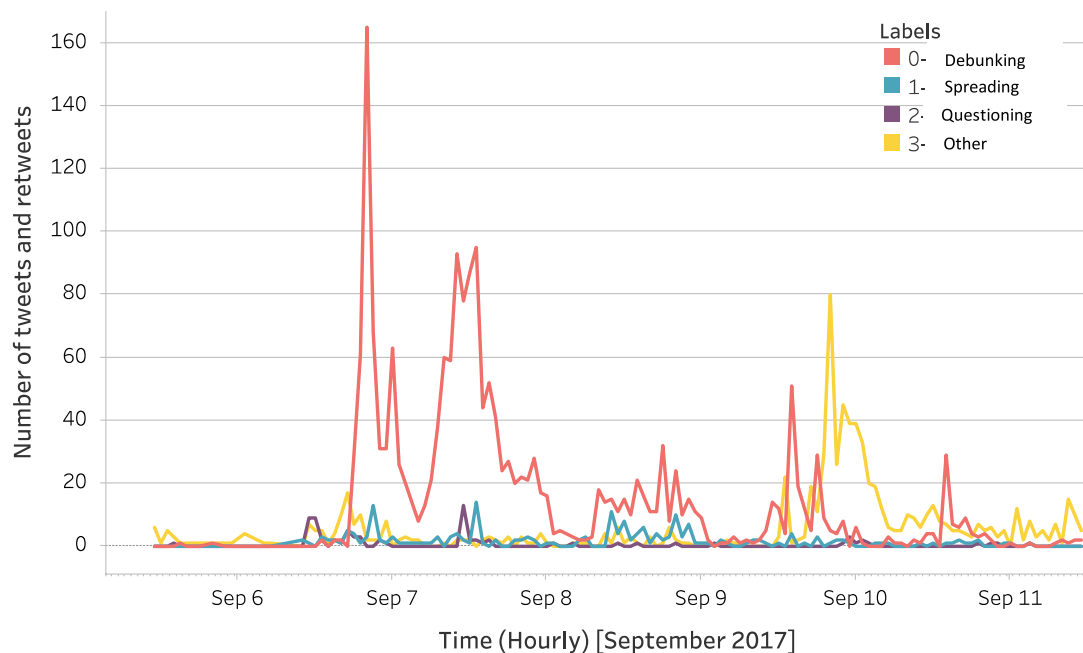
The lifespans of the false immigration rumor in both hurricanes were extracted and compared. In this research, rumor lifespan is defined as follows: The rumor lifespan begins at the time of the first related tweet and ends at the time of the first debunking tweet which follows the last spreading tweet (or retweet). At this time, no new spreaders enter the network in our dataset, and all spreaders have been debunked. Therefore, since the last tweet at this point is a debunking tweet, and the misinformation is no longer being spread, the false rumor is over. In the case of Hurricane Harvey, the false rumor started on August 22, 2017, at 23:49:09 and ended on September 10, 2017, at 09:00:38, with a lifespan of 18 days, 9 h, 11 min, and 29 s. In the case of Hurricane Irma, the false rumor started on September 5,

Table 4 Example tweets that required cross-validation, and the final decision regarding the label chosen

Tweet message	Coder 1		Coder 2		Final decision
Real lives are at stake here. If undocumented die because they are afraid to go to shelters @POTUS is #Complicit! #Harvey	FRS	O	O	O	O; this user is clearly commenting on the topic and is not spreading rumor-related false information
You are not being very clear. What is the “false” rumor, that you will or will not ask for immigration status?	FRQ	O	FRQ	O	FRQ; this user is questioning the validity of the false information and is seeking clarity on the topic
I hope undocumented people can feel safe in these shelters	O	FRD	FRD	O	O; this user is sharing their feelings/opinions, but is not providing true or false information on the topic
<i>FRS</i> false rumor spreading, <i>FRD</i> false rumor debunking, <i>FRQ</i> false rumor questioning, <i>O</i> other					



(a) Tweets and retweets during the rumor lifespan in Hurricane Harvey.



(b) Tweets and retweets during the rumor lifespan in Hurricane Irma.

Fig. 1 No. of tweets and retweets versus time in hour unit for Hurricanes Harvey and Irma

2017, at 14:44:24 and ended on September 11, 2017, at 11:57:11, with a lifespan of 5 days, 21 h, 12 min, and 47 s. It is observed that the rumor in Hurricane Harvey lasted 3.1 times longer than the same rumor in Hurricane Irma. We also observe that the two rumors were happening concurrently for almost 5 days, and ended within 27 h of each other, suggesting that the spreading and debunking of the false rumor in Hurricane Harvey helped to contain the simultaneous spreading of the false rumor in Hurricane Irma.

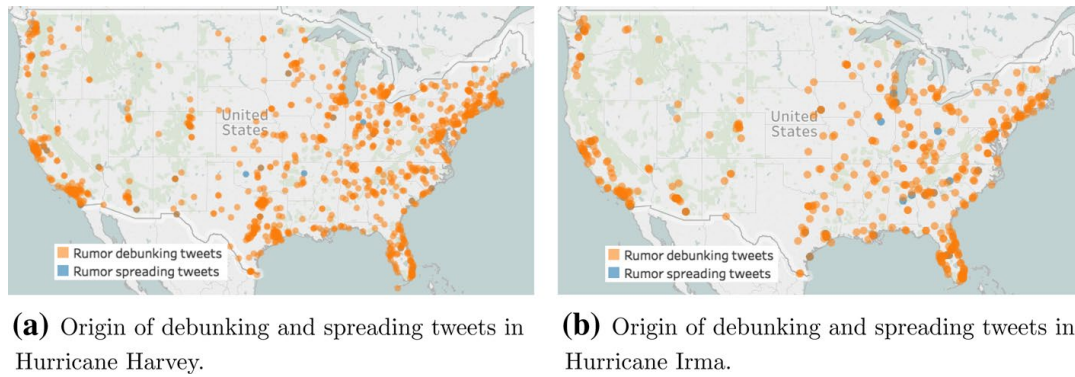


Fig. 2 Debunking and spreading tweets in Hurricane Harvey and Hurricane Irma distinguished by city of origin

4.2 Debunking efforts

As provided in Wang and Zhuang (2018), over 85% of Twitter users who were exposed to false information during disasters responded by spreading the falsehoods due to the lack of debunking information at the time of their post. Upon receiving debunking information, between 78 and 97% of the spreaders did not delete nor clarify their tweets. It is evident that if debunking information arrives on Twitter after a spreader has posted, this user will usually not change their content and will remain a spreader. Due to this, it is critical that Twitter users who have been misinformed receive debunking information before they spread the misinformation. This will lead to less rumor spreaders on the network.

With the data coded, we were able to identify the major debunking accounts via manifest CA. We looked at accounts who were verified by Twitter and also accounts who had a large interaction (likes + retweets) on their postings. A verified account is an “account of public interest,” and this distinguishment can only be given by Twitter (<https://help.twitter.com/en/managing-your-account/about-twitter-verified-accounts>). Some of the major GO accounts in our dataset who debunked the misinformation on Twitter were FEMA, DHS/CBP/ICE, the City of Houston, and the City of Miami. Some of the major news accounts in our dataset who debunked the misinformation on Twitter were The Hill, CNN, NBC, and The Washington Post. Non-government organization (NGO) accounts such as Futures Without Violence and American Civil Liberties Union (ACLU) also posted rumor debunking tweets.

For Hurricane Harvey, @HoustonTX was chosen for a deeper analysis based on their first debunking tweet in Table 1. For Hurricane Irma, @CityofMiami was analyzed based on the debunking tweet in Table 3. These accounts were chosen for comparison because they were both the first local level GO accounts in the affected areas whom responded to the false rumor on Twitter, and their debunking tweets also had the greatest interaction over the 1-day period which followed their postings. This illustrates the significant role that these local GO accounts played in the dissemination of debunking information. The interaction was compared for both of these official city debunks. When looking at both posts, it is staggering how much more interaction @HoustonTX received. With 71,567 retweets and 143,743 likes, @HoustonTX had 395 times more interaction than @CityofMiami, who only had 248 retweets and 297 likes. This can be explained in part because @HoustonTX has more than twice the followers of @CityofMiami (238k and 114k, respectively) as of May 2018. Although @HoustonTX proved to have a much wider reach in their posting,

the postings from all major accounts are critical in the debunking of false information on Twitter. Since Twitter users are more likely to spread false information rather than true information (Vosoughi et al. 2018), it is markedly important that the truth comes out, and Twitter users are able to get the correct information from credible and reliable sources. The interactions that these two accounts received suggest that their tweets played a significant role in disseminating the rumor correcting information to the public, and the cumulative distributions of their interactions compared to the rest of the debunking accounts are provided in Fig. 3.

4.2.1 Debunking efforts in Hurricane Harvey

In Hurricane Harvey, we observed 1440 unique and original debunking tweets. Out of these tweets, 15% (217 of 1440) came from verified accounts and the other 85% came from unverified accounts. The 217 debunking tweets which came from verified accounts collectively received 194,710 retweets and 412,603 likes. The 1223 debunking tweets which came from unverified accounts collectively received 1792 retweets and 3664 likes. Diving deeper into the tweets from verified accounts, we observed 9 GO accounts, 93 news accounts, and 106 other accounts (NGOs, celebrities, and all other verified accounts). The 9 GO accounts collectively received 176,760 retweets and 387,824 likes. The 93 news accounts collectively received 15,187 retweets and 20,541 likes. Lastly, all of the other

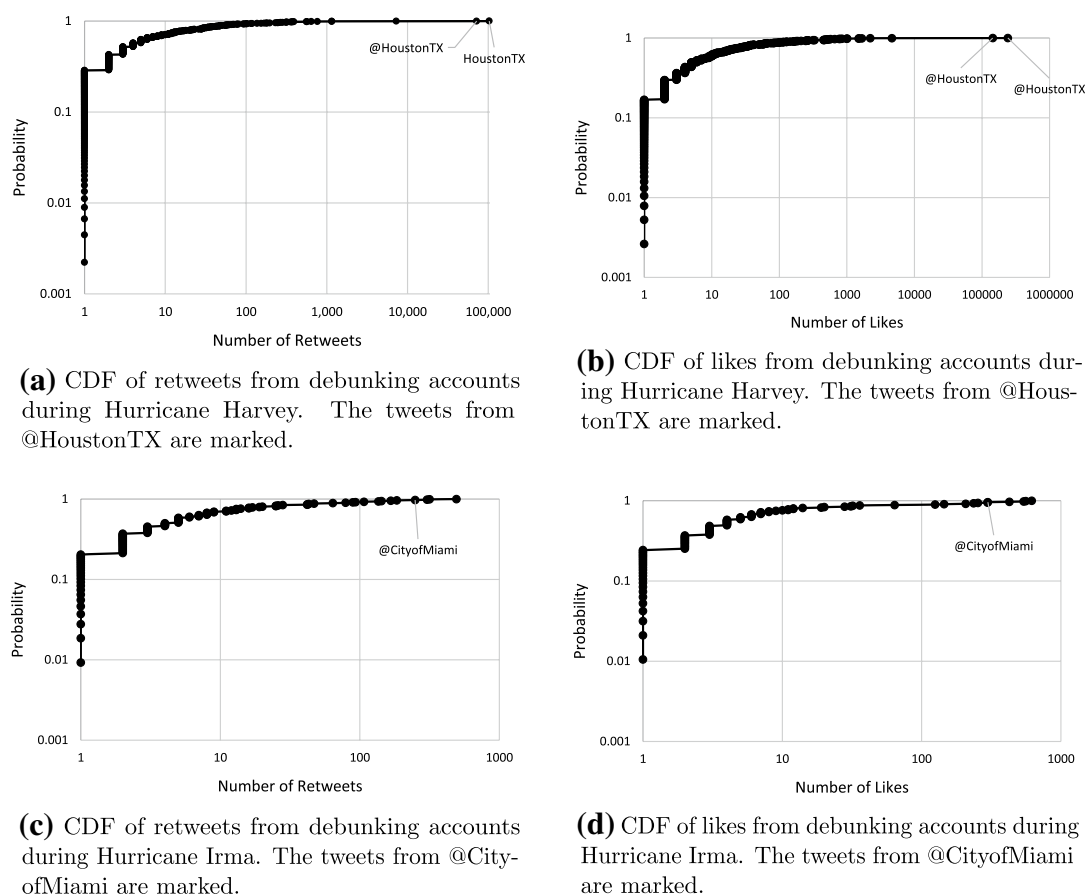


Fig. 3 Cumulative distribution functions (CDFs) of the number of retweets and likes that debunking accounts received in Hurricane Harvey and Irma, with a log–log transformation

verified accounts received 2763 retweets and 4238 likes. Most of the GO accounts, such as @HoustonTX, @ICEgov, @CityOfDallas, @USAgov, @austintexasgov, posted their tweets between August 28 and August 30, and @HoustonTX and @ICEgov posted three and two separate tweets, respectively. The tweets from @HoustonTX differed every time, with one tweet being posted in English, one in Spanish, and the third being posted in both languages. The first tweet from @ICEgov read “Routine non-criminal immigration enforcement ops won’t be conducted @ evacuation sites, or assistance centers such as shelters or food banks,” and the following tweet (2 days later) read “Immigration enforcement operations are not being conducted at evacuation sites, or assistance centers such as shelters or food banks.” The second posting offered more clarity to the public by clearly stating that immigration enforcement would not be taking place at shelters and other evacuation sites. The tweets from all remaining GO accounts clearly stated that there would be no identification checks at shelters, such as the following tweet from @CityOfDallas: “We will not ask for immigration status or papers from anyone at any of our shelters. #HurricaneHarvey.” Following these collective efforts, only eight new unique spreading tweets were posted in our dataset for the remainder of the rumor’s lifespan.

4.2.2 Debunking efforts in Hurricane Irma

In Hurricane Irma, we observed 259 unique and original debunking tweets. Out of these tweets, 13% (34 of 259) came from verified accounts and the other 87% came from unverified accounts. The 34 debunking tweets which came from verified accounts collectively received 19,140 retweets and 26,154 likes. The 225 debunking tweets which came from unverified accounts collectively received 588 retweets and 902 likes. Taking a closer look at the tweets from verified accounts, we observed 5 GO accounts, 8 news accounts, and 19 other accounts. The 5 GO accounts collectively received 16,917 retweets and 21,844 likes. The 8 news accounts collectively received 1386 retweets and 2812 likes. Lastly, all of the other verified accounts received 837 retweets and 1498 likes. All of the GO accounts, including @CityofMiami, @ICEgov, @fema, @CBP, and @MiamiDadeBCC, posted their tweets between September 6 and September 8, and @ICEgov posted two separate tweets. The tweets from @ICEgov were both identical and were posted 2 days apart, reading “When it comes to rescuing people in the wake of #Hurricane #Irma, immigration status is not & will not be a factor.” The tweets from all remaining GO accounts clearly stated that there would be no identification checks at shelters, such as the following tweet from @MiamiDadeBCC: “#Update: Thursday 9/7 @MiamiDadeCounty has opened more shelters. Immigration status will NOT be inquired. See list below. #HurricaneIrma.” Following these collective efforts, only five new unique spreading tweets were posted in our dataset for the remainder of the rumor’s lifespan.

When comparing the rumor debunking efforts between the two hurricanes, we note many similar features. First, we observe the portion of debunking tweets coming from verified accounts as 15% and 13% in Hurricane Harvey and Hurricane Irma, respectively. Second, in both cases, the verified accounts received much greater interaction on their debunking tweets, although there were many more unverified accounts who posted debunking tweets. In Hurricane Harvey, the postings from GO accounts made up for 93% (564,584 of 607,313) of the total verified account interaction, and in Hurricane Irma, they made up for 86% (38,761 of 45,294). When focusing only on the retweets that verified accounts received, the postings from GO accounts made up for 91% (176,760 of 194,710) and 88% (16,917 of 19,140) in Hurricanes Harvey and Irma, respectively. Similarly, when focusing

only on the retweets that the verified accounts received, the postings from news agencies made up for 8% (15,187 of 194,710) and 7% (1,386 of 19,140) in Hurricanes Harvey and Irma, respectively. These results imply that GO and news accounts play a significant role in the dissemination of misinformation debunking news during natural disasters.

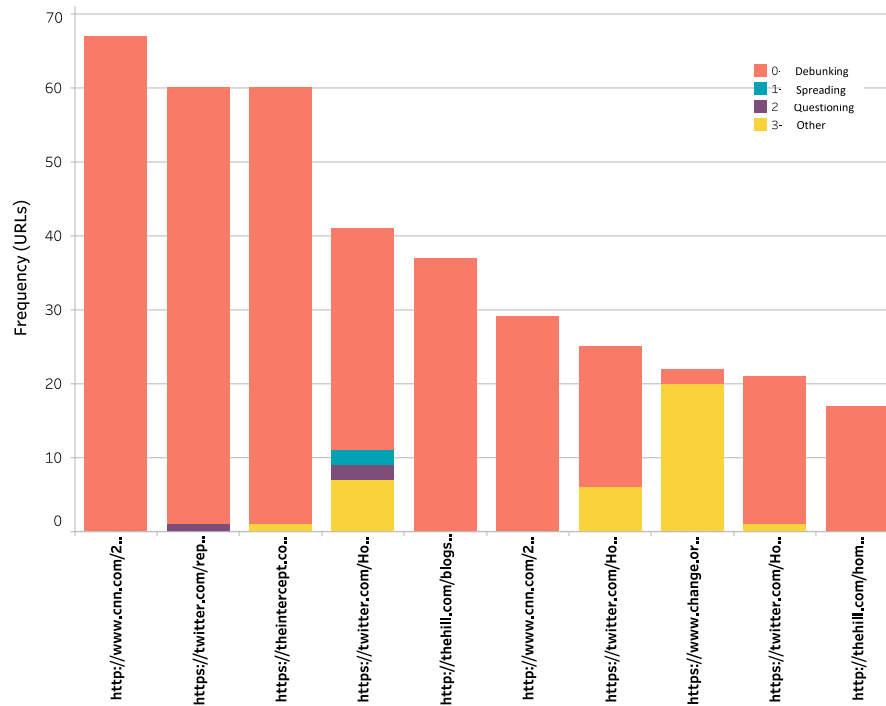
4.3 Cross-platform sourcing

If a tweet contained a URL(s) in its message, the URL(s) was extracted to identify the source. Cited information flows from the host source to Twitter, and from Twitter to other platforms if the Web site explicitly cites messages from Twitter, such as containing a figure of a tweet. In addition, a Web site could have multiple different URLs directing traffic to the same content. Therefore, we assign the URLs that have the same Web site content only one unique message ID, to avoid duplicating messages contained by URLs. For all of the unique tweets in Hurricane Harvey, the percentage of tweets with zero links, one link, and two links are 42% (854 of 2032), 58% (1170 of 2032), and less than 1% (8 of 2032), respectively. For the Hurricane Irma case, the percentage of tweets with zero links, one link, and two links are 44% (266 of 601), 55% (332 of 601), and less than 1% (3 of 601), respectively. Removing all the duplicate URLs directing to the same Web page content, 406 and 153 pieces of information were shared via URLs in tweets collected during Hurricane Harvey and Hurricane Irma, respectively. Given that over half of the users in both disasters cited a URL in their tweets, it is evident that social media users rely on information from other sources to support their misinformation-related messages. Diffusion features of this information will be analyzed in this section to see how cross-sourcing helps in increasing the information distribution across an online social network.

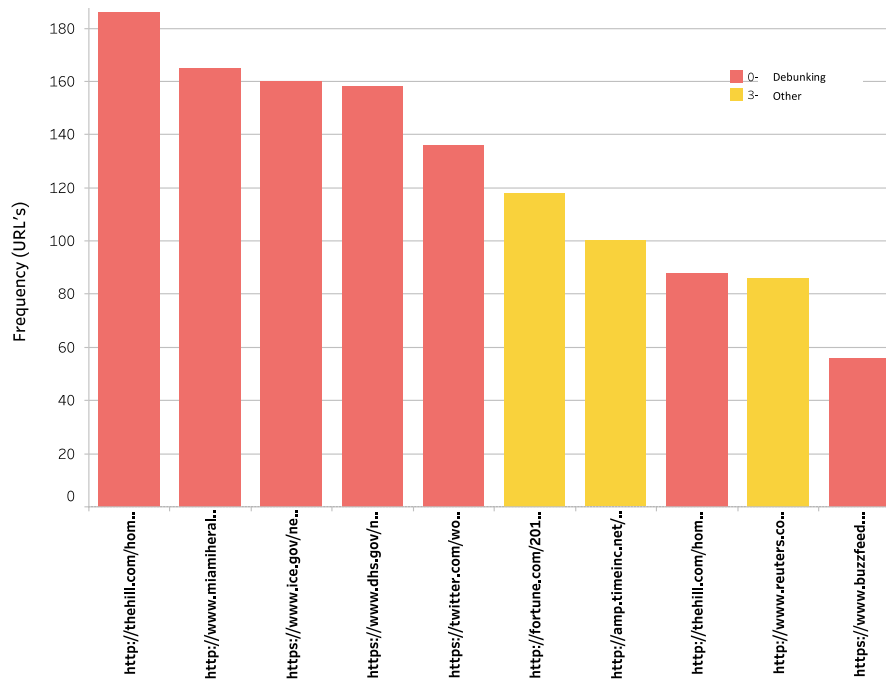
4.3.1 URL citation frequency

We were able to extract the most common URLs that were used as an information source, and the top ten are provided in Fig. 4. Through manifest CA, we also determined whether these URLs were used to debunk, spread, question, or comment/share opinions (other) on the false rumor. In both cases, it is evident that the majority of users utilized URLs in their posts to validate their debunking content. In Hurricane Harvey, 86% (1008 of 1170) of URLs in tweets were used to validate a debunking message, and in Hurricane Irma, 53% (176 of 332) of URLs were utilized to do the same. In a few cases, users may have utilized the same URL in their tweets to convey a different message to their network. An example of this can be seen in the case of Hurricane Harvey, as many people cited the @HoustonTX debunking post in their tweets. Some users simply employed it as proof to their followers that indeed this rumor was false. In two cases, users cited this URL to spread the false rumor, although the URL contained debunking information. In a tweet that reads “Very important, anyone at any shelter will ask for immigration status or papers @KHOU #HarveyRelief,” we see user @AmyGilleoKHOU use this debunking information as a source in her post, although the content of her post actually spreads the misinformation.

Twitter users in Hurricane Harvey and Hurricane Irma cited articles from government Web sites such as ice.gov and dhs.gov to disseminate the debunking information to their respective networks. Other major news sites were used to help debunk the rumor, such as cnn.com, thehill.com, miamiherald.com, and houstonchronicle.com. Inner sourcing from Twitter itself also accounted for many of the URLs that Twitter users cited in their posts. Inner sourcing occurs when users cite another account’s tweet by adding the tweet’s



(a) URL citation frequency during the false rumor in Hurricane Harvey.



(b) URL citation frequency during the false rumor in Hurricane Irma.

Fig. 4 Frequency of the top ten URLs used as information sources in both hurricanes

URL to the content of their new post. An example of this is provided in the following tweet: “In case you missed it: IMPORTANT message from the city of Houston. No IDs will be checked & no immigration papers asked at shelters. #Harvey <https://twitter.com/HoosierState/status/905123456789012345>”

[HoustonTX/status/902609037056933888](#)." Instead of using Twitter's retweet feature, this user chose to provide the direct link to the tweet from @HoustonTX which provided the debunking information in both English and Spanish.

When further analyzing the content on the Web pages that were used as URLs in debunking messages, it was clear that for both hurricanes, there was little difference in the messages that were being released. In Hurricane Harvey and Hurricane Irma, the URLs from the government and news agencies clearly stated that immigration enforcement was not underway at shelters. In most cases, such as thehill.com, cnn.com, nbcnews.com, nytimes.com, miamiherald.com, and theintercept.com, news agencies were citing information and press releases from governmental sources in their postings. These governmental sources included FEMA, DHS-ICE, the City of Houston, the City of Miami, the City of Dallas, among others. Furthermore, the content was being cited throughout the lifespan of our dataset, with no clear temporal patterns, or patterns relating to the interaction on tweets that contained URLs. The information from all of these sites was being transferred to Twitter to combat the immigration rumor in both of these natural disasters.

4.3.2 The domains cited

By identifying the domain names of each URL in the dataset, we find 177 and 68 platform agents (including Twitter) from the URLs in Hurricanes Harvey and Irma, respectively. The inner sourcing from Twitter was 22% and 18% in Hurricane Harvey and Hurricane Irma, respectively. Among all of the outside sourcing platforms, we found that Facebook takes less than 3% in both disaster cases and the majority of resources came from traditional Web sites such as news agencies. For instance, in both cases, information from "The Hill" was cited by almost 15% of the users whom included at least one link in their tweet, and this was the first most utilized news agent in both datasets. Even less information flow between Twitter and YouTube occurs in our dataset, suggesting less than 1% in the Hurricane Harvey data set and 0% in the Hurricane Irma dataset. Table 5 shows the most popular domains cited in our two datasets.

Table 5 Most frequently cited domains in tweets for Hurricane Harvey and Hurricane Irma

Hurricane Harvey		Hurricane Irma	
Source	%	Source	%
Twitter	21.88	Twitter	17.88
thehill	14.40	thehill	14.78
washingtonpost	9.79	fortune	11.88
chron	5.37	miamiherald	9.21
houstonpublicmedia	4.38	ice.gov	8.78
cnn	4.20	dhs.gov	8.46
theintercept	3.50	reuters	5.89
newsweek	2.93	amp.timeinc	5.35
facebook	2.14	dailycaller	3.48
abcnews.go	1.98	buzzfeed	3.10
snappytv	1.96	nbcmiami	2.25
ice.gov	1.89	orlandosentinel	1.93
others	25.58	others	7.01
Total	100	Total	100

Given the significant citation frequency that The Hill received in debunking the false rumor in both disasters, we take a closer look at the content that they posted and when it was posted. For Hurricane Harvey, The Hill posted four separate articles which debunked the false rumor. The first article, which was posted on August 25, 2017, cited a press release from Texas Governor Greg Abbott, where the Governor announced that immigration status “will not be an issue.” The next articles from The Hill, which were posted on August 29 and 30, 2017, cited information for the City of Houston and the City of Dallas, respectively. These articles spread the debunking information that was released by the local government authorities, and also cited information from the federal government regarding the false rumor. For Hurricane Harvey, the last post from The Hill was posted on August 31, 2017, and cited the Border Patrol in saying that authorities were only in the hurricane affected areas for rescue and safety.

The Hill released one article during Hurricane Irma, which had multiple URLs that directed to the same page. This article, which was released on September 6, 2017, cited information from the Department of Homeland Security which stated, “When it comes to rescuing people in the wake of Hurricane Irma, immigration status is not and will not be a factor.” The articles from thehill.com were cited on Twitter throughout the lifespan of the false rumors in both hurricanes to help spread valid content to the network.

5 Conclusions and future research directions

5.1 Concluding remarks

Through research and analysis, we have drawn and developed many insights into false rumor debunking features. First, we witnessed that the same false rumor lasted three times longer in Hurricane Harvey than in Hurricane Irma and also had over three times more tweets associated with it. This suggests that the online and social media exposure and debunking of this rumor in the case of Hurricane Harvey helped to contain the rumor spreading later in Hurricane Irma. Given that similar cases of misinformation often spread during disasters, as can be noted on FEMA’s rumor control pages, these results prove to be important. By debunking misinformation during a given disaster, the same misinformation may have a lesser impact in future disasters, implying that the debunking efforts by major agencies and other users are worthwhile.

When reviewing the rumor debunking efforts, it is observed that the postings from verified Twitter accounts received more retweets and likes than postings from unverified accounts, although only an average of 14% of all debunking posts came from verified accounts. In both Hurricane Harvey and Hurricane Irma, it was the GO accounts on Twitter who had the greatest interaction on their postings, helping to spread the correct information through Twitter’s network and combat the rumor. Out of all the verified accounts, GOs made up for 90% of the total retweets between both hurricanes. Since retweets further spread the posted information through Twitter’s network (Twitter <https://help.twitter.com/en/using-twitter/how-to-retweet>), it is clear that the postings from verified sources, and especially GO accounts, are critical to the diffusion of rumor correcting information during

natural disasters. Second to GO accounts, news agencies also play an important role in disseminating rumor debunking information and were responsible for 8% and 7% of the retweets that verified accounts received in Hurricane Harvey and Hurricane Irma, respectively. These results show the importance of rumor debunking information from verified accounts. The public clearly uses this credible information to further spread the debunking information, in order to offer a safer and more informed environment on Twitter. These results also imply that the efforts and resources spent by major agencies, such as GOs, are critical to the dissemination of valid information in plight situations.

Based on the URL citation frequency, we conclude that news sites, such as [cnn.com](#) and [thehill.com](#), and federal government sites, such as [ice.gov](#) and [dhs.gov](#) (third and fourth most cited URLs in Hurricane Irma), are the most used and sourced external platforms when it comes to sharing rumor correcting information. When posting rumor debunking articles on their Web sites, it was clear that news organizations often cite governmental press releases. We found that over 50% of users in both hurricanes used a URL in their tweet when posting information about the false rumor. We also conclude that cross-platform sourcing occurs more frequently between Twitter and traditional Web sites than between Twitter and other similar social network services, such as Facebook, YouTube, and Instagram. In both hurricanes, URLs were used most frequently in tweets to validate debunking messages (86% and 53% in Harvey and Irma, respectively). From this, we conclude that information from external sources is critical to Twitter users in their attempts to debunk false information on the network. In our investigations, we found that many users cite different URLs that direct traffic to the same Web page. After further analyzing this feature, we conclude that users most frequently cite news domains in their postings, especially when debunking false rumors. The attainability and accuracy of such information, along with the debunking messages from verified Twitter accounts, are critical factors to rapidly and efficiently ending the spread of false rumors and misinformation on social media during natural disasters.

These findings will be beneficial to government agencies, news agencies, and disaster managers across the USA, and around the world, as they offer insights into corrective action and real-world application. Primarily, it is essential that government agencies have a system in place to utilize their social media accounts during the case of extreme events, especially during times of misinformation circulation. Through this research, it is clear that Twitter users rely on government accounts in order to obtain information regarding evacuation and safety. It is critical to the public that information from these accounts be valid, easy to understand, and timely. Additionally, offering a credible source in these postings has been proven to play a vital role in the cross-platform information sourcing, and eventual delivery of corrected information to those affected.

Results of this research contribute needed knowledge to the literature on misinformation debunking during disasters, while bridging the research gap on cross-platform information sharing when rumors are spread during disasters. By posting rumor debunking articles during disasters, government and news agencies are offering critical information that will likely be disseminated throughout Twitter's network to contain the false rumors spread. Likewise, when government and news accounts post debunking messages directly to Twitter, their tweets are retweeted, liked, and cited by other users in order to spread the correct content.

5.2 Future research directions

These case studies and results, along with previous research, serve as a catalyst for continued investigations into rumor control efforts, rumor management systems, and the spread of misinformation during natural disasters at a large scale. As a result of the similarities in user locations in Fig. 2, future research should investigate the geographical patterns of user response to misinformation on Twitter during disasters. Such patterns in response may be due to population density, disaster vulnerability in specific regions (e.g., being located on a coast, being located on an earthquake prone fault line, etc.), relative locations and distances of the user in comparison with the recent/ongoing disaster, and also the general activity of Twitter users in regions which are active in responding to the recent/ongoing misinformation.

Additionally, future research in this domain can study why false rumors end at their respective times. One explanation for why the rumors ended at the specific times in this study may be related to the hurricane activity. For Hurricane Harvey and Hurricane Irma, the false rumors started before the hurricanes made landfall, as residents were seeking safety in preparation for the storms. Hurricane Harvey ended on September 2, 2017, and when the false rumor ended on September 10, most residents were not be seeking shelter anymore. This represents one logical explanation for why the false rumor may have ended at this time for Hurricane Harvey.

Further potential future research directions consist of: (1) creating a database of different false rumors spread during different natural disasters and analyzing these big data to draw new theories and offer new insights, (2) creating and/or better utilizing machine learning algorithms that can help researchers classify tweets and identify false rumor spreading, (3) understanding the economic costs associated with misinformation propagation to make sense of investments toward mitigation and preparedness, and (4) optimizing debunking strategies given different scenarios and rumor attributes. Collectively, these tasks will build knowledge on the features and impacts of rumors and misinformation management, and this knowledge will contribute to a safer online environment.

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Appendix 1: Search criteria used for tweet collection

See Table 6.

Table 6 Search criteria used to collect all tweets and retweets in both cases

Hurricane Harvey		Hurricane Irma	
Keyword(s)	Hashtag	Keyword(s)	Hashtag
Immigration	#HurricaneHarvey	Immigration	#HurricaneIrma
Immigration	#Harvey	Immigration	#Irma
Immigration, Harvey		Immigration, Irma	
Immigration status	#HurricaneHarvey	Immigration status	#HurricaneIrma
Immigration status	#HurricaneHarvey	Immigration status	#HurricaneIrma
Immigration status, Harvey		Immigration status, Irma	
Immigration enforcement	#HurricaneHarvey	Immigration enforcement	#HurricaneIrma
Immigration enforcement	#Harvey	Immigration enforcement	#Irma
Immigration enforcement, Harvey		Immigration enforcement, Irma	
Immigration check	#HurricaneHarvey	Immigration check	#HurricaneIrma
Immigration check	#Harvey	Immigration check	#Irma
Immigration check, Harvey		Immigration check, Irma	
Shelter	#HurricaneHarvey	Shelter	#HurricaneIrma
Shelter	#Harvey	Shelter	#Irma
Shelter, Harvey		Shelter, Irma	
Undocumented	#HurricaneHarvey	Undocumented	#HurricaneIrma
Undocumented	#Harvey	Undocumented	#Irma
Undocumented, Harvey		Undocumented, Irma	
Hurricane Harvey	#Undocumented	Hurricane Irma	#Undocumented
Harvey	#Undocumented	Irma	#Undocumented
Undocumented, Shelter, Harvey		Undocumented, Shelter, Irma	

Appendix 2: Data coding rubric

See Table 7.

Table 7 Coding rubric used to define the different categories

Category	Definition
False rumor debunking	A tweet which contains valid information regarding the false rumor, delivering correct information to Twitter's network
False rumor spreading	A tweet which contains false information regarding the false rumor, delivering misinformation to Twitter's network
False rumor questioning	A tweet which questions the veracity of the false rumor, inquiring on the truth or falsity of the rumored information
Other	A tweet which contains opinions, comments, feelings, or general dialogue on the false rumor topic, but <i>does not</i> contain any valid or false information regarding the false rumor
Not-related	A tweet which is not related to the false rumor case in any way; these tweets are removed from the dataset before analysis

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