The Use and Non-Use of Technology During Hurricanes

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Hurricanes can cause catastrophic damage; it is critical for those affected to access information about conditions, loved ones, and resources. Prior work in the HCI and CSCW communities has focused on how social media can be vital during natural disasters; non-social media technologies have been under-researched. To understand how technology other than social media can support or harm people during crises, we explore hurricane survivors' *use and disuse* of multiple kinds of technologies in online surveys with 138 US participants. We find substantial technology use supporting survivors' comfort and safety *other than social media*. We also observe that designing technologies for high-resource environments—as with many mainstream apps—causes users to decrease use of potentially critical technologies during utility outages, which are common during hurricanes. With themes of both (a) broad technology use and (b) conditions preventing technology use, we make recommendations for technical design, policy, and research to empower communities susceptible to hurricanes.

CCS Concepts: • **Human-centered computing → Empirical studies in collaborative and social computing**.

Additional Key Words and Phrases: Human Computer Interaction, Crisis Informatics, Non-use

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1 INTRODUCTION

Tropical cyclones, e.g., hurricanes, cause death and injury, physical damage to infrastructure, and billions of dollars in economic impact [80]. Personal technology, such as smartphones and home computers, can be a critical part of mitigating impact for affected communities. For example, communities come together on social media to exchange vital information about well-being and aid during the immediate aftermath of a disaster [21, 23, 75, 110, 121, 130], and researchers have studied or designed apps for use by individuals and local governments during crises [113, 115, 129]. Though prior work about technology-mediated disaster relief indeed benefits individuals and communities

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during and after a natural disaster, we observe two gaps in research about technology use during this time, as noted below.

Gap in prior work: technology use other than social media during natural disasters. In order to best allocate resources, design technology, and implement policy, it is critical to have a *complete* view of technology use and non-use during crises. While there is a plethora of work on social media usage and the usage and design of made-for-crisis apps [115], there is little work about how *other kinds* of technology and information sources are used during crises. While the utility of social media (e.g., Twitter [23, 65, 75, 110]) is well documented, we lack a rich understanding of how other technologies and information sources—for example, weather apps, news sources, and communication tools—are adopted and used (or not used) during crises, and how these technologies respond to the underlying needs driving technology use during crises. While these types of technologies may not be designed with the same potential for crowdsourcing information and public study, they may fill other needs for users and understanding why users choose to use or not use certain apps, as well as how these technologies complement social media, can help direct future research, technology design, and policy.

Gap in prior work: decreased or stopped technology use (non-use) during natural disasters. During natural disasters, public infrastructure is often damaged, and access to electricity, internet, and cellular service may be decreased or completely lost for many. For example, after 2021's Category 4 Hurricane Ida, more than one million people in Louisiana were without power [3]. Decreased or lost access to utilities may affect what technologies people choose to use and whether they can use them at all. Despite a significant body of work on technology non-use among both the general population [10] and among poor regions of the global south that lack reliable critical infrastructure [126], existing work in the HCI and CSCW communities on crises focuses on those who *can and do* use technology—Twitter, Facebook, etc [90, 103]—and misses the *many, many* people who lack unfettered access to electricity, internet, and cellular connectivity after a natural disaster. It is important for the HCI and CSCW communities to study the entire spectrum of technology use with regard to natural disasters because the constraints imposed by a natural disaster (e.g., lack of electricity and connectivity) can drastically change how technology can be used. When those without access are excluded from datasets, technology built based on that data (only about those who *can* use technology) excludes those who *might* use technology if it were designed for their needs. Utility outages and utility restoration are also not distributed equitably [35, 104], and, thus, a research community that does not study the effect of these barriers to technology use misses an opportunity to address systemic inequity. Following the lead of many others, including Costanza-Chock in their book *Design Justice*, we urge the HCI and CSCW communities to *design for the most vulnerable* [24] communities who may be affected by hurricanes, which requires including them in datasets.

Addressing these gaps in HCI and CSCW research is critical to supporting emergency responders, communities affected by hurricanes, and other stakeholders and practitioners. These gaps represent areas where our current knowledge and research fall short, potentially leading to partially-informed technologies and policies. By taking efforts to address these shortcomings, we can gain a deeper understanding and accuracy in addressing the needs of stakeholders and practitioners.

To address these gaps, we conducted a broad qualitative survey with 138 participants from areas in the mainland US that regularly experience hurricanes and tropical storms. We chose to study just one type of natural disaster—tropical cyclones, the meteorological term covering hurricanes, tropical storms, typhoons, etc [78]—because different natural disasters differ in terms of predictability, preparation, short term experience, and long term recovery. We focus on use and non-use during three of the four stages of emergency management, as defined by the US Federal Emergency Management Agency (FEMA)—*mitigation* (long term resilience efforts), *preparation*

(short term preparedness efforts), and *response* (the period during the "immediate aftermath of the disaster") [32, 33]—in order to capture behavior centered around crises rather than "regular operations" (which occur concurrent with the fourth stage of emergency management, *recovery*) [32]. 99 of our participants were living in hurricane-prone areas, recalling their experiences of past hurricanes; in order to complement that historical data, we also recruited 39 participants who were either experiencing a hurricane currently or who had just experienced a hurricane. Our IRB-approved surveys explored the following research questions during emergency preparation, mitigation, and response:

- **(RQ1)** What **needs and circumstances** during a hurricane drive technology adoption, use, and disuse? How do these needs and circumstances drive technology use and non-use during the phases of the emergency lifecycle?
- **(RQ2)** Holistically, what does technology use look like during the immediate response phase of a hurricane, and in what ways does that usage represent a **change** (increase, decrease, adoption, disuse) from users' typical technology use?
- **(RQ3)** How do people respond, technologically, to the circumstances created by **physical infrastructure damage**, e.g., loss of power and loss of connectivity? What coping strategies do they develop, or what risks or costs do they take on by not using technology?

We find that there is substantial personal technology use outside oft-studied social media, and that people may adopt *new* sources of information and technologies during hurricanes, such as new weather apps and new local news sources. However, we also find that decreased or severed access to electricity, internet, and cellular service drives individuals to decrease or stop the use of some technologies—particularly everyday technologies—and that users prioritize technology use based on their needs, the perceived utility of the app, and the resource consumption of the app, leading them to deprioritize apps for which the utility is outweighed by the app's battery, data, and time consumption.

Designing for low-resource contexts—which occur during the *response* to the storm—is critical to support stakeholders and practitioners. Our findings provide a *holistic* view of individuals' technology use during, before, and immediately following hurricanes, as well as the barriers to usage. From these results, we make recommendations for future research and technical design to support technology use in the low-resource contexts so often created by natural disasters, e.g., network design, system design, and security and privacy considerations.

2 RELATED WORK

In this paper, we focus on the changes in technology use during hurricanes and the needs and circumstances that drive those changes, adding to bodies of work about both the *spectrum* of technology use (Section 2.1), and technology use during natural disasters (Section 2.2). We do so by drawing attention to voluntary and involuntary limited use, changed use, or temporary disuse as a response to the disaster's circumstances. In Section 5, we build on and contrast to solutions proposed in prior work, discussing their potential fit for hurricane survivors.

2.1 Technology use and non-use

The spectrum of technology use. A significant body of work in HCI and CSCW has focused on the idea of users *and non-users*, treating technology use as a spectrum rather than a binary [95]. Foundational work explores a number of reasons for limited or non-use—some personal choices, and some due to environmental or social barriers—and urges HCI and CSCW researchers to consider people throughout the entire spectrum of technology use in order to address systemic barriers and design mismatches, as well as effects on indirect or incidental users [9, 11, 94, 98]. For example, prior

work has explored those who limit their use of certain technologies for ideological, philosophical, or wellness reasons [5], e.g., people who choose to leave Facebook due to concerns about data use, social media addiction, and productivity [10]; or people who limit use of Internet of Things (IoT) devices due to, for example, privacy and security concerns, or disappointment with the device's performance [42].

Barriers to technology use. More closely related to technology disuse during natural disasters is research focused on systemic, infrastructural, resource, or design barriers that prevent or limit the use of technology. Some barriers may be temporary, while others are persistent; some are created intentionally, while others are created through neglect or a systemic lack of resources.

Internet blackouts during periods of political strife are temporary and intentional barriers to technology and internet use. Prior efforts have found that during such times, people develop a variety of coping mechanisms (e.g., increased adoption of proxy tools) as well as decreased technology use due to the lack of connectivity [4, 13, 26, 28]. Though intentional internet blackouts, slow-downs, and censorship occur for a different reason than an outage caused by a hurricane (and therefore, coping mechanisms may have different efficacies and privacy requirements), the circumstances share immediacy and an increased need for information about the local context.

A separate body of work has focused on technology non-use in contexts with limited infrastructure or resources, e.g., poor and/or rural communities, in which barriers persist and may be systemic, resource-related, or design-related. Wyche et al. have, over a number of papers, focused on the spectrum of technology use in communities in Kenya, finding that a lack of infrastructure—causing slow network speeds—changes and constrains technology use [125–127]. In a 2013 study of internet cafes in rural Kenya, Wyche et al. explored how slow network speeds and frequent power outages, in combination with high monetary cost to access the network (including transportation to internet cafes, cost to access the computers, and the time to wait for websites to load), presented significant barriers to potential internet users, limiting or entirely preventing use [126]. Later, in 2015, Wyche et al. investigated Kenyan farmers' (lack of) use of a mobile app with information about agricultural pricing information, finding that the extremely low usage rate was due, again, to a lack of network and electric infrastructure, as well as the monetary cost of accessing the internet. They also found that the physical conditions that (often old) phones were used in, e.g., bright sunlight, directly hampered usage and that the hardware tended to break [125]. In contrast to the communities that Wyche et al. have studied, others have found multiple poor and rural communities that *do* have sufficient and reliable access to internet and power infrastructure, removing those particular barriers to use (though there may exist other barriers, such as literacy, physical safety, and monetary cost) [62, 100].

While our work takes place in the US, in both rural and urban communities, we studied communities that experienced (temporarily) limited network and electric resources; we, therefore, draw from and build on work about technology in other resource-limited contexts to work towards coping strategies and designs that are more resilient to damaged or limited infrastructure.

Solutions to systemic infrastructural barriers to technology use. Drawing on research showing the profound limitations that a lack of reliable infrastructure places on technology use, prior work has proposed, designed, deployed, and studied solutions to limited network and power capacity.

For instance, a body of work has studied communities that self-administer cellular networks rather than rely on a regional service provider, in some cases installing the networks for the communities or measuring usage [49, 50, 54, 99], and in other cases exploring various aspects of self-management, such as maintenance and congestion control [53, 55]. These networks are typically self-managed by rural and/or remote communities, providing stable and reliable internet access through a cellular connection for communities that regional service providers do not serve [54].

Others have focused on disruption-tolerant networking protocols and implementations (e.g., mesh networking) as a mitigation for limited or lost connectivity, especially during a local or regional disaster [40, 47, 58, 91, 116, 118]. For example, Gardner-Stephen et al. developed *Serval*, a mesh-networking system for use on mobile phones that leveraged phones' WiFi radios to pass peer-to-peer (P2P) messages; they specifically noted Serval's potential for use by those facing local disasters [39–41]. Others have performed follow-on work with Serval, including Baumgärtner et al., who evaluated its strain on a phone's battery [12]; however, work on Serval itself has stopped due to the gargantuan task of either convincing users to root their phones in order to use Serval, or "*influencing mobile phone regulators and manufacturers*" [74].

Our work provides an updated, present-day description of a community's needs and typical network capabilities during hurricanes in order to both motivate and provide ground truth on usage for this important body of work on delay-tolerant networking.

2.2 Use of technology during crises

We now explore prior work on technology use during natural disasters; we recommend Simon et al.'s 2015 survey or Reuter and Kaufhold's review of social media use during crises for a more thorough literature review [90, 103].

Social media use during hurricanes. Most research on technology use during hurricanes has focused on the use of social media, specifically, Twitter. Use of Twitter often increases substantially during crises [46, 51, 61, 77], and can be a vital source for locating emergency aid [75, 130], longer term disaster relief [77], and connecting with local emergency officials [128]. Research has also focused on social media use by local officials, finding that officials' messages vary in engagement, purpose, and effectiveness [36, 52, 66, 70, 128]. Our work explores the less-studied *non-use* and *decreased usage* of technology, in addition to the adoption and changed use of technology and Twitter. While social media is a critical tool in crises, democratizing dissemination of vital information, we also focus on the *barriers* to use and *disuse* of social media and other technologies.

General technology use during hurricanes. Shklovski et al. explored the adoption of technology by New Orleans musicians after Hurricane Katrina (in 2005) [101]. They found that mobile phones were a critical resource and that musicians adopted new technologies in response to changing needs and resource constraints—for example, many used SMS for the first time due to the low connectivity and power requirements. Ferris et al. surveyed New Jersey residents who evacuated after 2012's Hurricane Sandy, investigating the role technology (social media, text messaging, phone calls, news media) played in their decision to evacuate. They found that technology was used for preparation, but that use decreased after the storm (except text messaging) [34]. Schwartz also studied the response to Hurricane Sandy, finding that those who lost access to technology felt both increased mindfulness and groundedness and increased powerlessness, boredom, frustration, and anger at the lack of control, information, and connectedness [97]. Der-Martirosian et al. studied telehealth adoption by veterans during the weeks surrounding 2017's Hurricane Harvey, finding that telehealth use *increased* for the medically vulnerable [29].

Our results support both the criticality of technology and its decreased usage during disasters. We build upon these important prior works by (1) providing an *updated* view of technology use during hurricanes, (2) examining the use of *various types* of technologies during hurricanes, and (3) qualitatively exploring *why* people used technology the way they did.

Social media use during other crises. Many have explored increased social media use during other crises [84], e.g., wildfires [121], flooding [21, 121], terrorist attacks [82], earthquakes [65, 93, 106], and the Covid-19 pandemic [107]. Some include the effect of destroyed infrastructure in their

analysis, including Li et al., who observed that Twitter's short text-based nature made it one of the few technologies adopted when cellular and power infrastructure were destroyed during the 2008 earthquake in Sichuan, China [65]. Research has also focused on the online communities of digital volunteers who help those seeking information during a disaster [23, 107, 110], and on social media use by emergency management or local governments to distribute critical information and monitor the community in real time [63].

Additionally, researchers have focused on mis- and disinformation during crises and the role of communities in supporting or correcting rumors, e.g., during Hurricane Sandy [45], Hurricane Irene [27], and the Boston Marathon bombing [109]. Gupta et al. analyzed 10,000 fake image tweets during 2012's Hurricane Sandy, finding that there were few original images and that a handful of people were responsible for most retweets [45]. Lovari et al. found that local officials were concerned about spreading misinformation on social media [70], while Endsley et al. found that people trust information from news media (both local and national) more than other sources but that social ties also influence trust (e.g., who the info is from) [31].

Crisis apps. A growing body of work focuses on apps specifically made for use during a crisis; our work builds on this work by gathering data about real-world use of such apps. In a 2017 literature review, Tan et al. analyzed 49 papers about crisis apps; 35 built specifically for disasters (e.g., "Hurricane Hound"), and the rest general-purpose apps (e.g., Facebook). They focused on built-for-disaster apps, categorizing them by *purpose* (e.g., information dissemination) and *contribution* (e.g., preparedness), and identifying user perceptions of crisis apps as a gap in literature [115]. Since their review, Appleby et al. found that crisis apps increased users' trust in local institutions (e.g., emergency services) by creating a sense of shared responsibility during a crisis, and that users perceived made-for-disaster apps as more reliable than general-purpose social media apps during disasters [6]. In a 2020 study, Tan et al. conducted a mixed-methods study about what makes users *keep* crisis apps, finding that utility and dependability were key [114]. Several have studied older adults' perceptions and use of crisis apps [113, 129], e.g., Zhang et al., who studied how older adults used crisis apps during a natural gas explosion in Pennsylvania, finding that engagement with the apps was low, but community involvement was critical to app adoption. They also found that older adults lack trust in crisis apps, citing concerns about misinformation, scams, and general concern about certain platforms [129].

Systemic inequity during crises. Recent work within the HCI and CSCW communities has explored how technology can create or increase inequity during disasters. Soden et al. argue that the disaster technology and informatics communities created gaps and "silences" during the aftermath of the 2015 Nepal earthquake that "*foreclosed opportunities to address important challenges that the people of Langtang faced*" [106]. Madianou explored how the digital divide amplified existing social inequities during 2013's Typhoon Haiyan in the Philippines, leading those who used social media and smartphones to recover more quickly economically and those who lacked technology or connectivity to "languish behind" [71]. It is well documented that natural disaster response reflects and can deepen systemic inequities, e.g., access to assistance provided only in English in the US, or in places easily accessible by public transit [35], or infrastructure and housing being less sturdy in poorer neighborhoods [71], or researchers being accountable to funders rather than the communities they are studying [72].

Vulnerable populations are disproportionately affected during natural disasters [18]. For instance, people of color [119] and people in low income communities [7] often live in flood-prone, low lying areas and are massively affected during hurricanes as they suffer from loss of jobs and difficulties in obtaining unemployment benefits. The elderly, people with disabilities, and people with chronic health conditions are at a higher risk of trauma because they are either unable to visit physicians

or due to exacerbated mental health conditions [18]. Additionally, Schumacher et al. identified that there was an increase in Intimate Partner Violence (IPV) during Hurricane Katrina in 2005 [96].

High-level reflection on the purpose and direction of crisis research remains rare. Crawford and Finn, in 2014, argued that there are ethical and privacy implications to using the publicly scraped data typically present in crisis informatics work (e.g., Tweets), and additionally highlighted the inherent limits of analysis of social media data—that is, that a skewed minority of people use social media apps during a disaster [25]. Soden et al. present an interdisciplinary workshop on flood data as a methodological contribution towards uniting experts from disaster research, social science, artist communities, and the local area [105]. Gaillard et al. propose a disaster researchers' code of conduct urging researchers to reflect on who benefits from their work and to amplify the work of locals [37, 38]. Most recently, in 2022, Soden et al. published a set of guiding principles for the HCI community on how to center *people* when designing communication for hurricane-prone communities; we observe that many of the same themes arise in our work, e.g., the variety of needs and circumstances driving technology use, and the need to develop beyond technology and *for* people [104]. We add to this critical body of work by providing another view of technology disuse and suggestions for a wide variety of researchers, policy-makers, and technologists.

3 METHODOLOGY AND BACKGROUND

Our goal was to examine technology use or lack of use during hurricanes. Due to human subject biases associated with recalling prior behaviors and intentions [15, 83], we preferred data collected during or close to a hurricane; however, actually collecting sufficient data during or immediately after a hurricane would have been logistically improbable and potentially dangerous or unethical. We thus chose to deploy three modularized, related online surveys—one retrospective over many years, one during a hurricane, and one soon after a hurricane. Qualitative surveys are a common tool used for inquiry into a geographically disparate population and have been previously used to study the non-use of social media [10]. These surveys were safe for the researchers to deploy and for participants to complete, and let us quickly prescreen for specific geographic locations. Participant safety was paramount; we discuss further ethical and safety considerations in Section 3.6. We implemented surveys in Qualtrics and recruited participants on Prolifc, an online survey recruitment platform.[1]

Specifically, we deployed our surveys:

- Retrospectively over 10 years of hurricane experience (**Retrospective survey**, Section 3.3)
- During a hurricane (**During-hurricane survey**, deployed during 2021 Hurricanes Ida, Henri, and Nicholas, with people currently experiencing them, Section 3.4)
- Shortly after Hurricane Ida (**Post-Ida survey**, deployed when the news reported residents regaining electricity, with people affected by Ida, Section 3.5)

The retrospective survey serves as the main source of data, with the most participants. However, we used the during-hurricane and post-Ida surveys to complement, expand upon, and corroborate the retrospective data. Each survey consisted of a subset of our survey *modules*, described in Section 3.2 and shown in Figure 1.

3.1 Background: Three of the 2021 hurricanes in the mainland US

We recruited participants for our retrospective survey from coastal or coastal-adjacent zipcodes from Texas to North Carolina because these areas are the most frequently affected by hurricanes in the mainland US [81].

In 2021, six storms affected the mainland US [79]; we recruited participants during three of them:

[1] prolific.co

- **Tropical Storm Henri**, which arrived at the US North East on **August 22** with heavy rain and flooding, 1-3 feet of storm surge, and left 100,000 people without power [85, 102]. Two people died [85]. Though Rhode Island and other North East states were not in our target population, we collected data as a final pilot run; we included the data because it was high quality.
- **Hurricane Ida**, the worst storm—**Category 4**[2]—to affect the mainland US in the 2021 season. **Louisiana**, where it made landfall on **August 29**, experienced six-foot storm surges and 150 mile-per-hour wind [22]. More than a million people in Louisiana lost power [3], which took weeks to restore to all [60]. Hurricane Ida traveled to the **north east**, and its remnants caused record-breaking rain and flooding in the mid-Atlantic and New England[14]. Ida caused the death of at least 91 people over all the states affected [48].
- **Hurricane Nicholas**, a **Category 1** hurricane that affected the Gulf Coast on **September 14** [64]. With storm surges around 4 feet in Texas, and rainfall varying from 4-10 inches, flooding caused property and economic damage, as well as two deaths [64].

3.2 Survey Modules

We designed our surveys to reflect the breadth of our research questions and to allow participants to tell us something unexpected, standard in qualitative work [112].

We iteratively developed our surveys from scratch through diligent topical background research, pilot survey runs, and two semi-structured interviews with people who had experienced hurricanes and other natural disasters (data not included here). We developed a mix of free-response answers, matrix questions, and multi-check answers; most multiple choice or multi-check questions had a corresponding question or option that invited participants to write free response text about any options that were missing, or anything else that was relevant. Through multiple rounds of pilot surveys, we asked pilot participants whether they felt the survey had captured their full experience (as related to our research questions about technology use and non-use during hurricanes), and if not, we changed the survey. All pilot data collected was approved by our institution's IRB, and crowdsourced workers were paid ($10 for a 30-minute interview; surveys paid as detailed in Sections 3.3, 3.4, and 3.5).

To create both consistency across survey versions and flexibility for different survey deployment contexts, we created 9 *survey modules*, summarized in Figure 1. Sections 3.3, 3.4, and 3.5 show how the modules fit together in the surveys since not all modules were present in each survey; Appendix B presents modules verbatim.

Disaster preparation. This module asked participants about both general disaster preparation and preparation that involved information or technology. We first asked participants to select from a list of suggested disaster preparations that applied to them; we created this list by surveying the first two pages of non-ad Google search results for a search query about hurricane preparation and grouping suggested items into categories (e.g., food and water, shelter, etc.) [1, 8, 16, 69, 86, 111, 117, 123]. We added to this list during our pilot surveys when pilot participants indicated preparations not already covered by the list.

Next, we asked participants to select from a list of potential disaster preparations that involved technology or information. Some of these preparations, e.g., preserving paper or digital copies of documents and having alternate two-way communication methods, were drawn from the hurricane preparation guides we surveyed. Others, e.g., authentication method backups and external smartphone batteries, addressed initial hypotheses about the security and privacy implications

[2]Hurricanes are measured by wind speed using the Saffir-Simpson Hurricane Wind Scale (commonly referred to as Category 1 - Category 5); storms less than Category 1 are Tropical Storms.

of losing access to utilities or one's home. We also asked about any crisis apps they downloaded. Finally, through a combination of free responses and multi-check questions, we asked participants about barriers to preparation and how they learned about each preparation.

Storm context. This module collected data about participants' *overall* experience with a specific storm, including broad questions like "What did you and your household experience?" This module also collected data specifically about how the storm impacted their daily routines, how their access to utilities changed, and their expectations and concerns for the near future. This data shapes our understanding of participants' technology use and served as prompts to help participants recall storm specifics [15].

Use of disaster kit. This module asked participants specifically about any changes to the items in their disaster kit, if they had one. If they made changes, we asked them to explain what the change was and why they made it. This module adds data to the previous one by collecting additional data about storm context and spurring further recall.

Reflections on preparations. This module, deployed only in the post-Ida survey, encouraged participants to reflect more deeply on how they used the items in their disaster kit, whether those items were useful, and what might have been missing.

Technology use during the storm. This module collected estimates from participants about how much they used technology in a number of ways during the storm (e.g., "getting weather information," "playing games," and "browsing on social media"), and how that compared to whatever was normal for them.

Use of apps. This module explores app use and disuse during hurricanes. We asked participants to name up to three apps they used, either in daily life or in an emergency, in each of seven categories: weather, national or international news, local or regional news, social media, text communication, video or audio communication, and in-case-of-emergency (ICE) apps. We first drew app categories from Google Play and the Apple App Store, but we refined them through pilot surveys with multi-generational participants experienced with disasters.

After naming at least one app, participants categorized the apps they had entered into three groups: (a) those used during a disaster but not during everyday life, (b) those used during everyday life but not during a disaster, and (c) those used during both everyday life and a disaster. Then, through a series of free response questions, we prompted participants to reflect on *how* and *why* they used apps in each category the way they did, asking questions like: "What did you use these apps for?" and "Did you encounter any issues or concerns?"

Broader reflections on technology use. This module asked participants to more broadly reflect on changes in and characterizations of their use of technology during a storm by asking questions like, "How did your use of technology change during the storm?" We revised and added to the questions in this module after the retrospective survey to ask more specifically about the importance of technology, and we were careful to craft questions that did not presume that technology use *should* be important to participants.

Information security issues. To explore our original hypotheses about security and privacy events occurring during hurricanes, this module asked participants to tell us about information security and device-access issues they experienced during the storm and whether or not they believed these were directly related to the storm itself. The retrospective survey included a short version of this module with a single broad free-response question since pilot studies indicated many participants did not recall specific incidents from years ago (in line with [15]).

Demographics. We asked participants standard demographic questions, including gender, race and/or ethnicity, household income, age, and political leanings. Questions about gender, race, and/or ethnicity included a free-response option to self-describe in addition to or instead of any number of the common checkboxes. We also asked for their zipcode and how many years they had lived in the area to further contextualize their survey responses. We also invited participants to tell us anything else we should know about them, demographically, if the questions we asked or the prescribed answers did not fit their identity. This section appeared at the end of the surveys in order to help mitigate stereotype threat.

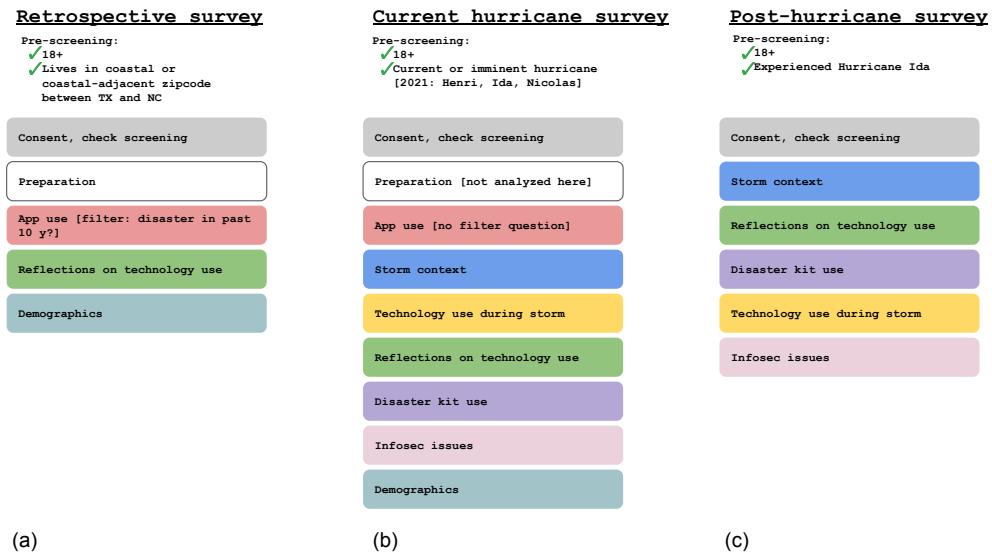

Fig. 1. Subfigures (a), (b), and (c) illustrate the modules included in each survey. See Appendix B for full survey text. In reaction to results from the retrospective survey, and in preparation for collecting data from those currently and recently experiencing hurricanes, we revised some of the modules in the retrospective survey and created new modules with more in-depth questions and more contextual questions.

3.3 Retrospective Survey

Recruitment and screening. For our retrospective survey, we recruited participants who lived in coastal or coastal-adjacent zipcodes from the Gulf Coast of Texas through North Carolina, since over 90% of hurricanes that have affected the US mainland have occurred between Florida and North Carolina [2], and recent significant and destructive hurricanes have occurred along the Gulf coast, e.g., Hurricanes Katrina (2005) and Harvey (2017). We conducted a pre-screening survey to identify geographically eligible participants who were at least 18 years old.

Our surveys ran shortly after Prolific went viral on TikTok and gained thousands of new, young, female survey-takers [19], leading some surveys (run by other researchers) to initially report extremely skewed gender imbalances, with over 90% female respondents. [3] Therefore, we balanced our sample by screening equal numbers of women and non-women in a survey with questions

[3] https://twitter.com/SebastianDeri/status/1423768044610854913

about location and gender, and then opened the survey to all participants screened as eligible, regardless of gender.[4]

Survey content. The retrospective survey consisted of three main parts, as shown in Figure 1a. Approximately the first half of the survey asked participants about their hurricane **preparation** strategies. Then, using the **app module**, for participants who had experienced a disaster in the past 10 years, we asked about their app usage during everyday life and disasters. We next prompted participants to further consider their use of technology during a disaster in the **reflections on technology use module**, including a brief question about any scams or other information security issues.

3.4 During-hurricane Survey

Participant recruitment and screening. We additionally recruited people experiencing a hurricane or expecting to experience a hurricane in less than 48 hours. During three of the six named storms to reach the mainland US in 2021—Tropical Storm Henri, Hurricane Ida, and Hurricane Nicholas—we screened participants via Prolific in areas that were directly affected by the storm. We asked participants whether they were being affected, including whether they were sheltering in place or had evacuated (see Appendix C.2.1 for screening survey text). If they were affected, we invited them, via private message on Prolific, to take part in our longer survey; we used private messages because we were recruiting participants one at a time, and Prolific enforces a time limit that we did not want to impose on participants. Appendix C.3 contains our recruitment message, which emphasized that participants should only complete the survey if they were safe. We screened and surveyed people periodically throughout the duration of storm; we stopped when our surveys stopped filling up with participants or when most participants said they were no longer being affected by the storm. We note that our use of online surveys necessarily limited our participants to those who had safe internet access; we discuss this limitation in Section 3.7.

Survey content. This survey expands upon the themes from the retrospective survey and adds questions to establish context and current technology usage. It began by asking participants about their **preparation** strategies and then moved to the **app module**. We then asked what they were experiencing, both generally and specifically regarding technology use, in the **storm context module** and the **technology use during storm module**. We next presented a modified and expanded set of questions from the **reflections on technology use module**, asking them to consider changes in technology use, what was most and least important, and what was missing. We then asked them to reflect on how they used the items in their disaster kit in the **disaster kit module** and for any information security issues in the short **infosec module**, using questions modified from the retrospective survey.

3.5 Post-Ida Survey

Participant recruitment and screening. Hurricane Ida, the most destructive hurricane to reach the US mainland in 2021, left over a million people in Louisiana without power and later caused devastating flooding in the northeast. Thus, our use of online surveys—a methodology that requires participants to have internet access and implies that they are well-supplied with electricity—could not reach those most affected by the storm. Therefore, when mainstream news media reported that utilities were being restored, we recruited people who had been affected by Hurricane Ida. Our screening survey asked participants how severely they had been affected, and we initially recruited people who had been most severely affected (see Appendix C.4.1 for screening survey text). As

[4]We asked for gender rather than biological sex in our screening survey in order to follow best practices in HCI [108].

Survey	When deployed	Avg min	Payment	# Participants	# Screened
Retrospective	Aug 23-Sept 8	21.5	$5	99	536
During-hurricane	Henri, Ida, Nicholas	24.7	$12	26	120
Post-Ida	post-Ida: LA, NYC	23.6	$5	13	63

Table 1. This table shows the dates of deployment, payment, number of participants, and average completion time for the three surveys. Each screening survey paid $0.25 and took on average less than one minute.

with the during-hurricane surveys, we stopped screening when recruitment became slow due to lack of participants.

Survey content. Because we were specifically recruiting people who had been severely affected by the storm, we removed the app and preparation modules to reduce the burden on participants. We asked participants generally about their experience during the storm (**storm context module**), their technology use (or lack of) during the storm (**reflections on technology use module**), and how they had used or not used the items in their disaster kit (**disaster kit use module**). Finally, we asked them to quantify their use of technology in a typical 24 hours during the storm (**technology use during storm module**) and to relate security and privacy issues in a short **infosec module**. In an unfortunate oversight, we did not include a demographics section in this version of the survey. However, we obtained age information since it is automatically provided to Prolific researchers; this is the only demographic data we report for this survey. Because marginalized communities are historically more badly affected by natural disasters [35], it is particularly unfortunate that we lack demographic data for this group.

3.6 Safety and Ethical Considerations

Ethical treatment of participants and participant safety was paramount. We followed general best practices for online surveys, meaning that we obtained approval from our institution's Human Subjects Division (IRB), did not collect personally identifying information from participants, did not ask for more sensitive data than we needed, and none except screening questions were mandatory. Our consent text was intentionally short but informative, lacked jargon, and gave participants a way to contact us outside the survey platform (though none did).

Additionally, we realized that our during-hurricane design might incentivize participants to prioritize the survey over physical safety. Though we could not verify participants' safety, we explicitly told them, in both recruitment and consent text, that they should complete the survey *only* if they could do so safely, and that there was no time limit. We also indicated that we would compensate them for the survey parts they were able to complete.

Table 1 summarizes payments and average completion times for each survey. Consistent with best practices for ethical treatment of human subjects, we paid participants at an hourly rate that at least matched the minimum wage in their region, and typically exceeded it. We set a high hourly rate for the during-hurricane survey ($12 for the survey, 24.7 min average) for two reasons: (1) we wanted to compensate participants well due to their circumstances, and (2) our pilot studies showed this survey would take longer, approximately 30-40 minutes.

3.7 Limitations

Though online surveys are powerful tools for reaching many participants over a wide geographic area, crowdworkers may not be representative of the general population: participants in their 20s are usually overrepresented [87, 92] and may not reflect the racial, economic, political, and

education demographics in their area. Recent work has also investigated whether crowdworkers' security and privacy behaviors reflect the general population, with varying results [59, 88].

By definition, our methodology excludes people who do not or cannot participate in online surveys, including people who lack access to the internet, time to complete the surveys, or do not use smartphones or computers. This means that our participants likely overrepresent those who have access to technology and connectivity in general and, specifically for the during-survey design, those who were safe enough to focus on matters other than physical safety during the 2021 hurricanes.

Additionally, we limited participants to those in the mainland US who could take the survey in English because designing a cross-cultural and cross-language survey presents significant challenges (along with opportunities) and because islands may experience significantly different evacuation options, aid available, and infrastructure. However, we encourage future researchers to explore the communities that we were unable to include, as our work adds to an already US-centric field, and excluding non-English speakers may have excluded some marginalized communities within the US.

Additionally, non-longitudinal online surveys such as ours may not capture participants' true motivations and behaviors since there is no opportunity to follow up with participants. Paid online surveys also incentivize respondents to go as quickly as possible to increase their hourly earnings, so respondents may not always give detailed or specific answers to free response questions, or may skip questions entirely.

3.8 Analysis

We conducted qualitative analysis on the free response answers from the surveys, using a single thematic codebook developed iteratively by three researchers [17]. The lead researcher acted as the primary coder, coded all the data, and created the initial codebook. The researcher first grouped the questions by modules for ease of analysis and built a codebook with hierarchical codes with six high level codes and 50 leaf node codes [112]. To ensure criticality and integrity of the codebook, a secondary coder independently coded 20% of the retrospective data, and >50% of the other surveys (due to the small sample size) [122]. The coders met regularly to compare their codes, discussed differences and similarities, and iterated the codebook. We occasionally also met with a third researcher who helped identify inconsistencies in the codebook and extract themes. See Appendix A for the codebook. We do not measure or report Inter-Rater Reliability (IRR) because we iteratively developed the codebook by meeting multiple times to resolve disagreements in codes and extract overarching themes in the data. Since we followed an iterative process to develop the codebook, reporting IRR was not necessary [73].

We additionally developed analysis scripts to conduct basic descriptive statistics for the quantitative data about demographics and app usage. We removed one participant's data because their qualitative responses were clearly copy-pasted and nonsensical.

4 RESULTS

We now turn to the results of our surveys about technology use and non-use during hurricanes. We begin with contextual results about demographics and participants' experiences during storms (Section 4.1). We next turn to the needs and circumstances driving technology use during and in preparation for hurricanes (Section 4.2), and then present results about the role of technology and informatics during the *preparation* and *mitigation* stages of emergency management [32] (Section 4.3). We next discuss technology use—particularly *changes* in technology use, including disuse—during hurricanes, i.e., the FEMA emergency management *response* phase [32]. Finally, we explore coping strategies for lost access to utilities (Section 4.5).

Gender (N=109)		Age (N=121)		Race and/or Ethnicity (N=112)	
Man	39	18-29	94	Amer. Indian/AK Native	3
Non-binary	10	30-39	14	Asian	14
Woman	63	40-49	8	Black/African Amer.	10
Multiple	3	50-59	2	Hispanic/Latinx/Spanish	36
		60+	3	Indo-Caribbean	1
				Middle Eastern	1
				South Asian	3
				White	56
				Multiple	12
Income (N=92)		Politics (N=108)		Education (N=109)	
< $10k	7	Democrat	82	High School	20
$10k-39k	16	Republican	26	Some college	35
$40k-59k	27			Associates	15
$60k-79k	16			Bachelors	29
$80k-99k	10			Masters	8
>=$100k	16			JD, MD, PhD	2

Table 2. This table summarizes participant demographics over the surveys. Due to an oversight, we did not collect demographic data other than age from the 16 post-Ida participants. Race and ethnicity categories have been slightly compressed (see Appendix B.4 for the verbatim wording). Indo-Caribbean is an identifier written in by a participant; all others were checkboxes given as options to participants. "Multiple" means that N participants are represented in more than one of the above rows.

Each section of our results highlights how technology used during "regular operations," in FEMA's language, can be misaligned with users' needs and resources during *preparation, mitigation*, and *response*, yet people still turn to it and in some cases preferentially use it over technology built especially for crises. Our results explore design misalignments and alignments between technology used during everyday life, and preparation for, mitigation of, and response to hurricanes.

4.1 Participant Demographics and Storm Context

We had 138 total participants (Table 1): **99** in the retrospective survey ($R1$ - $R99$), **25** in the during-hurricane survey (D_H1 - D_H9 for Tropical Storm Henri, D_I1 - D_I12 for Hurricane Ida, and D_N1 - D_N4 for Hurricane Nicholas), and **13** in the post-Ida survey (P_I1 - P_I13). Of this 138 total, 112 (81.2%) submitted free response responses to at least one question in the survey (all but screening questions were optional). All participants completed the survey, potentially due to being paid crowdworkers, despite the during- and post-hurricane participants being given the explicit option to be paid for any part of the survey they completed.

In the following sections, we choose to report the number of participants whose responses corresponded with a given thematic code; however, due to the qualitative nature of our data and our relatively small sample size (N=138), we emphasize that we have *not* performed statistical analysis and calculated statistical significance on our dataset, so results should not be interpreted with strong quantitative authority.

Demographics. Table 2 summarizes participant demographic characteristics. As is common in online surveys [92], our participants were largely young and educated; of our 138 participants, 94 were under 30, and 89 had at least some education beyond high school. A majority of our participants—63—identified as women. Exactly half of our participants identified as white, and

	Electricity	Potable water	Natural gas	Cell service	Internet
N=	27	23	19	27	26
avg	69.7%	75.6%	82.3%	69.4%	58%

Table 3. This table shows access to utilities during a given 24 hour period during a storm, from participants surveyed in the during-hurricane and post-Ida surveys. N indicates the number of data points; not all participants filled out each question or each line. Average M% means that on average, participants reporting having access M% to that utility for a typical 24 hour period during the storm. Due to low sample size, these numbers should not be generalized or interpreted with statistical significant; we present these numbers as context for understanding participants' responses.

slightly less than a third identified as Hispanic, Latinx, or Spanish. Black and African American participants are underrepresented in our dataset; thus, our data may lack important perspectives from those historically affected most by storms due to systemic disparities in natural disaster aid [35]. Republicans are also underrepresented in our dataset, meaning that our data is not politically representative of the majority of voters in the states we recruited from (and because political views correlate with trust in information sources [57], a divide in political views may also affect storm preparations and technology use and information gathering during the storm).

Experiences with natural disasters. It is important to understand this context because extreme weather and damaged infrastructure shape participants' preparations (Section 4.3), needs (Section 4.2) and technology use (Section 4.4) and drive some to develop workarounds strategies to fulfill their needs (Section 4.5).

Fifty-eight of the 99 retrospective survey participants mentioned experiencing a hurricane or another major natural disaster (e.g., an ice storm), with 13 mentions of Hurricane Harvey and 8 of Hurricane Irma. Due to the qualitative nature of our results, these numbers may be higher. The collective memories of these participants represent the institutional knowledge of many of the communities that regularly prepare for and experience potentially devastating storms.

Most described public services, common resources, and other parts of the community being affected, i.e., electrical and cellular or internet outages, but also closed schools, damaged and closed roads, gas, food, and ice shortages, and damaged homes. Some participants in the retrospective survey additionally described an outage caused by a natural disaster other than a hurricane.

Table 3 shows participants' access to utilities, for those who were currently experiencing a storm or who had recently experienced Hurricane Ida. Responses show a lack of consistent access to basic utilities like electricity, potable water, natural gas, and cell and internet connectivity. We did not ask participants in the retrospective survey for such detailed estimates, but issues with electricity arose in 56 responses, while 26 mentioned internet outages, 15 mentioned cellular outages, and 5 mentioned general connectivity issues.

In the following sections, we explore how the lack of connectivity and electricity is in tension with the increased need for safety, communication, and information, and leads to changed technology use and un- or under-met needs.

4.2 Needs and circumstances driving technology use during hurricanes

To further contextualize our results about technology use and disuse during and prior to a hurricane, we now present individuals' *needs* during a hurricane, addressing our first research question.

In line with prior work on how individuals respond to disasters [44], we observe technology use revolving around physical and psychological **safety**, **information** about the local situation, and **communication**. Indeed, prior work found that use of Twitter and other social media can help

fulfill these needs during crises [90]. Here, we examine how these needs drive technology use and disuse.

Technology was a critical tool in staying informed and communicating about the weather, the local community, and with loved ones: Perhaps unsurprisingly, much of participants' technology use was driven by the need for **weather information** (70) and storm tracking. Some participants specifically sought out *detailed* weather information, such as *R*70, who used local news to "*see... the weather that doesn't show on default apple weather app.*" Accuracy also drove participants' choice of app; *R*96 used Clime to see radar "*for a more accurate sense of what was going to happen.*"

An umbrella over many needs, **communication** with others massively drove technology use, with 55 participants mentioning communication generally, and 19 specifically indicating that they used technology either to check on others or to communicate their own safety to others. As Goltz et al. observes, checking in on loved ones is a common stage of disaster recover [44], and the volume at which participants mentioned communication as the reason they were using an app shows that this reasoning is present in our dataset as well. Speaking to the connection between communication and all other needs, particularly psychological safety, P_I10 indicated that if they had not been able to use technology, they "*would not be able to get in touch with people & feel assured when I did so.*"

Participants also commonly sought information about their **local community** in the aftermath of the storm (39) or generally valued **staying informed** (51). P_I131 wrote: "*once we would get enough service [technology] was used a great deal to check in with family and get updates on the town and restoration of the basic needs.*" Prior work documents that information-gathering is a critical step in the disaster recovery process [44]; our data supports this broad need, and—as with weather information—highlights its importance.

Safety and security—psychological, physical, and financial—drove technology use as well as disuse: Some participants tied the need for local information to immediate and **physical safety** or comfort needs. Ten participants used technology to fulfill basic needs like food and water, and 12 used it to find longer term disaster assistance (e.g., through FEMA, or local authorities). *R*91 wrote that their "*local news, WECT, was keeping everyone up to date on where to go for gas, ice, and other supplies as well as updates on storm recovery.*" Others relied on their phones for emergency weather advisories and warnings. Nine participants also considered their need to call for emergency help. P_I138 wrote that "*in a serious flooding situation, I would need to call for help with my exact location. There's an app I keep on my phone called 'what3words' that allows for location within a few feet.*" 4 participants used technology to help them either plan or execute an evacuation, including by finding routes and digitally preparing documents. Prior work on risk communication has explored the complexities of appropriately communicating disaster and weather risk information to the public [67, 68, 104]; our findings complement this body of work by underscoring the public's need for accurate and up-to-date weather information, and showing how they currently seek that information during a hurricane.

The need for **entertainment** (20) and **psychological safety** (12) also drove participants' use and disuse of technology. *R*1 avoided "*news websites ... because they tend to make you more scared,*" while for others, news and social media provided comfort: *R*68 used "*Reddit to have a distraction,*" and P_I129 noted that if they had been unable to use technology, they "*would have had much more anxiety and a lot more boredom.*"

Participants also mentioned **financial security** and **schoolwork** (21). Both lack of connectivity and physical damage to the community prevented participants from working online or commuting. P138 wrote: "*I'm self-employed online. Because I was trying to save battery power on my phone, I only used it to connect with my loved ones and friends and couldn't work.... I lost 8 days of income; I had some money in the bank, but couldn't access an ATM, so my rent was late to my landlord.*" P_I13's

words reflect broader themes of prioritization and rationing, and speak to the varied physical and technical constraints present during a natural disaster.

Finally, in response to questions specifically about **security and privacy**, 40 participants brought up price gauging, scams directed at people recovering from natural disasters (e.g., fake roofing companies), misinformation, and loss of important documents. Misinformation can plague social media during a hurricane, e.g., during Hurricane Sandy [45] and after Hurricane Irene [27]. While some communities have been able to control misinformation after a disaster [27], others have not [109], and we note that our participants' reports of misinformation, or fear of it, belie the tension between credible, pre-established trust in news sources not on social media, and the important real-time community-sourced information on social media that can help people find resources and safety during and after a storm.

4.3 Technology use for storm preparation and mitigation

We now present results from the 99 retrospective survey participants about the role of technology and informatics in household hurricane *preparation* and *mitigations* [32], including participants' *general* preparedness for hurricanes. In our study, we combined data about people's *preparation* (short term efforts) and *mitigation* (long term efforts) [33], because they may overlap in practice. It is important to understand the full context of *all* preparations and mitigations—technical, non-technical, and information-related—because participants may prioritize some needs over others.

The most common preparations included storing extra food and/or water (89) and preparing extra batteries, candles, or some source of external power (83), as shown in Figure 2. Structural preparations of their home (such as closing shutters and taking in plants) were also common (61). Preparations related to technology or informatics were also prevalent: 54 participants each downloaded apps and kept smartphone batteries charged, while preparations to protect documents or information were slightly less common (40 prepared physical documents; 38 made digital preparations). Twenty-eight prepared with alternate communication methods, such as radios.

Preparing documents and information: a variety of strategies, predicated on physical needs and technical abilities. The catastrophic flooding caused by hurricanes can destroy important household documents that are time consuming, bureaucratically difficult, and costly to replace. Forty participants protected paper documents (i.e., storing originals or copies by their definition of secure), and 38 protected documents digitally (e.g., keeping photos of paper documents). Participants identified 22 types of document assets, most commonly, birth certificates (20), family photos and videos (15), and social security cards and passports (14 each). Many mentioned waterproof or fireproof storage; some used plastic bags to waterproof, while others used safes. Five participants mentioned ease of accessibility (*R*84: "*Social security cards and birth certificates are in emergency bags in case we need to evacuate*"); others valued resilience to flooding (*R*57: "*Store it high up in a closet contained in a box of folders*"); while most mentioned physical security, i.e., a safe.

Thirty-eight kept digital backups of documents (including digital copies of paper documents). Of those, 28 kept copies in the cloud, 10 on USB drives, 6 on an external hard drive, 3 in email, and 2 on a local computer. *R*12 wrote: "*My mom keeps the digital copies of our documents on google drive and we have pictures of everything on our phone.*"

These strategies for securing information digitally and physically reveal both tensions and alignments with computer security best practices. For example, while storing paper documents digitally makes document preservation more robust against physical threats like floods (e.g., by storing it in the cloud), it also opens users to harm, e.g., from data breaches. Indeed, two participants rely on trusted parties to keep documents safe, e.g., *R*6, who "*email[s] the docs to myself and family members.*" This tension between physical information security and digital information security

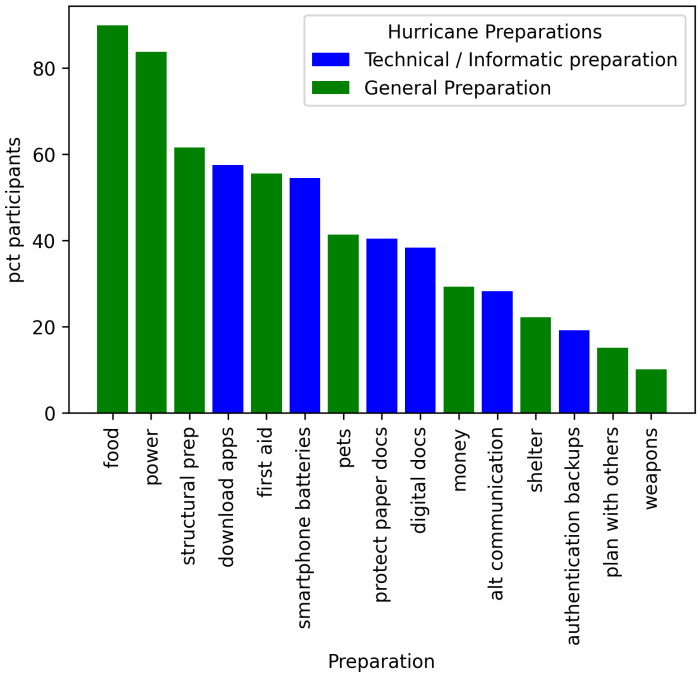

Fig. 2. Participants' household hurricane preparations; green categories—general preparations—are drawn from existing preparation recommendations and pilot surveys. Blue categories indicate informatics or technology preparations.

manifests differently for people depending on their vulnerability to flooding and structural property damage. The variety of preservation techniques is striking; while participants adapted their physical protections to their physical threat models for the storm, these same kinds of reasons were absent from their explanations of digital storage. As noted in Section 5, the burden to close the gaps between practices that address the physical security threats from natural disasters and practices that address cybersecurity threats rests on designers and technologists.

Approximately half of participants downloaded apps in preparation for a storm. Smartphone apps can aid in preparation for, during, or in the recovery period of a crisis (see Section 2). Just over half of our participants (54) had downloaded apps in preparation for hurricane season, with most being weather tracking apps (57 mentions). There were 13 mentions of news apps (e.g., Univision News), 9 of map or navigation apps (e.g., Google Offline maps), and 8 of alert apps, including four mentions of the FEMA app. One participant said they downloaded apps for identifying plants "*in case for some reason we have to bunker down in the woods and need to forage*" (*R*97). We return to the use and disuse of these apps *during* hurricanes in Section 4.4.

Preparations enabling access to technology or the internet were not uncommon. We also studied preparations enabling access to information or technology, including smartphone batteries, backups of authentication, and alternative communication devices.

Twenty-eight participants' preparations included some form of alternate connectivity. Most common were WiFi hotspots (19), for the situation where they have cellular connectivity but "*...[not] power, we are able to connect to the internet to make phone calls or text*" (*R*50). Eight participants had

Walkie Talkies in their emergency kits, e.g., *R*9, whose family had "*Walkie talkie that we give our neighbors to use so we can communicate if we don't have any phone services or ran out of battery.*" Six had two-way radios, and one had a satellite phone. For some participants, an alternative form of communication was important in case of an urgent emergency during an outage ("*We have real walkie talkies incase of a big emergency*" (*R*96)); others indicated less urgent but still important connections with others, e.g., checking in with neighbors. In Section 4.5, we further discuss the impact of downed infrastructure and return to use of these preparations during hurricanes.

As reviewed in Section 2.2, prior work has focused on technology use during natural disasters, rather than the role technology plays in preparation for disasters, and whether the preparation for disasters impacts people's lives in other ways (e.g., the security and privacy implications noted here). Our findings about preparation extend Crawford et al's exploration of the limits of crisis data, i.e., that data collected about a natural disaster *only during* a natural disaster cannot capture the full picture of technology use and non-use for those affected by disasters [25].

4.4 (Changes in) Technology Use during the Response to a Storm

We now turn to the specific technologies that participants used—and did not use—during the *response* to the storm, as well as why and how this use represents a change from everyday use. We now return to the analysis of our full dataset for the remainder of this paper rather than just the retrospective survey (as in Section 4.3). Figure 3 shows apps participants used/did not use during both the disaster and everyday life, as driven by the needs explored in Section 4.2. Figure 4 shows app use by category, and Table 4 shows the apps or technologies that participants wrote in each category. Through this section, we report both the number of participants who mentioned an app, as well as the number of apps mentioned, as participants often mentioned more than one app.

This section explores the spectrum of technology use by *category* of technology, using the categories in our surveys: social media, text communication and video/audio communication (presented together), news (local and national presented together), and in-case-of-emergency (ICE) technologies. Because some apps fit in more than one category, we report apps and technologies using participants' categorizations, and we emphasize that the thematic needs, barriers, and values that emerge from our data are more important than the definition of each category.

As explored below, we find that participants used or wanted to use everyday technology during the acute *response* to the disaster [32]. We find that participants change their use of this technology to fit their needs and circumstances (Section 4.2), as well as due to technical design misalignments that restrict their use.

Social media: useful but a massive power drain. As shown in Figure 3, Twitter, Facebook, and Instagram dominated participants' social media usage. Figure 4 shows that 72 participants indicated use of social media apps during disaster (117 mentions). Of those, 8 instances occurred *only* during disaster, while 26 participants indicated apps used specifically *not* during disaster (66 mentions), meaning that about half of the participants who used social media stopped using it during a disaster, while only 6 had social media that they used *only* during a disaster.

Participants' reasons for using social media during the storm echoed the greater driving needs during the storm, explored in Section 4.2, and are in line with prior work about uses of Twitter during hurricanes, e.g., for crowdsourcing aid [23], for humor [77], and for information about the local community [65].

For some, social media was a critical part of disaster recovery, aiding in situational awareness and communication with loved ones. D_N1 "*use[d] social media to know about my surroundings, friends posting how bad is in their area, to know about communities that might need help, to know when is the storm going to pass.*" D_I6 added that they used social media for "*entertainment purposes.*"

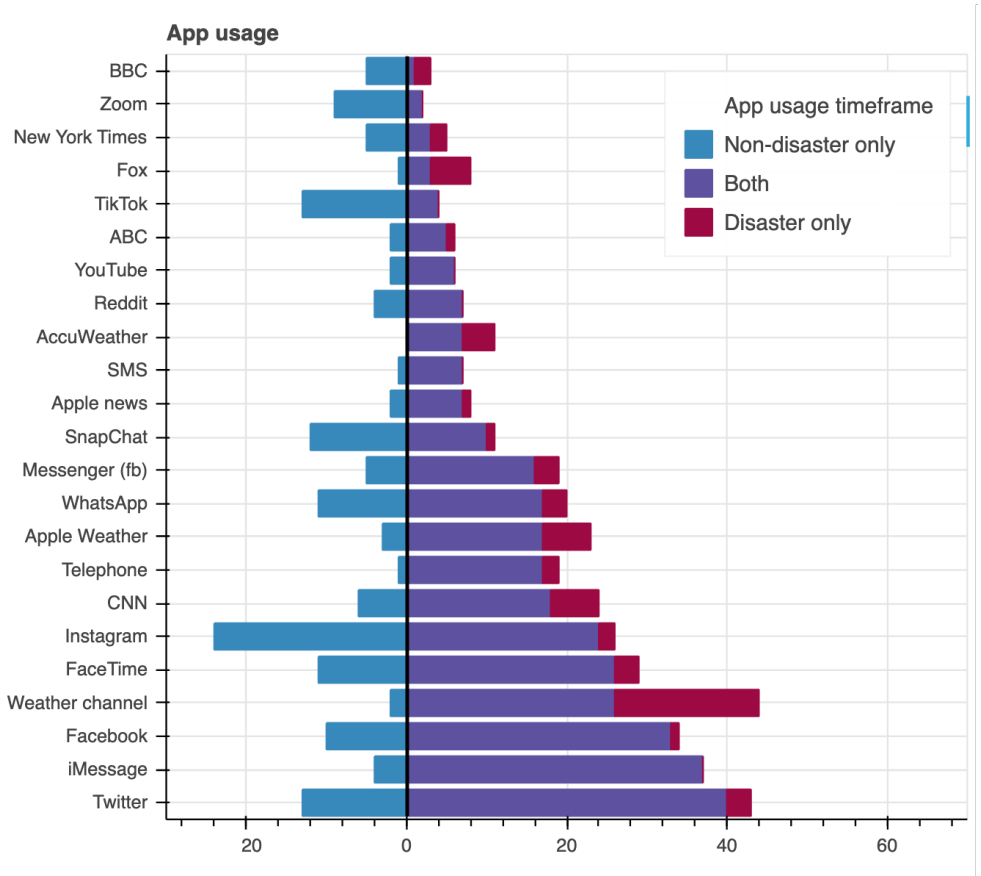

Fig. 3. This figure shows which apps participants reported using during disasters only (red), never during disasters (only everyday use) (blue), or both during disasters and during everyday life (purple). News sources are counted as national news by default or as local news if given a qualifier like "ABC channel 12" or "FOX 7." Note that we assume that "weather channel" refers to "The Weather Channel" corporation, the same as weather.com

Participants also noted the utility of social media in crowdsourcing local information immediately after the storm to share information and assistance, as prior work has explored [65, 90, 103]. *R*7 explained that "*Reddit has been a great source in the aftermath of storms because there's so many people from different communities sharing information with everybody. You can usually find information about power outages, relief funds, food offerings, etc in real time.*" Additionally, *R*18 used social media to offer help to others, writing that "*during the recovering period, social media apps and apps to stay connected to people were mostly used to put the community back up. I used it to find harshly hit areas in need of supplies and to contact friends in need of help.*" Not present in our dataset were participants seeking emergency help from local officials, as has been documented in prior research [66], e.g., about boat rescues after Hurricane Harvey [75].

Our results diverge from most prior work on social media use during disasters by showing significant *disuse* as well as use; to our knowledge, the field is only beginning to record the full spectrum of technology use during disasters [9, 71]. As shown in Figures 3 and 4, many

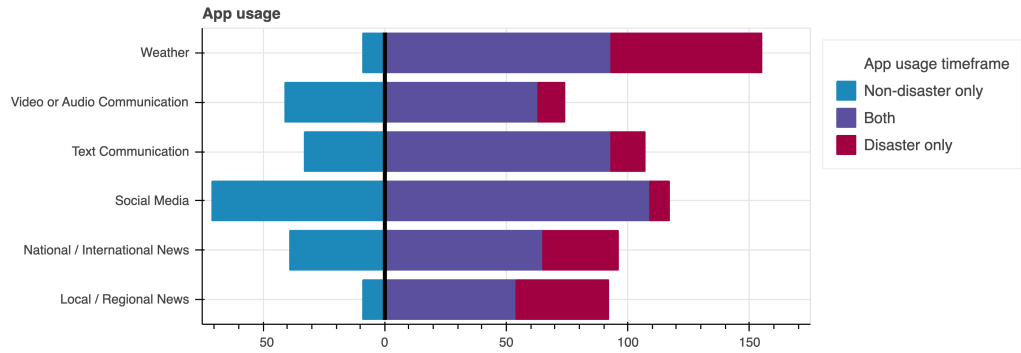

Fig. 4. This figure shows which categories of apps participants reported using during disasters only, never during disasters (only everyday use), or both during disasters and during everyday life. News sources are counted as national news by default or local news if given a qualifier like "ABC channel 12" or "FOX 7."

participants actually stopped using social media (some more than others) during the disaster, despite its communicative, entertainment, and informational value. Many cited battery drain or lack of connectivity as a reason to ration or completely stop using social media, like *R*1, who wrote: "*I don't use TikTok during an emergency because I need to conserve my phone battery....*" *R*14 explained that the energy cost was not worth the value: "*I use these apps for connecting socially but not in direct communication. I didn't feel the need to use these apps for entertainment at the cost of depleted energy stores.*" Similarly, multiple participants expressed that it was "*not important to be checking ... social media during serious times*" (*R*17) and thus deprioritized social media. *R*14, for example, had other ways to connect with family during the storm and thus did not need to use social media—"*My family usually just commincates through text messaging so I don't need to use social media to contact them during a disaster.*"

Thus, participants expressed two stories of social media usage: one as a critical tool in communicating, crowdsourcing, gathering information, and maintaining psychological safety, and another as not worth the battery drain, or unimportant. We emphasize that latter has been understudied, particularly within the HCI and CSCW communities, and that excluding those on one side of the spectrum of technology use contributes to systemic inequities in research. Our work adds to a small but growing body of work about those who are unable or unwilling to use technology during a disaster due to severe resource constraints.

Video, audio, and text communication: necessary, but some drain power. Next, we discuss communication tools, grouping together video, audio, and text communication tools because they sometimes overlap. As Figure 4 shows, text, audio, or video communication tools—like iMessage, Skype, or a telephone call—roughly echoed the usage of social media: considerable disaster use, some of which was only during disasters, but a clear drop-off during disasters. Disaster usage was high: 55 participants identified video/audio apps used during a disaster (e.g., FaceTime) (74 mentions); 78 participants identified text communication apps used during a disaster (e.g., SMS) (107 mentions). However, 30 participants noted video/audio apps that they used in everyday life but *not* during a disaster (41 mentions), and 26 participants recorded text apps also not used during a disaster (33 mentions). We summarize apps with more than 5 mentions in Figure 3 and show all apps mentioned in Table 4. Broadly, this data shows that participants stopped using video/audio tools more than they stopped using text messaging apps, but it also shows an additional skew

present in our dataset: 51 participants said they used FaceTime, Apple's built-in video chat app, showing that our participants had a high rate of ownership of Apple devices.

Participants identified messaging apps as critical to their communication strategies during the storm, sometimes in combination with social media. $R26$ "*texted family members and friends,*" and $R14$ used "*Facebook, Facebook Messanger, Facetime, and Whatsapp ...to update friends and family as well as communicating plans and coordinating any required relief.*" D_N2 indicated that their text and audio increased—"*I spent more time calling and texting family than usual in order to give and get updates on the state of the storm*"—and $R7$ "*used facetime to see video footage of the actual storm and its damage that it caused.*"

As Figure 4 shows, many participants stopped or decreased use of video or audio tools during the storm. As with social media, for many, this change was due to the drain on battery life ("*Video greatly reduces battery life*" ($R98$)). Some participants attributed their disuse to insufficient connectivity throughout the storm. P_I5 described how the diminished cellular connection throughout Hurricane Ida affected their ability to communicate with loved ones: "*I could communicate normally for the initial part of the storm on Sunday evening. Around ~10 PM, I lost LTE, and then dropped down to 4G, and then just bars. I could send SMS messages, but not iMessages, on AT&T. I woke up Monday morning around 9/10 AM and had no service. Around 4 in the afternoon, calls and SMS texts would come through sporadically, but often had to be resent or attempt multiple times for the call to come through. I had more or less normal cell reception by that evening, although it felt slower than normal.*"

Participants also expressed the idea of *prioritization* of certain communication tools, often the ones that required less power and bandwidth. D_I10 wrote: "*I don't need to FaceTime or Zoom anyone. As long as I can hear their voice, I'm fine.*"

These usages reveal a duality similar to social media usage and reflect the need for detailed, up-to-date, and accurate information about the community and loved ones explored in Section 4.2 and prior work [44], dampened by electrical and connection outages caused by downed infrastructure.

News: local news use rises during disasters. Many participants used news apps or websites, as Figure 4 shows. We find that both local and national news usage increases during a disaster, but local news use increases more: 76 participants mentioned local news sources used during the disaster (92 news sources), with nearly half of the news sources (44) used *only* during the disaster. Sixty-seven participants mentioned national news sources during the disaster (96 news sources), and 25 of those participants said they used them *only* during the disaster (31 sources).

However, many more participants indicated that they *stopped* checking national news during the disaster: 25 participants identified 39 national news sources that they had stopped using the disaster, while only 7 participants indicated 9 local news sources used only during everyday life. Indeed, D_H8 wrote "*i have been watching the news more than i would normally.*" These results point to the critical importance of local news organizations as a source of detailed, accurate, and up-to-date information for many during a natural disaster, with some using local news alone and some to complement social media or communication tools. Participants identified approximately 65 unique local news organizations,[5] which includes apps, websites, television channels, radio stations, etc.

Participants preferred news sources that were accurate, timely, and detailed; for many, this was their local news outlet. D_I10's local news provided "*a storm tracker that I'm using and [they] are constantly giving updates on the hurricane.*" $R74$'s local news station had more detailed weather information than their standard weather app; they used it for "*seeing the weather that doesn't show on default apple weather app.*" During the recovery period, $R62$'s local news "*gave instructions for*

[5]This number is approximate because some participants made ambiguous entries, such as "local news" or "channel 10." We did not count non-specific entries like "local news," and we counted channel 10 as its own local news source that could, for example, overlap with something like "KHOU."

#	Social Media	#	Text Comm.	#	Video & Audio Comm.
62	Twitter	54	iMessage	51	FaceTime
61	Instagram	34	WhatsApp	14	Zoom
56	Facebook	23	Messenger (FB)	12	WhatsApp
21	TikTok	11	Messages	8	Skype, Telephone
18	SnapChat	9	SMS	7	Discord, Messenger (FB)
10	Reddit	7	SnapChat	6	SnapChat
7	YouTube	6	Gov alerts	4	YouTube, Google Duo
2	WhatsApp	5	Telegram	2	Radio, Line, Zello
1	Discord, Gab, Telegram	3	Line, Instagram	1	Boss, Facebook, Fox, Instagram Marco Polo, Microsoft Teams, Oovoo, Telegram TextFree, TikTok, Walkytalkies
		2	Facebook, Discord, TextNow, Signal, GroupMe, Zello		
		1	WeChat, TextPro, Text me, TextFree		

#	Weather	#	National News	#	Emergency tech (ICE)
39	Weather channel	39	CNN	12	911
34	Apple weather	14	Apple News	11	Telephone
18	Local news	11	New York Times	6	FEMA
12	Accuweather	10	BBC, Fox	5	Emergency Alerts, iMessage
10	Weather.com	9	ABC	4	WhatsApp, Zello
6	Google, Weather Underground	8	Google, local news	2	FaceTime, ICE - In Case of Emergency app Radio, Red Cross, Twitter
5	NOAA	7	NBC, Twitter	1	Apple Notes, “Bank app”, Broadcastify, Citizen, Clime, CNN, Compass, First Aid, Flashlight, “Gas finding app”, Gmail, Google, Google maps, Google offline maps, Instagram, Invisawear, iOS emergency, Life360, Local emergency website, Local news, “Maps”, maps.me, Noonlight, “phone app for 911”, PictureThis, Pulse Point, Ring, Severe Weather Alerts, Storm shield, Text Now, Waze, Weather.com, Wells Fargo, 211
4	National Hurricane Center, WeatherBug	5	NPR		
3	Hurricane Tracker, Facebook, National Weather Service	4	Assoc. Press, Reddit		
2	Clime, Dark Sky, MyRadar, Space City Weather, Storm Radar, weather.gov	3	MSN		
1	ABC Weather, Apple News, CNN, Critical Weather, Emergency Alerts, FEMA, Instagram, Microsoft Weather, Max Hurricane Tracker, My Hurricane Tracker, MyWeather, RadarScope, RadarTracker, RZ Weather, Storm Stracker, Univision, Weather Alert, Windy, 1Weather	2	Facebook, NewsBreak, Telemundo		
		1	Axios, Buzzfeed, Citizen Daily Mail, Drudge Report, Estrella, The Guardian, Instagram, Morning Brew, Newsplace, New York Post, USA Today, Reuters, TV, Washington Post, YouTube		

Table 4. This table shows the number of participants who wrote in each app name in each category. For “Messages” in the Text Communication category, it is ambiguous what exactly participants—we hypothesize that it refers either to Android or iOS’s built-in messaging apps.

fema and for local places giving ot supplys like food ,ice...gas..and tarps." Reflecting the need for physical safety, some additionally turned to local news to check on local mandates and official warnings or orders, like *R*14, who used their local news app to "*see if there was any local mandates we needed to know about.*"

While most participants agreed that local news was vital during the disaster, they were split on the utility of national news. Some valued national coverage of the disaster, like *R*91, who "*used CNN to see what was being shown nationally about the disaster*," while others did not find national news had the level of detail and timeliness that they needed: "*Reddit, CNN and BBC don't have the local coverage, in real time, that I was looking for.*" D_I4 additionally wrote how they trusted their local news to be more accurate simply because it was local: "*I tend to trust my local news and politicians to keep me up-to-date than national news. They are not experiencing the hurricane in New York.*"

Weather apps: highly adopted and various. Consistent with their driving need for weather information, participants indicated substantial usage of weather apps or websites, including *adoption* of new apps or websites. As Figure 4 shows, 110 participants identified 155 weather apps or websites used during the storm, with 42 participants indicating they newly began using 62 apps or websites. Participants indicated 36 unique sources of weather information, the most diverse category in our dataset; additionally, 16 people indicated local news sources, and one person, Instagram.

Echoing the reasons why they used certain news and social media apps, participants preferred weather sources that had detailed, accurate, and timely information. Many participants acquired *new* apps or other sources of information specifically for the storm. *R*16 "*downloaded the local weather app as advised from the local weatherman*," highlighting the influence of local news on technology use and information consumption. Recalling Soden et al.'s work on the importance of properly communicating risk and preparation information to the public [104], *R*96 explained that, for them, it was important to have multiple sources of weather information and forecasts. They downloaded "*more weather apps ... because I found only having one app to rely on for weather was bound to get you mixed up sometimes and either over-prepping or under-prepping.*" Under-prepping could have physical safety or financial consequences (e.g., damage to personal property, loss of ability to work), while over-prepping could also have financial and personal consequences if one unnecessarily evacuates or buys unnecessary equipment.

The pattern of reliance on both weather and local news apps as well as the volume of adoption of new apps or information sources points to the critical importance of weather information sources—as with local news—during natural disasters. In Section 5, we explore the idea of weather and local news apps as safety-critical technology during a natural disaster.

In-case-of-emergency (ICE) technologies: bespoke apps rarely showed up in our dataset. Finally, we turn to technologies specifically built for emergency circumstances, referred to in the crisis informatics literature as ICE apps, and built for the *response* phase of emergency management. In our survey, we only loosely defined ICE apps to let participants respond as they saw fit, so some participants wrote in '911,' i.e., the phone number to call for emergency help in the US, and others considered emergency alerts to be an ICE technology. Because personal emergencies can occur at any time, we do not report data split by when participants used ICE technologies and instead focus on what technologies participants used and why.

Thirteen participants mentioned 911, and 7 mentioned regional emergency alerts, which may come in an app, a text, or an emergency message broadcast to all phones in a region. Six participants used the FEMA app and 2 had the Red Cross app—both apps by national or international organizations that help with storm response and emergency alerts. A few participants had bespoke ICE apps to send out personal information or detailed location information if they needed to be rescued. *R*51 had the app Invisawear "*to send emergency contacts my location*," and P_I13 prepared by downloading

the app what3words: "*in a serious flooding situation, I would need to call for help with my exact location. There's an app I keep on my phone called 'what3words' that allows for location within a few feet. Assuming I could keep the phone dry and operable, I'd use that for sure.*" Other crisis apps included My SOS Family, Pulse Point, Life360, FirstAid, and Noonlight. Another participant noted the iOS emergency feature. Prior work has explored how people use social media to supplement the existing emergency phone system (911) when it goes down during a disaster [128, 130].

Participants also noted a variety of tools not typically considered ICE apps. Some mentioned map apps, such as Google Maps, as critical to finding safe driving routes when cellular infrastructure was impacted. *R*14 "*didn't have internet and cell service was spotty so we used maps.me* [an offline map app] *for navigation.*" Multiple participants wrote in communication tools like "telephone" and "iMessage" and "WhatsApp." Others wrote in news and weather apps, and two had apps to listen to emergency services activity. Four mentioned analog technologies or apps that replace analog technologies (flashlight, compass, radio). The inclusion of these general-purpose apps and technologies points to their importance in emergency situations and highlights the importance of developing regular apps with low-resource contexts in mind, as we discuss in Section 5.

4.5 New Technology Use Strategies that Emerge Due to Downed Infrastructure

Finally, we turn to models of technology use adopted specifically because of electrical, cellular, and internet outages, common during hurricanes and other natural disasters. It is important to study the patterns of technology use that emerge in the resource-constrained and physically dangerous environments caused by hurricanes because these new strategies fill gaps left by technology largely designed for a different use case.

Power outages caused participants to ration their phone use and find alternative charging methods. Power outages are extremely common during and after hurricanes and may last for hours, days, or weeks. Thirty-seven participants restricted technology use to preserve their phone battery. As explored in Sections 4.2 and 4.4, some participants used apps with lower power draw, or used apps less frequently, at the cost of communication, information gathering, and psychological safety and entertainment. Recalling a bad winter storm from earlier in 2021, *R*89 wrote about how the lack of electricity left them starved for information: "*I was on my phone less, I was able to eat and bathe and stay warm through heat from the stove but I was unaware of what was going on in the world.*" Participants rationed electricity to prioritize what they needed (or expected to need) their phone the most for; for example, *R*80 explained that if their power went out, they would "*try to save my battery for needing to contact friends or EMS in case anything happened.*"

Participants described a combination of phone use rationing and alternative charging sources until electricity came back. Many participants' alternative charging sources were external smartphone batteries, but some used their cars, and others traveled locally to find somewhere to charge their phones.

Thus, we observe that damaged electrical infrastructure significantly constrains technology usage after a natural disaster, at times costing participants information, communication, work, and emotional health, recalling findings from Madianou et al. about communities in the Phillipines [71, 72]. However, individuals ration their power usage or find alternative power sources that somewhat mitigate the concerns, depending on the length of time. In Section 5, we explore recommendations for researchers, technologists, and policy makers to reduce the burden on those experiencing a hurricane.

Complete connectivity issues were largely insurmountable. Cellular and internet infrastructure is commonly damaged or destroyed by storms. In contrast to power outages, where participants can

ration their use of their phone battery or external batteries, there is no commercially available and affordable replacement for downed cellular and internet infrastructure.

Most participants who had no connectivity, i.e., lost both cellular service and wired/wireless internet, did not mention workarounds. However, some obtained offline technologies, including walkie talkies (or walkie talkie apps), local travel, and one-way radios. P_I9, for example, had "*to drive into town to get service to be able to respond to people.*" Likewise, P_I11 "*literally drove over to my in-laws house to ask them things...it was annoying.*" Driving, however, depends on the individuals having safe transportation and safe roadways, which is not always the case after a natural disaster. Six participants used radios, commonly recommended pieces of a disaster kit that receive news in a low-power and low-connectivity environment.

Others used offline apps, or apps they believed were offline. Two participants downloaded Zello, a walkie-talkie app, including P_I11, who "*downloaded Zello because I heard you could use it when you didn't have good phone service. I used it to communicate with my mother who was in a much harder-hit area.*" However, Zello does not actually work without a data or internet connection [43] and was the cause of misinformation following Hurricane Ida [20]. P_I6 observed: "*People were ... posting incorrect information about how the app Zello can be used when the phone lines go down.*" The adoption of new apps creates potential computer security and privacy risks, as we discuss in Section 5.

Partial connectivity was largely manageable. Not all lost connectivity completely: losing electricity might mean losing internet, but not necessarily cell service. $R8$, for example, described that they were able to"*use... a mobile hotspot for wifi and used candles for light.*" Indeed, multiple participants who retained cellular connection relied on the mobile data plans for connection—$R14$ "*had access to the internet through our data plans on our phone*" and P_I4 even "*bought additional data for the month so we could stay connected, up to date, and entertained until power was restored.*"

We see, then, that communities *can* make do with partial connectivity. However, there are costs to doing so, e.g., loss of information or communication because of deprioritization or the financial costs of purchasing additional mobile data or an electrical generator.

5 DISCUSSION AND CONCLUSIONS

Our results show that those affected by hurricanes have varied strategies for fulfilling their needs, but a common set of needs, circumstances, and barriers. Through our surveys of people affected by hurricanes, we show that a wide range of technologies are of critical importance to those affected (in line with prior work about the utility of social media); however, we also explore how hurricanes often limit technology use, and we urge the HCI and CSCW communities to design for those in resource-constrained situations, who *might* use technology if it were not a drain on their resources, rather than for those who already *do* use technology during crises.

Here, we step further back and synthesize our results for a broader audience. Our recommendations address a wide range of researchers, technologists, and policy-makers, in hopes of various and interdisciplinary solutions. Here, we propose several directions for technical solutions to problems that are ultimately caused by the failure to adequately protect physical infrastructure, so we emphasize that at a high level, **policy makers** must continue to push for resources to fix and protect physical infrastructure, especially in communities that are vulnerable to natural disasters.

Connectivity issues can be addressed at multiple levels. One key finding (see Section 4.5) is that complete loss of connectivity—both internet and cellular service—is essentially insurmountable, and a partial loss of connectivity led participants to ration technology use and potentially missing critical information. Though there have been and are a number of efforts to develop and deploy

technologies that ameliorate connectivity issues (see Section 2.1 for a brief overview of technical efforts), we observe that none were widely and successfully used amongst our participants.

While tempting to push for the inclusion of peer to peer (P2P) networking protocols or modes in popular apps—apps that are *already* widely installed and used, removing the barrier of group adoption [26]—we acknowledge that imposing P2P on users who do not explicitly opt in can lead to severe safety issues, e.g., how victims of intimate partner violence can be tracked using Apple devices that are turned off due to the P2P nature of Apple's device locator protocols [30]. While we argue for neither one nor the other, we implore researchers, technologists, and policy-makers to ask how to make disruption-tolerant networking communication protocols ubiquitous, *yet still safe for all users.* More broadly, we observe that hurricane survivor-victims *need* connectivity, for physical and psychological safety, and that resiliency can be implemented at multiple levels (infrastructure, personal hardware, software, protocols), but that any implementation should be evaluated against the most vulnerable people in the community it serves [24].

Systems and app developers should design for low-resource contexts in order to reduce the difficulty of electricity rationing. Another central finding was the importance of power rationing (Sections 4.4 and 4.5). We strongly recommend that app developers design a low-power (or low-connectivity) mode that users can opt in to or out of. This could mean different things for different apps: pre-fetching data when connected to power and not on the OS's lower power mode, lowering the quality of video and images, not showing ads, reducing or stopping automatic uploads (e.g., backups). This type of power rationing could also be done at the operating system level, like existing low power modes on iOS and Android, and could prompt the user to opt-in to low power mode if the area is experiencing (or about to experience) a significant natural disaster. Through the many technical options here, we stress that users must be kept in control, as the ones who will understand their situation and limitations best; technology should adapt to their situation but not prescribe their options.

Moreover, we urge **all developers** to *develop for crisis* and, specifically, to develop with low-resource and high-importance contexts in mind (which may also extend beyond natural disasters and beyond crisis). Prior work shows that it may be difficult for users to adopt new communication platforms quickly during a crisis, e.g., a political revolution [26], so we emphasize that all apps should be designed with crisis usage in mind, meaning: usable during low-power and low- or no-connectivity. The makers of Zello, the walkie talkie app that multiple participants thought was usable offline and that now (as of 2022) advertises itself as "*ideal for emergency and disaster events,*" wrote on their blog that "*Zello's role of communication in natural disasters was never anticipated when we created the app*" [120]. We urge *all* app developers to design for crisis so that people can use their normal suite of apps to fulfill their needs—e.g., a game may bring much-appreciated emotional support or distraction, a news app may provide critical information, and a communication or social media app may help connect with loved ones or immediate aid. We also note that crises can include adversarial contexts—such as the rise in intimate partner violence during Hurricane Katrina [96], or scams directed at people experiencing natural disasters—so part of developing for crisis is considering a wide variety of threat models and empowering users with appropriate and accessible technology to address complex needs.

Technologies used during, after, and in preparation for crises have substantial security and privacy implications. Through our results (Sections 4.2, 4.3, and 4.5), we observed parallels and tensions between disaster preparation/response and security and privacy best practices; we strongly recommend that **security and privacy researchers** investigate these further. Recall, for example, participants' storage of sensitive documents in preparation for a storm (Section 4.3)—i.e., in the cloud, on external hard drives, in email. Though the security community does not tend to agree

on specific, prioritized, and actionable advice [89], some might say that users should never store unencrypted sensitive documents in the cloud, or in emails, but these *were* effective hurricane preparation strategies for some participants. However, there is no technical reason for these practices, namely, document storage safe from both technical adversaries and flooding, to be at odds. This tension, and others like it, offers an opportunity for both security and privacy researchers and crisis researchers to consider how their work fits into users' lives more broadly.

Additionally, weather, social media, local news, and other sources can provide safety-critical information—information that dictates a decision about physical safety. As discussed, it is important for developers to create technology that matches the low-resource use cases of a natural disaster, but it is *also* key that we treat these technologies and information sources as safety-critical during a disaster and that we thus form appropriate threat models about potential adversarial interference. For example, popular local weather websites or social media accounts of local officials might become high value targets during a crisis if an adversary wanted to disrupt disaster aid and recovery programs, extract money from the target, or harm people in the affected communities physically and financially with disinformation. Indeed, many groups have studied post-crisis misinformation on social media, but our recommendation is to consider harms and avenues of attack beyond misinformation on social media, e.g., vulnerabilities or overpermissioning in weather apps.

Mitigations can be non-technical in nature as well. For example, the diversity of local news and weather information sources suggests that people *do* adopt some new technologies and information sources in preparation for and during crises; they also point to the importance of having quality, well-funded local news and weather sources.

Researchers should continue to study both technology use and the barriers to or gaps in technology use in stressful and low-resource situations. Despite the extraordinarily valuable existing body of work on technology built for disasters and social media use during disasters, we find that substantial gaps remain. Following the lead of research on the spectrum of technology use, particularly in poor and remote non-WEIRD contexts [9, 126], we encourage **crisis researchers** to ask questions like: What *other* technologies are people using? What technologies are they *not* using, and why not? What technologies do they need but not have, if any? We recommend future work branching out to study the diversity of experiences during disasters, including people who are unable or unwilling to use technology. Studying the entire spectrum of technology use is critical to beginning to address inequities caused by misalignments in technical design, disaster response, and social systems [25]. Further, researchers should investigate additional gaps in the stakeholders considered. For example, while research has been done on analyzing the use of technology by emergency responders (e.g., [52, 56, 63, 70, 76]), that subfield of study is also worthy of continued investigation.

Through our methodology and analysis, we recognize that it is inherently challenging to study the spectrum of technology use during a hurricane: those who can use technology are by definition overrepresented in during-hurricane online surveys, and surveys relying on recollection of past events suffer from known human biases of recollection as data collection occurs farther from the event, but closer to the event, and it is infeasible or unethical to try to recruit people who are adversely affected by the disaster. Additionally, as discussed in Section 3.7, online surveys have known demographic biases and overrepresent people who use technology and people who are not marginalized. We invite future researchers to improve on our methodology for studying technology non-use during a disaster; we considered a paper diary study with hurricane-prone participants and ran into an institutional logistical impasse with implementation, but recommend data collection techniques that do not wholly rely on technology [124], given the nature of the research questions.

Conclusions. Here, we have identified two gaps in prior work about technology use during natural disasters: (1) that prior work lacks a complete view of technology use during natural disasters,

and (2) that much of the work in the HCI and CSCW communities focuses on technology use, rather than technology disuse. These gaps cause these communities to miss an opportunity to serve marginalized and underprivileged communities, who may have higher barriers to technology use after a natural disaster that affects electrical and connectivity infrastructure. We present a broad view of technology use and disuse during hurricanes in the mainland US, and we offer broad future research directions to a wide variety of researchers, technologists, policy makers, and practitioners.

Throughout this paper, we explored how hurricanes can limit resources, causing changes in technology use and information needs, and how limitations on electricity and connectivity can cause competing needs and uses of technology that leave people unable to fulfill all technology and information needs. We also suggest that this prioritization may be caused by system design that does not support low-resource contexts, and that designs that do not support these contexts do a great disservice to communities that have historically experienced systemic disaster aid and infrastructure failures after natural disasters. We focus heavily on how the consequences of failed physical infrastructure interact with technology access, and how technical design can potentially *accommodate* physical infrastructure failures, but should not be considered a complete solution, as the issue more broadly stems from infrastructure not suited to a warming planet.

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A CODEBOOK

Our codebook is shown in Tables 5 and 6, split across multiple tables for readability.:

Category	**Code**	**Definition or example**
Needs	Find resources	Finding gas, groceries, batteries
	Emotional stability & psych. safety	e.g., don't look at the news because it makes you scared
	Entertainment	"pass time," entertainment, stave off boredom
	Evacuation routes	Find the safest route out of disaster
	Be informed	Stay up to date w/info, know about family, etc
	Communicate	Talk to friends and family
	Communicate – Safety check	Tell ppl you are safe. Includes passive safety checks
	Financial stability	School/job impacted or other financial impact.
	Physical safety	General safety & emergency info & alerts.
	Get help in an emergency	e.g., use ICE app, send emergency contacts location
Info needs: *Quality of info*	Accurate & trustworthy	Information is correct and they trust it
	Volume	e.g., nothing important missing. Includes detail.
	Timeliness	News is up-to-date / current
Info needs: *Type of info*	Weather info	Radar, forecasts, etc
	Assistance	Find / give storm recovery help
	Info about community	See the extent of the damage, get local news & advisories. Does *not* incl. emergency alerts.
	Info about the world	Keep up with the news in general (not local)
	Learn what to do	Learn what they should do, individually, to recover from, ride out, or prepare for the storm. *Not* learn where to get, resources find evac routes, or generally stay informed.
Tech use during storm	In-case-of-emergency	Mention of a specific app in a free response question or it's abundantly clear what app or technology their response refers to
	Text communication	
	Audio / video comm	
	Weather	
	Social media	
	Local news	
	National news	
	Unk. communication	Communication tech but unclear what kind
	Other news	News but unclear whether local or national
	Other app	
Infosec issues	[no subcode]	Any mention of misinformation, scams, or anything *they* considered security/privacy

Table 5. Our codebook (part I).

Category	Code	Definition or example
New strategies: *Keep phone running*	Ration electricity	Decreasing use because they're relying on another electricity source, don't use X app because it drains the battery. Can infer if they're talking about a power outage and they say they used their phone less.
	Alternate charging methods	Phone bank, neighbor's house, etc
	Phone settings	Lower brightness, low power mode, etc
New strategies: *Keep in touch*	Advance check-in times	Plan to check in anticipation of downed infrastructure
	Visit in person	Went to check on friends/family
	Offline communication	use apps that work offline or they believe work offline
	Rely on people not as affected by the storm	e.g., neighbors, friends
	Manually relay messages	Used messaging apps or phone calls to spread info about others / between others
	VoIP apps	Call over wifi instead of the tele phone
	Telephone	Used the telephone
New strategies: *Connectivity*	Ration time online	limit time using connectivity
	Travel locally	Go somewhere that has connectivity
	Use mobile data	Use mobile data instead of internet
	Radio	Use a one-way or two-way radio
	Mobile hotspot	Connect to the internet using a mobile hotspot
New strategies: *Get/share info*	Crowdsourcing / digital volunteerism	Look for / share info on social media
New strategies: *other*	Living arrangement change	e.g., candles. includes "no tech"
Storm context: *Storm*	Debby	Name of hurricane they experienced
	Florence	
	Harvey	
	Ike	
	Irma	
	Matthew	
	Sally	
	Unnamed hurricane	
	Non-hurricane	Some other natural disaster (specific)
Storm context: *Outages*	Electricity	Power outage — may have generator or batteries
	Cellular	Cellular service outage
	Internet	Internet outage (WiFi or terrestrial internet)
	Unspecified loss of connectivity	Some connectivity outage, not specified (cell / internet)
	Unspecified outage	Some outage, not specified
	Concerned about outage	Worried that an outage will happen

Table 6. Our codebook (part II). This table is a continuation of Table 5. Codes and categories are displayed in no particular order and are split only for readability.

B APPENDIX: HURRICANE SURVEY MODULES

There were 3 different surveys in this project, comprised of similar/the same questions. We present the modules here, then show how they fit together.

Survey flow information is denoted by `text like this`.

B.1 General preparation module

Q1 What natural disasters occur in your area?

- Floods
- Wildfires
- Cyclones, hurricanes, and/or tropical storms
- Blizzards and/or ice storms
- Droughts
- Extreme cold
- Extreme heat
- Tornados

Q2 In general, how do you and your household prepare for natural disasters / extreme weather?

- We stock extra food and/or water
- We stock supplies to create a temporary shelter (e.g., tent, plastic sheeting, duct tape)
- We stock external sources of power or light (e.g., batteries, generator, candles)
- We stock medical or sanitary supplies (e.g., first aid kit, medications, contact solution)
- We stock extra currency (e.g., cash, travelers checks, etc)
- We have weapons prepared (e.g., pepper spray, firearms)
- We physically prepare our home or community
- We plan with others in our community
- We make specific preparations for our pets (e.g., extra food, backup power for aquariums, etc)

Q3 What technology or information-related preparations do you and your household make for natural disasters / extreme weather?

- We put paper copies of important or sentimental documents in a certain safe and/or accessible place (e.g., identification, insurance deeds, etc)
- We maintain or update digital copies of important or sentimental documents (e.g., in the cloud, on a portable USB drive in a safe place, etc)
- We download certain apps or software (e.g., FEMA app, local weather app, Google offline maps)
- We keep backups of authentication methods (e.g., written copies of important passwords, written copies of multi-factor authentication codes, alternative hardware authentication devices)
- We have external smartphone batteries
- We keep alternate two-way communication methods (e.g., standalone mobile hotspot, pocket WiFi, satellite phone, two-way radio)

Q4 If there is anything else that you do (or plan to do) to prepare for a natural disaster, please write a sentence or two here about it:

Q5 If there are any preparations that you would *like* to do, but you cannot for some reason, please write a few sentences here: (a) what would you like to do to prepare, and (b) why can you not do it?

`Q6 displayed if more than 1 box from Q2 is checked`

Q6 In general, how did you learn about (or decide to do) these preparations? Check all that apply.

- friend or family member
- neighbor or community member
- online search about disaster preparation or something similar other online search
- news story
- online ad
- offline ad (e.g., billboard, newspaper ad, etc)
- public service announcement
- informational website: *[free response box]*
- applied from other aspects of my life
- I previously experienced a hardship in which I needed or wanted this
- Other *[free response box]*

`Q7 and Q8 are displayed if the corresponding box from Q3 is checked`
Q7 You indicated that you keep paper copies of documents. Please tell us briefly about (a) how you store the documents safely, and (b) what sort of documents you have stored.
Q8 How did you learn (or decide) to keep paper copies of important documents as part of your disaster preparation? Check all that apply.

- friend or family member
- neighbor or community member
- online search about disaster preparation or something similar other online search
- news story
- online ad
- offline ad (e.g., billboard, newspaper ad, etc)
- public service announcement
- informational website: *[free response box]*
- applied from other aspects of my life
- I previously experienced a hardship in which I needed or wanted this
- Other *[free response box]*

`Q9 and Q10 are displayed if the corresponding box from Q3 is checked`
You indicated that you keep digital copies of documents.
Q9 Please tell us briefly about (a) what kind of storage you are using (e.g., the cloud, USB), and (b) what sort of documents you have stored digitally.
Q10 How did you learn (or decide) to keep digital copies of important documents as part of your disaster preparation? Check all that apply.

- friend or family member
- neighbor or community member
- online search about disaster preparation or something similar other online search
- news story
- online ad
- offline ad (e.g., billboard, newspaper ad, etc)
- public service announcement
- informational website: *[free response box]*
- applied from other aspects of my life
- I previously experienced a hardship in which I needed or wanted this

- Other *[free response box]*

`Q11 and Q12 are displayed if the corresponding box from Q3 is checked`

You indicated that you have downloaded or plan to download certain apps or software as part of your disaster preparation.

Q11 What apps or software do you (or did you) download? Please be specific and write as many as you can remember.

Q12 How did you learn about (or decide to download) these apps? Please check all that apply.

- friend or family member
- neighbor or community member
- online search about disaster preparation or something similar other online search
- news story
- online ad
- offline ad (e.g., billboard, newspaper ad, etc)
- public service announcement
- informational website: *[free response box]*
- applied from other aspects of my life
- I previously experienced a hardship in which I needed or wanted this
- Other *[free response box]*

`Q13 and Q14 are displayed if the corresponding box from Q3 is checked`

You indicated that you keep backups of authentication methods.

Q13 Please tell us briefly what those backups are. Note: this question is not asking you for your passwords; we are asking if, for example, you keep a copy of your passwords in or near your emergency kit, or if you use a cloud-based password manager. Do not tell us your passwords.

Q14 How did you learn (or decide) to keep backups of authentication methods? Please check all that apply.

- friend or family member
- neighbor or community member
- online search about disaster preparation or something similar other online search
- news story
- online ad
- offline ad (e.g., billboard, newspaper ad, etc)
- public service announcement
- informational website: *[free response box]*
- applied from other aspects of my life
- I previously experienced a hardship in which I needed or wanted this
- Other *[free response box]*

`Q15 and Q16 are displayed if the corresponding box from Q3 is checked`

You indicated that you keep external smartphone batteries.

Q15 Please write a sentence or two about how these fit into your disaster plan. For example: how many do you have, when do you charge them, do you use them for other purposes, etc.

Q16 How did you learn (or decide) to acquire these technologies? Please check all that apply.

- friend or family member
- neighbor or community member
- online search about disaster preparation or something similar other online search
- news story

- online ad
- offline ad (e.g., billboard, newspaper ad, etc)
- public service announcement
- informational website: *[free response box]*
- applied from other aspects of my life
- I previously experienced a hardship in which I needed or wanted this
- Other *[free response box]*

`Q17 and Q18 are displayed if the corresponding box from Q3 is checked`
You indicated that you keep alternate two-way communication technologies (e.g., standalone WiFi hotspot, pocket WiFi, satellite phone, two-way radio, etc).
Q17 Please tell us specifically what those technologies are.
Q18 How did you learn (or decide) to acquire these technologies? Please check all that apply.

- friend or family member
- neighbor or community member
- online search about disaster preparation or something similar other online search
- news story
- online ad
- offline ad (e.g., billboard, newspaper ad, etc)
- public service announcement
- informational website: *[free response box]*
- applied from other aspects of my life
- I previously experienced a hardship in which I needed or wanted this
- Other *[free response box]*

Q19 If you had any issues with the questions in this section, please let us know here!

B.2 Apps used during everyday life and/or a specific disaster

Q1 Please tell us the names of 3 apps or websites you use in each of the following categories. Please put down apps that you use frequently either during a crisis, or during non-crisis times, or both. *Note: It's fine to leave some blank if you don't have 3 apps in a category; if one app fits in multiple categories you only need to input it once.* ***You must input at least one app.***

`Participants wrote any number of apps in the 21 spaces shown in Figure 5. There were three spaces for apps in each of the seven following categories: weather, national / international news, local / regional news, social media, text communication, video or audio communication, in-case-of-emergency`

`One survey employed a filter question here to ascertain whether participants had experienced a disaster in the past 10 years.`

`We then showed participants the apps they had entered next to three categories about how they had used the apps and asked participants to sort the apps into the appropriate categories, as shown in Figure 6`

Q2 Please drag the app names into the appropriate categories (order does not matter).
`Categories:`
[Scenario A] I have used this app during a disaster, but not during everyday life
[Scenario B] I have used this app during everyday life, but not during a disaster
[Scenario C] I have used this app during both a disaster and everyday life

Fig. 5. Screenshot of the Qualtrics interface where participants entered apps they have used, with example data (data not shown to participants)

We then asked free-response questions about the categories of apps:

SCENARIO A:
Q3 What did you use these apps for?
Q4 Did you encounter any issues or have any concerns with these apps?
SCENARIO B:
Q5 Please briefly explain why you could NOT use these apps or website during the disaster, or why you choose not to.
SCENARIO C:
Q6 How did you use these apps during the disaster?
Q7 Did you encounter any issues or concerns with these apps or websites during the disaster?
Q8 If you had any issues with the questions in this section, please let us know here

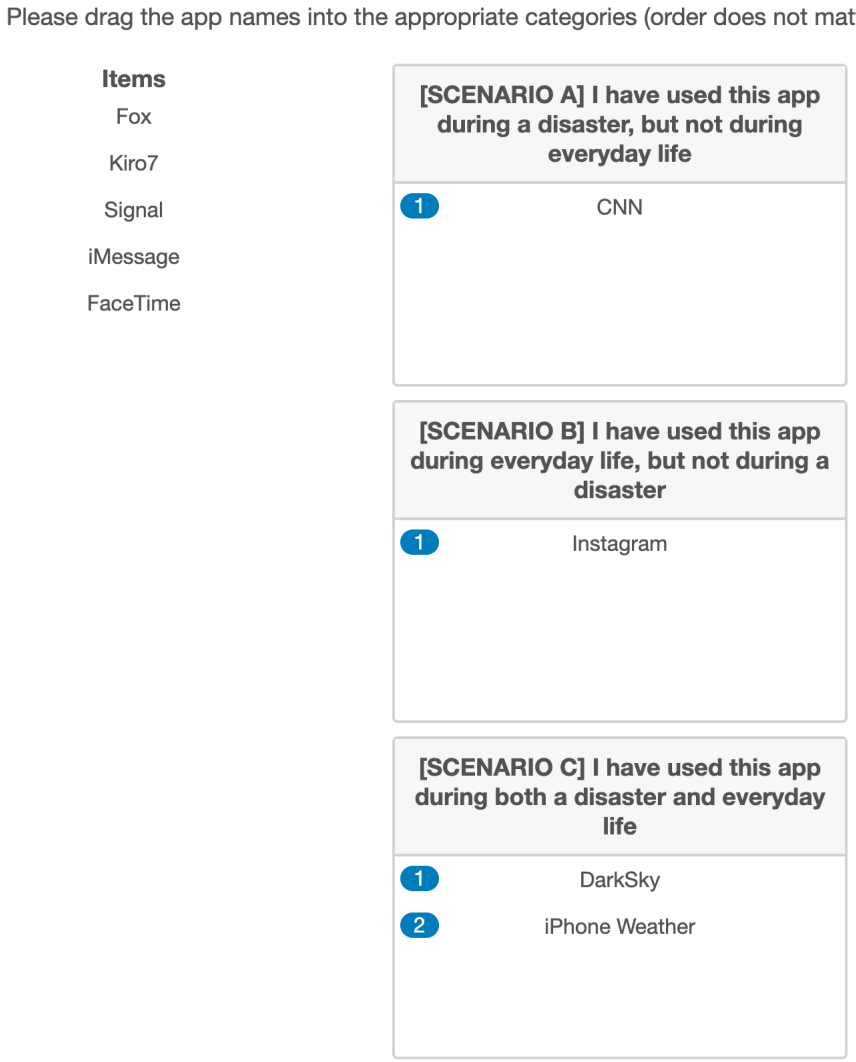

Fig. 6. Screenshot of the Qualtrics interface where participants sorted the apps they had entered previously, with example data (data not shown to participants)

B.3 Reflections on use of technology during the disaster

Our survey evolved after our baseline run because we thought, based on pilot interviews and surveys, that participants might be able to answer more specific free response questions more immediately after or during a disaster. Both versions of this question broadly cover self-reported changes in technology use during a storm. The questions from the survey deployed at the start of hurricane season, then, ask specifically security and privacy issues, while the questions from the survey deployed during and immediately after a hurricane ask more specifically about what

was or what would be most critical about their technology use, and then ask generally about technology-related concerns.

B.3.1 Questions deployed at the start of hurricane season.

Here we're going to ask a little more about your experience using technology during the disaster that affected you or your community. When answering these questions, please be as specific as possible!

Q1 How did your use of technology change in the recovery period after the disaster? [free response]
Q2 For example, what new apps or technologies did you use? What apps or technologies did you stop using? [free response]
Q3 Did you or anyone you know encounter any scams directed at people recovering from a natural disaster, or any other security and privacy issues?
Q4 If so, please tell us briefly about them. [free response]
Q5 Did you lose power, internet, or cellular service for an extended period of time? [yes, no]
Q6 If you had any issues with the questions in this section, please let us know here

B.3.2 Questions deployed during or immediately after a hurricane.

Q7 How did your technology use change from normal during this extreme weather, if at all? Please be specific / detailed.
Q8 Did you use your phone / computer / tablet at all during this extreme weather? [yes, no]
`If the participant used technology during the storm, display the following three questions`
Q9 What did your phone / computer / tablet provide that was *most critical / important* **during** the situation?
Q10 What did your phone / computer / tablet provide that was *most critical / important* **in preparation** for the situation?
Q11 How do you think your experience would have changed if you hadn't been able to use your devices?
`If the participant did not use technology during the storm, display the following two questions.`
Q13 Why didn't you use your phone / computer / tablet?
Q14 How do you think your experience would have changed if you had used your devices?
`Display the following questions about concerns to all participants.`

`For participants currently experiencing a storm:`
Q15 What are your biggest technology- or internet-related concerns right now, if you have any?
`For participants who recently experienced a storm, display the following 3 questions:`
Q16 What were your biggest concerns during the situation?
Q17 What were your biggest technology- or internet-related concerns during the situation, if you had any?
Q18 What are your biggest technology- or internet-related concerns right now, if you have any?

B.4 Demographics

It is important that we understand the skew of our study sample, so this section asks for your demographic information. We have done our best to not ask unnecessarily invasive questions.

However, we would like to remind you that all questions in this survey are optional and that you are not required to share any of this information with us.

Q1 What is your age? [free response]

Q2 What is the highest level of school you have completed or the highest degree you have received?

- Less than high school degree
- High school graduate (high school diploma or equivalent including GED)
- Some college but no degree
- Associate degree in college (2-year)
- Bachelor's degree in college (4-year)
- Master's degree
- Doctoral degree
- Professional degree (JD, MD)

Q3 Choose one or more races or ethnicities that best fit your identity by checking all that apply. You can also (or instead) self-describe in the next question.

- American Indian or Alaska Native
- Asian
- Black or African American
- Hispanic, Latinx, or Spanish
- Native Hawaiian or Pacific Islander
- Middle Eastern
- South Asian
- South East Asian
- White

Q4 If you prefer to self-describe your race and ethnicity instead of or in addition to using the checkboxes above, please do so here. [free response]

Q5 What is your gender? Check all that apply.

- Woman
- Man
- Non-binary
- Prefer to self describe: [free form]

Q6 Information about income is very important to understand. Please indicate the answer that includes your entire household income in 2020 before taxes.

- Less than $10,000
- $10,000 - $19,000
- $20,000 - $29,000
- $30,000 - $39,000
- $40,000 - $49,000
- $50,000 - $59,000
- $60,000 - $69,000
- $70,000 - $79,000
- $80,000 - $89,000
- $90,000 - $09,000
- $100,000 - $149,000
- $150,000 or more

Q7 Do you think of yourself as closer to the Republican or Democratic party?

- Republican
- Democratic

Q8 What is the name of the town or city in which you live? [free response]
If you are not comfortable giving this, you can give the name of a nearby large city or town, or skip this question.
Q9 What is your zip code? [free response]
Q10 For how many years have you lived in your area? [free response]
Q11 If the above questions did not fit your identity, or if there is anything else you think we should know about you, demographically, please write it here. [free response]
Q12 If you had any issues with the questions in this section, please let us know here [free response]

B.5 Storm context module

`One of the following was displayed, as appropriate:`

- You indicated that you are experiencing a hurricane or tropical storm (or related weather).
- You indicated that you are expecting a storm or other extreme weather in the next 48 hours or so, or that you were expecting a storm that did not occur.

`During a storm, the following question was displayed:`
Q1 Briefly, what's going on? Please write at least one sentence, and feel free to write more. [free response]

`If participants that they were or had been expecting a storm, the following question was displayed:`
Q2 What type of weather do/did you expect?

`For surveys deployed after a storm, the following two questions were displayed instead:`
Q3 Please briefly describe your experience of the storm. Was there extreme weather and, if so, what happened? What did you and your household experience? [free response]
Q4 How long did it last? [free response]

`The following questions were modified to include the correct tense based on whether the participant was currently experiencing a storm or had recently experienced a storm.`
Q5 How much has the storm interrupted your daily routine? [None, a little, a moderate amount, a lot, a great deal]
Q6 For the past 24 hours, for what percent of the time have you had the following at home....

`Participants were shown slider scales from 0-100 for each utility, as well as a 'not applicable' button, as show in Figure 7`
Q7 In what ways has the extreme weather interrupted your daily routine? What do you want to do but are unable to? [free response]
Q8 In general, what do you expect will happen in the next 24 hours? [free response]
Q9 In general, what do you expect will happen in the next 7 days? [free response]
Q10 What are your biggest concerns currently? [free response]

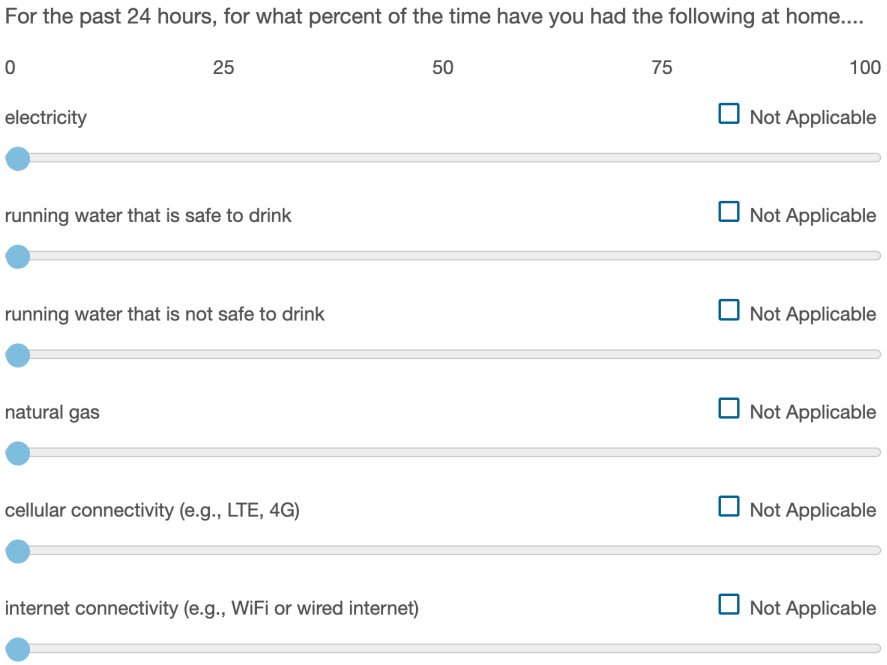

Fig. 7. Participants indicated the availability of certain common utilities at home during the storm using the sliders pictured.

B.6 Technology use during the storm module

This section was mostly comprised of two tables that asked participants to estimate how much time they spent on a category of activity like 'social media' in the past 24 hours. These two tables are shown in Figures 8 and 9
For participants who were currently experiencing a hurricane:
Q1 Please estimate the number of minutes you spent on each activity in the past 24 hours.

For participants who had recently experienced a hurricane:
Q2 Please estimate the number of minutes you spent on each activity in a typical 24 hours during the storm.

Participants were presented with an 8x4 grid of boxes to fill in. The columns were:

- Total time spent on this activity (Approximate). Please use the format "Xh Ym", e.g., 1h 15m for 1 hour and 15 minutes.
- Name of your most used app or website (or N/A)
- I was able to do as much of this as I wanted (Yes/No)
- Is this more or less than your typical use? (More/Less/About the same)

The rows were:

- Communicating with local people
- Communicating with non-local people

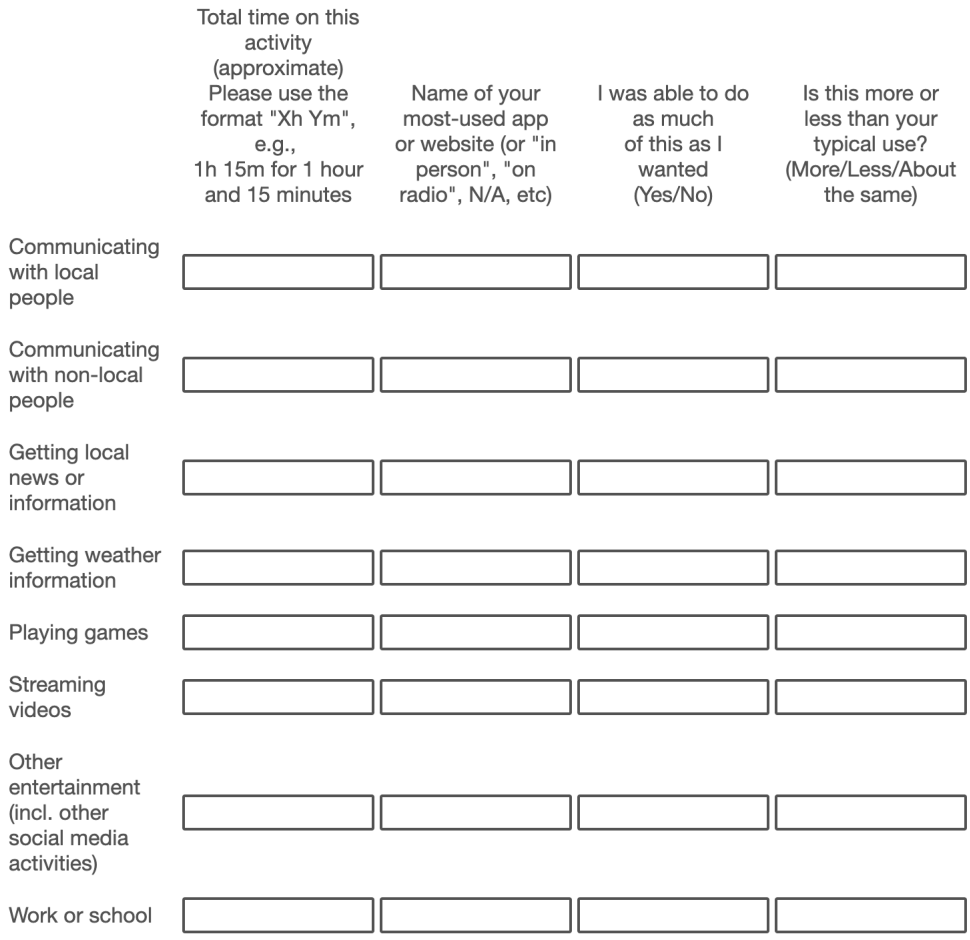

Fig. 8. Tech use table: high level task

- Getting local news or information
- Getting weather information
- Playing games
- Streaming videos
- Other entertainment (incl. other social media activities)
- Work or school

Q3 For any of the above activities that you were not able to do as much as you wanted: why not? [free response]

`For participants who were currently experiencing a hurricane:`

Q4 Please estimate the amount of time you spent on each kind of communication in the past 24 hours.

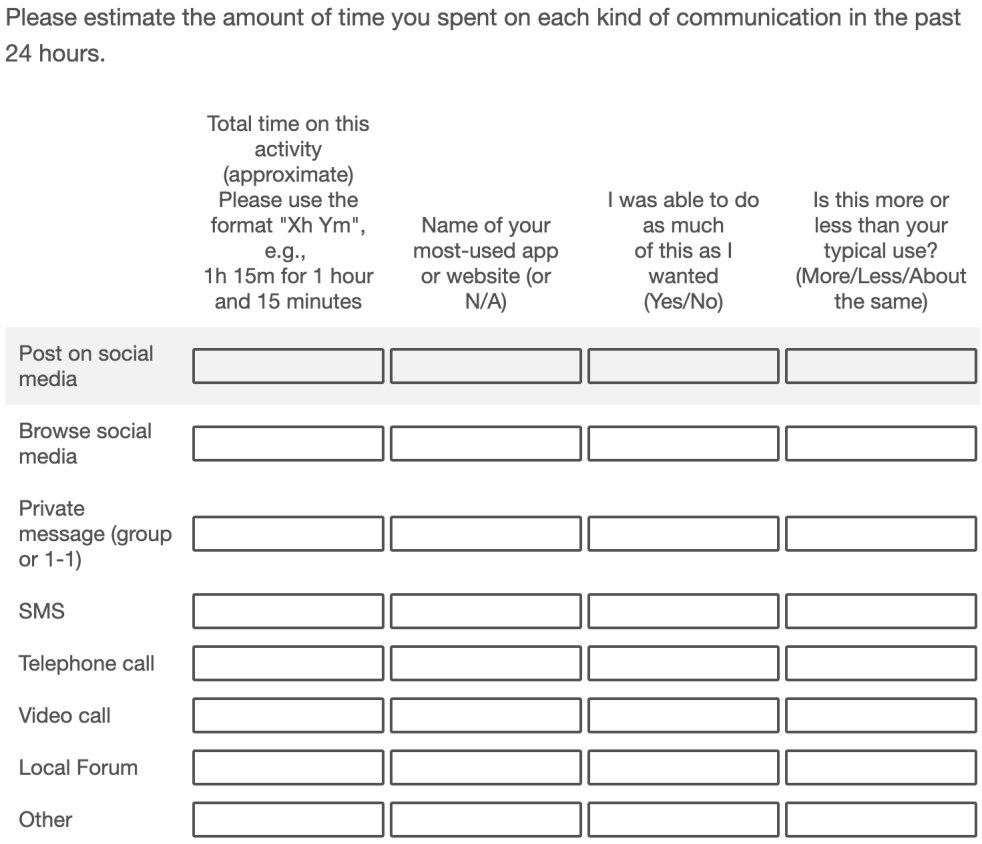

Fig. 9. Tech use table: type of technology used

`For participants who had recently experienced a hurricane:`

Q5 Please estimate the number of minutes you spent on each kind of communication in a typical 24 hours during the storm.

`Participants were presented with an 8x4 grid of boxes to fill in. The columns were the same as the above. The rows were:`

- Post on social media
- Browse social media
- Private message (group or 1-1)
- SMS
- Telephone call
- Video call
- Local Forum
- Other

Q6 For any of the above activities that you were not able to do as much as you wanted: why not? [free response]

B.7 Module: recent InfoSec issues

In the this section, we're going to ask about some **things that you might have experienced in the past week**. In both categories (information security and device access), we have given several options for issues you might have experienced. Please do not be limited by these options; if you have experienced a different issue, however YOU define "issue" or "problem," we would like to hear about it! Check whatever fits you best, and please explain in the text boxes provided in the next question.

Q1 Information security:

- I experienced a scam, identity theft, stolen financial information (or attempts)
- My password(s) was/were stolen
- I was locked out of an account
- I encountered misinformation
- Another issue related to computer or information security or privacy

`If any of the previous choices are selected, display the following one question:`

Q2 You indicated that you experienced some sort of computer or information security or privacy issue. Please write a sentence or two about what happened. [free response]

Q3 Device Access:

- I got a new phone, tablet, or computer
- I got a new smarthome device (e.g., Alex, WiFi-enabled lightbulbs, Ring camera, etc)
- Another change in access to technology

`If any of the previous choices are selected, display the following one question:`

Q4 You indicated that you gained or lost (or got rid of) a piece of technology. Please us briefly what happened: what kind of device did you either gain or lost, and why?

`If either of the second two choices are selected, also display the following one question:`

Q5 If there is anything in particular you did with your new device(s) to prepare for a weather-related emergency, please explain here and be as specific as possible. [free response]

B.8 Module: Disaster kit usage and reflection

B.8.1 Questions deployed in the current hurricane survey.

We would like to learn about how you're using the items in your disaster kit. Please use the space below to list the items you've used from your kit.

Q1 Is there anything that you wish you had in your kit?

Q2 In the past week, have you changed anything about your disaster preparation?

- Yes, I have added items to my kit
- Yes, I have removed items from my kit
- Yes, I did something else (e.g., speaking with insurance, taking photos, etc)
- No changes

`If "Yes, I have added items to my kit" is selected, display the following questions:`

Please tell us a little about the changes you made to your disaster preparation....

Q3 What did you add? Why?

Q4 Who or what caused this addition? How did you hear about this item, or hear that it should be in your disaster kit?

`If "Yes, I have removed items from my kit" is selected, display the following questions:`
Please tell us a little about the changes you made to your disaster preparation....
Q5 What did you remove? Why?
Q6 Who or what caused this removal? How did you come to decide to remove this item?

`If "Yes, I did something else" is selected, display the following questions:`
Please tell us a little about the changes you made to your disaster preparation....
Q7 What were the changes you made? Why?
Q8 Who or what caused these changes? How did you hear about these changes, or learn that these changes would be useful to you?

B.8.2 Questions deployed in the post-hurricane survey.

Q9 What items from your disaster preparation kit did you use, if any? [free response]
Q10 Consider your preparation. Is there anything you will change in the future? [free response]
For the next two questions, think about any digital or technical preparations you made – for example, maybe you took pictures of important documents, made backups, made copies of passwords, set up specific smart home rules, etc.
Q11 Which of these were useful? [free response]
Q12 Which do you expect will be useful in the future? (feel free to consider hypothetical or unlikely scenarios). [free response]
Q13 If you could invent a magic item or a magic solution to make extreme weather less impactful on you and your community, what would it be? Don't consider cost or what is "possible" with technology or infrastructure. [free response]
Q14 Which of the following applied to you during the storm:

- I used the food or water in my disaster kit
- I used the supplies in my disaster kit to make or fix my shelter
- I used my emergency supply of power or light (e.g., candles, flashlights generator, etc)
- I used my supply of medical or hygiene equipment
- I used the extra currency in my disaster kit
- I used the weapons in my disaster kit
- I used the plans I made with others in my community
- I used my preparation of paper documents (e.g., I saved paper documents somewhere and referenced the documents, took them with me when I evacuated, etc)
- I used my preparation of digital documents (e.g., I saved documents digitally somehow and referenced the documents, used them to get a replacement paper document, etc)
- I used apps I downloaded specifically for the storm
- I used my external smartphone batteries
- I used my alternate communication methods

`Based on which of the options above were selected, the appropriate free response questions were displayed below:`

Q15 You said that you used the paper documents that you had prepared before the storm. Please write a sentence or two about why you had to use them and what you did with them. [free response]
Q16 You said you used the digital documents that you had prepared before the storm. Please write a sentence or two about why you had to use them and what you did with them. [free response]
Q17 You said you used apps you downloaded specifically for the storm. What apps? What did you use them for? [free response]
Q18 You said you used external smartphone batteries. For how long did you rely on the external smartphone batteries? What did you do with your phone while you were relying on the batteries? [free response]
Q19 You said you used alternate communication methods. What did you use? Why? Did it work? [free response]

C HURRICANE SURVEY FLOWS

The following subsections give the consent text, the survey modules, and any extra questions that appeared in the surveys. We also include the recruitment messages for the during-hurricane survey, since we sent individual messages to participants. See Figure 1 for a visual representation of how the modules appeared in each survey.

C.1 Retrospective Survey

C.1.1 Screening. **This is a screening survey** for a survey by researchers at `institution1` and `institution2`. `Institution1`'s Human Subjects Division reviewed our study, and determined that it was exempt from federal human subjects regulation. We do not expect that this survey will put you at any risk for harm, and you don't have to answer any question that makes you uncomfortable; however, if you do not answer all the questions, you will not be eligible for our future survey.

We expect this screening survey will take less than a minute to complete. If you have any questions, you may email `lead researcher` at `study-specific-gmail`. If you are eligible, we may send you another survey on Prolific. Thank you for taking our screening survey!

Are you at least 18 years old? [no, yes]
Do you live in an area that is affected by hurricanes or tropical storms? [no, yes]
What is your zip code? [free response]
What is your Prolific ID? [free response]

C.1.2 Survey. `Before any major hurricanes had hit the US`

This is a survey about natural disasters and technology use by researchers at `institution1` and `institution2`. `Institution1`'s Human Subjects Division reviewed our study, and determined that it was exempt from federal human subjects regulation. We do not expect that this survey will put you at any risk for harm, and you don't have to answer any question that makes you uncomfortable. In order to participate, you must be at least 18 years old, live in an area affected by hurricanes or tropical storms, and be comfortable completing the survey in English.

We expect this survey will take about 20 minutes to complete. This survey asks about your experience using technology during a natural disaster (for example: hurricane, flooding, earthquake, tornado, extreme cold, etc). Though the survey focuses primarily on your experience with technology before, during, and after such a disaster, we will ask some questions about your experience during the disaster itself. Thus, it is possible that some questions will evoke unpleasant or traumatic memories for you. Though we appreciate your full answers, your well-being comes first, and you are welcome to skip any questions that you do not want to answer. You may also withdraw from the

study at any time, but if you do not reach the end of the study you will not recieve the completion code, so you will not be paid.

Based on your responses, we may ask you to complete other surveys some time in the next three months. However, you are not agreeing to do future surveys simply by completing this survey today.

If you have any questions about this survey, you may email `lead researcher` at `survey-specific-gmail` or message us on Prolific. To start, please answer the two questions below...

Are you at least 18 years old? [no, yes]

Do you live in an area that is affected by hurricanes or tropical storms? [no, yes]

What is your prolific ID? [free response]

Preparation module *(Section B.1)*

App module *with the following question to filter out people who had never experienced a disaster (Section B.2)*

In the past 10 years, have you experienced a disaster that had a considerable impact on you or your community?

A disaster could be a natural disaster, like a hurricane, or it could be an manmade accident, or it could be something like a terrorist attack.

Considerable impact is however you personally define it; there is no wrong definition. The impact could be financial, physical, emotional, or something else.

If you are not sure if something "counts," we recommend saying yes and not answering questions if they do not apply. [yes, no]

`If yes, the following free-response question is displayed:`

Please briefly write a sentence or two about what happened.

Tech reflection module *(Section B.3)*

C.2 During-hurricane survey

C.2.1 Screening Survey. **This is a screening survey** for a survey by researchers at `institution1` and `institution2`. `Institution1`'s Human Subjects Division reviewed our study, and determined that it was exempt from federal human subjects regulation. We do not expect that this survey will put you at any risk for harm, and you don't have to answer any question that makes you uncomfortable; however, if you do not answer all the questions, you will not be eligible for our future survey.

We expect this screening survey will take less than a minute to complete. If you have any questions, you may email `lead researcher` at `study-specific-gmail`. If you are eligible, we may send you another survey on Prolific. Thank you for taking our screening survey!

Are you at least 18 years old? [no, yes]

Are you currently being affected by `[hurricane name]`?

- Yes, I evacuated
- Yes, I am sheltering in place
- Yes, other: [free response box]

What is your zipcode? [free response]

What is your Prolific ID? [free response]

C.2.2 Survey.

C.3 Recruitment message for the during-hurricane survey

`We sent the following text as a direct message on Prolific to participants who were eligible for the during-hurricane survey.`

Hi!

You are eligible for our next survey, which is about technology use during a hurricane. Please find it here: `[qualtrics url]`

If you chose to do the next survey, we will bonus you $12. We expect it will take you about 40 minutes. We understand that 40 minutes is a long time and you may lose power or internet; just do your best – we'll pay you for any portion that you complete (i.e., if you complete about half, we'll pay $6) :)

(If you would prefer, we can release this as a formal study through the interface; we're just doing these one at a time so we thought it would be easier to message you directly).

Let us know if you have any questions and please stay safe! Best,

`[two researchers' names]`

This is a survey about natural disasters and technology use by researchers at `institution1` and `institution2`. `Institution1`'s Human Subjects Division reviewed our study, and determined that it was exempt from federal human subjects regulation. We do not expect that this survey will put you at any risk for harm, and you don't have to answer any question that makes you uncomfortable. In order to participate, you must be at least 18 years old, live in an area affected by hurricanes or tropical storms, and be comfortable completing the survey in English.

We expect this survey will take about 40 minutes to complete. This survey asks about your experience using technology during a hurricane or tropical storm that may be happening right now. We understand that 40 minutes may be a long time, or that you may lose connection. Just do your best and stay safe!

Though the survey focuses primarily on your experience with technology before, during, and after such a disaster, we will ask some questions about your experience during the disaster itself. Thus, it is possible that some questions will evoke unpleasant or traumatic memories for you. Though we appreciate your full answers, your well-being comes first, and you are welcome to skip any questions that you do not want to answer. You may also withdraw from the study at any time, but if you do not reach the end of the study you will not recieve the completion code, so you will not be paid. If you have any questions about this survey, you may email `lead researcher` at *study-specific-gmail* or message us on Prolific. To start, please answer the two questions below ...

Are you at least 18 years old? [yes, no]

Please check the box below that most accurately reflects your current situation:

- I am currently experiencing a hurricane or tropical storm (including flooding, heavy rain, high wind, etc) or I evacuated for one
- I expect to experience a hurricane or tropical storm within 48 hours (i.e., I am under a hurricane or tropical storm watch or warning)

What is your Prolific ID? [free response]

***Preparation module**, modified tense as appropriate (Section B.1)*
***App module** (no filter question) (Section B.2)*
***Storm context module** (Section B.5)*
***Tech use during storm module** (Section B.6)*
***Technology reflection module** (Section B.3)*
***Infosec issues module** (Section B.7)*
***Demographics module** (Section B.4)*

C.4 Post-Ida survey

C.4.1 Screening Survey. **This is a screening survey** for a survey by researchers at `institution1` and `institution2`. `Institution1`'s Human Subjects Division reviewed our study, and determined

that it was exempt from federal human subjects regulation. We do not expect that this survey will put you at any risk for harm, and you don't have to answer any question that makes you uncomfortable; however, if you do not answer all the questions, you will not be eligible for our future survey.

We expect this screening survey will take less than a minute to complete. If you have any questions, you may email `lead researcher` at `study-specific-gmail`. If you are eligible, we may send you another survey on Prolific. Thank you for taking our screening survey!

Are you at least 18 years old? [no, yes]

Did you experience hurricane Ida recently?

- No
- Yes, I was severely affected
- Yes, I was moderately affected
- Yes, I was somewhat / slightly affected

What is your zipcode? [free response]

What is your Prolific ID? [free response]

C.4.2 Survey. This is a survey about natural disasters and technology use by researchers at `institution1` and `institution2`. `Institution1`'s Human Subjects Division reviewed our study, and determined that it was exempt from federal human subjects regulation. We do not expect that this survey will put you at any risk for harm, and you don't have to answer any question that makes you uncomfortable. In order to participate, you must be at least 18 years old, live in an area affected by hurricanes or tropical storms, and be comfortable completing the survey in English.

We expect this survey will take about 15 minutes to complete. This survey asks about your experience using technology during a hurricane or tropical storm that happened 1-2 weeks ago.

Though the survey focuses primarily on your experience with technology before, during, and after such a disaster, we will ask some questions about your experience during the disaster itself. Thus, it is possible that some questions will evoke unpleasant or traumatic memories for you. Though we appreciate your full answers, your well-being comes first, and you are welcome to skip any questions that you do not want to answer. You may also withdraw from the study at any time, but if you do not reach the end of the study you will not recieve the completion code, you will not be paid. If you have any questions about this survey, you may email `lead researcher` at `study-specific-gmail` or message us on Prolific. To start, please answer the question below ...

Are you at least 18 years old? [yes, no]

What is your Prolific ID numbers? [free response]

Based on a screening survey you filled out recently, we understand that you recently experienced `[Name of recent storm, e.g., "Hurricane / Tropical Storm Ida"]`.

Context module *(Section B.5)*

The next questions ask you about your disaster preparation and technology use during the storm that you just experienced. We appreciate your thoughtful, detailed, and specific answers to these questions.

Technology reflection module *(Section B.3)*

Disaster kit usage module *(Section B.8)*

Tech use during storm module *(Section B.6)*

Infosec issues module *(Section B.7)*

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