Island Cities and Disaster Risk: A Study of San Juan's Hurricane Early Warning System

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Abstract: Early warning systems offer a common framework for national, state, and local actors to prepare for, respond to, and understand disaster risk. Existing scholarship mostly examines early warning systems at an aggregate level for small islands, without many case studies of how early warning systems work in specific island cities. In order to address the need to expand the evidence base of case studies on early warning systems on small islands, this paper offers a multi-sector case study of San Juan's relationship and engagement with Puerto Rico's hurricane early warning system. It maps out various facets of the hurricane early warning system in San Juan; classifies them as hierarchical or heterarchical; and evaluates the early warning system based on the strengths and weaknesses of either approach. Finally, the paper reflects on possible implications of these findings to other island cities on subnational island territories similar to Puerto Rico.

Keywords: urban islands, island cities, early warning, disaster risk reduction, emergency management, Puerto Rico, island territories

1. Introduction

The purpose of an early warning system is to provide information concerning potential disasters to decision makers across sectors (government, Non-Governmental Organizations (NGOs), private sector, communities, et al.) so that they might work to minimize risk to life and property prior to, during, or after the manifestation of disasters (Villagran de Leon, 2012; Sellnow & Seager, 2013; Norris, et al., 2007; Manyena, 2006; UNISDR, 2004; Basher, 2006). For this reason, early warning systems are a key component of emergency management in that they allow for information to reach those who will be affected by disaster.

Within a typical early warning system, an actor monitors and gathers data about existing conditions; sends that data to a central location to be analyzed, produces forecasts based on that data; and then sends appropriate warnings to decision makers, responders, and at-risk populations (USAID, 2017). In the event of a hurricane, for instance, a hydro-meteorological authority might use satellites to collect data about developing storms; aggregate and analyze the data from a common database; produce forecasts about a storm's trajectory and magnitude; and send warnings about its potential impacts to

decision makers, responders, and at-risk populations (Benitez & Mercado, 2015; Justiniano & Mercado, 2016).

Since the effectiveness of early warning systems depends upon the accuracy of scientific data, existing research often characterizes early warning systems by their technological infrastructure and reliance on scientific knowledge (Thompson, 2003). However, a more holistic understanding of early warning systems must also take into account the fact that early warning systems are not merely technocratic, organizational constructs but also *social constructs*. That is to say, early warning systems are constituted and executed by human actors (Kelman & Glantz, 2014; Glantz, 2003).

In theory, early warning systems are *hierarchical* constructs in which information flows in a linear manner from a centralized authority downstream through a chain of command comprising various actors. In practice, they can also be *heterarchical* in nature, relying on decentralized networks of actors who are flexible to changing conditions such that new information can be disseminated without the constraint of moving up and down a hierarchy. *See Figure 1.* The various distinctions between hierarchical and heterarchical systems is discussed widely in management science and organizational theory (Meier, 2007; Ibarra, 1993; Hedlund, 1993; Anderson, 1999; Swyngeduw, 2005).

Increasingly, though, practitioners working with early warning systems emphasize the need to build effective "end-to-end warning systems," ones that do not merely focus on the communication of technical information but also how that information is mediated by different social actors (USAID, 2017). For example, highly early warning information can travel from a city government to first responders, who then continue to communicate the warning amongst each other in a variety of ways. Kelman & Glantz (2014) push this concept further and propose "end-to-end-to-end early warning systems," which adds people and communities in the process of constructing early warning systems. Inclusion of affected communities is a more holistic view of early warning, which considers both preparedness for and response to disasters. An end-to-end early warning system might involve scientists and subject matters experts conveying to a wider public that a hurricane will bring 160 km/h winds to an area. This information is often insufficient for a member of the lay public to make a decision about what actions to take. By contrast, an end-to-end-to-end early warning system, might convey that 160 km/h winds warrant that roofs and windows on shelters must be reinforced, or that power lines are subject to collapse due to the oncoming hurricane. More than that, it might also involve public education during non-disaster periods to reinforce public understanding of storm risk, and include mechanisms by which the public can communicate with and continue to educate each other during disaster periods. This inclusive approach is meant to serve affected populations in a timely way that will empower individuals to take appropriate actions. Successful hierarchical early warning systems make clear who the subject matter experts are and place emphasis on the importance of messaging coming from upstream. Successful heterarchical early warning systems would enable non-subject-matter expert actors to relay credible, up-to-date, and simplified information to each other about disaster risk.
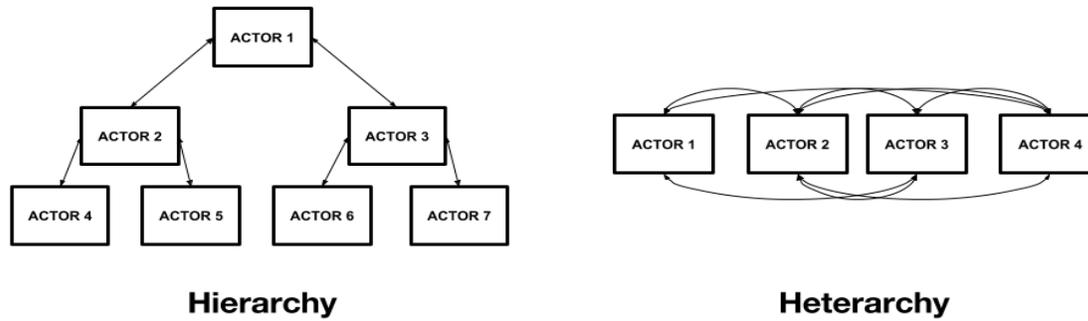
Figure 1: Illustration of heterarchical and hierarchical system constructs. Source: Lily Bui.

Disaster risk reduction (DRR) is an area of research and practice focused on ways to minimize and limit the adverse impact of hazards on societies. According to United Nations International Strategy for Disaster Reduction (UNISDR), disaster risk reduction is aimed at "preventing new and reducing existing disaster risk and managing residual risk, all of which contribute to strengthening resilience and therefore to the achievement of sustainable development" (UNISDR, 2017). Existing disaster risk reduction scholarship also deals with risk, and by extension disaster, as social constructs (Tierney, 2014; Beck, 2000; Burgess, 2015; Hewitt, 1998; Fowlkes & Miller, 1982). Disaster risk refers to the level of risk associated with the occurrence of a disaster and can be defined by the following conceptual model:

DR = H x [V/C) - M]

where DR is disaster risk, H is hazards, V is vulnerability, C is coping capacity, and M is mitigation by preventive action (Wisner, Gaillard, & Kelman, 2012, p.24). To be clear, this study *does not* set out to model this definition quantitatively but rather offers this definition as a theoretical framework to understand how disaster risk is conceptualized by leading scholars in the field. From the model, one can imply that a reduction of disaster risk can be achieved in two ways: by either decreasing hazards and vulnerability or increasing coping capacity and mitigation (Birkmann, 2006). Early warning systems attempt to address the latter: coping capacity and mitigation. By increasing a society's readiness to deal with disasters when they occur, early warning systems aim to reduce a society's disaster risk by reducing vulnerabilities.

Small, urbanized islands and archipelagos are cited as some of the most disproportionately vulnerable places with regard to exposure to hazards within international policy frameworks that address Disaster Risk Reduction (DRR) such as the Sendai Framework for Disaster Risk Reduction and the United Nations Sustainable Development Goals (UNISDR, 2015; UN, 2017; Aitsi-Selmi, et al., 2015). Yet, existing scholarship mostly examines early warning systems at an aggregate level for small islands (OAS, 2014; Thompson, 2003; WMO, 2016; Basher, 2006), without many studies of specific islands and their local contexts. Much has been observed about different centralization and decentralization strategies for managing early warning information (Thompson, 2003), but less is known about why, in specific cases, certain strategies are chosen over others and what the consequences are for impacted stakeholders.

In order to address the need to expand the evidence base of case studies on early warning systems on small islands, this paper offers a multi-sector case study of Puerto Rico's hurricane early warning system in San Juan. It focuses on investigating the conditions under which different approaches to early warning might help reduce disaster risk for various actors in the system. The study maps out various facets of the hurricane early warning system in San Juan; classifies them as hierarchical or heterarchical; and evaluates the early warning system based on the strengths and weaknesses of either approach. Finally, the paper reflects on possible implications of these findings to other island territories similar to Puerto Rico.

2. San Juan, Puerto Rico: Case Study Context

The Caribbean region is highly susceptible to hurricanes (often referred to as typhoons and cyclones in other regions of the world), and islands like Puerto Rico, located within the region, are vulnerable to their potential impact on life and property (UN OHRLLS, 2015; Lugo, 2000). Puerto Rico's island city of San Juan – the capital and focus of this study –has a population of 389,714 people, approximately 11% of the entire island's population of 3.5 million people (U.S. Census Bureau, 2011). Island-wide, the median household income is approximately $19,350 USD annually, whereas the median household income for New Orleans, a hurricane-prone, coastal city in Louisiana, USA, is around $36,964 USD according to the 2011-2015 American Community Survey (U.S. Census Bureau, 2016).

The island has dealt with multiple hurricane events in the past, and thus organizations like the Puerto Rico Climate Change Council, which comprises multiple government and non-governmental groups, invests planning efforts into managing the risks posed by disasters to its resources (Bush et al., 1995; Arbona, 2004; Rivera-Collazo et al., 2015; PR-CCC, 2013). Prior to Hurricane Maria[1] in September 2017, the last three major hurricanes that made landfall on the island caused a total of 17 deaths (direct and indirect) and $3.7 billion (USD) in damage to property and infrastructure. These hurricanes also passed close to San Juan, ultimately affecting the east side of the island more than the west side. *See Table 1 and Figure 2.*

Table 1: Damage to life and property in last three major hurricanes in Puerto Rico. Cost estimates are normalized by 2017 currency values in USD. Source: National Weather Service National Hurricane Center Tropical Cyclone Reports (2017).

Hurricane	Year	Intensity	Number of Deaths (PR)	Cost in Damages (PR)
Hurricane Hugo*	1989	Category 4	5	$2 billion USD
Hurricane Georges	1998	Category 3	12	$2.6 billion USD
Hurricane Irene	2011	Category 3	0	$1.12 billion USD

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[1] Hurricane Maria, the most recent hurricane to affect the island (September 2017), was not included in the scope of this study because the field work was carried out in months prior. However, details about its estimated death toll and cost in damages for Hurricane Maria are included in *Table 1* for reference.

Hurricane Maria**	2017	Category 5	TBD	$4.9 billion USD (estimate)
TOTAL			**>17**	**> $10.62 billion**

*Data for Hurricane Hugo from Center for Disease Control (1998). **Data for Hurricane Maria damage cost from Delk (2017). Given the lack of mortality data, accurate estimates are still missing (Barclay & Campbell, 2017; CBS News, 2017).

The Demographic Registry of Puerto Rico estimates deaths to hover around 1,052 people island-wide.
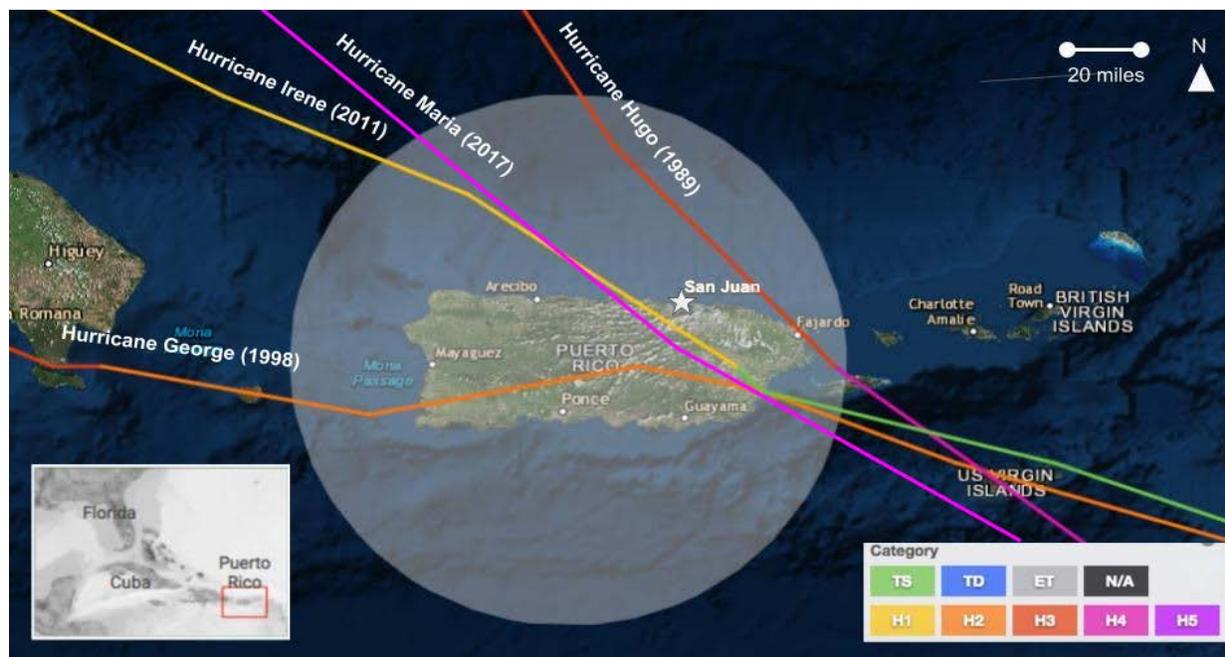

Figure 2: Trajectories for three previous major hurricanes in Puerto Rico. Source: NOAA (2017)

TS = Tropical Storm; TD = Tropical Depression; ET = Extratropical Cyclone; H1 = Category 1; H2 = Category 2; H3 = Category 3; H4 = Category 4; H5 = Category 5.

In the Caribbean, modern hurricane early warning systems began in 1945 with flight patrols into and above storms to capture remote photos of cloud systems. This model of data collection is still used: aircraft equipped with sensors collect meteorological data for the Hurricane Center in Miami – part of the National Weather Service (NWS) – which then disseminates this information throughout the Caribbean through regional organizations like the Caribbean Meteorological Organization, as well as directly to governments (Thompson, 2003).This information is then relayed through a network of federal, state[2], and local actors, who then take actions to mitigate any risks posed by oncoming hurricanes or storms.

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[2] Even though Puerto Rico does not have statehood status, the colloquial expression for island-scale, regional emergency management is "state-level" emergency management.

Apart from Puerto Rico's historical exposure to hurricane risk, the rationale for selecting San Juan as a case also has much to do with its location on an island with liminal geopolitical status as a commonwealth territory of the mainland United States. According to the 1900 Foraker Act, Puerto Rico is considered "foreign in a domestic sense" to the United States (Ayala, 2007; Duany, 2002), leaving it in a politically ambiguous position with regard to international policies such as the Sendai Framework for Disaster Risk that specifically address small island developing states ("SIDS"). The category of SIDS mostly refers to independent island countries, which in effect does not include Puerto Rico in some instances and does in others. Puerto Rico's geographical adjacency to other Caribbean small island developing states exposes it to the same types of hazards and risks as surrounding islands in the Caribbean that do qualify as SIDS (Schultz et al., 2016; UNISDR 2004; UNISDR, 2016). Thus, the case of San Juan, Puerto Rico may offer a way of understanding other island cities on subnational island territories.

3. Methodology

Semi-structured interviews
Over the course of twenty-seven days in January 2017 spent in San Juan, Puerto Rico, and surrounding areas, 47 interviews were undertaken with individuals and groups across multiple sectors engaged with Puerto Rico's hurricane early warning system. These sectors included government (at federal, state, municipal levels), NGOs, universities, community organizations, military, media, and communities. Individuals were identified and selected based on their involvement with the process of formulating, disseminating, receiving, and acting upon hurricane early warning system information. Other interviewees were identified through snowball sampling during fieldwork. Interviews were not conducted for attribution and informants are mainly referred to in the results section by their titles and roles as opposed to specific names. Ethics approval was obtained through the Massachusetts Institute of Technology human subjects research protocol (COUHES) before the study was conducted.

This data collection approach allowed for detailed, descriptive accounts of how hurricane early warning systems work, as well as "deeper dives" into the intersubjective experiences and interpretations of those who are affected (Weiss, 1994; Flyvbjerg, 2006). I conducted some interviews in English and other interviews in Spanish where interviewees expressed higher level comfort in the Spanish language. Interviews typically lasted between 20 and 40 minutes and were conducted one-on-one. In rare instances during which I conducted group interviews, I would ask one question at a time, then give all interviewees an opportunity to answer the same question. The interview instrument (*see Appendix*) was tested first with two key informants before being used for others. Some interviews were audio recorded, but the majority were recorded and transcribed via handwritten notes.

Participant observation
During field work associated with this study, I carried out a research fellowship with the Department of Natural and Environmental Resources (DNER) in Puerto Rico, a state-level government agency in charge of, *inter alia*, the management of natural resources in coastal areas. It also oversees the Puerto Rico Climate Change Council (PR-CCC), an

interdisciplinary group of policy makers and researchers concerned with climate change adaptation plans on the island.

Being embedded in the field within a government office allowed me to gain access to interviewees through exposure to the DNER and PR-CCC's social network. I also gained access to an annual conference called the Caribbean Regional Response Team meeting wherein 80 individuals representing several federal governmental organizations, including the military, involved with emergency response to disasters convened to set an annual agenda for the team. Through this relationship with the DNER, I participated in community planning meetings during which the main subject of discussion was climate change adaptation, which included community strategies for disaster risk reduction at a local level. Field notes were taken throughout this embedded field work and incorporated into the field data collected for this study. This model of "service learning" is based on an exchange between a researcher and community partner, creating an opportunity for researchers to make a local contribution while in the field (Stanton et al., 1999; Kendall, 1990).

Document review
Interviewees from multiple government agencies provided me with training materials that document Puerto Rico's early warning preparedness and response structures and timelines. I used these documents to corroborate findings from field interviews, and vice versa, during my analysis of Puerto Rico's early warning system structure. See *Table 5* in Appendix for a list of documents reviewed.

Analysis approaches and limitations
Audio and notes from all interviews were transcribed and translated to English using Microsoft Word. An *a priori* coding scheme was created in which interviewees were categorized by sector (e.g. "government") and sector type (e.g. "federal" or "state"). Responses for each interview question were logged for every interviewee, with these sector categories in mind. Then, an emergent coding scheme was created to further categorize major themes in the responses from interviewees. These coding schemes were also used to categorize notes from participant observation and document review. In the end, six distinct sectors and twelve sector categories, and four themes were identified. *See Tables 1 to 3 in Appendix.* I selected specific quotes from the transcriptions that best supported the arguments made in this paper based on the data.

Because the findings of this study are prone to intersubjectivity among interviewees and myself, the researcher, responses from the interviews were corroborated with each other, and follow-up interviews over the phone were conducted to clarify details in order to triangulate the data collected. Additional follow-up interviews with key informants were also conducted during April 2017 to validate the data collected in initial interviews, as well as to mitigate the potential bias and intersubjectivity of the author from having been embedded in the DNER during field work.

The case study approach to San Juan offers a means of producing context-dependent knowledge in order to understand what factors influence complex events and processes like those that constitute hurricane early warning systems (Flyvberg, 2006; George &

Bennett, 2005). However, the external validity of the study may be limited to island territories like Puerto Rico and not necessarily independent island states. This study was limited to San Juan, Puerto Rico, meaning that only the urban context was studied and represented. It is important to consider that the resources available for early warning in San Juan may not be as widely used or accessible in non-urban areas where information communications technology and infrastructure do not have extensive reach. For instance, some interview respondents indicated that communities in more rural areas of the island sometimes do not rely on television or the internet for news coverage. In addition, other groups that this study did not successfully reach and represent completely include marginalized populations such as prisoners and illegal immigrants.

4. Results

San Juan, Puerto Rico's planned early warning system is hierarchical
The study finds that the formal, planned structure of San Juan's hurricane early warning system is hierarchical, beginning with "originators" of early warning information, usually in the form of meteorological data. Scientists working for the government (e.g. National Weather Service (NWS) meteorologists) and within universities (e.g. Caribbean Coastal Ocean Observing System (CARICOOS) are key actors in this group. This information includes the trajectory, magnitude, time until landfall, and potential impacts of the storms in terms of damage to life and property. Warnings are then passed onto "decision makers" or "disseminators," who are often members of federal, state, and municipal government, the media (e.g. local TV, radio, and print media), the military, the private sector, or NGOs that have volunteered participation in emergency response (e.g. Red Cross, Salvation Army, and community organizations). All stakeholders who are originators and decision makers or disseminators put forth efforts to communicate hurricane early warning information to their civilian constituents upon becoming aware of the warnings (Benitez & Mercado, 2015; Justiniano & Mercado, 2016).

The following process diagram maps the flow of hurricane early warning information among stakeholders in San Juan. The diagram structure (*Fig. 3*) is based on document review, responses from semi-structured interviews, and notes from participant observation in the field. The diagram maps onto Thompson (2003)'s model for risk communication, the diagram categorizes actors as "originators," "decision makers/disseminators," or "receivers" of early warning information. This risk communication model was chosen over others given its available taxonomy for different actors in early warning systems.
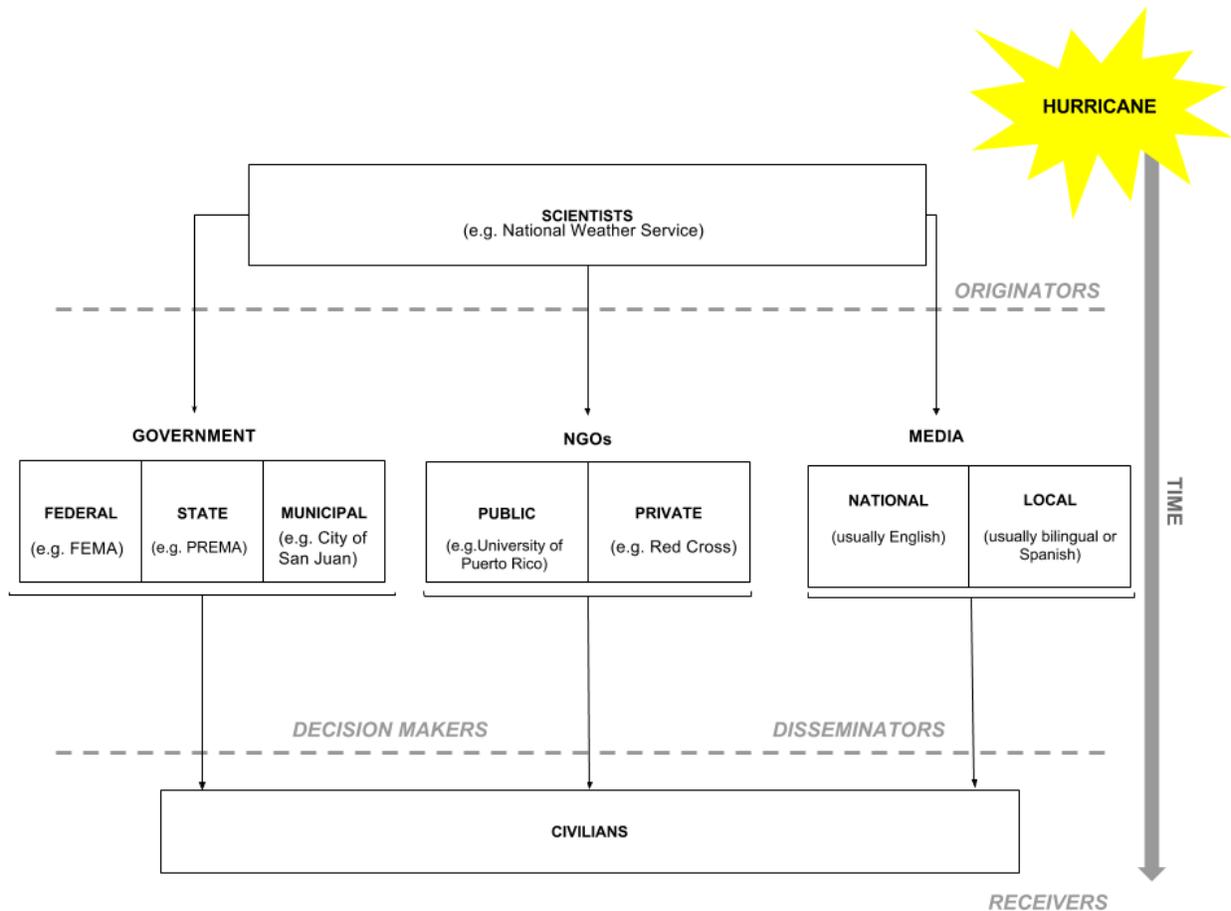
Figure 3: Diagram of San Juan, Puerto Rico's hurricane early warning stakeholders and formal information flows within it. Source: Lily Bui

The diagram illustrates how the early warning system is designed and perceived by planners and disaster managers. However, the flow does not perfectly capture the more informal interactions that occur among these actors – both upstream and downstream – which will be discussed in further detail in the following sections.

Strengths and weaknesses of hierarchical early warning system approaches
The key strength of hierarchical early warning systems is that they are predicated upon unified messaging from institutional actors. In the case of hurricanes, the NWS field office in San Juan prioritizes information coming from the upstream actors in the early warning system hierarchy over information from informal, heterarchical networks such as social media accounts from amateur meteorologists. Underlying the NWS' need to unify messaging is a desire to build trust, establish legitimacy, or coordinate early warning information effectively. If messaging from originators of early warning information is disjointed, unclear, or inaccurate, actors downstream of the early warning system hierarchy are less likely to trust it and therefore not take appropriate actions to reduce their own risk in the event of a hurricane. A unified communication approach also helps institutions and organizations responsible for responding to disasters determine what information is credible to concentrate delivery of aid and services. In San Juan, NGOs like

the Red Cross take action based on early warnings that originate from the NWS, as opposed to other sources of information. A San Juan Red Cross Disaster Response Manager says:

> We work directly with the National Weather Service to stay informed about hurricanes. We participate in their daily phone calls and get updates about the forecast along with other organizations. Sometimes we get early warning directly from Governor's Cabinet but that changes depending on who is in charge. We don't deploy our volunteers unless National Weather Service has issued a warning.

Other interviewees from NGOs also responded similarly. This suggests, perhaps, that in the event of a hurricane or disaster, a unified messaging approach from an authority is useful and effective in determining what actions to take as a consequence of receiving early warning information (Haynes & Pidgeon, 2007). In this case, the informant expresses less trust in other decision makers (i.e. the Governor's Cabinet) and more trust in the originator (i.e. NWS). This unified messaging approach is a deliberate part of the NWS's priorities.

Despite the advantage of clear messaging, hierarchical early warning systems consequently prioritize the needs of stakeholders upstream, meaning that community members are often not included in trainings for early warning system exercises or disaster planning. The Federal Emergency Management Agency (FEMA) Caribbean Area Office conducts monthly "table-top" exercises that involve utilities companies, nonprofits, private companies, and the military, in which decision makers in various sectors navigate disaster scenarios and practice making decisions about how to allocate resources. These exercises are meant to train decision makers in responding to different situations while collaborating across sectors and understanding the risks that disasters can impose upon the city. In addition, employees of the tourism department also receive formal training for emergency response from Community Emergency Response Teams (CERT) and are required to drill and practice emergency protocol to reach tourists on the island in case of a hurricane.

As yet, these training exercises do not include community members and are meant specifically for originators and decision makers or disseminators of hurricane early warnings. Potentially, this leads to actors at the top of the early warning system hierarchy being more prepared for hurricanes than actors at the bottom of the hierarchy, who are, incidentally, those the early warning system is meant to serve. A professor at University of Puerto Rico's School of Planning aptly states, in reference to the need to increase preparedness among actors at the bottom of the early warning system hierarchy:

> Social preparation is key. Now the decision makers seem prepared but if the community level isn't then we have a problem. The top is ready. The community needs work.

While federal and state emergency management agencies have created instructional programs and materials for hurricane preparedness, it is unclear to what extent this information reaches communities in San Juan. When asked how she prepares for storms and potential hurricanes, one resident of Puerto Rico admits that she does not take too many additional efforts to minimize hurricane risk:

> Last hurricane I remember is George in the 1990s. How do I prepare? My friends and I, we buy alcohol. Nobody cares. We play dominoes. My family already has

stuff: flashlights, candles, gas stove – we're not going to go buy extra stuff to prepare.

Two other long-time residents interviewed for this project, like this informant, expressed that they did not feel it was critical to take extra efforts to prepare for hurricanes, indicating that the perceived risk of hurricanes was relatively low.

Another weakness of San Juan's early warning system concerns language access issues. Many long-time residents of the island get to know about hurricane warnings from family members and close friends. One resident says:

My family and me [*sic*] don't watch American channels because they're in English. Mostly it's Channel 4 for storms and hurricanes. We trust it more if we hear news in Spanish like from [a Puerto Rican meteorologist].

This was a typical response among community member interviewees. An overwhelming majority of Puerto Ricans speak Spanish (94.5%), and a large majority self-report that they speak English "less than 'very well'" (83.3%) according to the 2011-2015 American Community Survey (U.S. Census Bureau, 2016). Among residents in San Juan, whose primary language is Spanish, local Spanish-language media and social outlets are the main source for hurricane information as opposed to national media outlets, which mainly use English. While the NWS does release early warning information in both English and Spanish, English is usually the primary language used to communicate, with Spanish translations following an hour or two afterward.

It is important to note that although the planned hurricane early warning system is hierarchical, the system itself is managed by human actors connected to social networks. At certain times, the hierarchical structure of the planned early warning system can be rendered flexible. For example, a Warning Coordination Meteorologist from the NWS Caribbean Office explains that sometimes s/he contacts civilians or civil society organizations directly, as opposed to going through disseminators or decision makers:

Sometimes I just pick up the phone and call people to let them know a storm is coming. I give away my personal phone number. We don't want to lose trust…[W]e have a more localized approach that emphasizes reporting on impacts of the information we have. That means translating models into [messages about how] communities will be affected and building relationships with organizations and leaders.

In this case, the justification for circumventing the traditionally hierarchical structure of the hurricane early warning system is to preserve or build trust with those the early warning system is ultimately meant to serve (i.e. civilians). This was both unexpected and atypical for an employee of a federal government agency. While an agency like the NWS does have authority over scientific information about hurricanes, the quote above indicates that individuals within the agency realize that trust in the NWS is not necessarily rooted in its ability to produce accurate science. Trust must also be socially reinforced through engagement with communities at risk.

Another way in which the NWS mitigates weaknesses in the hierarchical planned early warning system is by holding media briefings with major media outlets before each hurricane season. These briefings are meant to coordinate efforts so that the media reports on hurricane warnings in a standardized, unified way. Meteorologists directly

interface with media correspondents in order to discuss best practices for reporting about hurricanes and to debrief lessons learned from previous years' communications. Media correspondents also have an opportunity to respond to NWS recommendations and ask further questions about the technical language that NWS uses to describe things like hurricane trajectories and intensity.

Gaps in the hierarchical planned early warning system inspire heterarchical interventions at the community level
While hierarchical early warning systems are designed to provide unified messaging to at-risk populations, the relevant information does not always reach the intended audience. Part of the planned hurricane early warning system in San Juan also involves frequent preparedness trainings among disaster management actors. According to a public assistance leader at FEMA's Caribbean Area Office, community members are rarely, if ever, included in these exercises.

Realizing the need for preparedness trainings that target civilians, universities and nonprofits organize community workshops with their own resources that emulate scenario-based trainings with key community leaders. University of Puerto Rico Sea Grant sought training from the National Disaster Preparedness Training Center (NDPTC) in Honolulu, Hawaii – as opposed to FEMA or any other emergency management agency in San Juan, Puerto Rico – in order to conduct community emergency preparedness trainings with community members in Puerto Rico with the aim of increasing preparedness and public education about hurricane risk among civilians. The trainings focus on educating community members about hurricane risk so that knowledge can be shared among other community members without relying on institutions for preparedness. The Coastal Communities Specialist of the University of Puerto Rico Sea Grant Program explains:

> We do trainings with local community members and transfer and translate emergency preparedness into "rice and beans" so people can understand. Workshops for community leaders are coordinated with the [National Disaster Preparedness Training Center] and are free.

"Rice and beans" is a common Puerto Rican expression that refers to the most simplified version of something. This informant describes how technical information for emergency preparedness is boiled down in a way that non-technical, non-expert community members can understand it. While these trainings do not happen regularly, they represent how community-led efforts to construct heterarchical early warning mechanisms fill the gaps of hierarchically planned early warning systems. To adapt to the lack of hurricane preparedness trainings available to community members from upstream hurricane early warning actors in Puerto Rico, the University of Puerto Rico took the initiative to address this public education gap by acquiring the necessary knowledge to pass onto communities in need of it.

The use of social media to convey hurricane risk is also common practice in San Juan. Accounts from local news anchors, meteorologists, and community members issue messages to warn followers of their account to prepare for storms. Interview respondents reported that some social media accounts for local news channels and meteorologists contain messages in Spanish first, rather than then English-first NWS warnings. This

addresses language access issues that some respondents have cited as reasons not to refer to NW S warnings first. A representative of the Sea Grant team says:

> Small informal social media accounts do have value for people to follow, because they are trying to give people an "earlier" warning and something that doesn't come from a government or institution. People genuinely try to interpret models to "help" the public.

Strengths and weaknesses of heterarchical early warning system approaches
One clear strength of heterarchical early warning communication is that it provides alternative avenues for communicating with at-risk populations. Community-organized preparedness trainings offer public education about hurricane risk, enabling community members to look after each other rather than rely on institutions to do so. The use of social media platforms addresses specific gaps that the hierarchical planned early warning system misses, particularly that of language access.

Since more local and less formal social media accounts often do not represent larger institutions, messages of preparedness reminders and warnings for storms do not need to be approved by "official" sources, like they would if they had come from an institution. While beneficial in some instances, unofficial messages from social media accounts can also contribute to one of the weaknesses of heterarchical early warning systems: rumors.

Dispelling rumors on social media is often one of the biggest weaknesses and challenges for "official" early warning actors upstream. The NWS actively monitors weather-related social media accounts from amateur meteorologists who have large followings, but who ultimately do not have the final authority to declare when a tropical storm is officially a hurricane. In the case where the NWS has not officially declared a storm a hurricane, and a social media account uses the word "hurricane" explicitly in describing an oncoming storm, the NWS would use social media to respond to that post with the intent of clarifying the official message. The NWS Warning Coordination Meteorologist elaborates:

> The media is essentially the voice of the National Weather Service. This is also a moment where we emphasize the standards of reporting weather information and answer questions about best practices. We want to avoid misinformation…Rumors are the biggest challenge…[A] lot of "storm-mongers" or "weather weenies" who are amateur forecasters will promote themselves online and cause sensationalism.

Rumors and misinformation can spread on social media accounts with thousands of followers, so upstream early warning system actors will often take it upon themselves to pay attention to what social media accounts are saying and respond to clarify the official unified message.

5. Discussion
To be sure, this study does not attempt to make a normative argument about hierarchical or heterarchical approaches; instead, it uses the case of San Juan, Puerto Rico, to illustrate how both coexist and how, at times, they can complement or clash with each other. Understanding the strengths and weaknesses of San Juan in Puerto Rico's early warning system through the lens of hierarchy and heterarchy may also illuminate challenges that other island cities on island territories might face in disaster risk reduction planning. Other subnational island territories in the U.S. such as the U.S. Virgin

Islands, American Samoa, Guam, and the Northern Marianas similarly depend on federal agencies like the NWS and FEMA for disaster planning. These federal actors sit at the top of the planned hierarchy of San Juan's hurricane early warning system and have significant influence over how the early warning system is structured. If approaches to early warning are uniform across the U.S. island territories given the planned hierarchical systems imported from federal agencies like FEMA, similar challenges in hierarchical and heterarchical approaches (i.e. language barriers, rumor control, disconnect between top-down and bottom-up preparedness efforts, etc.) may also exist. Further research might be done to examine whether the same gaps exist between disaster managers and the communities they serve when it comes to early warning system design and implementation.

Future research may also look at hurricane early warning systems from a political-economic perspective to examine how Puerto Rico's political-economic status as an island territory with a US$70 billion debt to the U.S. federal government (Puerto Rico Government Development Bank, 2013) binds it to the periphery of disaster management from the perspective of the mainland. As a territory (i.e. not a fully incorporated state and not an independent nation), Puerto Rico is sometimes treated as "international" to the U.S. and other times domestic to the U.S. in disaster databases, reports, and government documents pertaining to disaster and risk management. The status of subnational territories like Puerto Rico raises additional questions about the extent to which territories are included in certain political jurisdictions for disaster risk reduction planning, and how their inclusion or exclusion qualifies or disqualifies them from technical support from governments and government agencies before, during, and after disasters.

6. Conclusion

This study finds that Puerto Rico's hierarchical hurricane early warning system is effective in San Juan, but insufficient in addressing the communication gaps that exist among communities downstream of the planned system. While hierarchically planned early warning systems offer a way to unify messaging around hurricane risk, they fail to reach all communities at risk due to issues such as language barriers. Heterarchical approaches are often the only means by which community-level actors can access trainings meant to prepare individuals and families for hurricane response. Communication mechanisms such as social media platforms offer a way for community members to receive warnings from local actors, but the problem of keeping information credible and consistent persists, requiring the intervention of authorities upstream in the hierarchically planned early warning system.

Effective early warning systems are ones in which information is more likely to flow between originators, decision makers, disseminators, and civilians. If the field of early warning systems wishes to improve end-to-end-to-end communication of information, upstream actors in the system must consider coordinating with existing community-level preparedness efforts occurring downstream during non-disaster periods. After all, it is people who are early warning systems for each other in the end.

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Appendix

Sectors represented by interviews

Sector	Sector Type	Total interviews
Government	Federal	12
	State	5
	Municipal	3
NGO	Private	1
	Public	7
University	Scientist	5
	Non-scientist	4
First responders	Civil defense	3
Media		1
Civilians	Resident	4
	Tourist	2
		47

Appendix Table 1. Total interviews organized by sector and sector type, with examples.

Organizations represented by interviews

Sector	Sector Type	Organizations
Government	Federal	FEMA, National Weather Service, USDA, Dept. of Interior Climate Science Center,
	State	PREMA, Department of Natural and Environmental Resources, Tourism Company,
	Municipal	PREPA Utilities, City of San Juan
NGO	Private	Red Cross
	Public	Salvation Army, Surfrider Foundation, CDEMA, CCCCC, Enlace, Fondita de Jesus,
University	Science	Tsunami Warning Ctr, CARICOOS, UPR Sea Grant, Arecibo
	Non-science	UPR School of Planning
First responders	Civil defense	U.S. Coast Guard, San Juan Police Department
Media		Voz Activa, El Nuevo Dia
Community	Resident	Various
	Tourist	Various

Appendix Table 2. Organizations represented by interviews, by sector and sector type.

Emergent Themes from Interviews
Early warning system sources
Early warning system platforms
Preparedness
Improvements to early warning systems
TOTAL: 4

Appendix Table 3. Emergent themes by which interview responses were coded and organized.

Language proficiency	% of population
Speak only English	5.3%
Speak Spanish	94.5%
Speak English "very well"	16.6%
Speak English less than "very well"	83.3%

Appendix Table 4. Language proficiency (English and Spanish) in Puerto Rico.
Source: U.S. Census Bureau (2016) 2011-2015

Document reviewed	Source
WFO Knowledge of Potential Peak Impacts (slides)	National Weather Service San Juan
Tropical Cyclone Products: Forecast Products by Emergency Management Phase and Location Specificity	National Weather Service San Juan
Wind Event Perspectives (slides)	National Weather Service San Juan
FEMA Digital Flood Map Products	FEMA Caribbean Area Office
FEMA Region maps	FEMA Caribbean Area Office
FEMA communication diagram for early warning	FEMA Caribbean Area Office
Caribe Early Warning System (Tsunami Model)	Tsunami Warning Center
Communication Protocol for Puerto Rico and the U.S. Virgin Islands	Tsunami Warning Center
Puerto Rico Volunteer Organizations Active During Disaster	American Red Cross: Puerto Rico

Appendix Table 5. Documents reviewed as part of study.

Interview questions (Spanish)

1. ¿Me puede contar algo sobre el ultimo huracán que recuerda? Cómo preparó usted?
2. ¿Cómo usted aprende generalmente sobre advertencias del huracán? *¿Un organismo gubernamental? ¿Televisión? ¿Radio? ¿Internet? ¿Organizaciones sin ánimo de lucro? ¿Aplicación móvil? ¿Letras? ¿Teléfono / SMS? ¿Gente que conoces? ¿Algo más?*
3. ¿Es su responsabilidad comunicar información de alerta temprana a otras personas? *Si o no.* En caso afirmativo, ¿a quién? ¿Qué plataformas utiliza para hacerlo? *¿Televisión? ¿Radio? ¿Internet? ¿Organizaciones sin ánimo de lucro? ¿Aplicación movil? ¿Letras? ¿Teléfono / SMS? ¿Gente que conoces? ¿Algo más?*
4. ¿Qué tipo de acciones toma usted cuando recibe la información del sistema de alerta temprana de huracanes?
5. ¿Cómo se prepara la gente para los huracanes?
6. ¿Qué tan seguro está usted en el actual sistema de alerta temprana de huracanes? *Mucho, algo, neutral, no mucho, no en absoluto.*
7. ¿Qué tan consciente se siente acerca del actual sistema de alerta temprana de huracanes? *Mucho, algo, neutral, no mucho, no en absoluto.*
8. ¿Cuánto cree que entiende el sistema de alerta temprana del huracán? *Mucho, algo, neutral, no mucho, no en absoluto.*
9. ¿Qué tan satisfecho está usted con el sistema de alerta temprana de huracanes? *Mucho, algo, neutral, no mucho, no en absoluto.*
10. ¿Cuánto ha dedicado usted al sistema de alerta temprana de huracanes? *Mucho, no mucho, neutral, algo, no en absoluto.*
11. ¿Hay mejoras que recomendaría para el sistema actual? ¿Dónde crees que son las mayores brechas?

Gracias de nuevo por su tiempo. ¿Está bien si que le contacte más adelante con más preguntas?

Interview questions (English translation)

1. Can you tell me about the last hurricane you remember and how you prepared for it?
2. How do you usually learn about hurricane warnings? A government agency? Television? Radio? Internet? Nonprofit organizations? Mobile app? Letters? Phone/SMS? People you know? Something else?
3. Is it your responsibility to communicate early warning information to others? Yes/no. If yes, to whom? What platforms do you use to do so? Television? Radio? Internet? Nonprofit organizations? Mobile app? Letters? Phone/SMS? People you know? Something else?
4. What kind of actions do you take once you receive hurricane early warning system information?
5. How do people you know prepare for hurricanes?

6. How confident are you in the current hurricane early warning system? Very much, somewhat, neutral, not much, not at all.
7. How aware do you feel about the current hurricane early warning system? Very much, somewhat, neutral, not much, not at all.
8. How much do you feel that you understand the hurricane early warning system? Very much, somewhat, neutral, not much, not at all.
9. How satisfied are you with the hurricane early warning system? Very much, somewhat, neutral, not much, not at all.
10. How much have you or do you engage with the hurricane early warning system? Very much, somewhat, neutral, not much, not at all.
11. Are there improvements you would recommend for the current system? Where do you believe are the biggest gaps?

Thank you again for your time. Would it be all right to contact you in the future with more questions?