Analyzing Social Media Data to Understand How Disaster-Affected Individuals Adapt to Disaster-Related Telecommunications Disruptions

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ABSTRACT

Information is a critical need during disasters such as hurricanes. Increasingly, people are relying upon cellular and internet-based technology to communicate that information—modalities that are acutely vulnerable to the disruptions to telecommunication infrastructure that are common during disasters. Focusing on Hurricane Maria (2017) and its long-term impacts on Puerto Rico, this research examines how people affected by severe and sustained disruptions to telecommunications services *adapt* to those disruptions. Leveraging social media trace data as a window into the real-time activities of people who were actively adapting, we use a primarily qualitative approach to identify and characterize how people changed their telecommunications practices and routines—and especially how they changed their locations—to access Wi-Fi and cellular service in the weeks and months after the hurricane. These findings have implications for researchers seeking to better understand human responses to disasters and responders seeking to identify strategies to support affected populations.

Keywords

Telecommunications, adaptations, social media, cellular phone service, Wi-Fi access

INTRODUCTION

During natural disasters and other crisis events, information is a critical need. People in disaster-affected areas need information to understand the unfolding event and to make decisions about how to respond. Increasingly, people are relying upon cellular and internet-based technology to fulfill this need. For example, disaster-affected people use mobile phones to share their status with friends and family (Sutton et al., 2008) and connect to social media platforms to exchange information about warnings, impacts, and response activities (e.g. Sutton et al., 2008; Vieweg et al., 2010; Bird et al., 2012; Simon et al., 2015). However, the modalities that people increasingly rely upon to exchange information during crisis events (using cellular, internet, and Wi-Fi technology) are acutely vulnerable—during the times when people need information most—to disruptions to the electrical grid and/or other telecommunication infrastructure (e.g. Simon et al., 2015; Palen and Liu, 2007).

This research looks at how people in Puerto Rico adapted to disruptions to cellular service and Internet access due to Hurricane Maria, which struck the island in September 2017. Due to the strength of the storm and existing weaknesses in the infrastructure on the island, Hurricane Maria had severe and sustained impacts on the underlying electrical grid and on telecommunication services that relied upon this grid. About 79% of the people on the island were living without power 30 days after the event (FEMA, 2018), and around 50% were still without power three months later (Robles and Bidgood, 2017). Contemporaneous media reports described how people in Puerto Rico adapted to these impacts—for example, by traveling to find better cellular service (Becker, 2017) or changing cellular phone providers (Brown and Respaut, 2017). Our work seeks to systematically study the adaptations used by everyday people to communicate in the aftermath of the storm.

Though previous research has examined how people adapt to disaster events generally (e.g. Wamsler and Brink, 2014; Heidenstrøm and Kvarnlöf, 2017) and to disruptions in telecommunication infrastructure more specifically (e.g. Ghanem, et al., 2016; Moreno and Shaw, 2019), those studies have relied primarily on after-the-fact interviews and surveys. In this research, we use an interpretative, primarily qualitative approach to analyze social media trace data from Twitter to better understand how disaster-affected people adapted to disruptions to cellular service and/or Wi-Fi access, both in the initial impact period of the event and over time. Specifically, we address the following questions:

- RQ1: How do people adapt to disruptions to telecommunications services (specifically cellular service and Wi-Fi access) during a significant, long-term disaster event?
- RQ2: How do social media users (specifically Twitter users) talk about those adaptations?

RQ1 helps to advance our understanding of societal resilience to disaster events, with potential implications for disaster-affected people and responders. RQ2 addresses persistent research questions about social media as a *signal*—contributing to an enhanced understanding of human behavior that may be readily available (for data mining in real-time or after the fact) on social media platforms and the kinds of signals that may be obscured (i.e. the adaptations that may be harder to see through digital trace data).

BACKGROUND AND RELATED LITERATURE

Adaptations to Disaster Events

Researchers have argued that to understand disaster response, we should look beyond the impacts of the events to include the ways that people change their behavior to adapt to new and changing conditions (e.g. Moreno and Shaw, 2019; Heidenstrøm and Kvarnlöf, 2017), both in the immediate aftermath and over time (Wamsler and Brink, 2014). This expanded perspective encourages us to—both accurately and productively—view disaster victims as agents in their own recovery (Heidenstrøm and Kvarnlöf, 2017; Wamsler and Brink, 2014). Including adaptations may also lead to more robust theories and models of disaster response and recovery and help us design infrastructure that better accounts for and supports adaptations and, ultimately, recovery.

The disaster sociology and crisis informatics literature contain several empirical accounts of how people adapt to power outages and other disruptions to the electrical grid (e.g. Moreno and Shaw, 2019; Heidenstrøm and Kvarnlöf, 2017; Ghanem et al., 2016; Bolin, 1994). Moreno and Shaw (2019) investigate how victims of the 2010 earthquake and tsunami in Chile cooked without electricity by using gas and wood stoves and organizing community kitchens. Though research from this perspective has noted how people charge their phones and other devices during electrical outages (e.g. Ghanem et al., 2016), it remains understudied how people adapt to loss or reduction of telecommunication abilities due to reliance on new modalities like cellular phones and social media.

Examining Organizational Responses to Impacts on Telecommunications Infrastructure

Researchers have described how organizations adapt to telecommunication disruptions. For example, Leitl (2006) describes efforts by organizations to support telecommunications after Hurricane Katrina—including businesses offering free Wi-Fi to affected customers. Poblet el al. (2014) relate how, in the aftermath of Hurricane Sandy, non-profits provided free public Wi-Fi connectivity to disaster-affected people in Red Hook, NY. Though this line of research provides a growing understanding of how organizations (including emergent organizations of volunteers) help to address impacts on telecommunication infrastructure, there remain open questions about how individuals adapt to these impacts—including how they utilize these changing resources. Understanding how people change their behavior to meet their dynamic needs could help to better inform these responses.

Social Media as a Sensor for Impacts and Adaptations

Existing research on adaptations have typically relied upon interviews and surveys, often conducted long after the event, to gain insight into how people responded to the event (e.g. Heidenstrøm and Kvarnlöf, 2017; Ghanem et al., 2016). Though these accounts can provide rich detail about a person or group's behavior, they are also limited by factors such as human memory and research-participant dynamics. To complement these perspectives, our work turns to the social media record to examine adaptations through data collected contemporaneously.

CoRe Paper – Social Media for Disaster Response and Resilience
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Amanda Lee Hughes, Fiona McNeill and Christopher Zobel, eds.

The ISCRAM community and the crisis informatics field have developed a body of research utilizing social media traces as source data for understanding human behavior during and after disaster events (e.g. Hughes and Palen, 2009; Vieweg et al., 2010; Wilensky, 2014). This research has tended to focus on impacts—particularly immediate impacts—of disaster events. A significant subsection has looked at adaptations in the form of organizational responses (e.g. Plotnick and Hiltz, 2016; Maitland and Peha, 2018) and the work of volunteers, including online volunteers (e.g. Starbird and Palen, 2011; Hughes and Tapia, 2015). Extending this body of research, our study uses social media data to look at how affected individuals adapt to long-term disruptions of communication infrastructure after a major disaster event.

Event Background

This research focuses on impacts on Puerto Rico from Hurricane Maria—and to a lesser, but still significant extent, Hurricane Irma—which hit the island in September 2017. Hurricane Irma, a Category 5 storm, passed slightly north of Puerto Rico on September 6, causing flooding and significant damage to both water and electrical infrastructure (Rivera and Alvarez, 2017). Hurricane Maria hit the island directly 14 days later (on September 20, 2017) as a Category 4 storm and had compounding impacts on an inherently vulnerable and now further weakened infrastructure (Kwasinski et al., 2019).

Impacts from the storms were catastrophic, multi-dimensional, and long-lasting. Thousands of lives were lost, with estimates varying between 2,975 (a number provided by the government of Puerto Rico: Sanchez, 2018) and 4,645 (an estimate from a study from the Harvard T.H. Chan School of Public Health: Kishore et al., 2018). There were impacts on the infrastructure that provides water—80% of Puerto Ricans lost access to water in the initial impact period, and 31% still lacked access after 30 days (FEMA, 2018). As recently as September 2018, thousands of Puerto Ricans were still living in substandard housing conditions as a result of the hurricanes (Robles and Patel, 2018).

In particular, the electrical infrastructure was severely damaged (Kwasinski et al., 2019). In the wake of Hurricane Irma, about two-thirds of the population of Puerto Rico was left without electricity (Scott, 2018). After Hurricane Maria, the entire island suffered a power outage. 79% of customers were still without power 30 days later (FEMA, 2018) and although $2 billion had been allotted to fix the grid (FEMA, 2019), a large number of Puerto Ricans continued to live without power ten months after Hurricane Maria (Laughland, 2018). Because of their inherent dependencies on the power grid, this caused both acute and long-lasting disruptions to telecommunications services. This study looks at adaptations to those disruptions.

METHODS

Data Collections

To answer our research questions about the short and long-term adaptations to disaster impacts, we generated a longitudinal dataset of tweets—initiated in the days before the hurricane hit Puerto Rico and extending for nine months following the event. This research relies on Twitter data collected, through their public APIs, in two distinct phases. The first phase used a keyword-based search (via the Twitter Streaming API), capturing in real-time tweets that contained any of these terms (`maria`, `puertorico`, `puerto rico`). This collection ran from August 24 to November 6 (2017). The resulting *Hurricane Maria Keyword Dataset* contains 30,269,284 tweets.

In the second phase, we generated "contextual streams" (Starbird and Palen, 2011) for accounts in the *Hurricane Maria Keyword Dataset* that we determined were likely "local" to the event. We determined likely locality in two ways. First, we identified 40,906 accounts that had place names (e.g. "Puerto Rico" or "San Juan") in their profile description or profile location. Next, we identified 2,882 accounts that sent a tweet with embedded geolocation coordinates showing it was sent from within Puerto Rico during the initial collection period. 2,303 accounts appeared in both subsets, so combining the two resulted in 41,485 local accounts. For each of these accounts, we collected (using the Twitter REST API) all of their public tweets that were still available at the time of our collection. The Twitter REST API limits this request to the most recent 3,200 tweets sent for each account. To capture a comprehensive set of tweets, especially for high-volume tweeters, we conducted this contextual stream collection step three times: first in January 2018 (to capture initial impacts) and then finally in June 2018 (to see longer-term impacts and adaptations). We stopped our collection in June 2018 after the number of relevant tweets fell to very small rates. The resulting *Hurricane Maria Locals' Contextual Streams Dataset* contains 55,136,043 tweets.

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Proceedings of the 17th ISCRAM Conference – Blacksburg, VA, USA May 2020
Amanda Lee Hughes, Fiona McNeill and Christopher Zobel, eds.

Methodological Approach

From within this vast dataset we worked to identify a diverse and low-noise sample of tweets that contain information about adaptations related to the effects of the hurricane on telecommunications infrastructure. We used an iterative method, combining a top-down, heuristics-based approach for identifying an initial sample with a bottom-up, grounded approach for expanding and refining that sample. First, using a pre-selected set of queries, we searched the dataset for all tweets with specific words or combinations of words—i.e. "buscar" and "señal" ("search" and "signal"). Next, we evaluated the utility of each query, measuring the ratio of relevant to irrelevant results (within a random sample) and removing queries with low signal-to-noise ratios. At the same time, using a grounded approach based on the tweets that we were surfacing through each query, we identified additional queries and added them to our list for evaluation. Our final set contains 30 queries (see Appendix A) which collectively generate a diverse and low-noise sample of 6,482 tweets.

The first author manually coded and worked with the second author to surface meaningful codes and themes. From this coding, we determined 1,603 tweets to be both relevant to the disaster and include impacts from and/or adaptations to telecommunications disruptions: 1,010 related to cellular service, 539 related to Wi-Fi, and the remaining 54 related to both cellular service and Wi-Fi. This curated sample is not a complete set of tweets related to these kinds of impacts, but it is low-noise and reflects many of the most visible ways that users were talking about them, allowing qualitative analyses into how users talk about telecommunications disruptions via Twitter.

Identifying Impacts and Adaptations

Through the manual coding process, we developed a grounded coding scheme to classify the different kinds of adaptations that appeared in these 1,603 tweets. A round of open coding surfaced potential classifications for the tweets, which we refined by coding a sample of our 1,603 tweets with these categories. Categories were iteratively updated: kept the same, eliminated if they were redundant, or added if a salient theme was not captured in the initial coding scheme. The primary contribution of this paper, presented in the findings, is a description of this coding scheme—i.e. of the kinds of adaptations that are visible in the Twitter record.

After finalizing the coding scheme, we manually coded each of the 1,603 tweets. We present some basic quantitative representations to give a sense of the relative frequency of the different adaptations. Although helpful to give an overview of the adaptations visible in our sample, the inherent limitations in our sampling and coding method mean we are careful not to make strong quantitative claims.

Note on Data and Anonymization

To elucidate what the adaptations are and how they appear in the social media record, we feature example tweets in our Findings. These tweets have been translated from Spanish by the first author, a fluent Spanish-speaker. To preserve the privacy of the people who shared these tweets, we anonymized usernames and omitted the original Spanish-language tweets.
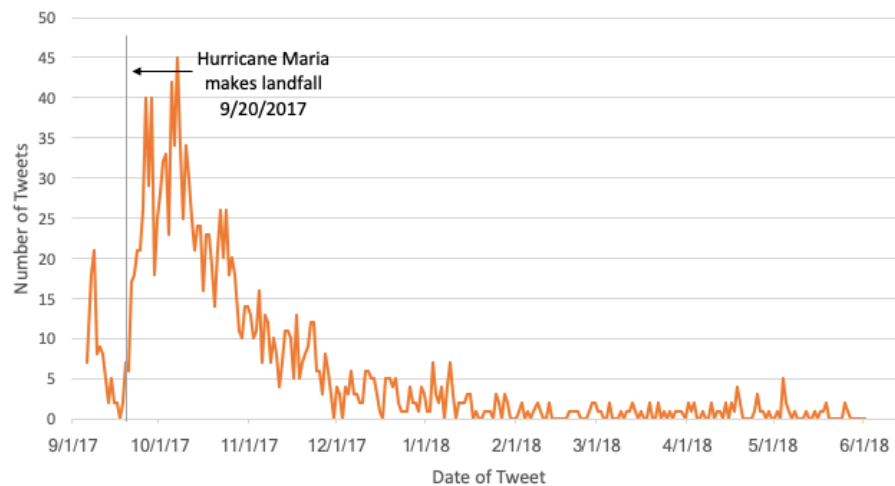
FINDINGS

Though we began this research with an open-ended goal to look for adaptations to all types of disruptions (prior to the development of the research questions presented here), preliminary analysis suggested that adaptations related to finding cellular service and/or Internet access were among the most salient in the Twitter data. This is perhaps due to the fact that people were often actively making those adaptations while they accessed the Twitter platform.

Close examination of the full contextual streams from a sample of accounts suggests that the Twitter users whose tweets we examined were mostly teenagers or young adults. This is likely due to the higher prevalence of youth using social media, especially during natural disasters (Spielhofer et al., 2019). Many of them appeared to be university students, for example mentioning their university in their profile description.

Aligning with media reports, our data show adaptations related to accessing telecommunications services during disruptions to the electrical grid in Puerto Rico continued for months following Hurricane Maria.

CoRe Paper – Social Media for Disaster Response and Resilience
Proceedings of the 17th ISCRAM Conference – Blacksburg, VA, USA May 2020
Amanda Lee Hughes, Fiona McNeill and Christopher Zobel, eds.

Figure 1[1] shows the number of tweets per day from affected locals that we identified as containing an impact or adaptation related to accessing cellular service or Wi-Fi. The graph illustrates a steady rise in tweets about impacts or adaptations during the first week after the event, building into a somewhat varied, but sustained volume over the next two weeks, followed by a long but slow decline of tweets through June 2018.

Figure 1. Daily tweets from disaster-affected locals referencing a telecommunication disruption or adaptation

Our analysis provided insight into diverse and creative adaptations to Wi-Fi and cellular service disruptions. In the findings below, we describe some of the most salient adaptations, grouped by similarities in the underlying behavior, rather than the specific telecommunication service. The findings are organized into four sections: adaptations where the user changed their location to gain access to cellular service; adaptations where the user changed their location to gain Wi-Fi; adaptations where the users leveraged Twitter to exchange information about how to adapt; and other interesting or potential impactful adaptations.

Changing Location to Get Cellular Service

The most common adaptation for gaining access to telecommunications was "changing location" to either find cellular service or use someone or somewhere else's' Wi-Fi which accounts for 654 (41%) of our 1,603 adaptation-related tweets. This adaptation category captures cases where a user changed their location to gain or improve access to a service, whether through an action as simple as going to another room in their house, or as involved as traveling to another city. Twitter users described changing their location both to get better cellular service and to access Wi-Fi. Though the underlying behavior (changing location) may have been similar for each, there are nuanced differences, detailed below.

Finding Cellular Service: Moving within the house

One seemingly simple adaptation to reduced cellular service was for a person to move within their own house or current building, for example going to another room, floor, or the roof. 122 (7.6%) of our 1,603 tweets contained a reference to a person going onto the roof of a building to get better cellular service:

```
Everyone is on their roof to get service. [2017-09-28]

Ok so my neighbor put a chair on his roof, sat down chilling and looking for
service. ((: [2017-10-16]

It is incredible that I have to go onto my roof to be able to do my homework
because I don't have service in my house. 😀😀😀 [2018-01-09]
```

The first two tweets, sent in the early impact phases of the event (one week and about a month after the hurricane), document how others—not just the tweet author—are adapting, suggesting this was a common or

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[1] The early spike in Figure 1 (around September 7, 2017) is due to adaptations after Hurricane Irma.

CoRe Paper – Social Media for Disaster Response and Resilience
Proceedings of the 17th ISCRAM Conference – Blacksburg, VA, USA May 2020
Amanda Lee Hughes, Fiona McNeill and Christopher Zobel, eds.

widespread adaptation. The third tweet, sent months later, indicates that this was a persistent adaptation that for some became part of routine life, though the "incredible" comment here suggests that this was a relatively new and perhaps unwelcome routine.

Finding Cellular Service: Traveling locally

The Twitter record also provided evidence of people traveling outside the home to nearby areas to get service.

```
I will walk to the hill, climb a tree and there I will find service and write to
you. ❣ If not, it will kill me.  [2017-10-21]
```

```
Since yesterday without service from @ClaroTodo. I'm doing to do the same… go 7
minutes from my house to find service. [2018-01-14]
```

Tweets from this category include mentions of different types of transportation used—for example cars, buses, bikes, and walking. Sometimes they include the distance traveled or time it took, or reflect both humor and frustration at the situation. In these cases, it can be difficult to distinguish between the actual adaptation and the abstracted or exaggerated one—though it is usually clear that the tweet author was affected by the disruption and adapting in some way similar to their "joke."

Finding Cellular Service: Going to another city or town

Another category of tweets revealed that disaster-affected people also traveled longer distances to get cellular service:

```
I had to go to Caguas to get service. 😂😂[2017-09-28]
```

```
We are good. Today we are pilgriming to San Patricio to find service.  [2017-10-07]
```

```
It seems like it was yesterday that I had to travel to 5 towns to be able to get
service and communicate. [2017-12-26]
```

The first tweet above records the tweeter making a trip to a specific city—in this case Caguas, in search of cellular service. This format was common for tweets about this kind of adaptation. The authors rarely stated how far they traveled, but the distance was perhaps implied by the stated destination.

In the third tweet, the user recalls a time when they did not know exactly where to get cellular service and had to devote time to searching for service, rather than traveling directly to a point where they knew there would be service. We saw several tweets with this kind of adaptation, which often contained expressions of frustration, suggesting that disaster-affected people who are trying to adapt to impacts to cellular service would benefit from knowing a specific location where they can access it, so they can save time (and energy) by limiting their physical searches.

Figure 2 shows the number of tweets we classified as "changing location" to access cellular service across the three categories. We identified more tweets documenting people traveling within their home or going to another city and fewer related to "traveling locally", although it is likely that tweets from the latter category were harder to find due to ambiguity in how people talk about that kind of destination—i.e. they often use place names which make it difficult to distinguish between local travel and more distant travel without more contextual knowledge about where individual users reside.
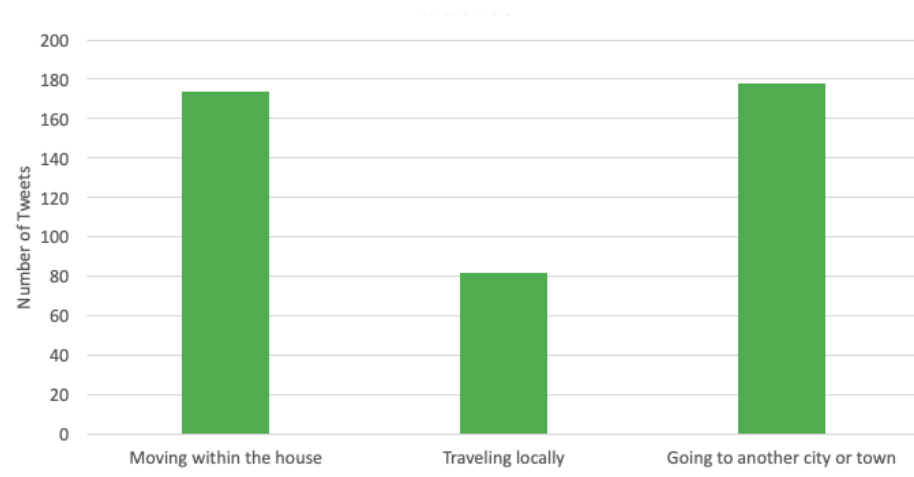
CoRe Paper – Social Media for Disaster Response and Resilience
Proceedings of the 17th ISCRAM Conference – Blacksburg, VA, USA May 2020
Amanda Lee Hughes, Fiona McNeill and Christopher Zobel, eds.

Figure 2. Where users went to access cellular service

Changing Location to Get Wi-Fi Access

Our *Hurricane Maria Locals' Contextual Streams Dataset* contains evidence of disaster-affected people using a wide variety of options to access Wi-Fi. Through our analysis, we identified the five most popular "places" where locals went to access Wi-Fi: a business, friend or family member, neighbor, library, and school. Figure 3 provides an overview of the relative volume of each type of tweet. We did not include tweets where the user seemed to have accessed someone else's Wi-Fi, but it was ambiguous from where (e.g., "`Stealing Wi-Fi is my favorite pastime`").
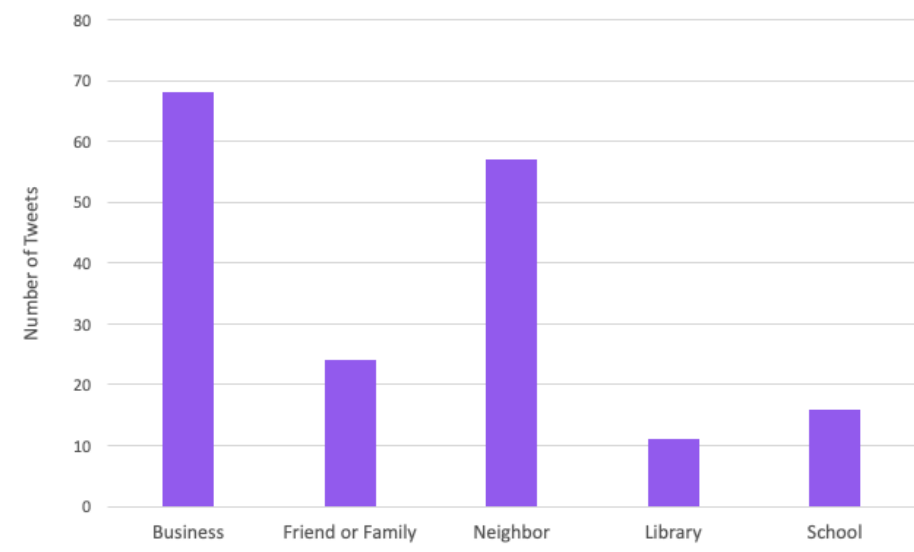

Figure 3. Places users went to use Wi-Fi

The most common way to access Wi-Fi in our dataset was by going to a business, although this can be partially attributed to bias in our sample, as a few of our search terms had specific business names (see Appendix A). During our initial heuristics-based querying, we noted and leveraged some linguistic cues that helped us further identify tweets related to Wi-Fi adaptations. A common way to explain "using" someone or somewhere else's Wi-Fi was "`robar wifi`" or "`chapiar wifi`" which literally translate to "stealing Wi-Fi". In the following paragraphs we describe the places users went to use Wi-Fi.

CoRe Paper – Social Media for Disaster Response and Resilience
Proceedings of the 17th ISCRAM Conference – Blacksburg, VA, USA May 2020
Amanda Lee Hughes, Fiona McNeill and Christopher Zobel, eds.

Accessing Wi-Fi: Businesses

People traveled to diverse businesses for Wi-Fi, including fast-food restaurants, local businesses, and hotel lobbies. The tweet record shows many people oftentimes used the establishment's Wi-Fi from the parking lot—and contains some tweet authors' reflections on this "theft."

```
#robbing Wi-Fi in front of Walgreens [2017-10-07]

At Wendy's, chilling in the car stealing Wi-Fi. [2017-11-09]

Man, I feel like a vile thief having to park in front of Wendy's to steal a little
Wi-Fi. [2017-12-12]
```

Though it is unclear if these adaptations are due to impacts from the hurricane (or whether the person just didn't have their own Wi-Fi), they do suggest a value for businesses to open up their Wi-Fi networks during times when telecommunications infrastructure is impacted—and to communicate that access is not contingent on purchasing goods or services.

Accessing Wi-Fi: Friend or family member's house

Another place people went for Wi-Fi was a friend or neighbor's house. For example:

```
My mom lives like a big shot, her power never went out, I came to steal Wi-Fi and
hot water. 😂💡🙌[2017-09-07]

In my best friend's house, there is electricity & Wi-Fi. #blessed [2017-10-14]
```

Similar to the case of accessing Wi-Fi from businesses, it was not always clear that this was an adaptation to impacts from one of the hurricanes, but often (e.g. first tweet above) it was. That tweet, sent during the impacts from Hurricane Irma, clearly indicates that the tweeter had been affected by the loss of electricity (no hot water), suggesting that this was indeed an adaptation to the hurricane. The second tweet is similarly clear about getting Wi-Fi at a friend's house due to disruption to electricity (that the person implies they are experiencing elsewhere).

Accessing Wi-Fi: Neighbors

Other tweets indicated people borrowing Wi-Fi from neighbors, which they went about in several different ways:

```
Thank you for the neighbors that shared their Wi-Fi password! Only way to
communicate in #Caguas #MariaPR [2017-09-22]

I love to go to my neighbor's house to use their internet. [2017-10-07]

I have to give thanks to my neighbor who always has Wi-Fi and always has it without
a password. #fastpassvipforheaven [2018-02-27]
```

One strategy was "stealing" Wi-Fi from a nearby neighbor who didn't use password protection (third tweet above). But the most common was simply to ask a neighbor for their Wi-Fi password and either go to the neighbor's property or use a weaker signal from the tweeter's own property. The first two tweets above show that behavior. Though the second and third may not be adaptations to the hurricane impacts, the first tweet certainly is, as the user thanks the neighbor for proactively sharing their password and helping others in the community communicate. The inclusion of a hashtag (at the end of the first tweet) also helps to reduce ambiguity about the impetus for that behavior.

Accessing Wi-Fi: Libraries

Libraries are an important resource for many disaster victims, providing a place with free Wi-Fi and computers (Hamilton, 2011). Our tweet record revealed people going to the library to use Wi-Fi, but this adaptation seemed limited in frequency. Through we searched specifically for "biblioteca" + "wifi" ("library" + "wifi") when creating our sample, we only identified 11 tweets with this adaptation. We discovered tweets indicating a user tried to go to the library to access Wi-Fi but was unable to because the library either didn't have Wi-Fi or it didn't work:

CoRe Paper – Social Media for Disaster Response and Resilience
Proceedings of the 17th ISCRAM Conference – Blacksburg, VA, USA May 2020
Amanda Lee Hughes, Fiona McNeill and Christopher Zobel, eds.

```
Only the library has energy but the plugs don't work and there isn't internet.
[2017-10-10]
```

Although the signal suggests people were turning to libraries to meet communication needs, there is also evidence that libraries were suffering from some of the same disruptions that members of the public were.

Leveraging Twitter to Exchange Information about How to Adapt

Aligned with accounts from previous events of social media users turning to those platforms to intentionally share information about adaptations—for example, users helping each other find gas during the impacts of Hurricane Sandy (Medley, 2012)—our *Hurricane Maria Locals' Contextual Streams Dataset* shows Twitter users leveraging the platform to find or share information related to adaptations around telecommunications impacts. We partitioned this into two categories: (1) users who exchanged information related to how to adapt to telecommunications impacts with their social media peers, or (2) users who reached out to Internet or cellular network providers for information regarding service.

Asking where to find cellular service or Wi-Fi

Many tweets showed users asking others on Twitter for information about where they could access either cellular service or Wi-Fi. Sometimes this happened directly (e.g. first tweet below), with a user mentioning or replying directly to another Twitter user with a question:

```
@anonymized In Caguas there is service by Bairoa. [2017-10-04]

If you are looking for a spot with good service, come to the Caguas plaza. [2017-
10-20]

Where can I get Wi-Fi in Arecibo?? [2017-11-20]
```

Other times (e.g. third tweet above), the questions were directed to a more general audience of the accounts' followers or perhaps people searching for specific keywords. In multiple tweets (e.g. second one above) people who had found cellular service let others know where they could find it as well. These activities show how disaster-affected people help themselves and others cope with disruptions from crisis events by utilizing social media to exchange local knowledge and emerging expertise about how best to adapt.

Reaching out to a cellular service provider

Prior work found people using social media to ask for help from emergency services (Spielhofer et al., 2019), and we found evidence that users also use Twitter to reach out to their Internet and cellular network providers after a disaster:

```
@LibertyPR good morning. Without internet service on 45 SE Urb Division in San
Juan. 😮😢😭[2017-09-14]

@tmobilepr I wanted to know in what area you have restored service… I'm from the
San Juan area. [2017-10-07]

@clarotodo you are charging me as if my antennas were fixed in 2 days … I am
juggling to try to find service… [2017-11-21]
```

The tweet record shows several variations of this, including asking when services would be restored, making the provider aware of a service outage, and asking where they could go to for better service. Many of the tweets with this type of information-exchanging adaptation contained expressions of frustration. Several users complained to their providers that they were being charged for a service that had not been fixed.

Other Adaptations Provide Insight into Dynamic Demands on Infrastructure during Crisis

There was also evidence of several other adaptations that were unexpected or otherwise notable but do not fit into the categories described above. Despite a low signal in our dataset, they may reflect more widespread patterns or represent novel or potentially problematic adaptations.

CoRe Paper – Social Media for Disaster Response and Resilience
Proceedings of the 17th ISCRAM Conference – Blacksburg, VA, USA May 2020
Amanda Lee Hughes, Fiona McNeill and Christopher Zobel, eds.

Changing cellular service provider

News articles about the aftermath of the event described how some Puerto Ricans switched mobile phone networks after Maria based on seeing which companies were quicker to restore service (e.g. Brown and Respaut, 2017). Aligned with those journalists' accounts, we identified some tweets (17) in our dataset in which users talk about changing providers:

```
On my way to Claro to make a contract for 10 years. #FirstForService [2017-09-26]

@clarotodo I have to change providers, Liberty doesn't have a date for when they
are doing to repair all the damage in my area. [2017-11-21]

I only have service in San Juan. They told me that T-Mobile and AT&T have it
everywhere. Is that true? I am going to leave Claro. [2017-11-07]
```

In some examples, it is difficult to determine the extent to which this adaptation was simply an action that users considered taking (perhaps just an expression of frustration), or if they ended up following through and changing their provider. The first tweet above mentions switching to Claro, while the third mentions leaving Claro, which suggests that the providers residents switch to or from may depend on the area in which they live and that there is a possibility that a high number of users may switch to a particular provider that has been faster to restore services in their area.

Stopping on roads and highways to access cellular service

The tweet record includes a few references to people stopping on roads and highways to access cellular service. This category was small (in terms of number of tweets mentioning it), but remarkable. The tweets below suggest that this was at least somewhat of a common practice among people who experienced a loss of cellular service:

```
You and me stopping in the road to look for cell phone service think about it.
[2017-10-04]

People should stop parking in the way to find service, that is so September. [2017-
11-17]
```

This implies an understanding that cellular service is more accessible on highways and roads but also demonstrates a willingness to partake in potentially dangerous and disruptive activities to gain access to telecommunications. The second tweet above, which states that parking on roads for service is "so September" (2 months ago), suggests that there was at least some recognition of the negative impacts of this adaptation.

Turning "buscar señal" (looking for service) into a game or hangout activity

Underscoring the pervasiveness and long-term impacts of these disruptions to telecommunications services, several users began to compare looking for service to a game or common pastime:

```
Now hanging out with friends is to go find service. 😂[2017-10-09]

Come over baby I'll take you to go look for phone service. [2017-10-17]

What a slow day. Someone come with me to look for Wi-Fi. [2017-11-05]
```

Although in many cases (like the first tweet above), this seems to be a humorous way to cope with long term service disruptions, it is also a reflection of a legitimate action taken by many users who were impacted. Several users in our sample turned to Twitter to recruit their friends/followers to go out with them to help them find service (third tweet above). This shows how disaster-affected people made changes to the routines within their social lives as part of their adaptive strategies—so that they could hang out with their friends and search for cellular service at the same time. This category of tweeted adaptations is particularly interesting because it reveals how disaster-affected people built a culture of resiliency, both through their humor and through the willingness to create new social norms and routines to accommodate their adaptations.

DISCUSSION AND CONCLUSION

Our findings provide a window into the diverse ways that people in Puerto Rico who were affected by Hurricane Maria adapted to long-term impacts on their ability to communicate. While previous work has examined the

CoRe Paper – Social Media for Disaster Response and Resilience
Proceedings of the 17th ISCRAM Conference – Blacksburg, VA, USA May 2020
Amanda Lee Hughes, Fiona McNeill and Christopher Zobel, eds.

responses of public entities and non-profits to facilitating access to telecommunications-related services in the wake of disaster events (e.g. Maitland and Peha, 2018), our work highlights the individual responses that disaster-affected people adopted—often relying upon themselves, their family, and their neighbors to meet their needs.

The most common adaptation was traveling somewhere to access telecommunications. We demonstrate how people changed their location in various ways—heading to their roofs to make phone calls or to the local Burger King for Wi-Fi access. We show how people turned to social media platforms to share information about adaptations with their peers, and to complain to their service providers about persistent impacts. Furthermore, we also highlight other salient adaptations that illustrate altered patterns of use of underlying infrastructure (including other kinds of infrastructure, like transportation) that in some cases represented long-term changes in how people organized their lives. We discuss implications for both researchers and emergency response planners in the following sub-sections.

Long-term Changes and New Routines

It is important to note that many of the adaptation tweets we identified are from long after Maria made landfall—mostly October through mid-December. People continued to "adapt" to telecommunications impacts for several weeks and even months after the hurricane, indicating that these tweeters have adopted (and perhaps evolved) long term adaptations into their everyday routines as they slowly begin to rebuild other parts of their lives. This is especially noticeable through how "buscar señal" turned into a hangout activity, demonstrating a reorganization of social routines to accommodate the time spent searching for cellular service. These adaptations are indicative of a kind of individual and community-level resiliency, as impacted people continue, despite notable frustration and exhaustion, to go through great efforts to maintain telecommunication abilities. Aligned with the framework presented by Wamsler and Brink (2014), this work shows that in the case of Hurricane Maria, residents in Puerto Rico had to move beyond short-term "coping" and make long term changes in their lives.

Understanding Adaptations Can Help Communities Become More Resilient

Our work extends from an argument that understanding individual and collective adaptations can help formal response efforts better plan for, support, and accommodate those adaptations. This research contributes to improved understandings of how infrastructure will be used differently during the aftermath of disaster events—suggesting changing stresses to both telecommunications and transportation infrastructure as people "move" both figuratively and literally away from an impacted service or area to a healthier part of the infrastructure. Our findings repeatedly show people traveling to access cellular service, which we can see—through tweets complaining about people stopping in the middle of the road to use their cellular phones—putting new pressure on transportation infrastructure. For example, we have several tweets, like one below, where users complain about traffic around larger cities, and theorize that the search for cellular service post-Maria has worsened traffic jams:

```
Please fix the service in the Caguas area so that people don't have to come to
Bairoa to look for it. The traffic is out of control. [2017-10-31]
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This is an example of where individual adaptations can compound and become detrimental at a larger scale—a phenomenon discussed by Wamsler and Brink (2018). The tweet record also shows people changing cellular service providers to get better service, as some companies were able to repair their equipment more quickly. These signals, if provided in real-time, could help service providers and responders adapt to the adaptations, so to speak. This is an idea we come back to at the end of this section.

This work also surfaces opportunities for formal response agencies to better communicate with the public in ways that help people recognize adaptive strategies that might be available to them and ways that they can help other impacted people adapt—e.g. by opening up their Wi-Fi network after a disaster to help their neighbors.

Leveraging Social Media as a Tool to Inform Others

Echoing observations from the field of crisis informatics, this research also reveals how social media was leveraged by affected citizens to share valuable information with each other and with "official" responders—in this case their cellular service providers. After Hurricane Sandy, Twitter users self-organized to help others find available gas, in some cases adopting specialized hashtags to exchange that information (Medley, 2012). After Hurricane Maria, we can see similar behavior among disaster-affected people, posting about where they have

CoRe Paper – Social Media for Disaster Response and Resilience
Proceedings of the 17th ISCRAM Conference – Blacksburg, VA, USA May 2020
Amanda Lee Hughes, Fiona McNeill and Christopher Zobel, eds.

managed to find cellular service or asking others where the best cellular service is near their current location. These ad hoc responses demonstrate the utility of social media platforms for facilitating real-time adaptations and collaborations for people trying to meet their own needs.

Twitter as a Signal of Adaptations to Telecommunications Impacts

One aim of our broader research project is to assess the utility of social media as a signal for adaptations to impacts from disaster events. This study provides some affirmative evidence of this proposition. Our findings suggest that social media, and specifically Twitter, are more useful for understanding adaptations related to disruptions of telecommunications than for other types of disruptions—for example, figuring out how to launder clothes during a water disruption. Our findings also indicate that people continued to talk about adaptations for months after the hurricanes hit, suggesting that the social media record could be used to understand how people continue to adapt over time. Some of the tweets provided evidence that people were growing frustrated, after several weeks, with traveling to find service and were thinking about other types of changes such as switching providers. Though our work did not systematically or quantitatively measure adaptations over time, there is potential for future work to make contributions in this way.

However, there remain difficult problems to solve. After approaching this data from several different directions, we eventually derived a heuristics-based approach to identify a relatively low-noise sample of tweets related to adaptations (that we could use for qualitative research). This required considerable effort—computationally-assisted, but manual work—to identify a relatively small sample of 1,603 adaptation-related tweets. There are likely many thousands more tweets related to telecommunications adaptations that we missed.

One cause of these missed tweets is ambiguity, a problem that we struggled with throughout the analysis, especially in our initial attempts to identify adaptations. People often talked about their adaptations in vague or implicit ways that leveraged other context that might not be visible in a single tweet. One way forward would be to use other tweets from a user's contextual stream to provide context for identifying an adaptation, a technique we plan to explore in future work.

We also encountered ambiguity later in our process—in our attempts to interpret adaptation-related tweets and classify them according to our coding scheme. At times, it was difficult to know if a behavior (like "stealing" Wi-Fi) was an adaptation to the effects of the disaster or just a regular routine for a young person who did not have Wi-Fi service in the home. As another example, in an early round of analysis, we attempted to code all tweets that indicated a changed location in search of cell service or Wi-Fi along a scale of distance traveled. However, it soon became clear that the way users talked about changing their location for Wi-Fi access and the way they talked about changing their location for cellular service were quite different. These differences are due, in part, to the nature of these two telecommunications modalities and the kinds of "places" one might go to access them. In particular, tweets with evidence that users changed their location to access Wi-Fi were often more ambiguous in distance traveled, but less ambiguous in terms of the specific place where they traveled to (e.g. the library), whereas tweets showing users changing their location to access cell phone service were more specific about the city they traveled to. It is possible that these kinds of ambiguities could be somewhat alleviated by mapping out popularly-referenced locations and using user contextual streams to estimate a starting location for each account, but some level of uncertainty will likely persist.

Other Limitations and Future Work

Related to some of the ambiguities described above, our work has several limitations related to the underlying data and our method for identifying adaptations within those data. One significant issue is that while Twitter is broadly used for this type of research due to the public availability of the data, other platforms (e.g. WhatsApp, Instagram, and Facebook) are more widely used but it is difficult to access that data. Because of this and other instances of non-use —e.g. among people who did not have telecommunication access at all and therefore could not post to social media—we cannot see or weigh adaptation behaviors among those who were not using Twitter. Our data sample is also restricted to people who use Twitter—people who tend to be younger and not representative of the total population. In addition, we limited our analysis to accounts that either posted a geolocated tweet or had a geolocation term suggesting they were in Puerto Rico. While this helped to reduce the search space (resulting tweets that were far more likely to be sent by affected people), these accounts likely represent only a small proportion of accounts operated by people in Puerto Rico.

Our heuristics-based approach relied on a kind of snowball sampling that built new searches upon prior successful searches, likely resulting in some unexplored search pathways. In addition, to make our sample

CoRe Paper – Social Media for Disaster Response and Resilience
Proceedings of the 17th ISCRAM Conference – Blacksburg, VA, USA May 2020
Amanda Lee Hughes, Fiona McNeill and Christopher Zobel, eds.

tractable for qualitative research, we limited our search terms to ones with low noise. Taken together, these limitations mean that there are likely additional adaptations that are not featured here.

These limitations open the door to future work that utilizes other approaches, e.g. interviews and surveys, to help contextualize and generalize the Twitter-based insights. Our findings, which reveal some of the adaptations that were salient, can help shape survey and interview instruments to help us answer these open questions. We also see the potential for machine-learning approaches (likely human-in-the-loop solutions) to systematically identify and classify adaptations across users and over time—both in real-time to inform disaster response efforts and after-the-fact to enhance our understandings of human adaptations to disasters through research.

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APPENDIX A

Search Terms

https://github.com/hcvw/iscram2020

CoRe Paper – Social Media for Disaster Response and Resilience
Proceedings of the 17th ISCRAM Conference – Blacksburg, VA, USA May 2020
Amanda Lee Hughes, Fiona McNeill and Christopher Zobel, eds.