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Information use and decision-making for evacuation at Fuego volcano, Guatemala

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INFORMATION USE AND DECISION-MAKING FOR EVACUATION AT FUEGO VOLCANO, GUATEMALA

By

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A DISSERTATION

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This dissertation has been approved in partial fulfillment of the requirements for the Degree of DOCTOR OF PHILOSOPHY in Geology.

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Dedication

To my paternal grandmother, Juanita Bartel, whose educational ambitions ended too soon

and my maternal grandfather, William Korte, who didn't believe that women should bother with a college education.

To my parents, Daniel and Wilma Bartel, who have supported me through many endeavors, and who both instilled in me the value of learning about the world and the people around us.

Finally, but not least, to the many people living around

and the people lost at

Fuego volcano:

may this work reflect, in some small way, your many truths.

San Miguel Los Lotes, May 2021

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Author Contribution Statement

Chapter 2: BAB led the research process by defining the research questions, leading development of the interview guide, conducting the majority of the interviews, analyzing the interviews, developing the timelines, and leading the writing process. Co-advisor REW contributed significantly to the interview guide, conducted several of the interviews, identified relevant social media posts and analyzed them for timing, contributed to the timelines, clarified translations, and contributed to the writing, especially of but not limited to the background information, and provided the foundation for Figure 2, which I then modified.

Chapter 3: BAB led the research process by defining the research questions, leading development of the interview guide, conducting the interviews, analyzing the interviews, and leading the writing process. Co-advisor REW contributed significantly to the interview guide, clarified translations, and contributed to the writing, especially of but not limited to the background information, and provided the foundations for Figures 1 and 3, which I then modified.

Chapter 4: As of 6 July 2023, this chapter has been accepted for publication in the journal Frontiers in Earth Science; the manuscript was co-authored with Dr. Ailsa K. Naismith of Bristol University. BAB led the research process by defining the research questions, determining methodology, leading the development of the interview guide with guidance from co-advisor REW, and leading the interview process. Co-author AKN contributed to each component, including conducting interviews, revising and coding transcripts, interpreting results, and writing and revising the manuscript. AKN produced Figures 1 and 3. REW clarified translations.

All committee members provided guidance throughout the research process. REW and AC provided feedback on the IRB submission.

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I could go on for days.

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Definitions

Guatemalan Spanish

aldea	Village or small town of approximately 20-100 families.
autoevacuación	Self-evacuation.
barranca	A channel or ravine; I more commonly use channel throughout this dissertation.
colonia	Small town, larger than an *aldea*.
finca	A large, privately owned agricultural plantation or farms, most commonly for coffee production.
ingenio	A sugar processing business.
ladino	A term used in Guatemala to describe someone of Mayan-Spanish descent.

Terminology

hazard, risk	The terms *hazard* and *risk* are used as defined in "Science for a Risky World — A U.S. Geological Survey Plan for Risk Research and Applications" (Ludwig et al., 2018): a hazard is a dangerous process or phenomena that may cause damage; risk is the potential loss of societally important assets caused by these hazards.
livelihoods	*Livelihoods* is used as described in Wisner et al. (2004) as "the command an individual, family or other social group has over an income and/or bundles of resources that can be used or exchanged to satisfy its needs. This may involve information, cultural knowledge, social networks and legal rights as well as tools, land or other physical resources" (p.12).
stakeholder	This dissertation uses the term *stakeholders* as it is used in, e.g., "USGS Next Generation Volcano Hazard Assessments, 2021: Progress and Prospects" (Ball et al., 2021), to represent all potentially interested or affected parties, including at-risk populations. I choose stakeholders over 'audiences' to avoid implying that communication is one-way, over 'partners' to avoid the implication of engagement between groups, over 'actors' because the term implies action, which is not always taken, and over 'decision-makers' because the latter often implies policy makers, while at-risk populations also need to make informed decisions about their current and future wellbeing.
vulnerability	*Vulnerability* is used as defined in Wisner et al. (2004) as "the characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard (an extreme natural event or process)" (p.11)

List of Acronyms

General acronyms

DRR	disaster risk reduction
EWS	early warning system
PDC	pyroclastic density current
PF	pyroclastic flow

Agencies and organizations

INSIVUMEH The *Instituto Nacional de Sismología, Vulcanología, Meteorología e Hidrología*, or the National Institute of Seismology, Volcanology, Meteorology, and Hydrology, is the Guatemalan agency responsible for environmental hazard assessment and monitoring.

CONRED The *Coordinadora Nacional para la Reducción de Desastres*, or National Coordinator for the Reduction of Disasters, is the Guatemalan system for civil protection, including emergency response. SE-CONRED, the *Secretaría Ejecutiva*, or Executive Secretariat, is the government agency responsible for its coordination.

UPV, DPV Previously the *Unidad Prevención en Volcanes*, or Unit for Prevention on Volcanoes, now the *Departamento Prevención en Volcanes*, or Department for Prevention on Volcanoes (as of 7 March 2022), is the group within SE-CONRED responsible for reducing risk resulting from volcanic hazards.

COLRED The *Coordinadora Local para la Reducción de Desastres*, or Local Coordinator for the Reduction of Disasters, is the volunteer civil protection group responsible for coordinating a community's risk reduction efforts.

COCODE The *Consejo Comunitario de Desarrollo*, or Community Development Council, is a local civic group created to make decisions pertaining to community development and distribution of public funded projects but also now used as a more general governing body

ICC The *Instituto Privado de Investigación sobre Cambio Climático*, or Private Institute for Climate Change Research, is a non-profit institution "dedicated to the research and development of projects for climate change mitigation and adaptation in the Mesoamerican region" funded and directed by the sugar sector

Abstract

For populations living with risk to rapid-onset environmental hazards, an effective early warning system (EWS) may be the most viable short- to mid-term solution for risk reduction. At Fuego volcano, Guatemala, more than 60,000 people distributed between more than 30 small communities live within the identified hazard zones for pyroclastic density currents (PDCS), highly lethal hot avalanches and surges of volcanic gases, rock, and ash. Despite ongoing risk reduction efforts by scientific and civil protection authorities, more than 400 people died during a paroxysmal eruption on 3 June 2018 when PDCs reached populated areas. A high-end resort, La Reunión, evacuated before the climactic PDCs, suffering no casualties, while the town of San Miguel Los Lotes did not, resulting in the loss of possibly 40% or more of its population. Since that event, paroxysmal eruptions continue to threaten the communities on Fuego's slopes. This dissertation uses a mix of ethnographic and other source analysis methods to address the following broad questions pertaining to a single case study:

- What information was available for evacuation decision-making leading up to the deadly 3 June 2018 pyroclastic density currents, how was it used by key stakeholders, and how did the ability to use this information impact the outcomes for La Reunión and San Miguel Los Lotes?
- Are evacuation decision-making practices since the 3 June 2018 disaster sufficient to avert disaster in a paroxysm of similar characteristics?
- How do cultural gender expectations impact evacuation strategies and how can women's experiences in evacuation inform future risk reduction strategies?

Results of these three studies indicate that the two government agencies were unable to fulfill their responsibilities of knowledge generation and decision-making during the crisis and the town of San Miguel Los Lotes was unequipped to make crucial evacuation decisions without this external support, while the La Reunión resort was able to evacuate independently. Current crisis management practices would be too slow and geographically too limited to avert a disaster with characteristics, including an escalation timeline, similar to that of the June 2018 eruption, in part because the system does not have well-defined acceptable risk thresholds on which to base evacuation decisions and no clear criteria for decision-making. Because communities prioritize women, children, and the elderly for evacuation while men stay behind to protect property, evacuations disproportionately leave men exposed to the threat and place the burden of evacuation with large families on the women. This research demonstrates the importance of explicitly including decision-making processes, resources and infrastructure for taking protective actions, and consideration of competing risks into EWS models. To be effective, an EWS must be designed within the limitations of the scientific, technological, economic, and socio-political context in which it operates.

1 Introduction

Natural hazards disproportionately impact populations that are already made vulnerable through social and economic factors, which often stem from deep-seated root causes and histories (e.g., Wisner et al., 2004). Ideally, risk reduction addresses the root social, political, and economic factors that drive the vulnerability, such as the causes that lead to people settling (or being settled) in precarious environments while lacking the resources and/or power to adequately respond to the hazards they then face (e.g., Wisner et al., 2004; Oliver-Smith, 1996). While addressing these root causes requires broad changes in power structures, more immediate solutions include effective early warning systems (EWS) and interventions that can reduce losses of lives, property, and livelihoods and/or improve quality of life in the short term. These interventions must still consider societal factors; they often exacerbate existing vulnerabilities within populations, preferentially serving subpopulations based on socioeconomic status, gender, and ability (e.g., Seager, 2014; Bradshaw, 2015; Stough and Kang, 2015), and/or resulting in unsustainable social and economic changes (e.g., Bowman and Henquinet, 2015). As several researchers have shown, EWS have historically focused on technology and infrastructure without adequate attention to human factors, resulting in inappropriate community responses to hazards (e.g., Mukhtar, 2018; Sufri et al., 2020), despite advice from the United Nations Office for Disaster Risk Reduction (UNDRR) to develop people-centered EWS (UNDRR, 2006). The research presented here focuses on the human dimensions of early warning systems for environmental hazards, with particular attention on the role of communication and decision-making processes in volcanic hazard-related risk reduction at Fuego volcano, Guatemala.

1.1 Social dimensions of risk

Central America is one of the world's most prone regions to geological, weather, and climate-related hazards, with Guatemala raking 10th in risk from 181 countries analyzed by the 2021 World Risk Report (Aleksandrova et al. 2021), susceptible to rapid-onset events such as earthquakes, volcanic eruptions, landslides, and flooding as well as slow-onset hazards such as drought exacerbated by climate change (e.g., Bundschuh et al., 2012). This region is also characterized by high levels of social vulnerability, shaped in part by decades of political, economic, and social instability (Bundschuh et al., 2012, Chomsky, 2020). In the 1980s, disaster research and practice shifted from focusing on hazards, seeing the related disasters as inevitable, to incorporating the role of societal drivers, seeing disasters as indicative of social vulnerability (e.g., Hewitt, 1983; Susman et al., 1983, in Tierney, 2019). Many scholars now frame disaster as the intersection of hazards with vulnerability, with an emphasis on the latter (e.g., Wisner et al., 2004; Oliver-Smith, 2016). To reduce risk to disaster, we must understand and reduce vulnerability, which results from root (deep-seated) causes, dynamic pressures (intermediate factors), and unsafe conditions (immediate threats) (Wisner et al., 2004).

Vulnerability frameworks first focused mainly on class disparities (Tierney, 2019). Yet, vulnerability is not distributed equally within a geography, class, or ethnicity. Mathie and Cunningham (2003) point out that communities (whether defined by place or demographics) are heterogeneous, and not always harmonious. Seager (2014) argues we need to go beyond the household level when examining vulnerability and risk reduction, as vulnerability is not uniform

within family or living units. For example, in the case of early warning systems (EWS), the United Nations report "Making Disaster Risk Reduction Gender-sensitive: policy and practical guidelines" (2009) describes that in many cultures women have less access to information than men, for example through exclusion from public spaces where announcements might be made, reduced access to cell phones and internet, and lower literacy rates. Individuals with disabilities often have special needs in evacuations and information access (e.g., Stough & Kang, 2015). Thus risk reduction is inherently an equity issue, on multiple levels.

Risk reduction must also consider other cultural factors. Mercer et al. (2012) emphasize the importance of recognizing these cultural factors in vulnerability and resilience assessments, for example the impact of oral histories about past disasters and of religious beliefs. The authors stress the need to develop context-relevant disaster risk reduction (DRR) strategies through 'insider'-'outsider' collaboration. They advocate for utilizing both local and scientific knowledge in risk assessment and risk reduction strategies.

1.2 The problem: Reducing risk to pyroclastic density currents at Fuego volcano

Fuego volcano, Guatemala, is one of Guatemala's three most active volcanoes, in a volcanic corridor stretching northwest-southeast parallel to Guatemala's coast (e.g., Bundschuh et al., 2012). Fuego threatens populations on and near its flanks with pyroclastic density currents (PDCs) (e.g., Escobar Wolf, 2013), fast-moving flows and surges of hot gasses and volcanic debris that can overbank the gullies that usually channel them. PDCs on 3 June 3 2018 resulted in the destruction of part of a golf resort, a bridge on a major thoroughfare, and the town of San Miguel Los Lotes. An official count reports 430 deaths with many still missing (CONRED, 2019; Naismith et al., 2020); of these, the vast majority were in San Miguel Los Lotes, with some also at the bridge. While survivors of San Miguel Los Lotes and residents of select other communities in the high-hazard zone were relocated to government-built housing, the remainder of the 37 *aldeas*, or communities of approximately 20 to 100 families, within 7-10 km of the volcano's summit (SEGEPLAN IDEG GeoPortal (2023); World Bank, 2018) continue to be inhabited on the volcano's flanks.

PDCs and their impacts cannot be mitigated in situ; instead, the only reliable risk reduction strategy is evacuation (e.g., Cole et al. 2015; Lavigne et al., 2018; Escobar Wolf, 2013). Because of their high speeds and unpredictable pathways, evacuation must occur before initiation of the flow or surge. Several factors complicate effective early warning and evacuation at Fuego. Fuego has been in its current eruption phase since 1999, with low-level background activity punctuated by stronger 'paroxysmal' activity, sometimes but not always resulting in pyroclastic flows (Lyons et al., 2010; Naismith et al., 2019). Paroxysms can be frequent, occurring up to 18 times in one year (Naismith et al., 2019). Observed run-up to pyroclastic flow initiation is relatively short; entire paroxysms last only around 24-48 hours (Lyons et al., 2010; Naismith et al., 2019). Naismith (2021) found that eruption and response timescales are comparable at Fuego, and that response on this already short timeline is delayed by long periods of decision-making and warning.

Variations in histories of the villages around Fuego have resulted in an at-risk population with a wide diversity of cultures, economic levels, and infrastructure access. Settlements include two Indigenous communities relocated to the flanks of the volcano after Guatemala's civil war, as well as many *ladino* (Mayan-Spanish descended) communities; represent extreme economic disparities and their related socio-political implications; and rely on evolving sources of livelihoods from farming to the service sector (Escobar Wolf, 2013). Naismith et al. (2020) identified differences in direct communication with authorities between settlements on the west vs. the east side of the volcano. These differences have potential implications for equity in past and future evacuation efforts at Fuego. In this diversity of residents, resources, and relationships, Fuego epitomizes DRR challenges throughout Guatemala and in other countries with recent histories of war and corruption. Notably, the affluent La Reunión golf resort and hotel evacuated before the deadly flows in June 2018, resulting in zero casualties (World Bank, 2018), while the relatively poor *colonia* of San Miguel Los Lotes did not evacuate, and suffered a loss of possibly 40% or more of their population.

Three paroxysmal eruptions have triggered evacuations at Fuego since the eruption on 3 June 2018, including one on 7-8 March 2022 during my fieldwork in Guatemala. The 7-8 March 2022 paroxysm resulted in PDCs of up to 7 km from the volcano's summit and the partial evacuation of three communities on the west side of the volcano, where the first PDCs were observed. Although PDCs can descend multiple gullies throughout the course of an eruption, and did later descend a gully on the east side of the volcano on 7-8 March, no evacuation was mobilized for these other communities. This recent event provided an opportunity to examine current evacuation strategies and the factors impacting them, including information availability for decision-making, decision-making processes by agencies and residents, expected roles and responsibilities of agencies vs. residents, stakeholder relationships, and compliance with evacuation procedures.

1.3 Research approach

This research uses a case study approach. Case studies are crucial for disaster risk reduction research because they provide real-world examples of social outcomes; Flyvbjerg (2006) argues that case studies are critical because "a scientific discipline without a large number of thoroughly executed case studies is a discipline without systematic production of exemplars, and a discipline without exemplars is an ineffective one" (p.219). The case study approach taken here aligns with Merriam's (1998) description of and approach to a case as summarized by (Yazan, 2016), where a case may be broadly defined as any "unit about which there are boundaries" (p.27), such as a program, a group, or a policy, with the research direction open to adaptation during the course of data collection in response to new information, and a constructionist epistemology (as opposed to a positivist approach) where knowledge is socially determined and not absolute. However, I also follow Yin's (2002) approach in using multiple data sources, including but not limited to interviews, for triangulation (described in Yazan (2016)). This work also closely aligns with a Rapid Ethnographic Assessment (REA) as described by Sangaramoorthy and Kroeger (2020) in their book "Rapid Ethnographic Assessments: A Practical Approach and Toolkit for Collaborative Community Research" in that the three projects are relatively short-term, problem-

oriented, and use multiple data types, with a focus on semi-structured interviews. While the research outcomes are specific to the location of the case, my intent is that they also inform broader efforts to reduce risk globally, especially in low-resourced rural settings.

This case is defined as *Fuego evacuation DRR actors*, people who have influence on or are participating in the communication during and outcome of paroxysmal eruptions of Fuego and their related evacuations. These actors include, but are not limited to, at-risk populations (people living and working within hazards zones identified by the National Institute of Seismology, Volcanology, Meteorology, and Hydrology (*Instituto Nacional de Sismología, Vulcanología, Meteorología e Hidrología*, INSIVUMEH) and partners (INSIVUMEH, 2018)), agency staff responsible for eruption- and evacuation-related decisions and communication, journalists, non-governmental providers of resources such as transportation (e.g., the *Instituto Privado de Investigación sobre Cambio Climático* (ICC)), and external advisors (e.g., volcanologists).

I chose a qualitative approach for the entirety of this case because it allowed me to investigate the complex and personal aspects of decision-making. Semi-structured interviews with open-ended questions enabled data collection on both individual and institutional motivations and limitations that would have been difficult to anticipate, difficult to quantify, and potentially difficult for me, as the 'outsider' researcher, to understand without the context afforded by conversation. Interviews and participant observation afforded a depth and richness to data collection and interpretation inherent in personal experience and hearing stories of the experiences of others. As also noted in each chapter, all interviews and observations were conducted under and in accordance with Institutional Review Board (IRB) approval 1,760,726–2 from Michigan Technological University.

Finally, a note on positionality. I began this research having never been to Guatemala and knowing little about its specific histories. While I have learned through reading, fantastic mentorship, and the time I was able to spend there, my understanding of the cultural context in which risk reduction efforts at Fuego volcano operate is, and will always be, limited. I am a clear outsider, especially in the rural communities I visited: I am from a suburban, middle-class background, have spent most of my adult life in or adjacent to universities, am tall and light-skinned, and speak Spanish as a second language. Because of the latter, I miss much of the subtleties of interactions and even meaning in words spoken. However, also because of this, I may have received a particular openness as an outsider. While still blind to many aspects of rural Guatemalan life that are similar to my own socialization, such as gender norms of women as caregivers, I was able to recognize other aspects of culture that were more foreign to me, such as noticing that very few to no women in the rural areas drove. Other aspects of my identity enabled me to connect with different participants. Because of my background in geoscience I was able to connect with agency volcanology staff. Because of my status as a foreign researcher and affiliation with Michigan Tech, I gained access to staff from both target agencies for this study as well as staff from the La Reunión resort. In fact, while several emails to journalists went unanswered, all other people I recruited–most but not all through shared connections–agreed to interviews. The research presented in Chapter 4, on gender, may not have been possible as it is presented were I not a woman, not only because I would have been less likely to choose the topic

but also because my coauthor, A. Naismith, and I shared an identity with the participants who we interviewed that likely enabled them to speak more freely than had men also been present.

1.4 Dissertation goals and outline

This dissertation extends previous research at Fuego by investigating in more detail the availability and use of information to make evacuation decisions, the decision-making process itself, and how cultural norms (specifically, gender norms) manifest in the evacuation decision-making process.

At the time of writing, approximately 63,000 people from more than 30 communities live in areas that have been mapped as potentially exposed to PDCs from Fuego volcano. This dissertation aims to serve this population and others like it by investigating these decision-making processes that drive evacuation in the face of uncertainty. Three chapters contribute to a single case study. In Chapter 2, I investigate information availability and its use in evacuation decision-making leading up to the *tragedia* of 3 June 2018. In Chapter 3, I examine current practices for evacuation decision-making four and five years on from the disaster. In Chapter 4, I focus on that same event to study how cultural gender expectations impact evacuation strategies and how women's experiences in evacuation can inform future risk reduction strategies. My goal with this research is to contribute a better understanding of information use for decision-making at Fuego volcano to inform early warning system design in Guatemala and in other, similar environments.

All three chapters are related yet each is written for independent publication, resulting in some redundancies in background information, and all chapters include significant contributions from co-authors. The first two chapters were written in close collaboration with co-advisor Dr. Rüdiger Escobar Wolf and will require revision before submission to academic journals. The third chapter, co-authored by Dr. Ailsa Naismith of Bristol University, has been accepted for publication in a *Frontiers in Earth Science* collection, "Women in Science: Volcanology," at the time of this writing.

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2 '*La Tragedia*': A retrospective on information availability and use leading up to the 3 June 2018 disaster at Fuego volcano, Guatemala

2.1 Abstract

On 3 June 2018, pyroclastic density currents from Fuego volcano, Guatemala, destroyed part of the La Reunión golf resort and hotel, the National Route 14 bridge across the Las Lajas channel, and the residential community of San Miguel Los Lotes. While the resort evacuated completely before the devastating flows, tens of people were killed at the bridge and hundreds more in the community. Using ethnographic methods, I investigate the availability and use of information for assessing PDC risk leading up to the deadly PDCs on the day of the eruption and how this relates to the disparate outcomes. Specifically, I evaluate availability and use of information for four key stakeholders: the two government agencies responsible for risk reduction, the La Reunión resort, and San Miguel Los Lotes. Results indicate that the La Reunión golf resort and hotel was able to evacuate independent of any government intervention at the time of the crisis. San Miguel Los Lotes, as with other communities around the volcano, was unequipped to assess the risk posed by the eruption and lacked timely and adequate guidance from authorities. Failure to evacuate the town of San Miguel Los Lotes was the result of multiple factors in the crisis response system, including a lack of interagency collaboration and coordination, lack of clear protocols for evacuation decision-making and warnings, and lack of adequate attention to or understanding of the PDC risk posed by Fuego volcano. The 3 June 2018 *tragedia* is an indication that risk reduction efforts at Fuego were inadequate to prevent loss of life from PDCs not only in San Miguel Los Lotes but more broadly in the communities close to the volcano. To reduce future risk, the decision-making processes for issuing warnings must be clearly defined, agreed upon, and understood by the responsible agencies; the agencies must take responsibility for producing actionable information; and the warning system should be designed within the limitations of the scientific, technological, economic, and socio-political context in which it operates.

2.2 Introduction

On 3 June 2018, between 3:10-3:12 pm local time[1], pyroclastic density currents (PDCs)--highly lethal avalanches and surges of hot volcanic gases, rock, and ash–from Fuego volcano, Guatemala, destroyed part of a golf resort and hotel, a major bridge, and two thirds of a small town on the volcano's flanks (Figures 1 and 2). The official number of fatalities and missing stands at 430, and the actual number of fatalities is likely several hundred higher. None of these fatalities occurred in the resort and hotel, La Reunión, which evacuated before the violent flows

[1] Determined from video of the PDCs descending within San Miguel Los Lotes between 15:10-15:11 (Leonid Rosas, 2018) and an interview with a La Reunión staff member describing a vehicle GPS transmitter within the resort stopping transmission at 15:12.

descended; several tens occurred near the National Route 14 (RN-14) bridge over the Las Lajas channel; and the vast majority occurred in the town of San Miguel Los Lotes, at a bend in the RN-14 ~1.2 km from the nearest channel on the volcano's flanks. This research investigates the availability, flow, and use of information for decision-making, most importantly the decision on whether or not to evacuate, leading up to the climactic PDCs and how it impacted the outcome for, in particular, San Miguel Los Lotes.

Figure 1: Satellite images showing the three main areas impacted before and after the 3 June 2018 PDCs. According to Google Earth, the image in A is from 7 March 2018 and the image in B is from 14 November 2018. Image B was lightened for clarity. (Images from Google Earth.)

Producing and disseminating effective warnings to evacuate is far from straightforward, as evidenced by a broad body of literature on the subject drawing from both the physical and social sciences (for reviews and compilations see, e.g., Mileti and Sorensen (1990); Singh and Zommers (2014); and Fearnley (2019)). An environmental hazard must be detected or forecast, requiring that it is adequately understood; a warning must be understandable, compelling, and actionable, and reach the at-risk populations; and recipients must have the willingness and capacity to act on that information. These components, their relationships, and the other social and technological factors impacting the process are referred to as an early warning system (EWS) (e.g., Fearnley, 2019). All groundwork must be laid for the system well in advance of any crisis, including educating at-risk populations and practicing the process to ensure all actors are clear on roles, responsibilities, and procedures (Kelman and Glantz, 2014).

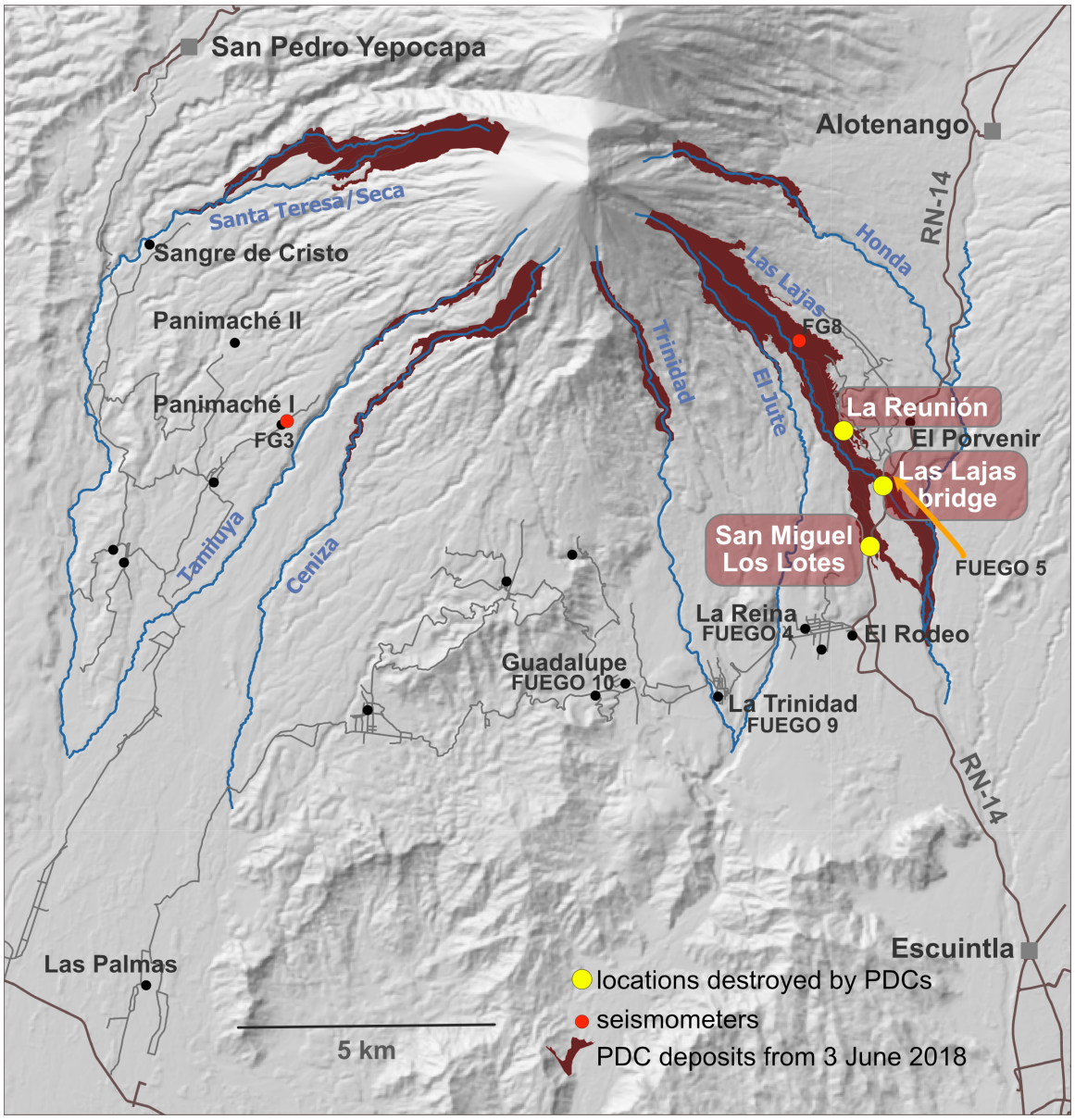

Figure 2: Map of Fuego and its surroundings indicating the three areas where PDCs impacted populations (the La Reunión golf resort and hotel, the RN-14 bridge over Las Lajas, and the town of San Miguel Los Lotes) as well as well as the locations of other communities mentioned in the text. The locations of CONRED radio bases are noted (FUEGO 4, 5, 9, and 10) as well as the locations of the two INSIVUMEH seismometers (FG3 and FG8).

The responsibility for each of the EWS components, or the system as a whole, varies between contexts (e.g., Jolly and de la Cruz, 2015). As described by Kelman and Glantz (2014), various stakeholders impacted by the threat can independently assess risk and make decisions about protective action based on their own observations and analysis, but typically monitoring, risk assessment, and warning are the role of the government and distributed between scientific and civil protection agencies. In some cases, the government also takes responsibility for deciding and enacting protective action; for example, in response to the reawakening of Tungurahua volcano,

Ecuador, in 1999, the Ecuadorian national government ordered an evacuation of the population around the volcano with advance notice of 30 hours, after which people were removed by the military (Tobin and Whiteford, 2002). At the other end of the spectrum, a stakeholder may enact a system, whether formalized or not, completely independently. In the oft-lauded case of Simeulue island, Indonesia, residents recognized signs of impending tsunami based on traditional knowledge and moved to high ground to escape during events in December 2004 and March 2005 (McAdoo et al., 2006). More commonly, responsibility and action lies somewhere in the middle; governments issue a warning and the decision of whether to take action and what action to take, e.g., evacuate, is made by at-risk populations and other stakeholders using that information along with other inputs and influences including personal observations, past experiences, social pressure and social cues, and news media (e.g., Drabek, 1999), and, increasingly, unofficial information on social media channels (Wood et al., 2012).

Also factoring into these individual and household decisions are potential or known costs of taking protective action such as, in the case of evacuation, negative impacts to livelihoods, disruption of social networks, and impacts to health (e.g., Tobin and Whiteford, 2000; Lane et al., 2003; Barclay et al., 2019). So, issuance of a warning is no guarantee that it will elicit the desired response. However, failures can occur at all levels and stages of a system. Both of the largest volcano-related disasters of the 20th century have been attributed in part to lack of or misuse of information by officials. In the case of the 1985 eruption of Nevado del Ruiz, Colombia, authors of retrospectives documented that volcanologists had identified the high lahar hazard but that the hazard map they produced met with strong opposition from economic interests (Hall, 1990) and that communication differed between the multiple jurisdictions between which the hazardous terrain was divided (Voight, 1990). During the 1902 eruption of Mont Pelée, Martinique, politicians reportedly obliged the inhabitants of the town of nearby Saint-Pierre to stay and vote despite intensifying activity (Scarth, 2002, in Fearnley, 2019). Both eruptions claimed more than 20,000 lives.

Based on their review of case studies, Mileti and Sorensen (1990) recommend that warnings contain information about the hazard, location, guidance, time, and sources. They acknowledge a particular challenge in providing this information with specificity and certainty for volcanic environments due to difficulty in the prediction, detection, and short lead time for some hazards, which certainly applies to PDCs. Still, volcano observatories and civil protection agencies exist to manage volcanic crises based on expertise, staff time, and resources not available to the general public. Although difficult, equivalent actors have successfully managed warnings and resulting life-saving evacuations in other contexts, such as at Mount Pinatubo, Philippines, in 1991 (Newhall and Punongbayan, 1996) and Merapi, Indonesia, in 2010 (e.g., Surono et al., 2011).

In this chapter I address the following question: Was there an opportunity to issue a timely evacuation warning to the town of San Miguel Los Lotes? The answer depends in great part on the information available and on the capacity of stakeholders, including government agencies and the population at risk, to use that information.

2.3 Approach and methods

This investigation uses ethnographic methods to build and analyze timelines of information availability and its use relevant to evacuation decision-making leading up to the climactic PDCs that destroyed the La Reunión golf resort and hotel, RN-14 bridge over Las Lajas, and town of San Miguel Los Lotes on 3 June 2018. I chose a qualitative design for this study for multiple reasons. First, and foremost, understanding the reasons for information availability and use requires studying these questions in the cultural context in which they occur, which necessitates a qualitative approach (Hoey, 2014). The research questions required collecting data that was not documented and was only available through key informants. Because the research addresses an event that transpired up to four years before data collection, an open dialogue was necessary to access memories; because of the sensitive nature of the subject matter, the personal, open-ended nature of semi-structured interviews was important to enable space for expressions of emotion and allowed interviewees some control in directing the conversation and their contribution. Finally, qualitative methods enabled a nuanced understanding of participants' experiences during the paroxysm not afforded by quantitative methods and, importantly, opened the research to unanticipated directions (Lareau, 2021). All interviews and observations were conducted under and in accordance with Institutional Review Board (IRB) approval 1760726-2 from Michigan Technological University.

2.3.1 Data collection and analysis

The timelines, context, and subsequent analysis are based on two primary data sources: digital information sources and semi-structured interviews (Table 1). The digital information sources, described below, were collected prior to fieldwork to create a preliminary information timeline based only on official information statements, official social media posts, and other select social media posts (Bartel et al., 2021; Bartel et al., 2022). Data collection then shifted to semi-structured interviews, which became the focus of analysis.

Table 1: Data types

Digital data sources	
Agency (INSIVUMEH and CONRED) information statements	
Source Text (pdf and/or Word) files obtained from the agencies by R. Escobar Wolf and/or S. Sennert (USGS-Smithsonian, Global Volcanism Program) - also publicly available on the agency Twitter and Facebook channels in image format	**Description** Agencies issued official information statements with updates on volcanic activity and recommendations; analyzed for time of release, description of volcanic activity, and usability of information content

Agency (INSIVUMEH and CONRED) social media posts	
Source Posts on Twitter obtained using Twitter's Advanced Search option (https://twitter.com/search-advanced?lang=en) to retrieve all posts from INSIVUMEH (@insivumehgt) and CONRED (@ConredGuatemala) spanning the time of the paroxysm (3 June 2018 - 5 June 2018, UTC), sorted by "Latest," and on Facebook using Facebook's account-specific search by year	**Description** Eruption-related posts; analyzed for time of publication and information content INSIVUMEH: https://twitter.com/search?q=(from%3A%40insivumehgt)%20until%3A2018-06-05%20since%3A2018-06-03&src=typed_query&f=live CONRED: https://twitter.com/search?q=(from%3A%40ConredGuatemala)%20until%3A2018-06-05%20since%3A2018-06-03&src=typed_query&f=live
Semi-structured interview and associated data	
Semi-structured interviews	
Source Conducted in person onsite in Guatemala and virtually using Zoom video conferencing software; recorded for audio; transcribed using Sonix.ai software	**Description** Interviews conducted with agency staff, external scientists, people living or working within Fuego hazard zones at the time of the eruption, journalists, and other stakeholders to document information flow (producers, channels, and timing) not evident in the above sources, as well as investigate how information was or was not used to make decisions *See interview guide in Appendix A*
Field notes and memos	
Source The author's Google Docs notes, research notebooks, e-mails, voice memos, and Telegram chats with advisor R. Escobar Wolf describing and discussing interviews, with the latter four pasted or otherwise uploaded into Google Docs	**Description** Written or recorded by researcher to document, share, and/or process new information and ideas, in some cases only accessible to the researcher and in other cases in conversation with and/or with feedback from others, especially R. Escobar Wolf; analyzed for emergent themes

2.3.1.1 Digital information sources

The 3 June 2018 eruption of Fuego volcano and its associated response was documented in part by government agencies, news media, public officials, and eyewitnesses, with much of this information available via social media. This digital media can be used to get a first approximation of what information was available publicly, from whom, and by when for decision-making during the crisis.

Social media

Twitter, Facebook, and YouTube were considered for analysis. While Facebook was by far the most used social media platform in Guatemala at the time of the eruption (61.6% of social media usage compared to 23.4% for YouTube and only 1.7% for Twitter on 3 June 2018 (Statcounter Global Stats, accessed 2022)), it is in great part a closed platform that requires users to be connected in order to share information, and is also not designed for discovery and searchability. Twitter, by contrast, was at the time the most open social media platform, and it was also easily searchable for past content. Both INSIVUMEH and Guatemala's civil protection agency, the National Coordinator for the Reduction of Disasters (*Coordinadora Nacional para la Reducción de Desastres*, CONRED) posted to their official Facebook and Twitter accounts but not to YouTube. Posts on Twitter were obtained using Twitter's Advanced Search option (https://twitter.com/search-advanced?lang=en) to retrieve all posts from INSIVUMEH (@insivumehgt) and CONRED (@ConredGuatemala) spanning the time of the paroxysm (3 June 2018 - 5 June 2018, UTC), sorted by "Latest" (Table 1). Agency Facebook posts were identified by searching on the year 2018 within each agency's Facebook page. Only a subset of the posts each agency made on Twitter, and no unique content, appeared on their Facebook pages. Because of this, I only consider Twitter posts in this analysis. The results of these searches were then culled to include only posts relevant to the eruption of Fuego volcano. In both cases, this culled set included official announcements (Special Volcanological Bulletins from INSIVUMEH and avisos, or announcements/notices, from CONRED), any mention of Fuego volcano in a post, and general guidance that pertained to the eruption regardless of whether it specifically mentioned Fuego (e.g., what to do in ashfall). The URLs and text content from these posts were then pasted into a Google Sheet created by R. Escobar Wolf that read the timestamp from the Twitter URL.

A second set of Twitter searches involved searching on keywords for the same time period, specifically on "Fuego" and "VolcánDeFuego," for which Twitter will return posts with any variation of capitalization (e.g., Fuego vs. fuego) or use of accents (e.g., volcan vs. volcán), as well as these keywords appearing with or without hashtags (i.e. fuego vs. #fuego). These results were skimmed to identify key tweets such as first mentions of an event or photos or video of activity. Like the posts from the account searches, the URLs and text content were pasted into a Google Sheet to organize the tweets for the timeline and extract the time information from the URL. YouTube videos were also used as a supplementary resource to determine the timing of events, e.g., the exact time of the descent of pyroclastic density currents. This information was retrieved by R. Escobar Wolf. Because interviews later indicated that social media played only a minor role in actual or potential outcomes for key stakeholders, most importantly that interviewees living around the volcano indicated they did not have Twitter accounts nor looked to

social media to seek information on the paroxysm until after the disaster, focus on information availability on social media was instead shifted to the information available through interview data.

Official information statements and records

INSIVUMEH produced seven Special Volcanological Bulletins throughout the duration of the paroxysm. Though these statements were available via Twitter as jpg image files, for ease of analysis I used pdf and/or Word files obtained from the agencies by R. Escobar Wolf and/or S. Sennert (USGS-Smithsonian, Global Volcanism Program).

Analysis

Social media posts and official information statements and records were used in two ways: First, to assess the timing and nature of volcanological events and human responses, e.g., at what time and where PDCs had descended and at what time authorities issued guidance or closed the RN-14. This information was entered into a spreadsheet to build the time sequence both of events and of when information about them was available. Second, information statements and social media posts produced by INSIVUMEH and CONRED were assessed for usability (i.e., whether information provided was actionable) based on best practices for warnings described by, e.g., Mileti and Sorensen (1990) and Drabek (1999), and in Sutton and Kuligowski's (2019) review of alert and warning messaging research for short messaging services.

2.3.1.2 Semi-structured interviews

The semi-structured interviews for this research were conducted with adults only (18 years and older) primarily in two different time windows and in Guatemala: November 2021 and January - June 2022. Semi-structured interviews were conducted considering guidance provided by Lareau (2021) and Jacob and Furgerson (2015) in that interviews roughly followed an interview guide with prompts and prioritized open-ended questions, including "big, expansive questions" (Jacob and Fergerson, 2015, p. 4) that allowed the participants to discuss what they found most relevant. While I prioritized meeting in person, some interviews were conducted remotely via a video conferencing software such as Zoom by myself or R. Escobar Wolf. Archibald et al. (2019) have found that virtual interviews, especially using video, can effectively allow for the rapport conducive to candid interview responses depending on the familiarity of participants with the technology used. While many interviews were conducted one-on-one, variations included interviews conducted with multiple interviewees (e.g., family members, fellow community members, or co-workers) to maintain a comfortable environment for the interviewee(s) and to use their time and attention efficiently. Sangaramoorthy and Kroeger (2020) acknowledge that group interviews can be effective, especially if the topic is a shared experience and not pertaining to information that would be considered private to individual participants. I conducted the in-person interviews in places of convenience to the interviewees, including at their workplace (e.g., the CONRED office in Antigua Guatemala, Guatemala), at their home, in a community space (e.g., a church in the community of La Dignidad, Escuintla, where many residents of San Miguel Los Lotes were relocated), or, for INSIVUMEH and CONRED staff, in the field during fieldwork when there was down time and we could find comfortable space out of earshot of others.

In all sessions, I or REW, as the interviewer, explained the project and received verbal consent to record audio and use data with names removed from all participants. Per the recommendation of Laurea (2021), I ran two audio recorders when possible for data collection, in case one failed. Data were collected in either Spanish or English, as preferred by participants. Each interviewee was assigned a code, which was documented with their name in a password-protected file, and that code was then used for file naming and later analysis.

Interviewees were recruited through a combination of purposive, snowball, and convenience sampling, following descriptions provided by Bernard (2016). Purposive sampling, or intentionally selecting certain participants to meet the goals of the research, was essential for ensuring inclusion of people in key roles in the eruption response. Sampling started with in-country contacts at INSIVUMEH and CONRED already known to MTU researchers. Additional participants were recruited through recommendations from these contacts, other interviewees, or other researchers for certain characteristics, e.g., lived in a community close to the Las Lajas channel (snowball sampling). Still other participants were recruited through convenience sampling, e.g., through connections made during community meetings or workshops I attended, or people local contacts introduced me to who were family members or lived nearby, where the primary goal was to increase the perspectives represented of residents living in additional communities close to Fuego at the time of the 3 June 2018 paroxysm.

Interviewees selected primarily through purposive sampling included staff from three of the four key stakeholder groups identified for this research: INSIVUMEH, SE-CONRED, and La Reunión (Table 2). These were people who were in positions directly related to production of information for decision-making (INSIVUMEH volcanology staff and SE-CONRED staff involved in the paroxysm response) and who had the authority to make evacuation decisions (La Reunión management). Additional interviewees from all three stakeholder groups provided context. Members of the fourth stakeholder group, residents of San Miguel Los Lotes, were recruited through snowball sampling. While I did not target community leadership, two of the interviewees were part of their COCODE, one of which was the COCODE president. Interviews included two one-on-one interviews, both in the relocation community of La Dignidad, Escuintla, and two group interviews, one in the relocation community of Parramos (three participants) and the other in La Dignidad (five participants). Additional interviews with residents of other communities around the volcano and who live outside the PDC hazard zone but were directly involved in the response, e.g., journalists and external scientists, provided helpful context in understanding the information flow leading up to and shortly after the climactic PDCs. There were 66 interviewees total who informed this research. Each interview lasted anywhere from 20 minutes to three hours.

Table 2: Semi-structured interview participation

	Total participants	***Interviews analyzed in depth***
Agency or business		
INSIVUMEH (scientific agency)	10	2
SE-CONRED (civil protection agency)	3	1
La Reunión (golf resort, hotel, and residences)	3	2
Communities		
San Miguel Los Lotes	10	4 all interviews: two one-on-one and two groups (1+1+3+5 participants)
Panimaché I	2	0
Panimaché II	2	0
Guadalupe	13	0
La Trinidad	11	0
La Reina	1	1
Santa Rosa	2	0
El Porvenir	1	0
Other		
External scientists	3	2
Volunteer firefighter	1	0
Journalists	3	0
NGO	1	0
Total	**66**	**12**

The analysis of the interview drove the level of transcription, which ranged from word-for-word with some descriptions of tone of voice, as described by Lareau (2021), to detailed notes (Sangaramoorthy and Kroeger, 2020). Interviews selected for detailed analysis were transcribed using Sonix.ai transcription software as a first pass and then corrected as needed by BAB with support from REW. Interviews analyzed in depth are indicated in Table 2. I chose to analyze 12 interviews representing a total of 18 participants (because of group interviews) in depth. These interviews were chosen for their importance in constructing the timeline of information availability to and use by the four major stakeholder groups. Other interviews were transcribed using the same software but without the attention to detailed corrections or were documented in notes capturing important information and key quotes (Sangaramoorthy and Kroeger, 2020). The 12 key interviews were coded in qualitative data analysis software (ATLAS.ti) using a flexible coding approach as described by Deterding and Waters (2021) for the following themes, determined from the primary research question and emergent themes identified through the interviewing and coding process: Timeline, Real-time information, Assessment of risk, Understanding of risk, Previous experience, System for response, Risk-reducing action, and PDC description. The associated subcodes are listed in Appendix B. These coded responses were then used to 1) build the timeline of information availability and use and 2) identify drivers, strengths,

and limitations in the production, sharing, and use of the different sources of information available to inform evacuation decisions.

2.3.1.3 Field notes and memos

As part of data collection, I documented observations, information, and reflections through written field notes and reflective memos, both in field notebooks and within Google Docs, some of which were shared with REW who commented, resulting in a text conversation; voice memos, alone and in conversation with research colleagues (recorded with permission), transcribed into Google Docs; and text discussions via the Telegram app with REW, saved into a Google Doc with permission as field notes. These notes and memos were revisited, annotated, and analyzed as recommended by Emerson et al. (1995) and Laurea (2021) to inform evolving theory and research questions.

2.3.1.4 Limitations

Limitations of this work include the following: Because the 3 June 2018 paroxysm occurred at least three years before interviews were conducted, and also because of personal trauma associated with the event, either through the role they perceived they had in the outcome or because of losses they suffered, participants may misremember or misrepresent the event and the circumstances leading up to it. Accuracy of analysis may be compromised by my own limited understanding of cultural contexts. Interviews with INSIVUMEH and, in particular, SE-CONRED staff in addition to those who participated in this research may add context that refines details of and constraints on information flow. However, those interviewed were the most engaged in the crisis that day. Interviews with additional residents of San Miguel Los Lotes may provide different perspectives on residents' experiences, such as whether they considered evacuating or did self-evacuate prior to the climactic PDCs, not represented in the participants sampled. More interviews would undoubtedly reveal more facets of the circumstances of the disaster. Still, the interviews conducted allowed me to triangulate and corroborate many of the details of what occurred that day, who did or did not have information leading up to the climactic PDCs, whether they were able to use it, and why. I believe the most important information, specifically that San Miguel Los Lotes received no actionable warning prior to the descent of the lethal PDCs, is accurate.

2.4 Part 1: Before the tragedy: Stakeholders, responsibilities, and information flow in crisis management

2.4.1 Authorities

EWS include several distinct components, which in practice usually involves different agencies, authorities at different levels, and the at-risk population, all of which need to work in coordination towards a common goal (Kelman and Glantz, 2014; Baudoin et al., 2016; Fearnley, 2019). Along those lines, Jolly and de la Cruz (2015, p.1188) state that: "Volcanic crisis management is a partnership between the vulnerable sectors of society, the scientists in charge of monitoring volcanic activity and assessing the volcanic hazard, and the government through its civil protection bodies." The scientists in charge of monitoring volcanic activity and assessing the

volcanic hazard and the government civil protection body in Guatemala are government agencies INSIVUMEH and SE-CONRED (the Executive Secretariat, *Secretario Ejecutivo*, coordinating the CONRED system), respectively (Table 3).

Table 3: Primary stakeholders, their responsibilities, and their information needs to fulfill those responsibilities in volcanic crises

Stakeholder	***Responsibilities during crises***	***Information needs during crises***
Scientific agency: INSIVUMEH	Generate and disseminate volcanic activity and hazard information through the collection and processing of data for decision-making	Volcano monitoring data (institutional and otherwise), as well as knowledge and model (mental, conceptual or otherwise) to interpret the information.
Civil protection agency: SE-CONRED	Generation and distribution of risk information including recommendations to at-risk populations and coordination of response	Hazard assessment/forecast, needs of residents, available resources
Private resort management: La Reunión	Make and enact decisions to ensure safety of guests and staff. (In practice during the crisis, they enacted all EWS steps independently, from assessing the hazard within their limited capacity to acting to mitigate the risk.)	Information about risk and recommended response. (In practice during the 2018 crisis, they independently generated their own hazard assessment/forecast within their limited capacity and from there their own risk assessment.)
Community authorities, e.g., COCODE / COLRED: San Miguel Los Lotes	Facilitate, communicate, and support decisions on behalf of the community	Information about risk, recommended response, and resources available

INSIVUMEH is primarily a producer and provider of information (Figure 3, Table 3): their mission statement is "To be a technical-scientific institution that **generates and disseminates geoscientific information**, through the collection and processing of data **for decision-making** that contributes to the benefit of the population" (author's emphasis; INSIVUMEH, 2023). For volcanic hazards, dedicated resources included a small team of volcanologists in INSIVUMEH's central office in Guatemala City, modest observatories staffed with two to three local observers (with one on duty at any given time) on the three most active volcanoes, and any functioning instrumentation–in most cases and especially before June 2018 the result of foreign aid. On paper, volcanology staff answered to as many as three levels of management, but during crises managed the information flow (and thus their decision-making) independently, using internal, unofficial protocol and judgment to determine what information to share and when. Volcanology staff shared the information via written bulletins that they distributed through an internally curated email list, including to INSIVUMEH's central communications group, which sent the bulletins to partner agencies including SE-CONRED. INSIVUMEH's central communication team also distributed the bulletins more broadly through the agency's website and social media feeds. At

the time of the 3 June 2018 crisis, INSIVUMEH had a very small team of volcanologists in their central office–four staff to monitor and assess three frequently active volcanoes, all close to populations–as well as observatories in two locations on the west side of Fuego. Therefore, when considering INSIVUMEH as a stakeholder we primarily will consider this small team of volcanologists, as their interactions and decisions determined INSIVUMEH's role in the crisis.

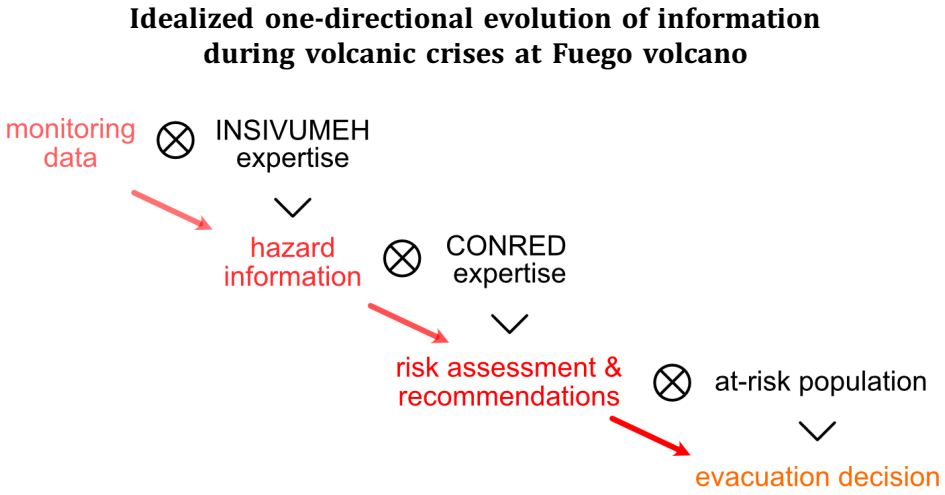

Figure 3: Idealized one-directional evolution of information during volcanic crises per roles and responsibilities in Guatemala. Volcano monitoring data are used by INSIVUMEH with their expertise to produce updated hazard information; CONRED uses that information with their expertise to produce updated risk information and recommendations; and the at-risk population of all levels uses that information to make informed decisions about evacuation.

CONRED is described as a coordinator more so than a producer. Per their mission statement, "CONRED is the body responsible for **coordinating disaster risk management** with public and private institutions, national and international organizations, and civil society at different territorial and sectoral levels, as an integral strategy that contributes to the sustainable development of Guatemala" (author's emphasis; CONRED, 2023), and SE-CONRED implicitly is tasked to help achieve these goals. As such, SE-CONRED distributes information to various stakeholders including the at-risk public and local authorities, and coordinates disaster risk management efforts before, during, and after crises. For volcano-related risk, this responsibility falls on two SE-CONRED entities. The *Delegados Departamentales* (Departamental Delegates) are staff pertaining to offices serving the communities within Guatemala's *departamentos*, or departments; at Fuego, that involves three separate departments. The Unit for Prevention on Volcanoes (*Unidad Prevención en Volcanes*, UPV; now *Departamento Prevención en Volcanes*) is a small group focused on volcanic disaster reduction that supports the regional delegates/departmental delegates, but also engages directly with at-risk populations as needed. SE-CONRED is a much larger and more tiered institution than INSIVUMEH, with the Delegados Departamentales answering to five levels of management and the UPV staff answering to four levels of management. Like INSIVUMEH's volcanology team, however, they do have some

decision-making agency. During a crisis, Delegados Departamentales and staff within UPV deploy to the communities around the volcano, monitoring the volcanic activity and speaking with residents. They may make recommendations about evacuation directly to local authorities without going through higher levels of the SE-CONRED system. However, the mobilization of resources often requires a request from local authorities, declarations of an alert level at the municipal level or higher, and convening of a Center for Emergency Operations (*Centro de Operaciones de Emergencia*, COE), also at the municipal level or higher.

CONRED is made of a tiered system of risk management bodies at each level of government: CORRED (regional), CODRED (departmental), and COMRED (municipal) groups are all organized and staffed by the corresponding level of government, e.g., the mayor's office in the case of the COMRED, where such levels of government have permanent staff. The lowest level, the COLRED (local), is a volunteer group within each community, the smallest of which, *aldeas*, may have populations of only a few families (tens of people). While SE-CONRED, and especially UPV, is responsible for preparing local communities to respond to risk, during a crisis they are responsible for distributing information to at-risk populations, including recommendations about protective actions, and then coordinating a response as requested by community authorities. Per the system, decision-making and responses for taking any protective actions fall to local civic structures. When local capacity for response is exceeded, response moves to the next level up, e.g., from *aldea* to municipality, etc.

In theory, local authorities use information (risk assessments and guidance) provided by SE-CONRED as well as their own observations of volcanic activity, interpreted through SE-CONRED (Delegados and UPV) educational efforts and their own experience, to make community-level decisions about evacuation unique to their geography and internal capacities. In June 2018, communication pathways between SE-CONRED and communities close to Fuego included a radio network, onsite visits from staff, and direct phone calls and messaging. Responsibilities and processes for local decision-making vary between communities (see Chapters 1 and 3), but in theory decisions are produced democratically by the whole community with the coordination of their Community Development Council (*Consejo Comunitario de Desarrollo*, COCODE) and then supported by their COLRED.

Ultimately, evacuation decisions are made by households and individuals, though the ability to make and act on these decisions appropriately depends highly on access to and trust in high-quality risk information (Drabek, 1999; Haynes et al., 2008), an understanding of that information and its implications (Sorensen, 2000; Twigg, 2003; Egerton et al., 2022), and the resources to take appropriate action if deemed necessary (Escobar Wolf, 2013).

2.4.2 At risk: La Reunión and San Miguel Los Lotes

Though geographically close, the La Reunión golf resort and hotel and the community of San Miguel Los Lotes, both destroyed by the PDCs from the 3 June 2018 paroxysm, were a world apart in terms of internal social structures, populations, and evacuation capabilities. La Reunión was opened to the public in March of 2009 as a privately owned, high-end destination for the wealthy both within and outside of Guatemala (CentralAmericaData, 2009). Previously a finca, or

coffee plantation, the grounds were turned into a world-class golf course, an upscale clubhouse with a restaurant, and chalets, all with views of the immense volcanoes of the surrounding area. This resort area crowded against the Las Lajas drainage to the west, which descended from the uppermost slopes of Fuego (Figures 1 and 2). To the east of the resort, La Reunión managed lavish residences, farther from the Las Lajas channel but all within the same property protected by gates and armed security staff.

The resort had a highly structured management system with clearly defined responsibilities and roles, headed by a general manager, now known for her role in calling for the evacuation in June 2018 (Canal Antigua, 2018; Ordoñez, 2021). Evacuation procedures were described similarly by multiple La Reunión staff interviewees. The general manager on duty was responsible for making decisions during a crisis, including whether to evacuate, with but not restricted to the input from the security staff and team leads. A WhatsApp group facilitated immediate communication among and between these two groups—security staff and management—with protocols in place to share security-related updates such as the Daily Volcanological Bulletin from INSIVUMEH, which was received directly via email to the security team. Once the most senior manager onsite made the decision to evacuate, staff immediately sounded the resorts' sirens and all staff left their normal tasks to take on their predefined roles in the response. Staff called to notify hotel guests, transported golfers from the golf course in golf carts, and accounted for each visitor in their logs. They had practiced these procedures through previous evacuations (at least nine since 2013) but also drills run as frequently as every month, midweek when there were fewer clients onsite. The head of security wanted their response time down to five minutes.

This system was enabled by multiple factors. As a private business, La Reunión had authority over the people within its purview, specifically the staff hired to serve the business and the guests on its private property. Owners and management had the ability to dedicate staff to the safety and wellbeing of the people within its grounds, could mandate staff roles and responsibilities, and hold people to account–as well as be held accountable by their clientele–in these roles. La Reunión staff refined these roles and responsibilities in response to eruptive crises at Fuego through their continued experience with paroxysms.

Several other factors facilitated evacuations at La Reunión, including the affluence and inherently transitory nature of their guests. All guests were on the premises temporarily, thus evacuating from the resort was not the same for them as evacuating from their primary home; they had few material things and few personal attachments to the place. Anything of great value that was left behind was likely insured. While staff needed to ensure all guests followed the orders to leave, they didn't need to support their evacuation, since guests for the most part had their own transportation, including even private helicopters at times–though there were none onsite on 3 June 2018. For staff working at the resort–many of which lived in San Miguel Los Lotes and other nearby communities–the resort had the resources internally to evacuate anyone lacking transportation to the main road. La Reunión management did not have to account for anyone's shelter once they were offsite.

The town of San Miguel Los Lotes, by contrast, was a small (~0.05 km2, or 4.75 hectares), compact community, or *colonia*. Its population is not represented in the 2018 Guatemalan

national census, but a relatively recent public project profile (which requires local census data) from March 2014 gives a total population of 1077 inhabitants (SEGEPLAN, 2014); the population was likely higher in 2018. Like many other communities on the volcanic slopes that represent the transition from the highlands to the Pacific Coast lowlands, San Miguel Los Lotes was on land that was formerly part of a finca. Although the community was relatively new, founded in 1964 (World Bank, 2018), most former residents interviewed for this study had multigenerational ties to the immediate area, in some cases born in and raising their own families in San Miguel Los Lotes on land obtained by and in a house now adjacent to a parent who had worked in a finca on Fuego's slopes. So for many, San Miguel Los Lotes was the only home they'd known. For example, one interviewee born in the colonia had a daughter who was just one month shy of her 15th birthday when the disaster occurred. Unlike most other rural communities around Fuego, San Miguel Los Lotes was directly on the RN-14 road, which bordered it on two of its four sides, on the east and southeast (Figure 1). Most other communities are accessible only via poorly maintained unpaved roads. Residents in the *colonia* relied on day labor, such as farm work in nearby La Candelaria finca or the Toledo factory pig farm, but also worked in the tourist and other sectors for which living along the RN-14 provided easy access by bus, easily arriving to the La Reunión resort or other employers in nearby cities like Antigua or Escuintla.

As described in section 2.4.1, governance of most small communities around Fuego centers on the COCODE, the civic group responsible (on top of their other livelihood responsibilities) for decision-making within the community, presumably through convening a community-wide meeting and producing a decision through democratic vote. This decision, in the case of an evacuation, would then be supported by the community's COLRED, their volunteer civil protection group that also provides the primary link to the rest of the CONRED system, most importantly its knowledge and material resources. The strength of the local (community level) authority and of community collective action in general vary from community to community, depending on a variety of issues, from their story as a community (e.g., unifying struggles they may have faced) to how they approach common significant community projects (e.g., local agricultural cooperatives), resulting in either more communally or individually focused groups. This local history and culture may influence their involvement with other groups like government agencies, their decision-making processes during a crisis, and their ability to coordinate residents and resources for action. Interviews indicate that, while San Miguel Los Lotes had a COCODE, their COLRED was inactive and appeared to be unfamiliar to the two COCODE members interviewed for this research. By contrast, other communities, such as La Reina, had a COLRED leader that was very active in disaster risk reduction efforts, engaged regularly with SE-CONRED through operating the radio base they hosted in their home, and was invited to participate in CONRED activities such as evacuation simulations. San Miguel Los Lotes lacked these direct communication channels with authorities, having no CONRED radio base within the community, and also no access to the INSIVUMEH observers on the other side of the volcano that were well-known to communities on the west side. They therefore as a community lacked the social capital that would have facilitated receipt or retrieval of official updates and advice.

In the case of deciding to evacuate, either on a community or household level, community leaders faced challenges not faced by La Reunión management, and residents faced challenges not faced

by the resort's visitors. In evacuating, residents of San Miguel Los Lotes would have to leave their permanent residence; they were unlikely to have insurance for any items that were valuable to them that they would have to leave behind; they were unlikely to all have their own transportation, relying on friends, neighbors, or bus to transport large families; and they were unlikely to have the means to easily take on the expense of private temporary lodging, instead requiring outside assistance from friends, family, or the government.

2.5 Part 2: Timeline of information availability and use

The chronology presented here details events–focused on information availability and use–starting tentatively 2.5 weeks before the day of the 3 June 2018 paroxysm but more rigorously starting at ~1:30 on that same day. Data sources for the timeline described in this section and presented in Figure 4 include interviews, social media posts, official information statements from INSIVUMEH and SE-CONRED, and seismic data from INSIVUMEH interpreted by advisor REW. Tables of more detailed timelines of information availability and production by INSIVUMEH and SE-CONRED are provided in Appendix C, along with a table of each of the four key stakeholders' primary information sources and a table summarizing PDC-related information published in each of INSIVUMEH's bulletins and a table summarizing information sources used by each of the key stakeholders.

Possible precursory activity, May - June 2018

Volcanic activity that could be seen as potentially precursory to the paroxysm started as much as two weeks earlier with observations of an active lava flow in the Ceniza channel on the southwest side of the volcano from 17-25 May, as reported by INSIVUMEH observatory staff and documented in INSIVUMEH Daily Volcanological Bulletins for the same dates and confirmed in data from Landsat, Sentinel 2 and ASTER satellite images (R. Escobar Wolf, pers. comm.). After 25 May the data on lava flows is unclear though several interviewees report remembering lava flows and/or crater glow the night before the paroxysm, on 2 June 2018. However, lava flows often occur without leading to paroxysm, so the start of a paroxysm, not the occurrence of lava flows, is a less uncertain indication of increased risk of PDCs.

01:00 - 03:30, 3 June 2018

Seismometer FG8 on the west side of Fuego (Figure 2) recorded increased seismic energy perhaps resulting from small PDCs (Escobar Wolf, pers. comm.) starting by ~01:30 and lasting until around 03:00. These earliest signs went unobserved at the time and can only be seen in retrospect, as the data were not transmitted in real time. The other operational seismometer on Fuego, FG3, on the east side of the volcano, was telemetered but not transmitting; the data were not recorded.

03:30 - 06:00

At ~03:30 on 3 June 2018, the INSIVUMEH Fuego Volcano Observatory observer on duty noted incrementing explosions and texted his main contact at INSIVUMEH central with no response. At ~05:30, he witnessed PDCs descending "in the Seca or Santa Teresa ravines and possibly others such as Cenizas" (BEFGO 27-2018, 06:00, Appendix C) on the west side of the volcano

and this time called his contact at INSIVUMEH central's volcanology unit, waking him up. Though reports and photographs indicate skies were clear elsewhere around the volcano, the bulletin indicates the observer couldn't discern the length of PDCs because of cloud cover on the west side. These PDCs prompted INSIVUMEH volcanology staff to produce the event's first Special Volcanological Bulletin, reporting the beginning of a paroxysm. Staff distributed this and all subsequent bulletins via email to a list of recipients that included external scientists who had researched Fuego, La Reunión, and INSIVUMEH's centralized communication hub. The latter then distributed the bulletins to SE-CONRED and other government agencies as well as posting the bulletins on the institution's official Twitter account, with only a subset posted to their Facebook page.

In the first bulletin, issued at 06:00, they described the paroxysm as Fuego's second eruption of the year, with PDCs on the west side of the volcano. They warn that the paroxysm is just beginning and PDCs could come down any of the barrancas around the volcano, as well as noting that the pyroclastic flows can fill the ravines.

06:00 - 11:00

SE-CONRED Staff recognized the elevated activity from both the first INSIVUMEH bulletin and also their own observations, based on their experience with the volcano; continuous ash emission was visible from the city of Escuintla from early in the morning. Records indicate the first report from a resident of a community on Fuego's south flank at 07:27, sharing that "smoke" was going west toward Sangre de Cristo. A record at 08:00 shows a contact in the community of Ceilán reported 'material' moving down toward Yepocapa, also west, likely describing a PDC. Staff made rounds to communities and reported by cell phone and radio back to the central office in Guatemala City, noting more ashfall on the west than the east flanks throughout the morning. Central staff posted these updates on Twitter.

The La Reunión resort security staff on duty received INSIVUMEH's special bulletin to the resort's general security email address at the start of their workday around 07:30 and distributed it to management and the security team via their internal WhatsApp group, per protocol. Management and security staff visually monitored the volcanic activity from multiple locations throughout the morning.

INSIVUMEH's second bulletin, timestamped 10:05 am, indicates staff observed continuing explosive activity over the preceding four hours, with additional PDCs on the west side of again indeterminate length (BEFGO 28-2018). They advised staying out of and away from ravines.

INSIVUMEH central staff worked to improve their information flow, contacting INSIVUMEH IT to resolve a network problem that cut off telemetry from FG3 the night before. They also contacted security staff at La Reunión to request a power cycle of a telemetered webcam at the clubhouse. Data plots in subsequent bulletins indicate FG3 came back online at 10:21 (BEFGO 33-2018, 22:00). However, the webcam system at La Reunión could not be brought back (it may have been damaged by a lightning strike), leaving them with only one telemetered instrument on the volcano during the paroxysm. The seismic amplitude data from FG3 was and remained saturated.

Security staff at La Reunión shared in an interview that when the INSIVUMEH volcanologist contacted him late in the morning to request a power cycle of the webcam, they also sent a text recommending that he pay close attention to the volcano's activity. The interviewee shared the impression this made on him: "For someone professional to tell you 'Be very, very alert,' then you have to put yourself on guard and (...) be able to implement what you've been taught." This message prompted him to go to the highest part of the resort to take photos and videos of the activity to share with the security team and management via their internal WhatsApp group, again per protocol. When asked if he shared any photos or videos with INSIVUMEH staff, he responded, "No, because the phone is corporate and if I don't have an authorization (...) I can't send anything, I can't do anything. If [my boss] tells me yes, then yes. At the time they told me everything you recorded, to no one. To nobody."

La Reunión security distributed the second INSIVUMEH bulletin to management.

11:00 - 12:30

La Reunión's general manager described noticing and being alarmed by strong volcanic activity at Fuego's summit from the clubhouse lobby's picture windows shortly after 11:00: "In a fraction of a second, the cone was covered and the gushes of gas that emanated from it were impressive. In less than five minutes, the flow began to drop at speeds I had never seen before" (Ordoñez, 2021, p.51, my translation). The sky turned dark. The explosions were loud and constant. "It was nothing like what I had experienced in my eight alerts of previous years" (Ordoñez, 2021, p.53, my translation).

After a brief gathering with security and management, the general manager made the call to evacuate. They sounded the resort's sirens and took on practiced roles to evacuate all guests (~180 people) and most of the staff (~120 people) within 90 minutes.

An interviewee from San Miguel Los Lotes who was out of the country reports that he got the first concerned message that day from his family around 11:00, sending videos and saying that it was cloudy, likely referring to the ash clouds from the PDCs. He told them to be calm and be ready because "if you have to leave, you have to leave." Another interviewee from San Miguel Los Lotes who was working in Antigua that day called to check in with her son late in the morning and they compared ashfall, her reporting ashfall in Antigua and him saying there was none in San Miguel Los Lotes, only clouds, again likely referring to ash farther up on the volcano's slopes. He asked that she call her father, who was working up in the La Candelaria plantation adjacent to La Reunión. Her father answered and told her not to worry, that he was headed home. She called again 15 minutes later and he said again not to worry, that he was home and everything was fine; her brother and sister, who also worked in fincas, were told to evacuate as well and were also home at midday for lunch, "everything is normal." Still another interviewee from San Miguel Los Lotes who was working in La Reunión as a caddy that morning said he evacuated with the first group of staff to the road because he had just finished his work at noon when the evacuation started. He went home to San Miguel Los Lotes on bus.

Throughout the day, staff and volunteers from the broader CONRED network (e.g., SE-CONRED, municipal-level staff, and COLRED volunteers) as well as spectators from nearby

communities, passersby, local and regional officials, and others came to or stopped on their way past the RN-14 road bridge over the Las Lajas channel to get a view of the volcano. Multiple interviewees, including journalists, described this behavior as normal, as evidenced by news coverage of past paroxysms. Residents described going to the bridge–either themselves or others–to monitor the volcano's activity or out of curiosity.

12:30 - 14:00

INSIVUMEH volcanology staff were notified between around 12:30-13:30 of stronger PDCs on the west side of the volcano by their observer, of fine ash out to ~50 km and 1 to 2 cm lapilli out to ~10 km from the volcano as pictured in social media posts that were pointed out by a journalist contact, and of the eruption cloud reaching 10,000 to 12,000 m in altitude above the volcano's summit by an external scientist monitoring GOES satellite data (the latter shortly before 13:00). All three of these measures–strength of PDCs, distribution of tephra, and height of eruption column–are indicators of increased activity, and in the case of the coarser tephra fall and the eruptive column height, also indicative of higher eruption intensity (mass discharge rate). INSIVUMEH staff, as well as external scientists, interpreted these observations to indicate the eruption intensity exceeded that of any recent paroxysms and was the highest intensity eruption since the first eruption of the current eruptive period, on 21 May 1999, or possibly since the VEI 4 eruption of October 1974, which caused widespread damage from tephra fall.

The same external scientist noted in an interview that the satellite data indicated the peak of column height was over by 13:00 or 13:30 and was detached from the summit, but that he was aware that activity could pick up again, particularly because they already knew that this was probably the biggest eruption since 1974, "so the worry was very clearly there in my mind and I think in other people's minds as well." Through social media, around 13:30, the same scientist saw the first images of PDCs directly hitting La Reunión, sharing in the interview that "that was the second big 'wow' moment, because this showed for the first time that PDCs were directly hitting a populated area." He stopped receiving responses from his INSIVUMEH contact shortly after first alerting him of the satellite data; it's likely INSIVUMEH staff did not see his later communication.

An increase of reports from within the broader CONRED network from 12:30-13:00 also describe an increase in eruption intensity: A "flow" at 12:30, likely indicating a PDC in the Las Lajas channel (radio operator Fuego 5); "stones" and "pyroclasts" (likely lapilli) falling in three locations up to 16 km from the summit, and ash fall at least 18 km away. Field staff also noted a change in the activity, observing that ash was now directed mainly to the east side of the volcano, which could be the result of a change of wind direction and not directivity of material from the volcano. However, the interviewee noted that "There were pyroclastic flows coming down, and companions were now reporting falling of larger material on the Sacatepéquez [northeast] side too." A record at 13:37 indicates that the radio operator in La Reina (Fuego 4) reported "flows in Honda, Las Lajas, the bridge, and El Jute; firefighters are turning back traffic in the area."

Although there are no reports of warnings in the SE-CONRED records, interviewees shared stories of various alerts around midday. One SE-CONRED interviewee shared that he suggested

contacts in the community of Las Palmas consider evacuating their town after receiving a report of a large PDC in the nearby Ceniza channel, which may have been earlier in the day. The same interviewee described urging SE-CONRED as well as municipal officials to activate more staff and raise alert levels when the eruption intensified at midday, and recommended closing the RN-14 past the volcano. According to multiple interviews, a volunteer COLRED leader rode from her home in La Reina on the south side of the volcano to the Las Lajas bridge calling out warnings to the ~4 communities along the way, including San Miguel Los Lotes, via a megaphone. It is not clear what these warnings consisted of and whom they reached.

At 12:55, La Reunión's general manager recorded a video looking west toward the clubhouse: active PDCs in Las Lajas extended past the clubhouse but had yet overbanked at that location. Evacuation of the resort was complete at that time. She sent this video to fellow staff and it was later posted on social media. A small crew of staff continued to secure the grounds and evacuate the adjacent La Reunión residences, east of the resort area and further from the Las Lajas channel.

INSIVUMEH staff posted third and fourth bulletins of the paroxysm at 13:45 and 13:55 (BEFGO 29-2018 and BEFGO 30-2018, respectively). In the bulletins, they described the eruption as "the strongest in recent years" and reported strong PDCs in six of the seven major channels on Fuego, including Las Lajas on the east side. They recommended that SE-CONRED raise the alert level and consider evacuating the hamlet of Sangre de Cristo, which was their first mention of evacuation; stated that climbing "the volcano" was prohibited to tourists; and recommended in all capital letters that the civil aviation authorities close the La Aurora International Airport due to ash.

14:00 - 16:00

At around 14:00, the resident from San Miguel Los Lotes who was out of the country received messages from his family that the activity was stronger and had gotten worse, summarized in the interview as, "A dark cloud is coming." They sent him photos every 20 minutes. He said don't be confident, something's going to happen.

Video of the 18th hole of La Reunión's golf course taken by security staff at 14:24 shows the clubhouse still intact. Shortly after taking the video, the staff member interviewed said he saw a strong flow approaching and fled: "everything started from there." When the general manager tried to go to the resort's visitor entry gate, ~ 250 m east of the Las Lajas bridge, the route was impassible; the nine upper holes of the golf course, the channel, and the cobblestone roads along the channel were covered with PDC deposits. The heat made it difficult to breathe. She was called on by two motorcycle officers to respond at two houses in the residential area where visitors refused to leave. She was unable to persuade them and was out on the main road to speak with officials about the two houses with the rest of the residents already evacuated by 14:45. SE-CONRED staff member Juan Galindo, who had been at the bridge, asked her for access to the resort with people from his CONRED team to assess the direction and speed the flows had come down, which she granted. All remaining La Reunión staff were out to the road by this time and out of the resort. They fled northeast to the town of Alotenango.

Following the fourth bulletin, and before the destructive PDCs, INSIVUMEH published three posts on Twitter, all about ashfall: a map of ash and tephra fall (14:36), a "Did you know?" educational post about what volcanic ash is (14:40), and a post with recommendations for how to protect against the hazards related to ash (14:57) (Figure 5).

CONRED staff and local residents stayed at the bridge after the segment of the RN-14 past Fuego was closed. They were still there when the first PDC to reach the bridge descended sometime after 14:30. Records timestamped 14:17 indicate the radio operator close to the bridge (Fuego 5) reported another flow in Las Lajas. A record at 14:52 pm indicates he reported a flow had reached but gone under the bridge and that the activity was diminishing[2]. However, this flow prompted SE-CONRED staff to flee from the bridge. Juan Galindo, on the northeast side, returned to the bridge, while the other fled southwest.

Reports suggest emergency response staff northeast of the bridge tried warning residents near the bridge and urging them to evacuate. SE-CONRED staff that fled southwest with the volunteer COLRED leader from La Reina stopped the truck at the entry to San Miguel Los Lotes to warn residents with their siren and megaphone, telling people to spread the alarm. They continued to call out warnings along the RN-14.

Interviewed INSIVUMEH staff shared that at around 15:00 pm they received a call from a personal SE-CONRED contact with the information that PDCs had reached the La Reunión resort, presumably the first INSIVUMEH staff had heard that the resort had been impacted.

Like CONRED staff and volunteers, residents had gone to the RN-14 bridge over Las Lajas, including the president of San Miguel Los Lotes' local governance, the COCODE. Another interviewee had gone with others up to the *arenera*, or sand quarry, at the north end of the town, which was also upslope. They were still in these vantage points shortly after 15:00, after the first flow to reach the Las Lajas bridge had already descended; both saw the next flows coming down that would destroy the bridge and bury much of San Miguel Los Lotes. Both fled toward their families within the town.

A GPS system in a vehicle parked near the La Reunión clubhouse stopped transmitting at 15:13 pm. A now deleted YouTube video (Leonid Rosas, 2018) including timestamps shows the PDCs reaching the Las Lajas bridge at 15:09. The same video shows the people who took the video driving south on the RN-14 road, being closely chased by the PDCs, and passing San Miguel Los Lotes at 3:11 PM. From the video it is apparent that PDCs must have impacted San Miguel Los Lotes only seconds to at most a minute after this.

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[2] Original: "Informa que la lava ya paso por el puente ya se observa que esta disminuyendo." English translation: "Informs that the lava has passed the bridge and [the activity] is now diminishing." Note that the term "lava" is used to describe lava flows, PDCs, and lahars and here likely refers to a PDC.

The SE-CONRED staff on the southeast side of the bridge returned the COLRED leader to La Reina so she could coordinate her own community for evacuation as needed. When he returned shortly after 15:00 with the intention of going into San Miguel Los Lotes to further warn them, he was unable to reach the entry: PDCs had reached San Miguel Los Lotes and residents were fleeing onto the road. He made eight trips evacuating survivors to the nearby town of El Rodeo, each time with fewer people.

Juan Galindo, on the northeast side of the bridge, as well as radio operator Fuego 5, no longer responded to radio or phone communication.

After learning of the PDCs impacting La Reunión, INSIVUMEH staff described calling his security contact there to check in, and that the La Reunión security staff member said he was by the bridge, recovering cadavers of people who had died.

At 15:36 and 15:37, radio operators reported loss of power in La Reina and La Trinidad, respectively, possibly reflecting the fact that PDCs had cut power lines along the RN-14 road some 20 to 30 minutes earlier.

After 16:00

INSIVUMEH staff produced three more bulletins that day, after the destructive PDCs descended. The bulletins make no mention of PDCs reaching populated areas. Instead, they describe their observations of declining eruption energy. In a bulletin at 16:50, they reported that "Moderate Pyroclastic flows continue to descend the Seca, Cenizas, Mineral, Taniluya, Las Lajas, and Honda ravines," recommending that SE-CONRED maintain the alert level and that the airport stay closed for several more hours (BEFGO 31-2018). At 19:20, they reported diminishing eruption energy but that "Some Pyroclastic flows are still reported, which can travel further since the ravines are full and continue to overflow," although the 22:00 bulletin reports that the last PDC was recorded on the seismometer at 18:45 (BEFGO 33-2018). In that last bulletin, they declared the paroxysm over, 16 hours after it began, and recommended that SE-CONRED maintain the alert levels and that people don't go in or near ravines due to lahar hazard.

2.6 Part 3: Deconstructing Disaster

2.6.1 Information availability for assessing PDC hazard

A fundamental question regarding the outcomes of 3 June 2018 pertains to the raw volcanological information: was enough evidence of increasing risk available, considering all information sources? Could the destruction of San Miguel Los Lotes have been foreseen with current scientific knowledge and technology? Key volcanological observations that pertain to PDC hazard assessment are shown in Figure 4, highlighting which of those observations were and were not available to INSIVUMEH in near-real time.

Based on patterns observed since Fuego reactivated in 1999, staff at INSIVUMEH and external scientific colleagues had identified multiple signs used to recognize increases in PDC hazard. First, PDCs occur almost exclusively during paroxysms and usually after other observable activity signaling the onset of a paroxysm. PDCs during a paroxysm often occur in the channels

in which staff have observed lava flows immediately preceding or at the start of a paroxysm. Moderate to large PDCs are almost always–but with some significant exceptions–preceded by smaller PDCs in that same channel. Higher intensity eruptions are likely to generate larger PDCs (e.g., 21 May 1999 and 5 May 2017). (For discussions on PDC mechanisms at Fuego, see Escobar Wolf (2013), and for a summary of the June 2018 PDCs see Charbonnier et al. (2023).) Lower capacity channels (shallower, narrower) can fill and overflow more readily than larger channels, though a series of high-volume PDCs–or even a single high-volume PDC–can fill even a large channel. Also, highly energetic PDCs can jump a channel at a sharp bend. Fuego's flanks–extending well beyond the distance of most of the closest communities, and perhaps as far as 10 to 15 km–are composed in good part and often predominantly of PDC deposits, indicating that all flanks of Fuego's edifice, much like a delta, have in the past and could again in the future be subject to PDCs inundation and deposition (Escobar Wolf, 2013). Still, it is impossible to know with certainty exactly when, where, and of what magnitude a PDC will be, on Fuego or on any volcano (Nakada, 2015; Valentine and Fisher, 2015; Lavigne et al., 2018).

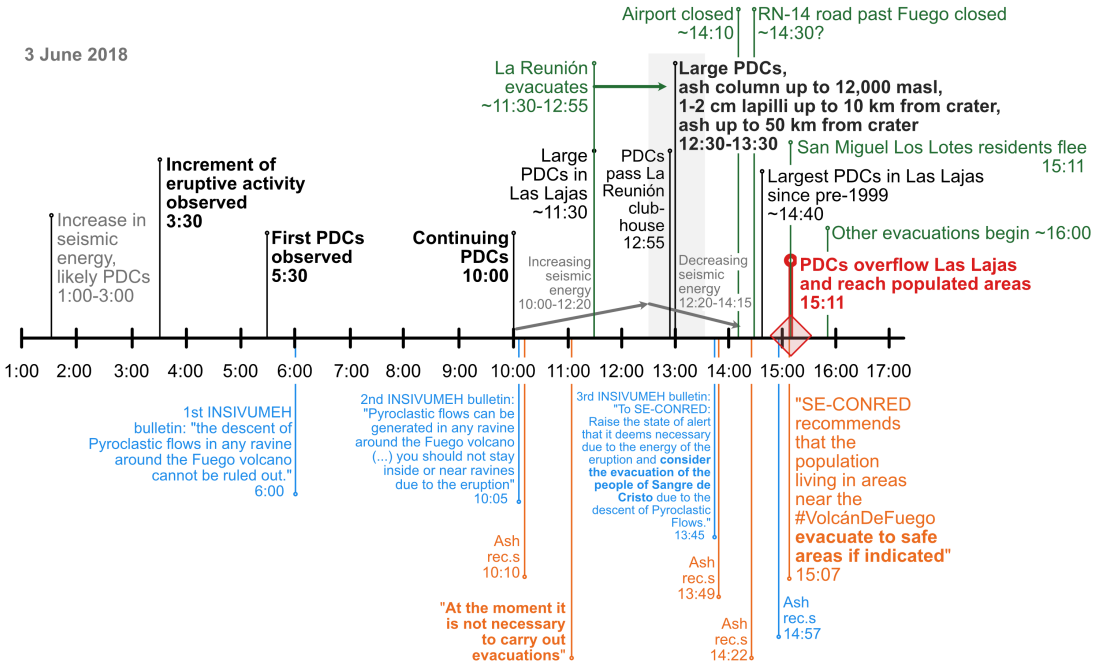

Figure 4: Timeline of significant volcanic activity known to INSIVUMEH in near-real time (black, bold) and not known (gray); guidance or warnings from INSIVUMEH (blue) and SE-CONRED (orange) in official information statements; risk-reducing actions (green); and the destructive PDCs (red, bold). See Appendix C for more detailed tables of timelines.

On 3 June 2018, Fuego produced multiple recognizable signs of increasing PDC hazard, starting by ~01:00 as evidenced by increased seismic energy perhaps resulting from small PDCs (Escobar Wolf, pers. comm.). These earliest signs went unobserved and can only be seen in retrospect, as they were recorded by seismometer FG8 on the west side of the volcano (Figure 2) that was not

transmitting data in real time but only storing them for later retrieval. However, INSIVMUEH's observer on duty did observe an increment in eruptive activity at around 03:30, 12 hours before the climactic PDCs, or T-12 hours as denoted in Table 4. The same observer reported PDCs on the west side of the volcano at 05:30, at T-10 hours, indicating an increment in activity and increased likelihood of stronger PDCs. This activity, including the continued occurrence of PDCs on the west side, continued through the morning, and could be interpreted as indicating an increased likelihood of larger PDCs as the crisis progressed–at least on the west side of the volcano. Bulletins indicate that the sole telemetered seismometer, on the east side of the volcano, came back online at 10:21 and the seismic signal amplitude was saturated, an indication of high seismic energy and another indication of heightened PDC hazard. By late morning, PDCs were occurring in the Las Lajas channel on the east side of the volcano (and possibly earlier, but not documented in sources analyzed here), at a minimum starting between 11:00-11:30 and stronger than any the La Reunión management on duty had seen–prompting their decision to evacuate. This information did not reach INSIVUMEH. However, around 12:30 eruption intensity escalated significantly as evidenced by an abnormally high ash column imaged in satellite data as well as reports of widespread dispersal of 1-2 cm lapilli and large PDCs in six of the seven active channels on both the west and east sides of the volcano, including Las Lajas. This uncommonly high intensity was recognized by and alarmed INSIVUMEH staff and external scientists as well as SE-CONRED staff who were in the field. After this ~one-hour long period of anomalous high eruption intensity, eruption energy declined significantly but briefly (Escobar Wolf, pers. comm.) before the descent of the largest PDCs of the paroxysm 1 and 1.5 hours later.

Table 4: Timeline of signs of increasing likelihood of large PDCs

Time in hours from climactic PDCs (T) [Local time]	***Signs of increasing likelihood of large PDCs***
T-14 [01:00]	Increased seismic energy over background levels and possible small PDCs
T-12 [03:30]	Increased eruptive activity over background levels
T-10 [05:30]	PDCs observed on west side (Seca, possibly Ceniza and other channels)
T-5 [10:00]	Continuing PDCs observed on west side (Seca, Ceniza channels)
T-3.5 [11:30]	Large PDCs in Las Lajas channel
T-2.5 to 1.5 [12:30-13:00]	Highest eruption intensity since 1974 (eruption column 10,000 m above summit; 1-2 cm lapilli up to 10 km from summit; large PDCs in six of the seven active channels, including Las Lajas)
T-0.5 [14:30]	PDCs reach RN-14 bridge over Las Lajas
T-0 [15:11]	PDCs destroy La Reunión resort, RN-14 bridge, San Miguel Los Lotes

Based on PDCs of sizes similar (volume and volumetric flow rates) to those observed since 1999, and even going back to larger eruptions from the 1940s through 1970s, it was highly unlikely to expect the much larger flows that occurred on 3 June 2018 and what they did: overbank the Las Lajas channel, fork into multiple flow paths, and divert from the established channel into San Miguel Los Lotes. It may have been possible to analyze such a scenario of a much larger PDC

prior to the 3 June 2018 eruption, and such larger and more extensive flows had been implicitly considered in the hazard assessment by Vallance et al. (2001), but this was not a scenario that seemed to play any significant role in communications or decision making on 3 June 2018, until the PDCs directly hit San Miguel Los Lotes. Such a scenario should be considered for future eruptions that reach similar levels of intensity or share similar potential generation conditions (e.g., a large accumulation of hot, unstable material in the upper flanks (Albino et al., 2020; Risica et al., 2022; Charbonnier et al., 2023) to the conditions on the morning of 3 June 2018, and the actions to be taken under such a scenario should accordingly lead to evacuations of populations potentially exposed to PDCs under such a scenario. Although a new PDC hazard map was produced as a result from the crisis, this has not yet explicitly been linked to such scenarios, and, equally importantly, any criteria and plans to evacuate all the exposed population.

In conclusion, although it could have been possible to more carefully consider the possible scenarios, including one in which communities like San Miguel Los Lotes would be directly impacted by PDCs, such considerations were not made on 3 June 2018. In that context, despite multiple signs of increasing PDC hazard around the volcano, observed as early as 03:30, and including, most importantly, the recognition of the anomalously high eruption activity between 12:30 and 13:30, there was no clear association made with the potential of PDCs reaching a community like San Miguel Los Lotes, something that should be addressed for future crises.

2.6.2 Production of information to inform evacuation decision-making

2.6.2.1 Assessing and informing on the hazard

Production of hazard information

INSIVUMEH was limited in their access to information needed to monitor and interpret the volcanic activity throughout the 3 June 2018 paroxysm. Much of this dearth of real-time information was because of attrition: despite Fuego's continuous state of unrest, instruments, power systems, telemetry, and internet were not prioritized and maintained by INSIVUMEH management. Most instrumentation acquisition and installation, and many key aspects of maintenance (spare parts, etc.), were the result of donations of equipment and expertise from external aid organizations and universities, while government resources were allocated elsewhere. Closed information networks managed by SE-CONRED also kept observations from INSIVUMEH that could have informed their interpretation of the eruption's evolution, including observations from CONRED field staff and the volunteer radio bases on the south and east flanks where INSIVUMEH had no direct observations. La Reunión staff also made crucial observations of early PDC activity in Las Lajas that could have informed INSIVUMEH's output. While INSIVUMEH staff augmented their available onsite observations and seismic data with information from news media, social media, and personal contacts, their small staff of only two responding employees in the central office was overwhelmed in their efforts to take in, interpret, and share information after the eruption escalated at midday.

Despite their limited information sources and limited staff, INSIVUMEH identified and communicated through special bulletins crucial elements of the eruption: that a paroxysm had started (03:30), that the paroxysm was producing PDCs (05:30), that the activity was sustained

(as published in the 10:05 bulletin), and–crucially–that the eruption was one of the strongest since the volcano reactivated in 1999 or possibly since its last sub-Plinian eruption in 1974 (by 13:30, published in bulletins at 13:45 and 13:55), all in near-real time. This latter activity raised concerns among external scientists, who discussed the potential for large PDC formation. One shared via an email interview that information he could access remotely caused him concern that large PDCs could reach populations:

> [I became concerned] around 12:00 to 12:30 (Guatemala time), when coarse tephra started to fall in San Miguel Dueñas, which prompted me to look at the near-real time satellite GOES images. That's when I realized that this eruption was bigger or at least more intense than anything we had since probably 1974! So for me, this was the big moment in terms of my change in perception. I did communicate this to [INSIVUMEH staff], first through [Facebook] (shortly before 13:00), and then in more detail in an email at 13:40.

He noted that the peak of column height was clearly over by 13:00 or 13:30, but that he was aware that activity could pick up again, particularly because they already knew that this was probably the biggest eruption since 1974, and shared that, "the worry was very clearly there in my mind and I think in other people's minds as well." Through social media, around 13:30 the same scientist saw the first images of PDCs directly hitting La Reunión, sharing that "that was the second big "wow" moment, because this showed for the first time that PDCs were directly hitting a populated area." He stopped receiving responses from his INSIVUMEH contact shortly after first alerting him of the satellite data; it's likely INSIVUMEH did not see his later communication.

Information missing from INSIVUMEH's input in a timely manner was this PDC activity on the east side of the volcano, including that they appeared threatening enough to spur the full evacuation of La Reunión around 11:30, and that they reached the elevation of the resort by 12:55, with photos posted on social media by 13:01 (Climagt al Instante, 2018) and videos of PDCs very close to, if not overbanking into, the resort by 13:39 (El Efra!!, 2018), all of which may have given an indication of the danger to the east side of the volcano sooner. While INSIVUMEH did post in their 13:45 and 13:55 bulletins that strong PDCs were descending in six of the seven main channels, including the Las Lajas and La Honda channels on the volcano's east side, it is unclear whether this was assumed based on the eruption's intensity or based on knowledge of the flows.

Because volcanoes are multihazard systems, warnings can vary and even contradict each other. The deadliest hazards, including PDCs, require evacuation; as already noted, evacuation for PDCs must happen *before* a deadly PDC initiates. Warnings to evacuate must be issued with enough lead time for residents to understand, internalize, and respond to the warnings. The process of milling, when people seek additional information in the face of a change in their known environment, e.g., receipt of a warning, delays action as people seek to answer basic questions about the change such as whether the information they have received is credible, when and where a hazard may occur, what impact it may have for them, and what they can do to reduce their risk to it; this process also often includes taking social cues from the people around them

into consideration (Drabek, 1999; Wood et al., 2018). Educating at-risk populations well before a crisis occurs can shorten the milling process by pre-answering these questions. For example, Mei et al. (2013) found that deaths occurred during the 2010 eruption of Merapi within the lower-hazard zone in part because residents, unlike those in higher-hazard zones who had received educational programs, did not know how to interpret warnings and what route to take to evacuate.

Much of the guidance from INSIVUMEH and SE-CONRED posted to social media during the 3 June 2018 paroxysm pertained to the most widespread but not most potentially lethal hazard: ash fall. One INSIVUMEH interviewee reflected in their interview that they had been distracted by analyzing ash during the height of the paroxysm. The most specific and urgent guidance published in a bulletin that day pertained to ash, recommending in all capital letters in their 13:55 pm bulletin that the air traffic control authority close the airport (BEFGO 30-2018). For people close to the volcano, protecting from ash can contradict protecting from PDCs; for ashfall, sheltering in place protects from respiratory and sight distress, and being present to clear roofs prevents collapse in the case of heavy tephra fall. However, the best and only reliably life-saving course of action in the face of PDCs is the opposite–to evacuate.

Some guidance and/or warnings from authorities did pertain directly or indirectly to evacuation. Guidance provided in INSIVUMEH bulletins and directed toward SE-CONRED, departments, and municipalities included raising and maintaining alert levels (as early as 06:00, BEFGO 27-2018); monitoring the volcano, especially on the west side; and ensuring roads needed for evacuation were passable, all of which are necessary predecessors to evacuation. Per interviews, SE-CONRED's guidance from field staff directly to stakeholders also included recommending department and municipal governments set alert levels and convene their emergency response teams.

However, specific recommendations and warnings to evacuate before the devastating PDCs were highly limited and arguably did not exist for practical purposes. The only community specified for an evacuation recommendation in INSIVUMEH bulletins was Sangre de Cristo, a small hamlet of ~40 people on the west side of the volcano. Sangre de Cristo is a reasonable target because it lies only 100 meters from the Seca / Santa Teresa channel, one of the seven most active channels on Fuego and one of the first channels reportedly subject to PDCs early that day. Sangre de Cristo also had already had at least one near miss, with a PDC in 2003 reaching within 1.7 km of the community. Subsequently, the government built a small shelter nearby on higher ground where residents could go in future crises; the hamlet subsequently evacuated to this nearby shelter at least seven times. Because of this infrastructure, an evacuation of Sangre de Cristo required no government resources during a crisis. Sangre de Cristo's location close to a barranca, known history of PDC risk, and the lack of resource expenditures from the government likely all contributed to INSIVUMEH's choice to list it by name in its bulletins.

INSIVUMEH listed no other communities by name in their bulletins, despite reporting that the eruptive energy at midday was possibly the highest since 1974, an eruption that highly impacted and spurred the eruption of multiple communities. The hazard that most wreaked havoc in 1974 was intense tephra fall over many of the nearby communities (Rose et al., 1978), as no PDCs reached any inhabited areas; perhaps INSIVUMEH focused on tephra–which is not immediately

lethal as is a PDC–as their primary concern on 3 June 2018 for this amongst other reasons. While INSIVUMEH did also report strong PDCs in six of the seven main channels associated with this intense eruptive phase, all of which threaten nearby communities, PDCs extending sometimes as much as 6 or 7 km from the summit had become a somewhat common occurrence during paroxysms, and as such, it is unclear (based on precedent set in other bulletins) whether they knew of PDC in all of these channels or reported them because they inferred from the eruption intensity that their occurrence was likely.

Would more information about activity on the east side of the volcano, for instance that large PDCs were coming down the Las Lajas channel, have provoked more specific guidance or more urgency about the threats of PDCs from INSIVUMEH for that side of the volcano? It seems unlikely, given that they did not provide guidance for any of the other communities using the information they had, aside from warning that "Pyroclastic flows can be generated in any ravine around the Fuego volcano" with the guidance that "you should not stay inside or near ravines due to the eruption" in their 10:05 bulletin (BEFGO 28-2018) and, in their 13:45 pm and 13:55 pm bulletins, that CONRED should "consider the evacuation of the people from Sangre de Cristo due to the descent of Pyroclastic Flows. As well as maintaining monitoring on the south, southwest and southeast flanks" (sic, BEFGO 29-2018 & BEFGO 30-2018). In the morning, they had acknowledged that "pyroclastic flows of the Seca ravine can fill the ravines again" (BEFGO 27-2018, 06:00) but did not warn of this occurring for any other channel, even after reporting the descent of strong PDCs in five other channels, including Las Lajas, at the height of the paroxysm.

Use of hazard information

Descriptions of how people made evacuation decisions indicated that the information INSIVUMEH produced was used very little, if at all, for this context. Likely reasons include that much of the information was observational and readily obtained directly by people already onsite at the volcano; information was not available to inform evacuation decisions at key moments (i.e., 11:30); information did not describe potential impacts; and information was general to the entire volcano, with the exception of mention of Sangre de Cristo, one of the volcano's smallest communities; and information was presented without urgency in tone with the exception of a recommendation in all capital letters to close the airport after the height of the paroxysm (in alignment with recommendations summarized by (Sutton and Kuligowski, 2019). It is no surprise then that the information INSIVUMEH produced was not impactful.

2.6.2.2 Assessing and informing on the risk

Production of risk information

Although lacking instrumentation, SE-CONRED staff had access to substantially more first-hand observational information than INSIVUMEH staff. Two SE-CONRED staff deployed to Fuego by mid-morning and a third was already near the volcano for unrelated reasons. Their network of volunteer radio base operators included observers on the west, south, and east sides of the volcano rather than only on the west side, although only three out of four volunteers who reported observations that day reported in before the destructive PDCs (Fuego 4, Fuego 5, and Fuego 10; Figure 2). They also had reports from the broader CONRED network, including SE-CONRED

regional staff and also civil protection staff within department and municipal governments. Like INSIVUMEH, they also had additional personal contacts providing them with observations.

SE-CONRED disseminated information through their social media feeds and in-person visits from staff in the field, in addition to direct phone calls and messaging. They also used the radio network to alert radio operators in cities and communities of the increase in Fuego's activity as it related to ash fall. Like INSIVUMEH, they posted only a subset of their Twitter posts on their Facebook page. A total of 47 posts interspersed with other content on their Twitter feed throughout the day pertained to Fuego's paroxysm, starting with the INSIVUMEH bulletin at 6:55. They began posting updates from their staff in the field at 8:13 am. The 14 posts sharing reports from field staff and CONRED affiliates consisted primarily of photos and whether there was ashfall and in some cases PDCs at that location, only one of which included a recommendation–to protect against ash.

Few posts pertained to evacuation. Before the escalation of eruption intensity at midday, SE-CONRED shared three posts containing recommendations, one post pertaining to ashfall (10:10) and two addressing evacuation: "For the moment evacuation is not necessary" (11:01) and "Have a safe place to go in case of a volcanic eruption" (11:59) (Figure 5).

Figure 5: Posts sharing recommendations and hazards information on the Twitter accounts of INSIVUMEH and SE-CONRED on 3 June 2018 prior to the 15:11 pm PDCs, aside from INSIVUMEH bulletins. Local times and translations added by the author. Six of the nine posts pertain to ash. Of the three pertaining to evacuation, none give specific guidance about who should evacuate or where they should go.

During and shortly after the height of the paroxysm, they posted only recommendations for what to do facing the threat of ash (12:41 and 13:49). At 15:07, a post recommended people near Fuego "evacuate to safe areas if indicated and avoid being close to channels or in danger." At 18:41 pm, they posted, “CONRED INFORMS to people near Fuego, eruptive activity continues; we recommend you find a safe place and stay away from areas at risk." At 18:49 pm, they posted, "Precaution: Get away from gullies and areas around Fuego Volcano, protect yourself in a safe place." No posts included guidance specific to or descriptions of PDCs. Because PDCs at Fuego can travel at a range of speeds, from several tens of km/hr to possibly a few hundred km/hr, the 3 June 2018 flows would have reached populated areas like San Miguel Los Lotes, 8 to 9 km from the summit, in as little as 2 or 3 minutes and most likely no more than 10 or 15 minutes. When SE-CONRED posted the 15:07 tweet about evacuating, the series of PDCs that destroyed the La Reunión clubhouse and villas, the RN-14 bridge over Las Lajas, and the town of San Miguel Los Lotes by 15:11 would have already been traveling down the Las Lajas channel.

Guidance and warnings may have been provided through other, undocumented communication channels. One CONRED interviewee shared that he suggested contacts in the community of Las Palmas consider evacuating their town after receiving a report of a large PDC in the nearby Cenizas channel. The same interviewee described urging SE-CONRED as well as municipal officials to activate more staff and raise alert levels when the eruption intensified at midday, and recommended closing the segment of the RN-14 road alongside the volcano. According to multiple interviews, a local volunteer COLRED leader from the south side of the volcano rode from her home in La Reina to the Las Lajas bridge calling out warnings to the ~4 communities along the way, including San Miguel Los Lotes, via a megaphone. It is not clear what these warnings consisted of and whom they reached.

The first PDC to reach the Las Lajas bridge, around 14:45 (perhaps as early as 14:30 according to estimates by witnesses, and probably not after 14:52, as this later time is constrained by a mention of it in the CONRED radio bases network communications), spurred a flurry of activity. Reports suggest the staff northeast of the bridge tried warning residents near the bridge and urging them to evacuate. When the staff on the southwest side of the bridge fled with the leader of the La Reina COLRED, they stopped the truck at the entry to San Miguel Los Lotes to warn residents with their siren and megaphone, telling people to spread the alarm. They continued to call out warnings along their way. He returned the COLRED leader to La Reina so she could coordinate her own community for evacuation. He described then returning to the RN-14 road with the intention to drive into and warn residents of San Miguel Los Lotes but the flows had already come down and people were fleeing into the road. He made eight trips evacuating survivors he encountered along the road to the nearby town of El Rodeo, each time with fewer people.

Reports about the content of warnings from CONRED before the deadly PDCs vary; a former resident of San Miguel Los Lotes interviewed by a reporter in the days after the paroxysm says CONRED staff came into the town to alert residents, but to tell them to shelter in place (POLO AMBROSIO GT, 2019, 00:01:12). Another interviewee shared that a friend had been visiting parents in San Miguel Los Lotes and heard warnings, and urged her parents to leave; they did, and that’s how they were saved. However, it is hard to confirm this story. If warnings did come earlier in the day, from SE-CONRED staff or COLRED leaders or others, what is clear is that this

was not an organized, unified warning effort and there was no logistical support from the government to facilitate evacuation. Interviewees in the town of Panimaché II on the west side of the volcano said they had no communication from authorities though they awaited word from CONRED about whether they would evacuate. At that time, they had no radio base–there were only four active radio bases among all the communities close to the volcano–and received information only through cell phones, when they had service, and through the TV and radio. San Miguel Los Lotes, similarly, had no radio base and no direct connection to authorities.

Multiple interviewees from civil protection who were onsite as well as residents of San Miguel Los Lotes described an urgent attempt by civil protection to warn residents of San Miguel Los Lotes, as much as 30 or as little as seven minutes before the deadly flows reached the town. The SE-CONRED staff and local COLRED leader who gave the warning described stopping at the entry of the town to urge residents to flee as they sped away from the first PDC to reach the bridge:

> What we told people is that the flow had already reached the bridge, the Las Lajas bridge. But the Las Lajas bridge is 1 km 200 meters or so from Los Lotes. Then the same people said No, not here, nothing will happen, because it doesn't come here.
>
> We told the people in the town, Run! Get out! Get out, get out! Because this is coming down covering the town. Get out, get out. And the people who were with me were shouting. People grabbed each other and ran into the alleys. In Los Lotes, they went into the alleys. 'My children,' they said. 'My dad, my mom!' And they ran inside to see if they could get their family out. But it was already coming.

These accounts agree with those of frustrated survivors who described the warning as only reaching those close to the road, and only as flows were already descending:

> They never told us anything. They never alerted us. They never told us that we were in danger–if they would have told us that we were in danger, we would have left. But no. Look, CONRED, when they were there at the Las Lajas bridge, they ran, but the lava was already behind them and they came shouting in the street 'Get out!' But many people on the other side couldn't hear because they were at home. Those of us who were inside didn't hear. Some who were walking in the street heard, but the lava was already coming behind them. When they came fleeing in cars and on motorcycles, the lava was already coming.
>
> It was last minute, right? Because the authorities were also running, right, in their cars, on the highway and with a [loudspeaker]. And they came saying that people should shut themselves in or get out, whatever they could. But there were a lot of old people who couldn't [flee] anymore. They couldn't [run], there were three people with wheelchairs. What were they going to do, right? There they stayed. There they stayed.
>
> They did not alert people, they were only at the Las Lajas Bridge, only focusing on the volcano, all its eruptive activity, how everything looked, where the great smoke of lava

was coming from and all that. And they never thought to go to [San Miguel Los Lotes] and say Look, get ready and leave, because of the situation.

Use of risk information

This research suggests that many residents around the volcano received no information from authorities before the destruction of San Miguel Los Lotes. Information posted on Twitter may have reached people living in metropolitan areas and passing by the volcano on the RN-14 road, but are unlikely to have reached and had any impact on the behavior of local residents. Interviewees who were living around the volcano at that time said that if they were on a social media platform they used Facebook–where only a subset of posts was available–and not Twitter. Regardless, the information published through Twitter was too general to be actionable. Instead, information from officials reached residents–if it reached them at all–through in-person visits, phone calls and texts, and the SE-CONRED radio network, where they could hear the reports of peers in other communities on the volcano.

This research also indicates that possibly only one community received a recommendation from CONRED to evacuate, with the exception of the drive-by warnings called out within 30 minutes from the climactic PDCs. That the CONRED staff interviewed recommended the evacuation of Las Palmas indicates a poor understanding of relative risk, since Las Palmas is one of the farther communities from the summit, at 17 km. Attention was probably on this town rather than other communities that are arguably more exposed to PDCs hazards because it had been at high risk of lahar hazards from a progressively aggrading lahar channel since June of 2017.

The interviewee described having a poor understanding of not only the relative risk posed to communities but also of the nature of PDCs. They described the either unrecognized or underestimated risk posed by being at the RN-14 bridge over the Las Lajas channel during the height of the paroxysm:

> Obviously that was also one of the mistakes that I think was made, placing all of us at the point precisely where the pyroclastic flow came down. We had no idea. But we went there because it is one of the best places to observe the activity of the volcano. And the mayor of Alotenango also arrived there, people from the Municipality of Escuintla and the governor of Escuintla arrived at the same point. Because they had been alerted that the activity was strong. And the governor calls me and asks 'Is it true that it's really strong?' 'Yes, yes,' because I was asking them to activate the COE, to declare a red alert, and activate the COE. And what he did instead of activating the COE was to go to that point, right? They came there.

The same interviewee described a gap in responsibilities between the understanding of hazards, which is the purview of INSIVUMEH, and the assessment of risk, which is needed to provide well-informed guidance to residents:

> They still argue that we don't have to interpret things, that INSIVUMEH has to tell us and we don't even have to interpret them, we simply share them as they say them, because they are the scientific entity. But INSIVUMEH is not the advisor to the

authorities or the communities, that's us. And if we don't know what this is, how are we going to give adequate recommendations?

2.6.3 Use of information for protection actions

2.6.3.1 Real-time inputs for decision-making

While bulletins from INSIVUMEH as well as a direct text from its staff signaled to La Reunión security and management that the agency's staff was concerned by Fuego's elevated activity, La Reunión management made the decision to evacuate based on their own observations, pointing out in later interviews that INSIVUMEH's 10:05 bulletin said nothing about evacuation. As described in section 2.5, around 11:30 the general manager observed and was alarmed by explosions and PDCs in the Las Lajas channel larger and more intense than any she had seen previously, called a meeting with staff and quickly made the decision to evacuate. They began the process immediately. The impetus for a similarly timed evacuation of neighboring La Candelaria finca was not addressed in this research, but interviewees indicated that staff from both employers were home in San Miguel Los Lotes by lunchtime. These evacuations began before or at the onset of the height of the paroxysm. As noted in section 4.1.3, La Reunión had completed evacuation of its golf course and hotel by 12:55, which overlaps with the height of the paroxysm, and of its residences by 14:45 (with the exception of two households that refused to evacuate), with flows in Las Lajas intensifying after a lull in activity.

Second-hand accounts describe some people self-evacuating from Santa Rosa, San Miguel Los Lotes, and El Porvenir after midday in response to either unofficial warnings (some possibly from the leader of the La Reina COLRED, via megaphone, and CONRED officials driving by) or in response to observations of the intensity of the eruption. One resident of El Porvenir, just northeast of the Las Lajas bridge, said he received messages from his supervisor in La Reunión in the afternoon urging him to evacuate his family, and similar stories regarding workers from La Reunion who lived in San Miguel Los Lotes and evacuated their families have also been told (Canal Antigua, 2018; Ordoñez, 2021). However, contrary to reports of evacuation (e.g., World Bank, 2018), interviews indicate there was no coordinated or supported evacuation in any community before the destruction of San Miguel Los Lotes, with the possible exception of Sangre de Cristo, which evacuates locally and without government support. Any evacuations before 15:11 would have been on the individual or household level and would have required that evacuees had transportation options (e.g., bus or private car) and a place to go away from the volcano.

Although the exact times aren't clear, records and social media posts indicate authorities had closed the RN-14 road past Fuego by 14:49, apparently in response to CONRED staff's recommendations based on their observations of PDCs in the Las Lajas channel. Although local residents, emergency management staff, and possibly others were still near the bridge, the road closure likely saved lives given the larger quantity of people who had been there earlier in the day and the amount of traffic accommodated by the route.

The response by people in San Miguel Los Lotes who heard the urgent warnings from CONRED staff fleeing the first PDCs to reach the bridge was described by an interviewee as chaotic and

confused, with people running back into the town to find their families. Interviewees from San Miguel Los Lotes described conflicting guidance over whether to shelter in place or to evacuate (PALO AMBROSIO GT, 2018, 00:01:12).

Most people took protective action only when seeing the devastating PDCs racing towards them or hearing calls from the people around them. A video from the northeast (La Reunión) side of the bridge shows people running as the PDCs reached the bridge, but some then stopping to watch from short distances away before the flows spilled up onto the bridge and began to emerge from the trees around it. In the same video, a SE-CONRED staff member is seen overtaken in his truck before he can escape. The truck was later found crushed and severely heat damaged in the PDC deposit. Two firefighters and their truck have not been found. The number of dead at the bridge is not confirmed but is likely in the few tens, per video footage and interviews. One interviewee estimated 12 dead from his town of El Porvenir, the community immediately northeast of the bridge.

People fled from the southwest side of the bridge as well, including an interviewee who ran towards San Miguel Los Lotes and was caught between the two forks of the flows. He was badly burned and later rescued by several young men who found him and carried him out. He survived after a month of treatment and recovery in the hospital.

In San Miguel Los Lotes, people either fled or took cover, and survival depended on what action people took in which place, due to differences in the severity of the flow impact, due to the town being at the very edge of the flow's reach. The interviewee who had gone up to the sandlot at the top of the town to get a clear view said he fled down the main street, and could have made it to the road but instead ran home to his family. They shut themselves in as the cloud overtook them; everything went dark and became searingly hot. They survived by breathing through cloth. They were lucky; they survived by sheltering in place only because they were at the edge of the flow. In places where the flow hit directly, residents who survived had fled into the farmland west of town; those who sheltered in place were buried in their homes and on the streets.

Unfortunately, the latter event–the destruction of San Miguel Los Lotes and the deaths at the Las Lajas bridge–is the threshold that, despite multiple signs of increasing risk, triggered widespread evacuation during the 3 June 2018 paroxysm.

Many authorities and residents reacted only as they learned of what happened to San Miguel Los Lotes or the Las Lajas bridge through radio, TV, and social media, and, for proximal communities, directly from the people who had fled into the neighboring bush and emerged along their road. According to information provided by one interviewee, by 15:30, the municipality of Alotenango declared a red alert and activated their center for emergency operations (COE). By 15:41, the COE of Escuintla was meeting with the governor. By 16:18, SE-CONRED declared an institutional orange alert. By 16:25, a departmental red alert was declared in Escuintla and a municipal red alert was declared in Yepocapa. By 16:49, 13 hours after the recognition of the paroxysm, almost 12 hours after the first pyroclastic flows, five hours after the La Reunión resort decided to evacuate, and four hours after the height of the paroxysm, shelters–and morgues–were

declared available in Escuintla. At 18:01 pm, a post on SE-CONRED's Twitter feed shared the locations of three evacuation centers.

Roads leading from communities on the south side of Fuego clogged with cars of residents, firefighters, military, and police. Residents on the west side of the volcano heard what happened via radio and TV news; interviewees reported that ~80 residents of Panimaché I tried to evacuate in a locally owned bus but were cut off by lahars. June falls in the rainy season in Guatemala and most communities close to the volcano are accessible only by unpaved roads crossing channels via fords; rain had begun in the afternoon and lahars were reported on the west side of the volcano by 15:24, including on the channel that some Panimaché I residents were trying to cross through a ford. Other residents learned of the lahars and were deterred from trying to evacuate.

Evacuations of most communities close to the volcano continued into the next day. According to the World Bank (2018), a total of 12,823 residents evacuated.

2.6.3.2 Imbalanced responses

Neither the La Reunión golf resort and hotel nor the town of San Miguel Los Lotes received actionable information, i.e., timely evacuation warnings, from authorities on 3 June 2018. They did have different access to information, but more importantly the staff in the resort and the residents in San Miguel Los Lotes had very different capacities to process and act on it.

2.6.3.2.1 La Reunión golf resort and hotel

From La Reunión staff's descriptions of events on 3 June 2018, government agencies–specifically, INSIVUMEH and SE-CONRED–played very little to no real-time role in their evacuation process that day. However, they did play–along with other significant factors–in laying the groundwork for the resort to make the decision to evacuate. Both INSIVUMEH staff and external scientists recognized from its foundation La Reunion's location relatively high on the volcano and abutting a major channel as high risk. Subsequent years of engagement from INSIVUMEH and SE-CONRED staff, as well as external volcano scientists, afforded the staff an understanding of the risks posed to the resort by PDCs. Direct access to the Las Lajas channel and a clear view of the volcano as well as the resort's accessibility from a major road, security, and internet connectivity all made it an attractive location for instrumentation, the installation and maintenance of which came with ongoing visits from INSIVUMEH and other members of the scientific community, as well as CONRED.

The same factors that made La Reunión ideal for monitoring instruments also set it up for success in essentially managing an early warning system (EWS) internally. The clear view afforded staff direct observations of the volcano's activity; its accessibility from the main road made evacuation relatively straightforward; dedicated security personnel meant it could closely and continuously monitor the volcanic activity for potential hazards, like PDCs; and relatively frequent interaction with INSIVUMEH and CONRED officials as well as other volcanologist enabled curious staff to learn more about the volcano's hazards in times of quiescence and provided direct access to INSIVUMEH bulletins through email.

Perhaps the most important contribution to their success was their own first-hand experience with crises and close encounters with PDCs in the Las Lajas channel. PDCs had flowed down the Las Lajas drainage on several occasions since 1999, perhaps most notably during that initial eruption in May of 1999 before La Reunión was established, when the PDCs made it close to the Las Lajas RN-14 bridge at the time. PDCs from eruptions on 13 September 2012 were perhaps the first close encounter for the relatively newly established golf resort, and were an immediate cause of concern. The diluted component of PDCs, called ash cloud surges, overbanked the Las Lajas channel and in cases damaged coffee plantations immediately uphill from the resort on three occasions in 2015: 30 June - 1 July, prompting INSIVUMEH to explicitly recommend the evacuation of La Reunion in one of their special bulletins (BEFGO 049-2015, 1 July 2015); 26 - 27 October; and 10-11 December. Other large PDCs that made it relatively close to the resort and damaged adjacent plantations occurred on 18-19 May 2016. Finally, PDCs that flowed down Las Lajas during 30 January - 1 February 2018 also reached relatively close to the boundaries of La Reunion's property. All these experiences with PDCs and their impacts undoubtedly shaped the perception of those in charge of assessing risks and threats at La Reunión.

Additionally, when INSIVUMEH conducted fieldwork to characterize the deposits after the occurrence of some of these PDCs, personnel from La Reunion accompanied them to grant them access to the area and as security. This also created a unique and valuable opportunity for the personnel from La Reunion, including the head of security, to see and learn what the PDCs could do and their associated hazard/risk. One security staff member described taking advantage of these opportunities to learn more about the volcano's behavior:

> From the bulletins [INSIVUMEH] sent, they said "pyroclastic flow." And I have always been just curious. I was with a scientist, and [I'd ask], 'what is a pyroclastic flow?' Or on the internet, 'what is a pyroclastic flow?' So you then look [at the volcano] and say, 'oh, it's a pyroclastic flow,' or with the plume–I've learned that that's the plume over there. Because before you just said 'Ah, there's the smoke.' So no, it's not smoke, that's the plume over there. So. This is how you learn, little by little.

In the six years leading up to June 2018, La Reunion evacuated guests during volcanic crises at least nine times. Each time, they called and enacted the evacuation of guests and visitors, kept a crew of staff on to maintain operations, and invited guests back after several hours when they assessed the crisis had passed. Through this process, the staff came to know the volcano's activity and their risk, and practice in real-life scenarios the process of evacuations. With their clear view of the volcano, staff were able to visually monitor its activity, including any flows descending the Las Lajas channel. They also had a system to disseminate information quickly: they had two-way portable radios to communicate between security personnel, the WhatsApp group for all team leaders and security staff, a face-to-face meeting with these staff to make the decision to evacuate, and a system of sirens that reached all parts of the resort and hotel areas to alert other staff and guests, as well as a pre-planned call-down system and in-person system enacted by staff to communicate with all guests and visitors. Their message was clear: everyone must evacuate from the premises. Finally, and very significantly, they had the resources to evacuate. All guests, residents, and some staff had their own private vehicles. Staff without their own transportation were easily evacuated to the road with resort minibuses. That is to say, they had the four

components of a people-centered early warning system as defined by Basher (2006) and promoted by the United Nations at the time of writing (Egerton et al., 2022).

As acknowledged by (Basher, 2006) and emphasized by Garcia and Fearnley (2012), it is not only the components of an early warning system but the linkages between them that determine the system's efficacy. Multiple factors contributed to La Reunión's ability to put these components in place and to execute them effectively, some of which have been commented on already by Naismith et al. (2020) and in the World Bank forensic report (World Bank, 2018), not least of which was its affluence. La Reunión and therefore its management was resource-rich: The resort's affluence afforded them ample monetary and personnel resources to devote to security, communication, and transportation. Management also had social capital, specifically their connections to INSIVUMEH and CONRED in addition to municipal governance. Importantly, however, they 1) chose to allocate these resources toward volcano-related risk reduction and 2) were willing to take on the risks of and known losses and hardships associated with evacuating (not only on 3 June 2018 but on previous occasions) in order to reduce these risks associated with not evacuating. This is not to say that affluence did not play a significant role in their ability to use the information available to them, but it is important to note that a similarly wealthy business may have the same opportunity to reduce their risk and not use it resulting in a different outcome. Even relocating the same resort with the same management to the location of San Miguel Los Lotes might have resulted in a very different outcome, given they would not have had the previous experience with PDCs that they did in their location immediately next to the channel.

Finally, as with so many volcanic crises, La Reunión's success can be attributed to its good practices but also to luck. They had many capacities, as described above, and fortunately, the weather and volcano's behavior aligned with those capacities. The late-morning view was clear enough to see the early onset of larger-than-normal PDCs in Las Lajas, which were large enough to alarm staff but not yet large enough to reach populations. There is nothing to say a flow of much longer runout couldn't have immediately followed, but the flow lengths increased incrementally, giving staff–thanks to rapid decision-making and mobilization–time to evacuate the upper reaches of the golf course and then the rest of the hotel and resort before flows reached and then overtopped those areas. The margin of error was quite small, with guests still evacuating the latter area when PDCs reached the level of the clubhouse without yet filling the channel, as evidenced by pictures and video later posted on social media (section 2.5). (By 12:55, this part of the property was evacuated of guests and visitors, flows had destroyed part of the golf course, and reached beyond the clubhouse. Note that INSIVUMEH's bulletin announcing PDCs in Las Lajas and recommending SE-CONRED consider evacuating Sangre de Cristo, on the other side of the volcano wasn't distributed until almost an hour later (13:45)--with no mentions of populations on the Las Lajas side of the volcano). The margin of error may not be in the resort's favor next time. The general manager herself described how close a call they'd had:

> Twenty-four hours later, when I returned and saw the size of the stones and all the material that the volcano had thrown, I realized that perhaps having stayed there for 15 more minutes would have made the difference in that we'd no longer be able to tell the story, right?

This is to say, La Reunión's system for responding to the threat posed by PDCs from Fuego met their internal capabilities to enact that system, and, fortunately, the volcano's behavior on 3 June 2018 fell within their system's limits.

San Miguel Los Lotes

By contrast with the La Reunión resort, San Miguel Los Lotes was much less obviously exposed to the PDCs hazard, and characterized by one of the lowest levels of engagement with risk reduction authorities of communities close to the volcano. San Miguel Los Lotes interviewees said the only engagement from SE-CONRED had been with their school, not the whole community. Interviewees and SE-CONRED documentation describe San Miguel Los Lotes' COLRED, their volunteer civil protection group, as inactive. Although, like La Reunión, the town was inside the PDCs hazard zone delineated by Vallance et al. (2001), its position farther away from the volcanic vent and from large channels (e.g., farther from the crater and from the Las Lajas channel as compared to La Reunion), meant that its priority as a highly exposed community was low, or perhaps even outside of the direct awareness of people in the community and/or authorities. While one CONRED staff member said San Miguel Los Lotes had been visited and residents knew to go down the road to El Rodeo, 1.5 km away along the RN-14 (and still within the PDC hazard zone), two other SE-CONRED staff who worked around Fuego said they either had never entered SMLL or had only visited the community once or twice. One described it as a place they just drove by, because it was on the main road, but thought more about the communities higher on the volcano and with more difficult evacuation routes:

> The closer to the volcano and the further away from the highway, for us that was more prioritized. For example, obviously La Rochela was where we had considered to be most at risk, right? I think [Los Lotes] had that same perception. But of course, partly because they were not within our prioritization either. And no, no, they didn't fully recognize their risk. But I think we were also unaware of it.

According to CONRED records, 10 of the more than 30 communities within the mapped PDC hazard zone evacuated sometime between 1999 and 3 June 2018; San Miguel Los Lotes was among the many that had not. They recalled one 'evacuation' where students were sent home from the school, which is also located in San Miguel Los Lotes, but described there was no further action to motivate households to evacuate from the town. Many SMLL residents worked in La Reunión and the surrounding fincas higher on the volcano and had experience with evacuations from these workplaces but had always evacuated to their homes in San Miguel Los Lotes, not further away from the PDC hazard. Where the World Bank analysis of the causes of the 3 June 2018 disaster suggests San Miguel Los Lotes opted not to participate in an evacuation simulation several months prior to the crisis, the town did not in fact have the opportunity to: the SE-CONRED co-organized and U.S. Southern Command (SOUTHCOM)-sponsored evacuation simulation was only open to two communities, Colonia 15 de Octubre La Trinidad and La Reina.

Interviews indicate that residents, including community leaders, had a poor understanding of PDCs and their potential impacts, that PDCs could reach San Miguel Los Lotes, and that

evacuation was the necessary protective action. People described not differentiating between PDCs and lahars, which they heard and seen in the Las Lajas channel nearby:

> It had erupted other times, but not of the magnitude that it was that day, right? Before, it came down like this lava. But the lava is…it's slow, right? It comes down slowly. Because once I even remember that I went to see it at the bridge that was destroyed. The time I went to see the lava was coming down slowly, right. And that day it was pyroclastic flows. A material that is quite fast.

Note that many residents living around Fuego use the term "lava" to refer to any material coming from the volcano, not differentiating between, for example, PDCs, lahars, and lava flows.

Multiple interviewees expressed feeling safe in San Miguel Los Lotes because they believed volcanic material would stay in the ravines, and they perceived their town to be far from ravines:

> Well, we felt safe, right? Because it was... the ravines are far away. They are far from the town. We used to listen sometimes when it rained, because it rains a lot, right? Then you could hear a river, a river formed and you could hear it in the distance, right? You could hear it, but it was far, it was far. So you trusted in the ravines, but if the surrounding ravines collapsed, well no, they weren't enough to hold it. And the material, it's all downhill to the town.

But we never thought that it was going to do so much because there were so many ravines. We thought that it would come down the ravines. But no.

They also lacked an understanding of the power of a PDC, as described by an interviewee in nearby El Porvenir speaking of people from his own town as well who had gone to the bridge over Las Lajas to view the volcano's activity: "They'd only seen pyroclastic flows up high, and they only looked like dust, they didn't see what comes underneath." A resident of San Miguel Los Lotes confirmed this:

> There were times when the smoke descended, like the ash and everything (...), but we never imagined what it really brought. We thought it was just smoke or ash, but. We never thought it was bringing branches and rocks and all that.

In short, residents of San Miguel Los Lotes interviewed for this study, which included two local leaders (the president and another member of their CODODE), expressed a poor understanding that they were at risk from Fuego's hazards:

> The volcano was always active, and quite strong. But as I just explained, we never expected that the volcano would finally destroy our home.

Therefore, despite 19 years of experience with the volcano's activity, leadership and other residents of San Miguel Los Lotes lacked the foundational understanding necessary to make evacuation decisions for their community and their families. Without this understanding, which is the first component of the people-centered EWS, whether they had the other three components of an EWS–detection, warning dissemination, and response–is moot. Without the crucial understanding of their risk, leadership and other residents were unequipped to use real-time

information to make their own risk assessments and subsequent decisions–until the flows were barreling down on them and the risk became clear, but with inadequate time to respond.

Finally, another word on luck. While luck worked in favor of La Reunión, with the volcano providing recognizable warning signs and then time for evacuation, luck worked against San Miguel Los Lotes. The town lies at the toe of the PDC deposits, as observed in Figure 1 and described by an external scientist working on risk reduction at Fuego:

> One of the great ironies of the tragedy of San Miguel Los Lotes is that if you look closely, the pyroclastic flow from Fuego volcano to San Miguel Los Lotes advanced more or less nine km. But it *just* made it to the last row of houses. So when it got to Los Lotes it was already going relatively slow and was about to stop. If the flow stopped some 300 meters sooner, it wouldn't have hit Los Lotes, or if Los Lotes had been 300 meters farther…

When looking back on 3 June 2018, it is important to note that the outcome of La Reunión is specific to La Reunión; that is to say, their evacuation is the result of how management chose to spend their attention and resources in the years leading up to June 2018, not only on the day of–but that the outcome for San Miguel Los Lotes, as noted in the World Bank forensic report (World Bank, 2018), is far from unique to them and could have been any other community around the volcano. No community, even those that had participated in drills in the months before the paroxysm, evacuated prior to the destruction of San Miguel Los Lotes and there was no clear, actionable government warning to do so; moreover, no resources for evacuation, including transportation or shelter, were made available or mobilized before the disaster. The outcome of San Miguel Los Lotes was not the result of the community's character in the years leading up to the disaster but of that of the Guatemalan government.

2.7 Discussion

2.7.1 The 3 June 2018 tragedy in an early warning context

Though the basic premise of early warning is seemingly simple, early warning systems are complicated, as they involve multiple components that have to work in coordination–they are by nature social processes, as described by Kelman and Glantz (2014) and others before them. EWSs manage information that includes significant uncertainty, which remains despite the advances in technology and scientific knowledge of the natural hazards they try to mitigate. EWS can fail because of neglect to how its components (institutions, agencies, or people) will respond in the face of crisis. Information availability to the different EWS components and the ability of those components to use it in decision-making is fundamental to EWS success. This analysis of information availability and use leading up to the fatal climactic PDCs of the 3 June 2018 eruption of Fuego volcano indicates that either information for decision-making was insufficient or that the key stakeholders involved in evacuation decision-making for the at-risk population did not have the capacities to use the information that was available to them. Multiple factors, existing well before the day of the eruption, contributed to this deficiency. The most important factors are discussed here.

Jolly and de la Cruz (2015) caution that long lulls in volcanic activity can lead to complacency and resulting neglect in upkeep of monitoring systems. Unfortunately, this negligence can occur at highly active volcanoes as well, as evidenced by the case of Fuego volcano. Despite its frequent activity, no telemetered instruments were operational at the onset of the paroxysm. Even with the information available, INSIVUMEH volcanology was so woefully understaffed that they were overwhelmed by and unable to consider additional information input when activity escalated and information flow increased at midday. That two team members were unavailable leading up to the climactic flows is a deficiency a team of this import should be able to withstand. Further, the lack of more robust decision-making systems and tools as used at other volcanoes, such as an alert level system for communicating hazard levels (e.g., Fearnley, 2013; Hidayat et al., 2022; Joseph et al., 2022) or event trees (Newhall and Hoblitt, 2002), scenarios (Doyle et al., 2014), or statistical models (Sobradelo and Martí, 2018) to guide forecasting and communication of uncertainty limited the information products (most critically, hazard forecasts) that INSIVUMEH could deliver in real time. Further, while staff received outside support from external volcanologists, there was no procedure in place for broader expert advice (described as crucial for successful crisis management at Pinatubo, Philippines, 1990 (Newhall and Punongbayan, 1996) and Merapi, Indonesia, 2010 (Surono et al., 2011)), or other external crisis assistance by outside experts to expand the analysis capacities of such a limited group of volcanologists during a serious crisis. Although challenging on such a short time frame, broader expert input may have helped redirect attention from the ash hazard to the more lethal PDC hazard, for example.

EWS functioning also suffered from lack of cooperation and limited interactions between INSIVUMEH and SE-CONRED. Agency procedures and protocols often neglect the potentially significant gains of working more closely together, either by ignorance of each other's capabilities and roles, or by the perception of competing roles, rather than shared goals. Interinstitutional relationships between these agencies have been strained in the past, and at times even hostile, as evidenced by a feud that gained much attention after the disaster, when both agency's heads publicly blamed each other for not fulfilling their roles during the crisis (Soy 502, 2018). Though conflict or lack of communication between authorities is not uncommon (e.g., Voight, 1990; Newhall et al., 1999), it is well recognized that strong partnerships are crucial for the success of EWS (Newhall, 2021; Jolly and de la Cruz, 2015). This lack of cooperation limited both INSIVUMEH and SE-CONRED staff's ability to fulfill their responsibilities. SE-CONRED had information through its staff and volunteer radio operators that INSIVUMEH did not, including real-time or near-real time updates on PDC activity in Las Lajas. SE-CONRED was limited in their understanding of the hazard likelihood–which was conveyed only very generally during the crisis by INSIVUMEH–and unable to adequately assess the evolving risk. At no point were INSIVUMEH and SE-CONRED staff in the same room to discuss the crisis until after it had occurred.

Most critically, lack of cooperation between the two agencies is part of a larger issue, which is a lack of clearly defined roles and responsibilities for EWS, including evacuation decision-making. Though systems vary between contexts (Baudoin et al., 2016), having clear roles and responsibilities during crisis and within an EWS are necessary for its success (Garcia and Fearnley, 2012; Kelman and Glantz, 2014; Jolly and de la Cruz, 2015). For example, a scientific

agency responsible for monitoring may change a volcano's alert level, which is then tied directly to action required by the civil protection agency (e.g., in Indonesia (Hidayat et al., 2022) and St. Vincent (Joseph et al., 2022)). Alternatively, the two agencies may decide the alert level together. For Fuego, however, not only was there no common alert level system established but there was no system for coordination in decision-making between the two agencies. Communication was greatly one-directional and limited to rigid channels, e.g., INSIVUMEH mostly communicating through written bulletins, with INSIVUMEH providing information for SE-CONRED and SE-CONRED then providing information for the public, leaving each stakeholder group to use the information as they see fit. What's more, SE-CONRED promotes the concept of *autoevacuación*, or self-evacuation, encouraging evacuation decisions at the local level, as reflected in the 15:07 Twitter post recommending that residents near the volcano "evacuate to safe areas if indicated."

This system of one-way communication in which the decision to call for evacuations is put on the level of local authorities enables authorities at higher levels, who may have access to better technical and logistical advice and resources, to absolve themselves of making such critical decisions during the most serious of crises, which may result in tragedies like that of San Miguel Los Lotes. Each EWS partner can say they have fulfilled their responsibility of passing on information, but a critical question is whether or not that information was good enough to make a decision, particularly the decision to evacuate, and if it wasn't, what should be the expectation of the quality and content of information being generated and communicated by different EWS components? As shown in Figure 3, one-way, linear information flows, if not subject to strict quality control, can become a game of telephone; the quality of the end output is controlled by the quality of the filters the information passes through (e.g., scientific expertise and civil protection expertise).

For a warning to be successful depends on multiple factors, including whether the information is actionable (Sutton and Kuligowski, 2019), trust of the user in the information's source (e.g., (Drabek, 1999; Andreastuti et al., 2016) whether the information is understood (Sorensen, 2000; Twigg, 2003; Egerton et al., 2022), and whether the information aligns culturally with its audience's values and beliefs. In the case of Fuego, we need look no further than the actionability of the warnings to determine that they were insufficient. To be actionable in a crisis, information (i.e., warnings) must address stakeholder's primary questions of who or where may be impacted, how they may be impacted, what they can do to protect themselves, and how to do that (Drabek, 1999). This information must be specific and ideally from multiple sources (Mileti and Sorensen, 1990); this is especially important on short timescales and where people are unfamiliar with the hazard, the information source, or the region; people seek additional information to increase their situational awareness before deciding on protective action, which delays the response (e.g., Drabek, 1999). INSIVUMEH's and SE-CONRED's official information output regarding evacuations lacked the specificity needed for a resident or even local authority in any community close to Fuego with the exception of Sangre de Cristo (the only community named in any official communication) to answer the question, "Does this warning pertain to my community?"

Analyzing messaging in official communication is moot if that communication does not reach the stakeholders who need it. This research indicates that multiple communities close to Fuego received no direct communication from authorities the day of the paroxysm. Multiple

communities lacked a CONRED radio base and received no visit from staff. Residents indicated that they did not seek out official information on social media, and regardless did not have accounts on Twitter, where most of the information was posted. The drive-by warnings described in sections 2.5 and 2.6.2.2 may have motivated some residents to evacuate, but it is almost certain that they didn't reach a significant portion of the population of San Miguel Los Lotes, and for the people who were reached, even the in-person and urgent call of alert shortly before the climactic PDCs confused residents who didn't know whether to take cover or flee. This, and other descriptions from residents of San Miguel Los Lotes, indicate the population had an insufficient understanding of their risk to make well-informed judgements on their own, or follow explicit recommendations on evacuations or other protective measures–the fundamental base of an early warning system, which acknowledges the importance of understanding the hazard, its potential impact, and how to protect against it (Basher, 2006; Kelman and Glantz, 2014; Egerton et al., 2022). Without this foundation, they were unable to enact any other part of the warning system on their own, most importantly taking action in the form of evacuations, and did not have sufficient guidance from authorities.

Comparing La Reunión and San Miguel Los Lotes as independent or standalone entities–despite the fact that both did have internal leadership structures–neglects the responsibility of government and its role in the outcomes of the June 2018 paroxysm. Instead, it is valuable to compare them in the context of both entities falling under the government's purview, although the former is a private business and the latter a town. Within this context, both entities should have had access to information that would enable them to make a well-informed decision (short of a government mandate to evacuate). That is to say, each entity should have been able to and known how to access such information and the information should have been appropriate for their needs, e.g., understandable and actionable within their means. To facilitate the appropriate protective action, either–but especially San Miguel Los Lotes–should have those resources provided by higher levels of government. Instead, both entities were left to essentially enact their own EWS, from understanding their risk to recognizing and assessing their threat to deciding on and taking protective action. While most individuals within the resort, especially visitors, would have been unlikely to be able to effectively make such assessments, resort management did have the capacity to do so, in great part because of prior engagement with government authorities. Without even considering the important role of availability of resources needed to take protective action in a comparison, residents of San Miguel Los Lotes entered into 3 June 2018 with a fatal disadvantage. Most residents, including the community's leadership, were unequipped to make such risk assessments. The Guatemalan government failed both entities the day of the paroxysm, but had succeeded in contributing through education to La Reunión's independence while having not done the same for San Miguel Los Lotes.

La Reunión was able to fulfill the role that is usually the responsibility of the external government through their management's understanding of their risk but also because of many other factors, some of which are addressed in World Bank (2018) and by Naismith et al. (2020). Underlying all these factors are other essential qualities that were most lacking in the government system: the willingness and commitment to dedicate resources to risk reduction for the safety of those under their responsibility, a clear system of roles and responsibilities in decision-making, protocols for

the response with practice and pride in efficiency, and a tolerance for 'false alarms,' or expending the resources and taking on the potential socioeconomic repercussions of evacuating in uncertainty.

2.7.2 Broader implications

The case of Fuego volcano, 3 June 2018, reinforces much of what hazard communication, EWS, and volcanic crisis management researchers have already said: EWSs often fail not because of technical faults but because of faults in the socially-produced components of the system (Garcia and Fearnley, 2012; Kelman and Glantz, 2014; Fearnley, 2019). Stakeholder roles and responsibilities must be clear well before a crisis (Garcia and Fearnley, 2012); communication and collaboration between the scientific and civil protection bodies must be strong (Garcia and Fearnley, 2012; Newhall, 2018, 2021); warnings must be actionable, with specific information about what protective action to take and issued with enough time to process that information (e.g., Drabek, 1999; Wood et al., 2018), and EWS procedures should be at least understood and at best meaningfully practiced by at-risk populations beforehand (e.g., Mei et al., 2013). While monitoring data are crucial for assessing evolving risk, forecasting capabilities will always be subject to both epistemic (knowable but not known) and aleatoric (unknowable) uncertainty. More importantly, assessing the risk is limited by the analytical capabilities within the EWS: the ability to process and produce information that is useful for informing potentially life-saving decisions. EWS therefore must be designed to these capabilities, most of which depend not on technology but on the human resources available to use it. The decision-making processes for issuing warnings must be clear and also designed within the limitations of the scientific, technological, economic, and socio-political context in which the EWS operates. This may mean that all involved need a certain degree of willingness to enact large-scale evacuations until the capabilities exist to refine forecasts and reduce uncertainty–or, to generate such forecasts in the first place. Failure to do so may result in disaster.

2.8 References

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3 Evacuation decision-making processes and behavior observed in the post-disaster context at Fuego volcano, Guatemala, 2018-2023

3.1 Abstract

This chapter analyzes evacuation patterns and decision-making processes for paroxysms of Fuego volcano, Guatemala, following the deadly June 2018 eruption and finds that current practices may be inconsistent with available *a posteriori* hazard proxies for those crises when it comes to decide who and when to evacuate. From the timeline analysis of the recent crises, their management would be too slow to avert a disaster with an escalation timeline similar to that of the June 2018 eruption. Importantly, the system does not have well-defined acceptable risk thresholds on which to base evacuation decisions. Shortcomings in the system design include: no clear criteria for decision-making (particularly for deciding who evacuated and when), inefficiency in decision-making processes that result in several-hour-long delays to deploy resources like transportation, and lack of proactive mobilization of resources, all of which are necessary given the short timescales of threat escalation, lethality of PDCs, long timescales of evacuation, and limited resource availability in the at-risk populations. Because of the importance of local geographical contexts, which impact factors such as timescales and risks of evacuation, authorities should determine acceptable risk thresholds and decision-making criteria with each community to ensure an agreed-upon understanding of the strategy. Success should be defined as evacuating populations before risk tolerances are exceeded, which requires defining conservative decision-making criteria based on current knowledge of paroxysm timelines and tolerating the expenses and risks associated with earlier evacuation. This research demonstrates the importance of explicitly including decision-making processes, resources and infrastructure for taking protective actions, and consideration of competing risks into early warning system models.

3.2 Introduction

Warning systems for volcanic hazards are among the most complicated, requiring decision-making in multi-hazard environments with great uncertainty in when and often even whether a threat will occur. One of the most lethal, rapid, and uncertain of these hazards is pyroclastic density currents (PDCs), searingly hot avalanches of volcanic gases, rock, and ash that may travel 100s of kms per hour and bury, bludgeon, and/or burn everything in their path. Because of their speed and unpredictable pathways, with the ability to surge over variable terrain and bodies of water, populations must be warned with time to evacuate hazard-prone areas *before* a potentially deadly PDC initiates. However, forecasting the timing, magnitude, directivity and even occurrence of a PDC comes with much uncertainty and each evacuation comes with a cost to residents, governments, and businesses impacted. In this complexity, deciding whether and when to evacuate is far from obvious. While a successful evacuation depends on multiple factors, it is this decision-making process, and the information feeding into the decision-making process, that is critical for a potentially life-saving evacuation to happen.

Evacuations at active volcanoes are relatively uncommon: Witham (2005) cites 248 evacuations during the 20th century, and a total of 491 volcanic "incidents" during that period, implying that only a few evacuations or even just volcanic "incidents" happen per year globally. Because of this, the world-wide community working to reduce volcano-related risk benefits greatly from each case analyzed, in particular for cases where high consequence hazards materialize, and although tragic cases that involve the loss of lives should be avoided at all cost, when such disasters happen, it is particularly important to learn from them in the hope of significantly reducing the likelihood of them happening again in the future. Because of the complexity of decision-making for volcano-related evacuations, the broader community of early warning system (EWS) researchers and practitioners have much to gain from volcano-related crisis management. Successes in volcano crisis management leading to life-saving evacuations have been attributed to, for example, long-term in-country expertise, and collaboration from the international volcanological community (Merapi, Indonesia, 2010 (Surono et al., 2011)) and strong relationships and trust between key stakeholders (Pinatubo, Philippines, 1999 (Newhall, 2021)). However, there is little research or documentation on how these decision-making processes are planned or play out in practice. Successes in evacuation practices indicative of potentially life-saving habits (i.e., successfully evacuating even when no destructive PDC occurs) have also been documented, most notably for the case of Tungurahua volcano, Ecuador, which was characterized by frequent PDC-producing paroxysmal eruptions during its latest eruptive period from 1999-2016. After an initial government-ordered evacuation in 1999-2000, researchers describe a system in which evacuation decisions were made and enacted locally with input from scientific and civil protection authorities (Armijos et al., 2017).

Fuego volcano, Guatemala, is similar to Tungurahua in its frequent low-level explosive eruptions punctuated by larger, paroxysmal eruptions that often produce localized PDCs threatening the communities on its flanks. Like Tungurahua volcano, Fuego is encircled by a population that has grown accustomed to its frequent activity. However, while Tungurahua ended its recent eruptive period with only five deaths related to PDCs (Mothes et al., 2015), an eruption of Fuego on 3 June 2018 produced PDCs that consumed a golf resort and hotel, a bridge, and most of a small town, resulting in a minimum of 430 deaths–although in the case of Tungurahua, PDCs did not impacted areas as densely populated as San Miguel Los Lotes. The Fuego volcano eruptive period continues at the time of writing (August 2023). The research presented here focuses on the decision-making practices since that tragedy, which determine where, when, and whether evacuations from Fuego's flanks occur and the factors that challenge their success. Specifically, I ask: Do current evacuation decision-making practices and behavior at Fuego volcano meet the needs of an EWS to avert another disaster with characteristics (potential areas exposed, hazard evolution, time scales, etc.) similar to the June 2018 disaster?

3.3 Approach and methods

For this research, I use ethnographic methods including semi-structured interviews and participant observation to investigate evacuation decision-making processes at Fuego volcano. I use primarily semi-structured interviews and analyze these together with field notes from participant observation and official documents as described below. A qualitative approach for this

research was necessary because it enables examination of the subjective and complex factors that define decision-making. Semi-structured interviews, in particular, give the opportunity through open-ended questions for the emergence of themes that I did not anticipate, nuanced descriptions of complex interactions, and iterative discourse (both within a single interview and, in many cases, between multiple conversations) to clarify concepts and perspectives. Understanding decision-making requires an understanding of motivation, which is difficult to reduce to quantitative measures.

3.3.1 Data collection and analysis

3.3.1.1 Semi-structured interviews and participant observation

I conducted semi-structured interviews for this research primarily in two different time windows in Guatemala: November 2021 and January - June 2022. Additional insight was gained during this same time period as well as in March and May 2023 from participant observation. All interviews and participant observations were collected under and in accordance with Institutional Review Board (IRB) approval 1760726-2 from Michigan Technological University.

Semi-structured interviews
Semi-structured interviews were conducted considering guidance provided by Lareau (2021) and Jacob and Furgerson (2015) in that interviews roughly followed an interview guide with prompts (Appendix A) and prioritized open-ended questions, including "big, expansive questions" (Jacob and Fergerson, 2015, p. 4) that allowed the participant or participants to discuss what they found most relevant. Most interviews were conducted one-on-one but some were conducted with multiple interviewees (e.g., family members, community members, or fellow staff) to maintain a comfortable environment for the interviewee(s) and to use their time and attention efficiently. Sangaramoorthy and Kroeger (2020) acknowledge that group interviews can be effective, especially if the topic is a shared experience and not pertaining to information that would be considered private to individual participants. I conducted the interviews in places of convenience to the interviewees, including at their workplace (e.g., the CONRED office in Antigua Guatemala, Guatemala and the Fuego Volcano Observatory (*Observatorio Volcán de Fuego*, OVFGO), operated by INSIVUMEH and located in Panimaché 1), at their home, in a community space (e.g., the 'salón' (community meeting room) in Guadalupe or the school in La Trinidad), or in the field during fieldwork when there was down time and we could find comfortable space out of earshot of others. All interviews were conducted in Spanish and audio recorded digitally with verbal consent from interviewees. Per the recommendation of Laurea (2020), I ran two audio recorders when possible for data collection, in case one failed. Each interviewee was assigned a code, which was documented with their name in a password-protected file, and that code was then used for file naming and later analysis.

Interviewees were recruited through a combination of purposive, snowball, and convenience sampling, following descriptions provided by Bernard (2016). Purposive sampling, or intentionally selecting certain participants to meet the goals of the research, was essential for ensuring inclusion of people in key roles in evacuation decision-making. Sampling started with in-country contacts at INSIVUMEH and CONRED already known to MTU researchers.

Additional participants were recommended by these contacts, other interviewees, or other researchers, or were selected for certain characteristics, e.g., did or did not evacuate during a given eruption (snowball sampling). Still other participants were recruited through convenience sampling, e.g., through connections made during community meetings or workshops I attended, or people local contacts introduced me to who were family members or lived nearby, where the primary goal was to increase the perspectives represented within a particular community. The distribution of interviewees living around on Fuego's flanks is shown in Figure 1.

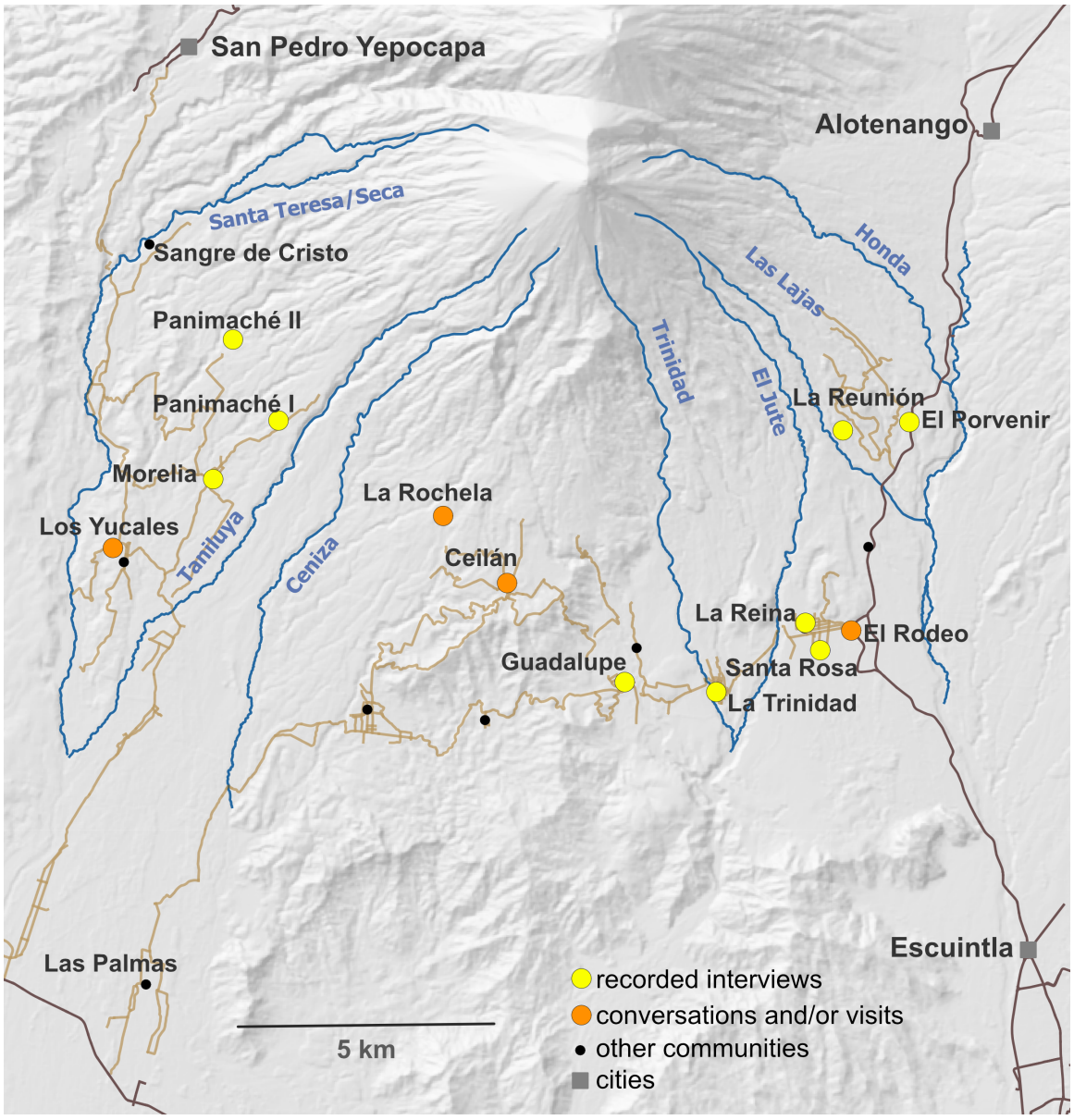

Figure 1: Map of Fuego volcano and its surroundings showing the distribution of communities in which interviews and/or participant observations (denoted as conversations and/or visits) were conducted.

Interviewees selected primarily through purposive sampling included actors involved in the evacuation decision-making process at multiple levels, targeting staff in the national government agencies responsible for volcano monitoring and civil protection (INSIVUMEH and SE-CONRED, respectively), staff from the Private Institute for Climate Change Research (*Instituto Privado de Investigación sobre Cambio Climático*, ICC), a non-governmental organization funded by sugar cane plantations that contributes to the coordination and procurement of resources to support evacuations, and municipal (COMRED) and local (COCODE, COLRED) authorities (Table 1). This research is not meant to be representative of the experiences of all people nor all entities involved in evacuation decisions and response at Fuego volcano. Instead, I attempted to talk to some actors at multiple levels in the system to gain perspective on how the system operates and why it operates how it does. One of three municipalities and leaders from four of more than 30 communities within the recognized PDC hazard zone are included in the participant sample. The communities were chosen for their geographical distribution and to ensure differences in community leadership and evacuation experiences. These communities include Panimaché I and Panimaché II, in the municipality of Yepocapa, both of which participated in the evacuation of 7-8 March 2022; and Guadalupe and the Comunidad Indígena de La Trinidad (hereafter La Trinidad), in the municipality of Escuintla (Figure 1), for which there was no official evacuation effort, although La Trinidad organized its own evacuation. This work is also informed by 64 additional interviews with residents in all four of these communities as well as five other communities (La Rochela, Santa Rosa, Morelia, Santa Rosa, and El Porvenir).

Only a subset of these interviews were analyzed in depth, chosen because as civil protection professionals and community leadership the interviewees were involved in and highly impacted decisions that had impact at the community scale. Interviews analyzed in depth are indicated in Table 1. These interviews were transcribed using a transcription software (Sonix.ai) that produced a transcript automatically that the author then reviewed for accuracy and corrected, maintaining the original language (Spanish). Other interviews were transcribed using the same software but without the attention to detailed corrections or were documented in notes capturing important information and key quotes (Sangaramoorthy and Kroeger, 2020). The seven key interviews were coded in qualitative data analysis software (ATLAS.ti) using a flexible coding approach as described by Deterding and Waters (2021) for the following themes, determined from the primary research question and emergent themes identified through the interviewing and coding process: Communication networks, evacuation strategy, decision-making process, decision-making factors, risk perception, attitude (toward others' evacuation choices), roles, improvements, and logistical process (Appendix B). The first three are of particular importance in this study. These coded responses were then used to analyze similarities and differences in how each community leader or authority described using information to decide on action, especially evacuation, during a crisis.

Table 1: Semi-structured interview participation

Location or agency	***Total participants***	***Number of interviews analyzed in depth***
INSIVUMEH (scientific agency)	10	0
SE-CONRED (civil protection agency)	3	1
Escuintla COMRED (municipal government)	1	1
ICC (non-governmental organization)	1	0
Panimaché I	10	1
Panimaché II	9	1
Morelia	10	0
La Rochela	1	0
Guadalupe	13	2
La Trinidad	11	1
Santa Rosa	2	0
El Porvenir	1	0
Totals	**72**	**7**

Participant observation

Participant observation that informed this study was documented through field notes and voice memos as recommended by Lareau (2021), and included SE-CONRED accreditations of local COLRED groups in Morelia, Panimaché II, and Ceilán; geological fieldwork with INSIVUMEH volcanology staff at the Las Lajas drainage during the onset of the paroxysm and PDCs on 7 March 2022; and community workshops organized by myself and/or researchers from the UK Global Challenges Research Fund-funded *Ixchel* project in Panimaché I, Los Yucales, La Trinidad, and Guadalupe. The work was also informed by a workshop 15-17 March 2023 on early warning systems for Guatemala's volcanoes involving staff from INSIVUMEH, SE-CONRED, the ICC, and the US Geological Survey, as well as researchers from Guatemalan, UK, and US universities, led by Bristol University as part of the Ixchel project; and conversations with INSIVUMEH volcanology staff and contacts in Panimaché II following a subsequent paroxysm and evacuation on 4 May 2023, the most recent at the time of writing.

These notes and memos were revisited, annotated, and analyzed as recommended by Emerson et al. (1995) and Laurea (2020) to inform evolving theory and research questions.

3.3.1.2 Supplementary data

Supplementary data were used to better understand the recent eruption and evacuation history of Fuego volcano to help frame the analysis. The interview data were supplemented by government census documents, government evacuation statistics, and INSIVUMEH Special Volcanological Bulletins describing Fuego's paroxysms, as well as PDC lengths as determined by remote sensing and field mapping and provided by R. Escobar Wolf. Distances reported throughout the analysis were estimated using Google Earth. I focus on the current eruptive period, from 21 May 1999 to present, with special attention to the period since 3 June 2018 when PDCs reached populated areas.

3.3.2 Limitations

Limitations of this work include the following: Individuals may not clearly or accurately express how the decision-making system actually works in their community and leaders may not share the same perceptions, values, and approach to decision-making as their fellow leaders. Indeed, in each community interviewees expressed conflicting views of how decision-making works (or how it worked on 7-8 March 2022). Interviewees may have eliminated or exaggerated descriptions of events, systems, or opinions either on purpose or unintentionally. Accuracy of analysis may be compromised by my own limited understanding of cultural contexts. Not all communities were sampled and the sample was not intended to be representative of those residents' communities. Still, these interviews give insight into how risk reduction professionals, leaders within at-risk communities, and other residents of these communities view and approach risk reduction decisions in times of crises. Where possible, information was corroborated by another source or sources.

The system is in constant flux; there were another two paroxysms since the completion of interview-based fieldwork (10-11 December 2022 and 4 May 2023), the latter of which resulted in evacuation. While I have talked with several of the original interviewees about these paroxysms, they were not included in the interview data collection. I do include aspects of both paroxysms in the analysis, but do not focus on them, although the 4 May 2023 evacuation had higher participation than 7-8 March 2023 and likely represents an improvement in evacuation procedures.

3.4 Results and analysis

3.4.1 Recent evacuation decisions

While evacuations and the decision-making for them pose challenges in all circumstances, decision-making for evacuations at Fuego are subject to particular challenges. Evacuations require mobilizing a potentially large and rural population, which requires external resources and the logistical challenges of reaching and evacuating a dispersed population via poorly maintained roads through high-risk areas. Residents must then disrupt their lives and livelihoods to go to evacuation centers in nearby cities, changing from their rural and temperate to an urban and tropical setting, staying usually in schools and other public use spaces that are not generally designed to host and shelter people for extended periods of time (e.g., in terms of privacy for sleeping spaces, access to water and sanitation, spaces for eating and other daily life activities). These decisions to take on the risks and costs of evacuating, both real and perceived, are made in great uncertainty. Many, but not all, paroxysms generate long (>4 km) PDCs (Figure 2). Even fewer generate PDCs long enough to reach communities (~7 km), and only one since the current eruptive period started in 1999 has generated PDCs that overbanked one of Fuego's seven major channels and reached populated areas–and the results were devastating (see Chapter 2). Communities lie within 0.5 km from six of these seven channels (Table 2).

Figure 2: Frames from the FG08 webcam at the INSIVUMEH observatory in Panimaché I showing the first pyroclastic flow at 12:58 pm (left) and a larger PDC at 1:15 pm (right), local time on 7 March 2022. Note that time stamps are in UTC. The flows are descending the Ceniza channel; later PDCs in the paroxysm descended the Las Lajas channel on the other side of the volcano as well. (Images courtesy of INSIVUMEH.)

Table 2: Major channels and the closest communities on Fuego volcano

Channel	***Longest PDC (km)***	***Closest community***	***Distance from channel (km)***	***Distance from summit (km)***	***Distance reached (km)***	***Date***
Seca/Santa Teresa	8	Sangre de Cristo	0.1	8.8	1.0	3 June 2018
Taniluyá	5.25	Panimaché I	0.4	7.5	2.25	16 July 2005
Ceniza	8	La Rochela	0.4	7.5 *but some houses within 6*	0.75	3 June 2018 (25 January 2017, 13 September 2012)
La Trinidad	7.5	La Trinidad	0.05	10	2.5	7 February 2015
El Jute	9.5	La Reina (Finca San Antonio)	0.5 (0.15)	10 (10)	0.75	21 May 1999
Las Lajas	11.7 / 5.5*	La Reunión resort	0.05	7	2.0	7-8 March 2022
La Honda	4.5	La Reunión residences (Finca La Candelaria)	1.35 (0.4)	6 (8)	2.0	31 January 2018

* Since 3 June 2018

There are currently no reliable precursory signs of paroxysm–aside from Fuego's constant state of unrest. PDCs in a given channel are often preceded by lava flows, and PDCs long enough to reach populated areas are often–but may not always be–preceded by shorter ones. Still, there is great uncertainty at the beginning of a paroxysm in whether, when, and where PDCs will occur,

and how large they will be. This makes deciding on whether, where, and when to evacuate challenging. Further, paroxysms–including those generating PDCs long enough to reach populated areas–may occur frequently (Figure 3); if communities were to evacuate for each paroxysm, this would have resulted in evacuations as frequently as every month for the most productive period of the current eruptive period from 2015 through 2017 (Naismith et al., 2019). The short timescale of Fuego's paroxysms, lasting from 24-48 hours (Lyons et al., 2010; Naismith et al., 2019), require that decision-making and any subsequent action is efficient to avoid as much as possible those evacuations that could be considered "unnecessary" while at the same time, and more importantly, not missing an evacuation that would avoid hundreds or potentially thousands of deaths. It is in this context that evacuation decisions have to be made.

3.4.1.1 Inconsistency in evacuation occurrence in relation to a posteriori hazard proxies

From the reactivation of Fuego volcano on 21 May 1999 to the time of writing (July 2023), INSIVUMEH reports 84 paroxysmal eruptions, 29 of which were confirmed to generate PDCs of 3 km or longer (Figure 3). Eight of these generated PDCs exceeding 7 km, the distance to the closest communities, although luckily, mostly avoiding populated areas. If the maximum PDC length is used as a measure of how hazardous eruptions have been, the occurrence of authority-supported evacuations is inconsistent with such as a PDC hazard metric. SE-CONRED reports seven government-supported evacuations for this same time period. Because evacuations are meant to reduce risk from PDCs, we might expect evacuations to correspond to the paroxysms generating the largest PDCs. However, only two of the seven evacuations correspond to the paroxysms generating these 7+ km PDCs. Focusing on the time since the deadly 3 June 2018 paroxysm, we observe the occurrence of seven paroxysms, all seven of which generated PDCs longer than 4 km, with three generating PDCs of close to or exceeding 7 km according to satellite data. SE-CONRED has reported three government-supported evacuations of communities during the same time period, though the evacuations do not correspond to the paroxysms with the longest PDC runouts. The largest supported evacuation occurred for the paroxysm generating the shortest PDC in this time period (4 km, November 2018), while no evacuation was supported for the paroxysm generating the longest PDC (7.5 km, December 2022).

PDC runout may not be the only criterion that can be used as a metric for the severity of the hazard, but other easy to assess options are not obvious. It's also important to clarify that in this context, PDCs runout length is used *a posteriori* to evaluate which eruptions experience a more severe PDC hazard, rather than suggesting it should be used in real time for decision making, as the measure of such a variable in real time is also difficult in practice. Because PDC runout length is difficult to assess in real time, inconsistencies in government-supported evacuations may result from basing evacuation decisions around multiple other indications of increasing hazard severity, including various parameters that reflect eruption intensity, such as ash column height and seismic energy, and also whether there are populations close to the channels estimated to be more impacted. Although a full analysis of volcanological parameters for each paroxysm is outside the scope of this research, looking at readily available ash height data indicates that from the 3 June 2018 eruption to present (NOAA, 2023), ash column heights were greatest for the paroxysm

associated with no organized evacuation (10-11 December 2022, Table 3). The next greatest ash cloud height was associated with the largest evacuation. Further, differences in the channel(s) impacted do not account for the differences in evacuation occurrence: the longest, 4 km PDC of the November 2018 paroxysm was in the La Trinidad channel, on the south side of the volcano, with additional PDCs in two channels on the east side of the volcano, though the paroxysm spurred evacuation of communities on both the west and east sides. The longest PDCs in each of the following six paroxysms were generated in the Ceniza channel on the western side of the volcano, spurring evacuations of only communities on the west side of the volcano, but only for two of the three paroxysms with PDC runout distances of more than 6 km. In all three recent cases, PDCs reached or almost reached the distance to the closest communities, but stayed confined to the channel. Notably, the closest community, La Rochela (Figures 1 and 3), did not evacuate (Table 3).

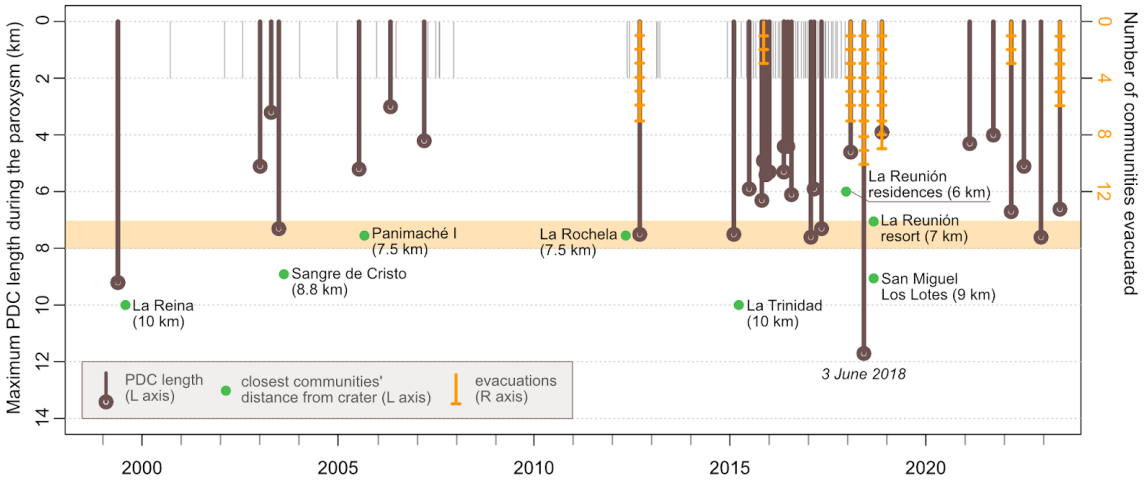

Figure 3: Paroxysms, maximum PDC length, and supported evacuations at Fuego volcano since 1999. Paroxysms with 2 km or shorter PDCs shown in gray. Maximum PDC length shown in dark red (length on left axis). Number of communities evacuated per CONRED shown in orange (right axis). Distance from summit to the communities closest to each channel (Table 2) is indicated by green circles placed closest to the paroxysm with the longest PDCs in the channel closest to that community.

The particularly high ash cloud may be partially responsible for the widespread evacuation of November 2018, but more likely the high evacuation participation resulted principally from the recent memory of the destruction of San Miguel Los Lotes just four months earlier. The major difference between the three paroxysms is that the December paroxysm, for which there was no evacuation, occurred at night on a Sunday.

Table 3: Paroxysms producing PDCs >4 km and evacuations since June 2018

Date	***Maximum PDC length and channel (and other channels impacted by PDCs)****	***Maximum ash cloud height above summit****	***Location(s) evacuated******
18-19 November 2018	4 km, La Trinidad (El Jute/Las Lajas)	4400 m	Morelia [196], Panimaché I [337], Panimaché II [70], Sangre de Cristo [24], Santa Rosa [35], El Rodeo [794], Guadalupe/El Zapote [2500], La Reina [90], El Porvenir (Alotenango) [67]
14 February 2021	4.3 km, Ceniza	1400 m	*No evacuation*
22-24 September 2021	4 km, Ceniza (La Trinidad)	1100 m	*No evacuation*
7-8 March 2022	6.75 km, Ceniza (Las Lajas)	3800 m	Morelia [256], Panimaché I [209], Panimaché II [57]
4 July 2022	5 km, Ceniza	1100 m	*No evacuation*
10-11 December 2022	7.5 km, Ceniza (Las Lajas)	6900 m	*No evacuation*
4 May 2023	6.5 km, Ceniza (Seca/Santa Teresa)	3800 m	Panimaché I [245], Panimaché II [157], Morelia [561], Santa Sofia [81], Los Yucales [51], El Porvenir (Yepocapa) [25]

* R. Escobar-Wolf, personal communication

** Rounded to the nearest 100 m; NOAA, Washington VAAC. https://www.ospo.noaa.gov/Products/atmosphere/vaac/FUEGO_volcanic_ash_archive.html

*** CONRED

3.4.1.2 Low evacuation participation

Statistics on past evacuations are not readily available, but what is available for the most recent two evacuations indicates low participation (Table 4). Based on these best available data, only 20% of the population of the three participating communities evacuated during the 7-8 March 2022 paroxysm (Table 3). Three additional communities declined to evacuate despite recommendations from CONRED. Instead, they signed *actas*, or agreements, acknowledging that CONRED had informed them of the threat and that they are staying at their own risk. This practice came into effect because of liability concerns resulting from the 3 June 2018 disaster. Participation improved for the subsequent 4 May 2023 evacuation, with the three communities that declined to evacuate in March 2022 participating–although at low levels (Table 4). Participation within the communities that evacuated in 2022 increased in all three, from a total of 522 people (20%) to 963 people (38%). Note however that contacts indicated that only elderly, women, and children evacuation from Panimaché II, which calls into question the high percentage of participation reported here; the number may either be inflated, reflect population increases since the 2018 census, or result from male household members being counted in the communities they work in rather than where their family home is.

Table 4: Evacuation numbers 7-8 March 2022 and 4 May 2023

Village	***Population****	***Evacuated 7-8 March 2022****		***Evacuated 4 May 2023****	
Panimaché I	389	209	54%	245	63%
Panimaché II	172	57	33%	157	91%
Morelia	1994	256	13%	561	28%
Total above	**2555**	**522**	**20%**	**963**	**38%**
Santa Sofia	2349	0	0	81	3%
Los Yucales	461	0	0	51	11%
El Porvenir	458	0	0	25	5%
Total	**5823**	**522**	**9%**	**1120**	**19%**

* From 2018 census numbers (INE Guatemala (2018)); populations likely increased between 2018 and 2022, which would imply an even lower percentage of evacuation participation than what we calculate here
** From CONRED

3.4.1.3 Timelines of evacuation exceed timelines of eruptive activity and potential hazard escalation

The 3 June 2018 paroxysms took 12 hours from the first recognition of the paroxysm to the deadly PDCs, 10 hours from the first observation of PDCs, and just four hours from the recognition of large PDCs in the Las Lajas channel to the devastation of a resort, a bridge, and a town alongside, over, and near that channel (this dissertation, Chapter 2; Figure 4). These large PDCs in Las Lajas triggered the La Reunión resort's management to decide to evacuate, which staff initiated immediately; evacuation was complete within 1.5 hours (Canal Antigua, 2018, 00:12:55), at which time PDCs were descending past the resort's main clubhouse. Within another 2.5 hours, the western reaches of the resort and its golf course were destroyed. Management succeeded in evacuating ~300 people who were there as temporary visitors with their own transportation or workers, via onsite resort minibusses, from a property along a major road. Considering this same timeframe on 7 March 2022, starting from observation of the first large PDCs in the closest channel (Ceniza), the first government-coordinated transportation would just have been arriving as the devastating PDCs descended four hours later, to evacuate a population of several thousand from their primary residences along poorly maintained dirt roads. (See Appendix D for a table summarizing the timeline of the paroxysm and evacuation.) The last government-coordinated transportation left a full 6.5 hours later, 10.5 hours after observation of the first large PDCs. The evacuation process, from authorities' evacuation recommendation to the last bus to leave (excluding other emergency management vehicles that were still in transit toward communities at 11:30 pm), lasted 9.5 hours, ~35% of the total 26-hour paroxysm (INSIVUMEH bull. BEFGO 012-2022).

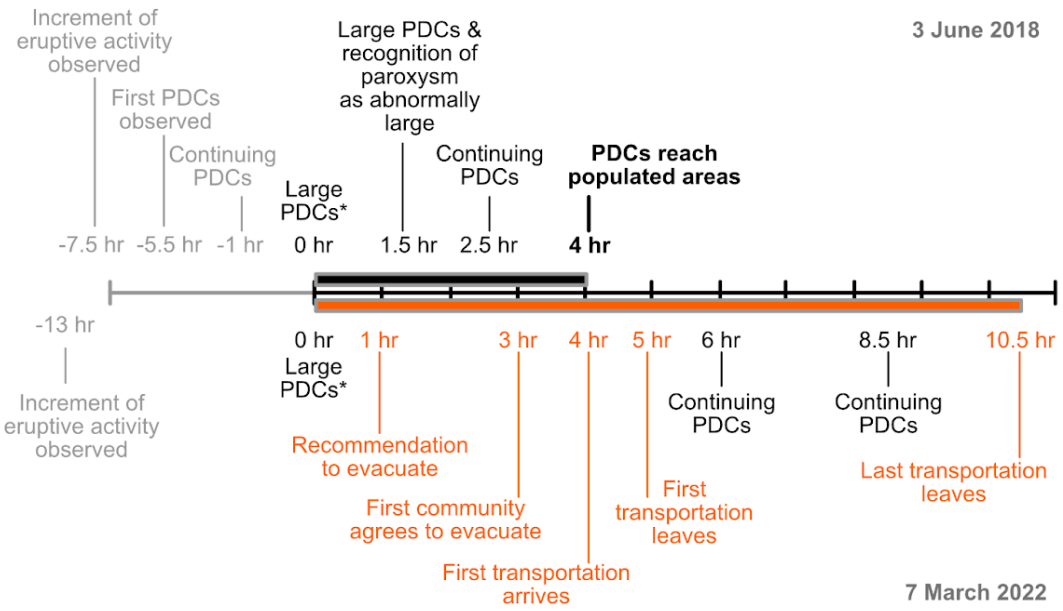

Figure 4: Timeline comparison of the 3 June 2018 and 7-8 March 2022 paroxysms. *"Large PDCs" refers to large PDCs in a channel of threat to the communities or entities that evacuated, not to the first occurrence of large PDCs during the paroxysm, which may have been elsewhere on the volcano and did not trigger evacuation in that proximity.

This timeline highlights the challenges not only of enacting evacuation but of making evacuation decisions, as also identified by Naismith et al. (in prep.).

3.4.2 Decision-making structures

3.4.2.1 Layered response system

EWS commonly involves a broad range of stakeholders, with the structures of decision-making and response responsibilities varying according to the nature of the institutions and the dynamics between those involved, including government agencies and the population at risk (Baudoin et al., 2016). At Fuego volcano, evacuation decisions engage government agencies; multiple levels of governance; private sector actors including plantations or factory farms and tourist ventures; and residents and other at-risk populations. Interviewees described a sometimes complex interplay between these actors during decision-making for evacuations, based around Guatemala's civil protection system, the National Coordinator for Disaster Reduction (*Coordinadora Nacional para la Reducción de Desastres*, CONRED). CONRED is a system, not a single entity, which may include actors of all sectors. The system was established to leverage existing capabilities of various government and private entities, which are coordinated as needed by a national agency-level organization, the Executive Secretariat or SE-CONRED. Guatemala's scientific monitoring agency, the National Institute of Seismology, Volcanology, Meteorology and Hydrology (*Instituto Nacional de Sismología, Vulcanología, Meteorología e Hidrología*, INSIVUMEH) is responsible for monitoring and providing information about volcanic hazards, including forecasting where possible, as INSIVUMEH leads CONRED's Scientific Council, tasked with

monitoring, assessing and studying all hazards, vulnerabilities and risks that may affect the country (Acuerdo Gubernativo 49-2012, articles 57 through 59). With regards to geological hazards, and in particular with volcanic hazards, INSIVUMEH leads and in practice executes most of the monitoring and hazard assessment.

SE-CONRED's small Department of Volcano Prevention (*Departamento de Prevención en Volcanoes*, DPV) focuses on risk reduction specific to volcanoes, directly supporting risk reduction efforts–including evacuations–with one technician dedicated to each of Guatemala's three most active volcanoes, including Fuego. The DPV as well as SE-CONRED regional officers are charged with working directly with communities via their local, volunteer civil protection group, or Local Coordinator for Disaster Reduction (*Coordinadora Local para la Reducción de Desastres*, COLRED), to educate residents about volcanic hazards, signs of dangerous eruptive activity, and taking protective action, as well as working with each community to develop crisis response plans. These COLREDs also coordinate the residents' response in a time of crisis. The intent of the CONRED system is for response to crises to initiate at the lowest level (COLRED) and move up as capacities are exceeded; that is, a response to a crisis within a community would start at the local level with a community's governance and move up to the municipal (COMRED) level as local capacities are exceeded, etc. (Decreto Legislativo 109-96, 1996).

DPV staff, as part of the SE-CONRED general policy, promote *autoevacuación*, or self-evacuation, where communities are self-sufficient in at least evacuation decision-making and transportation to a more accessible meeting point, as previously described by (Naismith et al., 2020) (Figure 5). SE-CONRED becomes the main point of contact for making recommendations and conveying these local decisions that trigger the mobilization of resources. Crucial resources are provided not only by higher levels of government, e.g., municipalities, but also by non-governmental organizations and private entities, most notably the nearby sugar producers via an informal partnership with the Private Institute for Climate Change Research (*Instituto Privado de Investigación sobre Cambio Climático*, ICC), which is funded by and serves the research interests of the sugar producers.

The decision to evacuate with government support is thus made at the community level. In theory, a meeting of the whole community is convened by the community's Community Development Council (*Consejo Comunitario de Desarrollo*, COCODE), created to make decisions pertaining to community development and distribution of public-funded projects but often also used as a more general governing body. A decision to evacuate would then be made democratically and supported–if action is required–by the COLRED, the civil protection group.

WE PROMOTE SELF-EVACUATION!

If you find yourself at risk follow these steps:

Put your **Family Response Plan** into action and have your **72-hour Backpack** ready
Download it from our website:
https://conred.gob.gt/pfr/

Listen to the official information shared by the authorities by communication channels.

Recognize the risk or emergency and prioritize your life and that of your family.

Start self-evacuation toward the designated safe point in your community and report to your local authority.

Using a mask and personal protection equipment at all times is indispensable.

Figure 5: A graphic promoting self-evacuation posted to both CONRED's and INSIVUMEH's Twitter feeds during the paroxysm of 10-11 December 2022; author's translation.

In practice, local authorities and other residents described the community-level decision-making process occurring in various ways, between and even within communities. Descriptions included decision-making by the whole community as intended, as a consensus between the COCODE and the COLRED, as a decision made by only the president of the COCODE, and as a decision made by only the leader of the COLRED.

However, many residents acknowledged that the final decision on whether to leave during a paroxysm–if the resources to do so are available–is made at the household or individual level, as described by a resident in Guadalupe:

> [The COCODE president] is the one who makes the decision. And he makes the decision to advise. And then people make the decision whether to leave their homes. Because he only advises, it's not obligatory. Whoever wants to leave, leaves, and whoever doesn't, stays in their home.

However, because of limited access to transportation and shelter, most residents depend on the willingness of actors within the CONRED system to support their evacuation. According to the 2018 national census, only one third of households in the three municipalities in which Fuego communities are located had motorcycles and even fewer had cars or trucks (San Pedro Yepocapa: 20% and 9%; Escuintla, 38% and 24%; and San Juan Alotenango, 17% and 10%, respectively (INE, 2018)). These percentages are likely skewed higher by the municipalities' urban centers and are thus lower for the rural communities close to Fuego. As described by a staff member of the Escuintla municipality's risk reduction team about communities within Escuintla,

> The problem is, yes they can decide. But they don't have a way to leave. When the mayor says let's evacuate, he brings them transportation, the municipality.

Therefore, because the vast majority of communities close to Fuego lack the material resources needed to evacuate, most notably transportation and shelter outside the hazard zone, their ability to evacuate depends on decisions and coordination at multiple levels of government and on public-private partnerships.

3.4.2.2 Delays in resource provision

Examining the timeline of the 7-8 March 2022 paroxysm and resulting evacuation reveals multiple delays between a recommendation to evacuate and the arrival of the resources necessary to do so. While SE-CONRED started to coordinate resources such as evacuation shelters and transportation with municipal and other resource providers as soon as deemed necessary, the resources were not mobilized until DPV staff conveyed the community-level decision to evacuate. Yet, the drive from the main road–where the buses are sourced–to the communities recommended for evacuation takes around 45 minutes. Transportation was first delayed when local authorities in Panimaché I decided to wait one hour after convening to monitor the trajectory of the volcanic activity, to gauge whether evacuation was necessary. Because of continuing PDCs during this time, the authorities agreed to evacuation around 4 PM. Transportation was then delayed as DPV staff waited on an estimate of evacuee numbers, requiring up-front decision-making at both the community and the household (or individual) level:

> When people say yes, we are going to evacuate, that's when you begin to mobilize resources. Because they were not going to mobilize resources and there's no one [to use them]. Because you have to move cots, food, rations. And if no one evacuates? Then it becomes a problem for you, it's a problem for you, because you're thinking they're pulling out resources, mobilizing resources and if no one evacuates? Then it's for nothing. Then the repercussions fall on you. (...) And you have to have data on how many people are going to evacuate. That's another problem. They call me, 'How many people are you going to evacuate?' 'A census is being carried out right now.' But, 'How many people?' Well, I can't give you a figure of 1,000 people and in the end only 100 leave. And moving resources is the same. And that's why I put out the COLREDes... So, 'Go write down how many boys, how many girls, how many women and how many men.' (...) They went to do the census. They went house to house asking, 'Look, are you going to evacuate?' 'Yes.' 'Are you going to evacuate?' 'Yes.' But in the end, those who had signed up no longer wanted to evacuate afterwards.

The first bus arrived to Panimaché I around 5 pm (Figure 4). It departed for the shelters in the city of Santa Lucia Cotzumalguapa around 6 pm. The ICC coordinated six buses total, the last of which left from Morelia around 11:20 pm. Additional emergency response vehicles from the police and military were just en route to Panimaché I at this time to urge the evacuation of more residents; evacuation continued into 8 March 2022, with the last evacuees reportedly arriving at evacuation centers around 3:00 am.

3.4.3 Informing decisions: Communication and criteria

The above section describes delays only from when the evacuation was first recommended, which was after the descent of large (>6 km long) PDCs. Deciding when to call for evacuation most fundamentally sets the clock for evacuation, and is a challenge for authorities in all hazard situations. Calling an evacuation too soon may result in more "false alarms," or evacuations perceived as unnecessary. Calling an evacuation too late may result in disaster, if PDCs reach populated areas.

3.4.3.1 Information produced by government agencies

A proposal by collaborating external scientists shortly after the 3 June 2018 disaster to establish evacuation criteria based on PDC length and eruptive column height was discussed but never adopted. Instead, staff continued to base decisions on when to provide information and what to provide primarily based on past experience with Fuego. Current protocols shared by INSIVUMEH staff in July 2023 include producing a Special Volcanological Bulletin, their primary means for sharing information, when a paroxysm starts, when PDCs come down different channels, and when several hours have passed since the last bulletin. INSIVUMEH does not use a quantitative forecasting method or probability-based decision-making tools such as event trees (Newhall and Hoblitt, 2002), statistical models (Woo, 2008), or other semi-quantitative methods. The bulletins describe anomalous activity based on observations from observatory staff as well as seismic and any other instruments operating on the volcano. The bulletins include recommendations to major stakeholders such as CONRED and sometimes the general public (e.g., BEFGO 118-2022).

The guidance provided publicly by INSIVUMEH to CONRED and other stakeholders in their bulletins has historically been very general. For example, INSIVUMEH's recommendation to CONRED in their special bulletin published shortly after the increase in PDC activity during the 7-8 March 2022 paroxysm reads "**Implement the state of alert and take the actions deemed necessary** in the communities located in the vicinity of the volcano ravines, especially the Ceniza, Trinidad and Taniluyá ravines, taking into consideration that the descent of these pyroclastic flows can produce ash falls in the areas close to the ravines where they occur, as well as interrupting the passage through them" (author's emphasis; BEFGO #009-2022).

Neither INSIVUMEH nor CONRED operate on alert systems that define or derive from volcanic activity levels or required actions; instead, INSIVUMEH provides guidance like that quoted here and others in the CONRED system may set regional alert levels (covering an entire jurisdiction) or institutional alert levels that activate staff and mobilize resources under their purview.

SE-CONRED is then responsible for conveying relevant risk-related information to the public in an understandable format, which they do via their own *avisos*, or notices, that generally summarize the INSIVUMEH bulletins with guidance for governments in one aviso and residents in another; SE-CONRED headquarters distributes the information on social media and also more directly to communities on the volcano via a network of VHF/UHF radios hosted by volunteer radio operators in their homes, a network that was augmented after the 3 June 2018 paroxysm. The SE-CONRED regional delegates and DPV separately distribute this information through

various informal communication channels: a WhatsApp group to community leadership, phone calls, text, and in-person conversations. Stakeholders are then expected to use this information to inform their decisions about evacuations, road closures, tourist ventures, etc.

SE-CONRED's public recommendations published in *avisos* are similarly general to INSIVUMEH's. All five paired sets of *avisos* pertaining to the 7-8 March 2022 paroxysm provided the same guidance throughout the event. Regarding evacuations, SE-CONRED recommended that governments "maintain monitoring and carry out PREVENTATIVE EVACUATIONS **that you consider necessary**" (author's emphasis; e.g., CONRED Notice No. 15, 2022). They recommended that residents "attend to the notices that municipal and departmental authorities make known as PREVENTATIVE EVACUATIONS" (e.g., CONRED Notice No. 16, 2022). Neither case specifies which departments, municipalities, or communities should consider evacuating. Information provided on social media is similarly general. However, more explicit guidance is provided through the undocumented, direct information channels such as phone calls, texts, WhatsApp groups, and in-person conversations, as described in interviews and observed in the field the day of the paroxysm. How much the information from authorities permeates the rest of the community depends on a community's location and internal communication networks.

3.4.3.2 Thresholds for recommendations and warnings

At what point is a paroxysm considered to pose a high enough risk of dangerous PDCs to trigger evacuation recommendations, and subsequent evacuations? While some authorities stated in interviews that evacuations should start before PDCs occur, it is clear that no supported evacuation has initiated before the first PDCs during the current eruptive period, since 21 May 1999. Instead, although communities are typically 'on alert' with an observed increase in activity, recommended by external authorities or decided internally (section 3.4.3.3), for the most recent six paroxysms, authorities haven't recommended mobilizing for evacuation until not only after PDCs were observed, but after they were found to be large enough to be threatening. For example, despite observations of short (5 km or shorter) PDCs during paroxysms in February and September 2021 and July 2022, no evacuations were recommended because other measures of eruption intensity (e.g., RSAM) did not rise to levels alarming to officials. Among risk factors described by external authorities are not only the length of PDCs and RSAM but the duration of the paroxysm, perceiving a longer paroxysm to indicate an abnormally large paroxysm and that, if PDCs are occurring, they may be filling channels and increasing the chance of subsequent overbanking. It is worth noting that even a single, massive PDC can fill a channel. Also, while in many cases shorter (e.g., 3 June 2018) PDCs precede PDCs long enough to reach populated areas, this may not always be the case. On 7 March 2022, though INSIVUMEH recognized the paroxysm had started by 09:10 (BEFGO 007-2022), evacuation was only actively encouraged by officials after >6 km-long PDCs in the Ceniza channel descended around 13:00 followed by even larger PDCs shortly after. The populated areas located closest to the crater are at around 7-8 km distance. These were the first and, as it turned out, the largest PDCs of the paroxysm.

Another important question is what area should be evacuated. When asked how they decided who should evacuate, authorities interviewed did not describe specific criteria and instead described

factors that indicate increasing risk. The following description, from a government employee in Escuintla, captures the common factors described by authorities from INSIVUMEH and DPV as well, specifically the proximity of a community to a channel and whether the volcano's erupted material is directed toward them:

> Regularly they evacuate the ones closest to the ravines. Closer. And it also depends on the direction, right? Because if it's only throwing material toward Yepocapa, only Yepocapa evacuates immediately. If it's only throwing material to this side, then those on this side. If it's throwing material toward Trinidad, then the people there.

However, this approach as described is not consistent with the fact that La Rochela, the closest community to the Ceniza channel, is not evacuated.

Lack of clear criteria and corresponding procedures as well as the importance of circumstances unrelated to the volcanic activity to evacuation occurrence is perhaps most clearly illustrated by the 10-11 December 2022 paroxysm. INSIVUMEH's first bulletin related to the eruption was time-stamped 19:00 with a warning of the potential for PDCs (BEFGO-118-2022); the next bulletin, at 22:05 announced the start of the eruption (BEFGO-119-2022); and the following two bulletins, at 23:15 pm and 00:05 that night, reported PDCs in Las Lajas and Ceniza channels, respectively (BEFGO-120-2022 and BEFGO-121-2022). Eruptive intensity remained high through the night and subsided around 08:00 the next morning (BEFGO-123-2022). No supported evacuation occurred, despite suggestions for evacuation in INSIVUMEH bulletins. Interviewees' simple explanation was that the eruption occurred at night. Though highly lethal, PDCs are largely silent (e.g., Loughlin et al., 2002) and may not be visible in dark or cloudy conditions. Despite observations and evacuations being more challenging at night, PDCs are no less dangerous. Subsequent analysis of PlanetScope visible and Landsat 8 and 9 thermal satellite images indicates the 10-11 December 2022 PDCs in the Ceniza channel reached even farther downslope than those of 7-8 March 2022 and 4 May 2023 (R. Escobar Wolf, pers. comm.); the longest PDCs in these other paroxysms occurred in the daytime and triggered evacuations (Figure 3).

3.4.3.3 Thresholds for community decisions

Input from authorities

While SE-CONRED promotes autoevacuación, or self-evacuation, in most cases, other than the small hamlet of Sangre de Cristo and the La Reunion resort, communities evacuate only with the recommendation of government authorities, most specifically SE-CONRED staff. An exception was a paroxysm on 13 September 2012, when several communities initiated evacuation before government recommendations or support, in response to the generation of large pyroclastic flows in the Ceniza and Trinidad channels.

However, not all communities choose to evacuate even when authorities recommend it. Community leaders expressed a range of views on how much weight to put on government guidance. Whether residents understand and use the content of the bulletins is unclear, but several interviewees described the bulletins as indications of the need to be on alert, like this community leader in Guadalupe:

> More than anything we had communication with CONRED because they're the ones who send the bulletin. A special bulletin that they send. So then you take into account that if it's a special bulletin it's because there's something dangerous.

Some community leaders described putting great importance on what authorities report to make decisions at the community level, like this leader describing SE-CONRED's recommendation to evacuate as an order–although he still describes each resident's decision as their own and based on their own judgment:

> It's something like this, when it's time to be evacuated, we wait for the order of the INSIVUMEH report for CONRED, and CONRED is the one that organizes the evacuation. So, by that means that they are going to evacuate people and move to Santa Lucía Cotz. But yes, it's a bit complicated, but here whoever leaves decides through the activity of the volcano. If it is very, very strong or with many dangers, then CONRED is the one that gives the order to evacuate.

Another community leader said they believed and distributed the government bulletins, but expressed strong distrust in the judgment of outsiders over their own:

> We've lived through three eruptions, unfortunately, we saw them from here, with sadness and much pain. And this has served us in living with the volcano. And to be paying attention to anything that might happen, independently of what others come to tell us. Because they come and tell us, "A new vent opened up, it's coming and filling up the ravines!" We know this isn't true. Because this has never happened. We do believe a little of what they say, but what we believe more is what we've seen.

Most community leaders described using official information as well as their own observations to make evacuation decisions at both the community and individual/household levels. This is exemplified by the leader of the Comunidad Indígena de La Trinidad describing the interplay between information and encouragement from authorities and residents' own assessments of activity:

> We met, we evaluated, and the situation, well, it was calm, there was no big explosion. So we said let's hold on for another while, but we already had the trucks coordinated. The trucks were already ready. So, [they're] not just for the cooperative. So just waiting for order, right? And indeed, that's how it was then, like 2:00 p.m., 3:00 p.m., something like that. And then the situation became more serious. So those from CONRED told me to make the right decision and that it was more difficult to work at night than during the day. But [considering] information from us seeing the volcano too, then we made an evaluation that it is better to evacuate people, self-evacuate. So it was.

Direct volcanic observations

Like authorities, residents steered away from describing specific criteria for evacuation and instead described signs of increasing volcanic activity that indicates an increasing risk of PDCs. Residents commonly described the occurrence and size of ashfall and larger tephra as concerning factors, as well as the sky going dark and obscuring their view of the volcano. Other factors

inducing fear and a feeling of urgency were the smell of sulfur, sonic waves rattling windows, ground shaking, and loud, continuous explosions. Members of COLREDs and COCODEs who had received training from SE-CONRED commonly shared examples of what they had learned about recognizing the different sounds from the volcano, as exemplified by this description from a participant in Guadalupe:

> We now know the sounds. This is the locomotive. This is the rumble of at least a storm. The sound of the plane. And we already have all that in mind. So, when it starts like a locomotive and doesn't calm down and is frequent, then that is where the decision is made, even if it's not visible, even if it is cloudy, but yes, this is increasing and the earth is vibrating. Well, what are we going to wait for, right?

Yet, this community has not evacuated since November 2018, and has not been recommended to by authorities. The following description, from another leader in the same community, is likely more apt:

> We've learned the sounds. Aside from the trainings they've given us, we've learned from the volcano itself. It booms pretty hard from the explosions. We know that the corrugated metal trembles. So that's what we hear normally, but when it thunders like a locomotive, this means that it has to be in the eruption phase. That puts us on alert.

Like this interviewee, most residents described these as signs to be on alert, stay close to home, and prepare for possible evacuation. This leader in Guadalupe described threatening volcanic activity during the 7-8 March 2022 eruption that kept them on alert but did not compel evacuation (and nor was one recommended by authorities):

> In March it came this way. And the black cloudiness. You could see it almost on the flanks. On the flanks of the volcano you could see the black that was coming down. So then we started putting ourselves on alert. But thanks to God it calmed down.

Descriptions of past evacuations indicate the volcanic activity had reached visibly high levels before evacuations have occurred, whether by recommendation from authorities or community-driven decisions, as exemplified by this resident's description of her community's decision to evacuate in November 2018, just five months after the devastating June eruption:

> They made the decision to evacuate because we were already scared by what happened in 2018. (...) on that date we saw that it was throwing in this direction and it was a lot! And you could see that it was all the way to here almost to the border of the village. Then the decision was made and it was coordinated with the COCODE. Then the people from the municipality were notified, they sent some buses and we left and those who had a car, well, they took their people out. Some went to shelters, others went with relatives.

As described in section 3.4.2.2, local authorities in the town of Panimaché I decided to wait an hour to make their evacuation decision during the 7-8 March 2022 paroxysm even after INSIVUMEH staff and residents observed what INSIVUMEH described in bulletins as "moderate to strong" and then "much larger" PDCs in a nearby channel and DPV staff recommended evacuation. Rather than following a set of criteria, local authorities wanted to see if

the volcano's activity would increase or decrease in that time–despite Fuego's history of waxing and waning in intensity multiple times in past paroxysms. While residents, including those receiving training through CONRED, may be able to describe the signs of intensifying volcanic activity and could describe at what point they would be 'on alert,' none could describe at what point they would decide to evacuate.

3.4.4 Competing and complicating factors

In-situ risk from PDCs is far from the only risk considered in evacuation decision-making, by both external authorities and at-risk populations. External authorities described conflicts in the decision to provide evacuation resources, as exemplified by DPV staff in section 3.4.2.2 expressing concern about mobilizing external resources that go unused. At-risk populations, particularly resource-poor populations (the vast majority of the population closest to Fuego), have much more at stake, both by staying put (potential loss of life) and by evacuating (e.g., potential loss of livelihoods). Residents described perceiving both environmental and human risks of evacuation that factored into evacuation decision-making for their communities, in the case of local authorities, and for themselves and their households, in the case of other residents. These factors in part explain both low community-level and low individual-level participation. They also indicate each community's needs for evacuation support–including decision-making protocols–is specific to their local geographical context. A summary of reasons interviewees shared for either encouraging or deterring or delaying evacuation is given in Table 5.

3.4.4.1 Environmental and socioeconomic risks

Environmental risks

Many additional factors deter residents around Fuego from evacuating even when transportation is available, including but not limited to the timing and conditions of that transportation. Residents consider the risks they may encounter en route to evacuation shelters along with the risks they may face by sheltering in place at home. Most of Fuego's evacuation routes cross one or more of its major channels and additional smaller drainages via fords, not bridges; if a lahar descends during an eruption, evacuation routes may be impassable until the lahar subsides. This is a problem in particular during the rainy season, from May through October. Leadership in the town of Guadalupe described their major concern about crossing these channels leading them to develop an alternative risk reduction strategy where instead of evacuating they plan to head for nearby high ground:

> *Resident 1:* We are going to a hill called La Cumbre, because if we leave for Escuintla there are channels. How many channels do we have? We have three channels. It's impossible to get out. It's looking for danger. It's better that we evacuate to the hill.
> *Resident 2:* Four channels. So we made the decision to not evacuate to Escuintla. It's a personal decision. The buses come. The municipal mayor sends the buses. Anyone who wants to evacuate to Escuintla can go to Escuintla. At least in my opinion, I am not going to Escuintla. I prefer to go to La Cumbre. Because I know it's a safe place.

A leader expressing similar concerns in Panimaché II described dangers associated with channels as a major deterrent to evacuating. Instead, they prioritized sheltering in place when the major threat is PDCs:

> We didn't rush out right away because it might be more dangerous to run away. Our people, who are from the countryside, a lot of times even an accident could happen to them with the vehicles. Or maybe a rapid descent of a pyroclastic flow in the ravine, which CONRED itself, INSIVUMEH itself, is telling us that it comes down at 200 kilometers per hour and here we are ten kilometers away. So if it's going 200 kilometers per hour, how do you know that we'll have time to get out? Because we're leaving right at the moment that the eruption is already happening.

The same leader described sheltering in place as the appropriate protective action for PDCs but evacuation as the appropriate protective action in response to heavy tephra fall, based on memories of their intense experience in the large eruptions in the 1960s and 1970s in which tephra fall caused widespread damage to structures and farming, resulting in the emigration of much of his community.

> Okay, so what we do is observe it, 'What is happening?' It gives us [signs], we understand, and we know that when it is in the channels, it is better not to approach the channels, it is better to go to high ground, but if it comes from above, then you have to withdraw, flee. At least until it passes.

This exemplifies the importance of experience on risk perception and decision-making; while experience can increase awareness of hazards, it can also result in prioritization of one hazard (in this case, the one directly experienced) over another, potentially more dangerous, one. The impacts of the large eruptions of the 1900s on intention to evacuate was addressed by Escobar Wolf (2013) and is being addressed in more detail by Naismith (in prep.). His approach to risk is an important example of the impact of experience on risk perception; in some cases, experience can increase risk perception (e.g., Andreastuti et al., 2016) but in other cases can lower it, either by leading us to believe future events are survivable or, as in this case, leading us to amplify risk of an experienced hazard at the expense of risk of another, potentially more deadly one. Despite educational campaigns from CONRED, residents may still have a poor understanding of the risk from PDCs in their location.

Table 5: Factors impacting community, household, and individual evacuation decisions

Factors that facilitate or encourage evacuation	Factors that delay or deter evacuation
The eruptive activity, and therefore hazard/risk, is perceived to be high	The eruptive activity, and therefore the hazard/risk, is perceived as low and/or decreasing
Presence of or close communication from officials	Lack of communication/guidance/presence from officials
Recommendation or order to evacuate	Lack of transportation or transportation that is perceived as unsafe
Transportation available	Nighttime
Daytime	Lack of a decision from local leadership to evacuate or a decision not to evacuate
Decision by and guidance from local leadership	Perceived risks en route (e.g., lahars in channels)
Concern for health and safety, especially of young children	Concern for property (looting, ash damage)
Knowing it is the last opportunity to evacuate (last bus)	Concern for livestock
	Concern about unsafe, uncomfortable, or insufficient shelter

Socioeconomic risks

Socioeconomic concerns also compete with volcanic risk in household and individual evacuation decisions, in particular concerns associated livelihood losses resulting from evacuation. Interviewees commonly cited looting, care of their livestock, and loss of work as primary concerns. These concerns result in delays in evacuation decisions and, like concerns about competing environmental hazards, alternative strategies to evacuating to shelters outside the hazard zones. For example, an elderly man in Guadalupe described his concern about looting, not lahars cutting off evacuation routes, as his reason to flee to the local high point:

> Because, you know, a lot of thieves. You leave the house locked. Then you return and there is nothing. They take everything. So we are going to go there, here at the edge of town, so as not to be all the way down there [in Escuintla].

This concern–as well as managing ash on roofs and taking care of livestock–has also led to tiered and partial evacuation strategies. In Panimaché I, Panimaché II, and Morelia, and likely other communities around the volcano, residents' expectation is that when an evacuation is called, women, children, and the elderly will evacuate first, as described by the leader of Panimaché II:

> We take in mind that women with their children have to carry bottles, diapers, and all the essentials, which is a large suitcase–it is better if they go ahead. Before it gets worse. While we, no, we have a flashlight in hand, we have the phone here, and that's how we hit the road running. Let's go. We don't carry anything.

The role of cultural gender norms in evacuations is discussed in detail in Bartel and Naismith (in press; also this dissertation, Chapter 4).

Government efforts to address the concern for looting during the 7-8 March 2022 evacuation were insufficient, according to the COCODE president of Panimaché I when asked about the police presence:

> Nah... they came here, but they only stayed for a while. (...) At around one in the morning they left. They came to take care of the town, but then they left. We were left taking care ourselves.

Similar to the ambiguity in answers about at what point in a paroxysm evacuations are necessary, residents were unable to articulate when they would know it is time for the residents remaining to protect their property to flee.

Known costs

Finally, even with safe transportation and ensured security of their homes, residents face hardships in evacuation. Though interviewees described improvements in evacuation centers over time, evacuation centers even at their most comfortable are in a different climate from home, quite literally: evacuees travel from their temperate, higher-elevation homes to lower, hotter regions. They are confined to public spaces in an urban environment, away from their domains. Cultural factors such as religious belief systems certainly factor into individual and group decisions, as mentioned in Chapter 4, with rumors that pastors in Panimaché I discouraged evacuation because it showed a lack of faith in God. However, belief systems interplay strongly with material factors and some of these expressions of fatalism are almost certainly a coping mechanism for what is inherently a difficult situation with no good options, as exemplified by this short quote from a woman in Guadalupe explaining why she did not evacuate with her community during the November 2018 paroxysm:

> Because there's the will of God, right? Yes. Because it's hard. It's hard to be in another place.

In these resource-limited communities, relying on the will of God may be an attractive option when evacuation presents a known hardship.

3.4.4.2 Community variations in place, personality, and power

As described in section 3.4.2, the onus for evacuation decision-making is at the community level. Although most communities cannot evacuate without government assistance, in current practice a community decision to evacuate may be required for the community to receive that assistance. The result is that households' and individuals' abilities to evacuate may well depend on a decision at the community level, which, as described in section 3.4.2.1, at best is made democratically by a community-wide vote and at worst may be made by civic groups or even individual authorities. A judgment by local authorities that evacuation is not necessary, or to wait to reassess, thus may deny willing residents the opportunity to evacuate, especially early in the paroxysm when the pace may be calmer and they may perceive travel as safer. This can be exemplified by the case of Panimaché II during the 7-8 March 2022 paroxysm.

Initially, local leadership deemed evacuation unnecessary the afternoon of the 7-8 March 2022 paroxysm, based on their assessment that the risk to the residents was higher evacuating than it was staying (see section 3.4.4.1.1). The same leader described the activity then decreasing and the community thus deciding to stay. Importantly, several interviewees complained that the leader was away from the community and out of communication during the day, when they perceived the activity to be the strongest. The leader described agreeing to evacuation at night, only once CONRED and transportation had arrived unsolicited:

> It wasn't strong anymore. So every hour we were considering whether it was getting worse or dwindling. And the ash fall. We saw that it was calming down. So people decided it was better to stay. But then it turned out that after that CONRED and a group of United Firefighters came and offered to help. So, we approved them to come. And we evacuated.

Once transportation was available, 57 people, mostly women with children, chose to evacuate. Multiple interviewees who did not evacuate said they would have evacuated if transportation had been available earlier, when they perceived the eruption as stronger and the travel conditions as safer (Bartel and Naismith, in press; this dissertation, Chapter 4). At least one of them did evacuate during the subsequent May 2023 paroxysm when transportation was available earlier in the eruption; among her motivations to evacuate, she described the activity as stronger than in March 2022 and the evacuation as faster, with the authorities coming with transportation more quickly and during the daytime.

Variation between communities in their approach to the threat of PDCs is exemplified by descriptions of decision-making processes as provided by leadership in the communities of Guadalupe and Comunidad Indígena de la Trinidad (hereafter La Trinidad). The leader of Guadalupe's COLRED described a conversation she had with the community's COCODE president when he came on the afternoon of 7 March to ask her whether she thought they should sound an alarm; she cautioned against alarming people, seeing more risk in the fear itself than in the volcano's activity:

> The president of the COCODE, we talked to each other around 3:00 p.m. He came to me and said, This is ugly. Yes, I am watching, I told him. What do you think? he asked. Should we sound the alarm? I think that maybe it's not good to alarm people, I told him. Because you are going to tell them, look, it's ugly, no, no, better go out with your megaphone and tell them to (...) get ready because we might have to leave for Escuintla or elsewhere. (...) But don't tell them, Hey look, it's [] already going hazy, because a heart attack is going to kill people, I told him. There are people who can't handle it, I tell him. So, 'Okay, that's fine.' And he left.

At that same time, their neighbors in the next town over began to mobilize. An authority in La Trinidad described being on alert since the morning, first calling a meeting at 06:30 with community leadership through their internally defined system (the COCODE and COLRED of the community as it existed before the 3 June 2018 eruption operates in the city of Escuintla, where much of the original community relocated with government support). The group of

representatives decided to reconvene at noon unless there was a significant change in the volcano's activity before then. They advised residents to stay home from the fields to keep their families together in case evacuation was necessary. With the intensification of activity in the early afternoon and advice from municipal COMRED staff to evacuate while there was still daylight, La Trinidad's leadership decided to evacuate, as described by the community's leader:

> In the 1:00 [pm] bulletin, for example, 1:30 I think it was, the bulletin says that the volcano tended to increase its activity. So when it says this, that is, orange turns red. And, the afternoon is coming. So, it is not the same to move people at night, and if we have daylight it is more practical. So we decided that it was better to move people, and that is why we began to organize, and it took us to 8:00 at night, starting at 3:00. Of course, calmly. It's not an emergency that means everyone runs, but, as I told you, people still [can] carry something to leave. Because in an emergency, believe me, I think we just pull the door and leave. So that is what we have taken into account.

While leadership in Guadalupe was concerned about alarming residents, and separately discussed a plan to go to higher ground locally rather than evacuating, because of the exposure to the hazard from channels on the evacuation route, La Trinidad leadership was coordinating evacuation and described earlier, proactive evacuation as a preferred approach to decrease the risk of problems en route, including the crossing of the channels early on before they would expose transiting population to higher risk. The contrast between the two communities' approach to evacuation between Guadalupe and La Trinidad is likely due to multiple factors, including community organization and risk perception. However, the most important difference is most likely the difference in resources available to each community: Guadalupe, like most other communities around Fuego, has no internal shared transportation resources (although leaders did describe they had identified private vehicle owners willing to assist in the case of an evacuation) and no designated evacuation shelter space. La Trinidad, by contrast, is organized around a coffee production cooperative with large vehicles that they used for the evacuation and many, if not all, families still have their Family Unit Transition Shelters (*Albergues de Transicion Unifamiliar*, ATUs) in Escuintla from their long evacuation following the 3 June 2018 eruption. While interviewees described the ATUs as now unmaintained and uncomfortable, and they do not receive government assistance as provided in the government-run shelters, the space is their own. These factors played not only into La Trinidad leadership's decision to evacuate their community and in other residents' decisions to evacuation their households, but in COMRED staff's decision to advise them to do so; one interviewee from Escuintla's COMRED shared that he had told La Trinidad leadership, the afternoon of the paroxysm, "You have transportation, you have somewhere to go, evacuate!"

3.5 Implications for risk reduction

Because of the short timescales of paroxysms (Lyons et al., 2010; Escobar Wolf, 2013; Naismith et al., 2029), decision-making processes for evacuation must be efficient. However, multiple factors limit the efficiency of these processes currently, resulting in later and longer evacuations than would be needed to avoid a disaster similar to the destruction of San Miguel Los Lotes with a similarly short intensification timeline (Figure 4).

3.5.1 Restructure the decision-making system

While some scholars argue for self-sufficiency of at-risk communities as the ideal (e.g., Villagrán de León, 2011), this is not realistic for populations that must evacuate but don't have the resources to do so. Populations in resource-scarce environments require external resources to support effective protective action and the level of engagement from government in early warning systems must take these capabilities into account (Baudoin et al., 2016). In that context at Fuego, residents should not be expected to make community-level decisions about evacuation that then determine the provision of external resources. Interviews indicate that local authorities may underestimate the risk posed by PDCs to their communities, potentially limiting residents' ability to take appropriate action. Instead, INSIVUMEH and CONRED should use their expertise and material resources to fulfill their mandates of monitoring and assessing environmental hazards, including volcanic hazards, and assessing and coordinating the response to subsequent risk, respectively.

3.5.1.1 Proactive provision of resources

Evacuations are delayed by these structures and also by stakeholders' aversion to take on costs and risks associated with evacuation. While CONRED interviewees complained of transportation being underused on more than one occasion, it is an essential expenditure as most residents living in the communities close to Fuego cannot evacuate without it. Evidence presented here indicates that having timely transportation available encourages evacuation. In the current system, if resources are not mobilized until community leaders communicate their decision to evacuate, at best transportation is delayed and at worst residents who want to evacuate do not have the opportunity to if their leadership has declined support. Authorities could have cut three hours off the 7-8 March 2022 timeline in Figure 4 by having a predetermined number of buses staged and ready to go at first notice of reaching a threshold of activity (e.g., the first sighting of "large PDCs"); buses would then have first arrived around one hour after the large PDCs, rather than four. By staging buses in the communities in case activity escalated to meet a threshold, buses would have been there already, saving potentially three or more hours and enabling residents to begin evacuating immediately. The current decision-making process as described by interviewees and an alternative, more efficient decision-making process that eliminates the need for a community-level decision to request resources are shown in Figure 6.

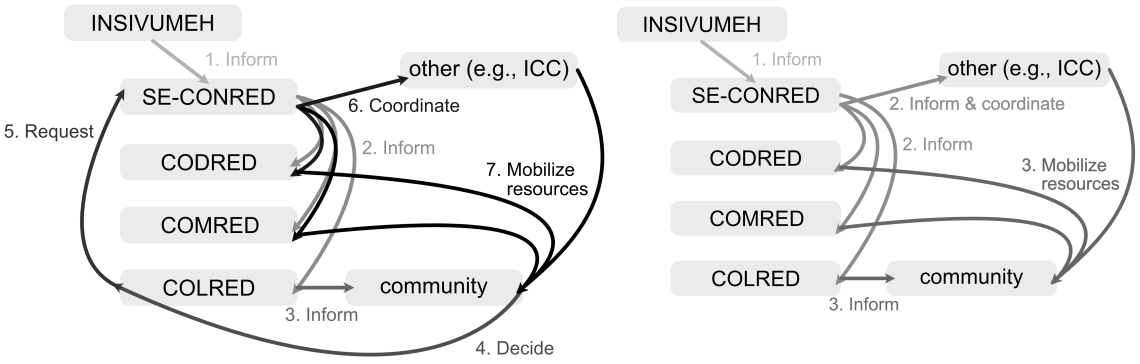

Figure 6: The decision-making process in current practices, as described by interviewees (left) and the decision-making process as it could occur by eliminated the need for a community-level decision to request transportation resources.

Furthermore, relying on the charitable contribution of the sugar cane industry may limit what transportation options can be provided to the population. Providing government-owned transportation or even securing government funding for private transportation may be an alternative (or complementary) solution to the problem, and allow the flexibility to provide adequate and early enough transportation options for potential evacuees. An argument can be made that even if such a resource is spent and not fully used during a crisis, the potential cost associated with it is far outweighed by the potential gain in risk reduction, through encouraging a larger number of evacuees and an earlier departure from the hazard exposed areas. For instance, the current cost for a round trip from Panimaché I to Santa Lucia Cotzumalguapa (the usual evacuation location) is around 20 quetzales per person (roughly $2.50 USD at the time of this writing). If a similar cost could be subsidized by the state to provide enough transportation early in the crisis, even if part of that resource isn't used, the investment per capita and per crisis seems rather modest–particularly considering the potentially disproportionate gain if such a modest per capita resource investment results in lives saved.

3.5.2 Define clear thresholds

Fuego volcano poses particular challenges to setting criteria at which to evacuate but also provides opportunities. It has frequent paroxysms (Lyons et al., 2010; Escobar Wolf, 2013; Naismith et al., 2019), a relatively large population spanning multiple political jurisdictions (Escobar Wolf, 2013), and an often sparse monitoring network. Depending on the thresholds for evacuation, the frequent paroxysms could result in high material costs to governments and also potentially evacuation fatigue for residents, lowering participation–which is already low. However, some of the same characteristics that challenge evacuations at Fuego provide opportunities in setting criteria and in encouraging evacuation. For example, while the 3 June 2018 evacuation lasted months for some residents, most paroxysms, as noted, are short (24-48 hours), which means evacuations are likely to last only one to several nights. The maximum number of paroxysms in one year since June 2018 is three. Compared with many other volcanic crises, this is a short duration evacuation, although a point could be made that for periods of extended heightened activity and frequent paroxysms (e.g. the. 2015 to 2018 period) a long-term evacuation should be the strategy to follow.

Paroxysms at Fuego since 1999 largely follow a pattern, even if the exact magnitude and duration of activity is uncertain. As described by Lyons et al. (2010) and Naismith et al. (2019), paroxysms generally start with effusion of short (<500 m) lava flows with an increase of explosive activity at the summit, followed by a more explosive phase producing a sustained eruptive column, continuous explosions, and occasional pyroclastic flows, then finishing with a decrease in eruptive energy and explosive activity. The entire paroxysm cycle typically lasts between 24 to 48 hours. INSIVUMEH has ample experience with these patterns and despite fluctuating monitoring capabilities, usually recognizes when activity shifts from background levels to abnormal, paroxysm-type activity, and publishes bulletins on the paroxysms initiation before large PDCs start to occur.

However, PDCs extending down Fuego's flanks do not occur during every paroxysm (Figure 3). Given the current lack of good criteria to predict if such PDCs will be produced during a paroxysm, before such PDCs are actually observed, such a criterion would currently be equivalent to evacuating at the beginning of each paroxysm. The viability of such an approach is something that may be seen as difficult by current authorities and decision makers, including the local population–especially in a period of paroxysms as frequent as occurred from 2015-2017–but it is a discussion that should at least happen.

Conversely, studying the characteristics and evolution of paroxysms in more detail, using the relatively better quality of observations and wealth of data for paroxysms since the 2018 disaster, may lead to establish potential criteria to forecast in real time, within acceptable levels of uncertainty, whether pyroclastic flows are more or less likely to happen for specific paroxysms, before such flows are observed, based on the analysis of observations and monitoring data. This could lead to deciding on evacuations during paroxysms before PDCs are observed, but without having to evacuate for each paroxysm. However, evacuation strategies must be developed using the information available, and until forecasting methods are improved, the evacuation strategy must be based around the current system capabilities and levels of uncertainty.

Developing decision-making tools such as community-specific thresholds for evacuation will be crucial in this process. Although every paroxysm is different, paroxysms in the current eruptive period, as described above, follow general anticipatable patterns within their 24-48 hr duration. Predetermining thresholds for evacuation based on these patterns would increase transparency, decrease uncertainty in the process, and result in quicker mobilization of resources. Rather than training residents to assess risk for their own decision-making, CONRED can focus on conveying or, better yet, developing specific criteria for taking protective actions with each community based on their specific geographical setting. Such criteria may range from general and very basic knowledge of what PDCs are, how to recognize them, and what to do when it becomes apparent that larger and potentially lethal ones are being generated, before such lethal PDCs may be heading towards people, to more elaborate criteria or guidelines for deciding when a community should evacuate. In the first extreme of the spectrum we would find information that could for instance have been useful to save the lives of people looking at PDCs on the Las Lajas bridge on 3 June 2018, including a CONRED officer and firefighters, e.g., learn to recognize what a PDCs looks like and know that if you are close to a channel in which a PDCs is moving towards you

you should immediately get as far and as fast from that channel as possible, even if the PDC is still hundreds of meters (or even more) away from you.

On the other end of the spectrum, regarding criteria or guidelines for evacuation of communities, one could establish under what conditions of activity such an action should take place, from perhaps a more risk averse or conservative perspective, e.g., evacuate all the communities inside a mapped hazard zone as soon as a paroxysm begins, to less risk averse options, like deciding to evacuate communities near specific channels once a PDC of a given size or length has been observed in that channel, a criteria that seems to be closer to recent evacuation practices.

This is also tied to the improvement in the speed or agility of evacuations. The most effective way to move the timeline of evacuation earlier is to agree on more conservative criteria, e.g., the first recognition of the paroxysm or recognition of the next intensification of activity. On 7 March 2022, the second special bulletin produced by INSIVUMEH described at 09:10 the continuous increase in the seismic energy, lava fountaining, a small ash plume, and continuous avalanching of hot material down the Ceniza and Trinidad channels. CONRED staff mobilized around the volcano around the same time. Mobilizing resources at this time rather than observation of the first PDCs–which were described as moderate to large, followed within 30 minutes by even larger PDCs–would have mobilized resources 4 hours before the occurrence of the PDCs, still a short time window given the evacuation process took over 7 hours from deployment of the first bus (~4 pm) to departure of the last bus (~11:20 pm).

3.5.3 Improve information flow

Beyond the general consideration INSIVUMEH and CONRED could increase their personnel dedicated to volcanic risk related tasks, e.g., hire more observers and open more observatories around the volcano, there may also be perhaps smaller actions that are easier to implement in the short run that could still have significant impacts. For instance, one may consider regular INSIVUMEH participation in the radio rounds, or direct access in real time to the CONRED communications database, to increase direct access to the observations available through this network, which would significantly augment their single point of human observation on the west side of the volcano. Increasing the number of cameras may also help in this regard, as well as guaranteeing that they are maintained and kept running. This also applies to all other instrumentation. The particular benefit of participation in radio rounds, as well as in-person outreach activities, is the opportunity to build trust and familiarity between the scientists and residents in each of the communities; currently INSIVUMEH only has this personal investment in communities on the west side of the volcano because of the location of their observatory in Panimaché I. This trust is crucial for effective warning and can be built through direct communication with at-risk populations (e.g., (Haynes et al., 2008; Stone et al., 2014; Mothes et al., 2015; Andreastuti et al., 2016).

Clear thresholds would also clarify messaging. Currently, as described in section 3.2.1, guidance provided in both INSIVUMEH bulletins and CONRED avisos is very general; residents go directly to sources such as the INSIVUMEH observers for information if they have the ability to do so. Messages from agencies should be more specific regardless of whether thresholds are

developed and agreed upon and should be tailored to this specific hazard context as opposed to relying on multihazard messaging that may recommend risk-inducing rather than risk-reducing protective action. A broad body of research on warnings points to the need for warnings to address key questions that at-risk recipients will have, including whether and how the threat pertains to them, what action they need to take to reduce that threat, and how to take that action; that is, messaging needs to be specific and comprehensive enough to be actionable (e.g., (Mileti and Sorensen, 1990; Wood et al., 2012; Bean et al., 2015). Message specificity is particularly needed for PDC hazards (potential occurrence and impacts, for what areas, etc., and from all that, the need to evacuate), as in recent cases most of the information content in crisis communication has just focused on ash fall, a much less lethal hazard. Residents around Fuego need to know whether their community should evacuate, where they should go, and how they can get there–all questions that various interviewees shared had gone unanswered in at least one past evacuation.

3.5.4 Define concrete goals and the measure of success for the EWS

Fearnley (2019) recommends defining success in the design of an early warning system, which is crucial for the important step of evaluating the system after each time it is enacted (e.g., Leonard et al., 2008). Authorities working at Fuego expressed concern about evacuation fatigue, expressed as 'never cry wolf syndrome,' wherein at-risk populations lose trust in and stop listening to authorities if evacuations are deemed unnecessary. Research on the impact of 'false alarms' (evacuations from areas that were not heavily impacted by the warned-of hazard) on future evacuations yields conflicting results (Thompson et al., 2017). Examples of 'false alarms' at other volcanoes include the case of La Grande Soufrière, Guadeloupe, in 1976, where a costly and disruptive evacuation heavily impacted government and residents alike with no ensuing paroxysmal eruption (Fiske, 1984) and Tungurahua volcano, Ecuador, where the national government mandated and enforced a months-long evacuation with similarly no paroxysmal eruption; the population of the town of Baños forced their way back into their community and agreed to live there at their own risk (Armijos et al., 2017). The social, health, and economic costs suffered by residents (Tobin and Whiteford, 2000, 2002, 2004; Lane et al., 2003) resulted in widespread distrust of the government and resistance to future evacuation. However, each situation is complex and we must consider multiple factors. It is possible that with better evacuation management, evacuated residents would have suffered less and maintained greater trust in the government. Also, authorities could not know with foresight in either of these cases that the volcanic unrest would not culminate in destructive paroxysms; if they had, residents and governments alike would presumably have seen the evacuations as warranted. Only with a better understanding of the volcanoes gained over time could scientists produce higher-confidence forecasts and recommendations (Mothes et al., 2015; Armijos et al., 2017). An example of the opposite situation, although not related to a volcanic crisis but to earthquake activity, was the tragic case of the L'Aquila earthquake in 2009, in which scientist and civil defense implied to or assured the population that taking protective actions (like sleeping outside of their houses) was not necessary, which was then followed by a destructive earthquake, resulting in hundreds of fatalities and the criminal prosecution of civil defense officials and scientists (Bretton et al., 2015).

Part of the aversion to evacuation has to do with the hardships faced. Eliminating these hardships completely is impossible, but minimizing them to reasonable levels should not bet, for instance through work to build and maintain trust in the authorities, build confidence in the EWS, and improve the evacuation experience may decrease the effect of evacuation fatigue and increase willingness to repeat evacuation procedures up to several times per year. Thus, success in applying the EWS, i.e., evacuating, should be clearly defined for–and ideally with–all key stakeholders, including residents. Authorities should focus on defining and achieving successes (e.g., evacuation of a predetermined percentage of the population recommended for evacuation by a predetermined metric such as a time window) rather than avoiding or worrying about 'false alarms.'

3.5.5 Co-create updated evacuation strategies

3.5.5.1 Assess competing risks

Concern about competing factors drives the at-risk populations around Fuego to adopt alternative strategies to evacuating to areas away from the volcano and their homes. These strategies include evacuating the most vulnerable population while others stay back to protect property and planning to flee to high ground rather than traverse what they perceive to be high-risk evacuation routes. These strategies should be assessed based on expert understanding of PDC hazards and discussed with each community to re-evaluate strategies along with thresholds for taking protective action.

Where a tiered evacuation strategy was described, interviewees said that a contingent of people would stay behind and flee in case of emergency. When asked to describe how they would flee, interviewees said they would leave in the remaining vehicles, such as pick-up trucks, or head to high ground. Like Guadalupe, several other communities have identified nearby high points that they described as safe that they plan to flee to in an emergency. In the cases of Panimaché I and Panimaché II, their high points are a 30 minute or longer walk from the villages. Guadalupe's high point is a 15-minute walk but also accessible by motorcycle, car, truck, or bus. Interviewees in all cases were unable to describe what conditions would prompt them to flee to these high points. Of concern is the fact that they plan to flee in an "emergency," which is presumably worse activity than what they have experienced since they have not taken this option before, and they anticipate being able to arrive before danger reaches them.

Higher points may be less exposed to PDCs relative to the communities, but may still be significantly exposed to large PDCs, and it's possible that communities are underestimating that risk, as large PDCs could still reach those locations. Even if the high points were less exposed and offered a last resort option to avoid the PDCs, it is also concerning that those staying behind may not be quick enough, or realize early enough that PDCs will reach them. Tragic examples of people trying but failing to outrun the PDCs on the Las Lajas bridge during the 3 June 2018 eruption, some on foot but even some in vehicles, have been recorded on video and illustrate this concern. Similarly tragic stories can be found in San Miguel Los Lotes, on the same day. The high speed of the flows, potentially reaching tens of meters per second, coupled with the non-obvious and non-intuitive trajectories or paths that they may take, could lead to disastrous

consequences for those left behind even as they try to escape the flows in a last-second effort to save their lives. Videos from the Las Lajas bridge on 3 June 2018 show how people on the bridge initially retreated from the immediate channel and the bridge, as the PDCs start to overtake the bridge, but linger around the road within ~100 m from the bridge, probably expecting that area to be relatively safe (which is a reasonable expectation to a certain point), but were caught off guard when a much larger PDC wave overtook the wider channel, including forested areas extending some 100 m from the narrower active Las Lajas channel. People may have expected the PDCs to remain constrained within that active channel, as many lahars that some could have witnessed during the previous 19 years, had been; and even the occurrence of a smaller PDC that barely reached the bridge and effectively remained confined to the active channel, in the previous half hour or so, may have given the false impression and false sense of safety, that PDCs would remain constrained. Such miscalculations are possible and perhaps even likely if people consider outrunning the PDCs at the last moment. This mismatch between the perceived capabilities of residents and characteristics of PDCs is similar to what eyewitnesses who survived an eruption of Montserrat described, following the descent of PDCs in which 19 people died within the exclusion zone; survivors described confidence in their abilities to sense and evade PDCs, whereas the PDCs took residents by surprise (Loughlin et al., 2002).

An additional consideration regarding the high points that communities may use as a last-resort (relatively) safe location to escape to, to avoid exposure to PDCs, is that none of these locations have shelters, so moving there implies being exposed to the elements. If this happened at night and with rain and ash fall, it is possible that the decision to evacuate there instead of remaining in their homes may become even less likely, given the harsh conditions people would have to endure there, exposing those left behind even more. Also to note, one interviewee in Panimaché I described how her husband and son lost their way when working in the fields on the slopes of the volcano during a past eruption because of low visibility induced by heavy ash fall; flashlights may not be effective in illuminating surrounding through air laden with ash. Summing up all these factors, it could mean that for those staying behind, survival will likely depend on luck more than on strategy, as it did in San Miguel Los Lotes (this dissertation, Chapter 2).

Also, promoting early evacuation could help address concerns about lahars and about evacuating at night, depending on the time of day–given the paroxysm is recognized in the daytime and early enough that lahar-triggering rains have not started, if during the rainy season.

3.5.5.2 Address competing risks

The emphasis on self-evacuation implies that communities have the capacities to both decide on and enact an evacuation; however, as described, they lack the expert judgment presumably provided by the government as well as the resources needed to evacuate effectively. The only populations at Fuego able to self-evacuate logistically are the businesses and a few communities which have the resources to do so. Private enterprises like the La Reunión resort and the Candelaria plantation have transportation resources and are not responsible for shelter (people are there temporarily and either live somewhere else or can go to a different lodging accommodation). Very few communities, like La Trinidad, have their own transportation and the government shelters in Escuintla left over from the June 2018 evacuation. Notably, these are the

only populations that evacuated on the east side of the volcano in March 2022. The small hamlet of Sangre de Cristo also used to have such an independent evacuation-shelter strategy, but the shelter is not in use anymore and their strategy for the recent crisis is not known; interviewees reported that there are very few residents remaining in Sangre de Cristo and that they spend only the day there, retreating farther from the volcano at night. A close analogy to La Trinidad and Sangre de Cristo–but not to most other communities around Fuego–is the communities around Tungurahua volcano, Ecuador, lauded for their local empowerment and self-evacuation practices (Stone et al., 2014; Mothes et al., 2015; Armijos et al., 2017). These communities at Tungurahua live similarly with the threat of PDCs but have government-built houses in communities outside the hazard zones that they retreat to as needed (Armijos, 2017). Aside from having much less exposed population than Fuego (an order of magnitude less by some estimates), it is not clear how transportation works for those communities that evacuate at Tungurahua. It is also important to note that some may have also considered Fuego also an exemplary case of risk management (e.g., the government-subsidized shelter and self-evacuations capacity by Sangre de Cristo, the local network of COLREDs and radio bases, etc.) prior to 3 June 2018, when the true capabilities of the system to avoid disaster were tested, to both tragic (in the case of San Miguel Los Lotes) and successful (in the case of La Reunión) outcomes.

The promotion of self-evacuation and also that all residents maintain or ready "72-hour backpacks" with enough provisions to last them three days, as described in Chapter 4, may send the message that people can't rely on the government for support and won't be provided for in the evacuation centers. Short of being able to provide off site housing for each family, the government should be able to provide safe and comfortable shelter conditions. CONRED is beholden to follow internationally recognized Sphere guidelines for evacuations centers (Sphere Project, 2018) and, as noted, interviewees described improved conditions from their first evacuation experiences. Efforts should continue to this effect. Rather than promoting self-sufficiency, messaging for these resource-scarce populations around Fuego should instead be addressing residents' concerns about evacuation such as looting, availability of transportation, and conditions of evacuation centers that lead them to develop alternative evacuation strategies where only part of the population evacuates, or to not evacuate at all.

3.5.5.3 Build upon existing efforts

The high levels of activity since 1999, including frequent paroxysms and the generation of large PDCs had put Fuego volcano high on the priority list of risk reduction efforts for CONRED, even before the tragic events of 3 June 2018. Such efforts included specific projects (e.g. PREVOL (Sánchez del Valle, 2002), BOSAI (JICA, 2012)) aimed to build relationship and communication networks with key stakeholders. Despite the tragic outcome of the 2018 eruption, and the system failure that this represents, in terms of early warnings and disaster risk reduction efforts, government agencies like CONRED and INSIVUMEH continue to work, hopefully with even more urgency and recognizing the uttermost importance of the disaster risk reduction needs at Fuego, in light of the events from 2018. Such efforts will hopefully build upon and expand the existing cooperation between municipal governments as well as with private institutions such as the ICC, as well as, crucially, the many communities and major businesses around the volcano. Relationships vary and require maintenance; even so, with these challenges, some important

progress has been made, e.g., most communities have active COLREDs and functioning radio bases. Despite inconsistencies between when people have evacuated and the level of hazard and risk that different recent crises have involved (e.g., the lack of evacuations for the 10-11 December 2022 crisis, which resulted in the longest PDCs runout since the 3 June 2018 eruption), there have been some significant evacuations, and some of the conditions in which they happen seem to show improvements compared with previous evacuations. The 4 May 2023 evacuation saw roughly twice as many people evacuating as the 7-8 March 2022 evacuation, and included two more towns on the southwest side of Fuego volcano. The road ahead is very long and there is much room for improvement, but if the modest signs of improvement in the recent crisis represent a trend, there seems to be good reasons to be optimistic for the future.

Despite efforts to promote autoevacuación, this study shows a government recommendation to evacuate is nearly essential before a community will evacuate–not least because they don't have the resources to do so–and even with this recommendation some communities will not evacuate. What's more, community leaders and other residents commonly lack the understanding of volcanic hazards that should be the domain of specialized technical/scientific agencies and authorities, especially INSIVUMEH. Because of the varied terrain and transportation infrastructure around Fuego, each community faces different susceptibilities to PDCs and challenges to evacuation. This, plus varied understandings of risk, has led to communities developing their own approaches to evacuation that may be misinformed or misaligned with official approaches, and could result in a significant underestimation of the actual risk that PDCs may reach them. Because of these variabilities and the crucial role of trust in responding to warnings (e.g., Haynes et al., 2008), co-creation of evacuation strategies in each community by collaboration between scientists, civil protection, and residents may produce strategies that are better understood and trusted (and therefore followed) by residents, and better supported by authorities (Cronin et al., 2004).

3.6 Discussion

As described by Kelman and Glantz (2014), EWS efforts and descriptions began with a focus on a top-down approach with experts and the infrastructure needed to forecast or detect threats such as PDCs, consistent with the 'dominant approach' that disaster risk reduction problems are best solved by engineering a technical solution focused on the hazard itself. Understanding the risk and then detecting or forecasting the hazard in an EWS has come to be referred to as the "first mile" (Kelman and Glantz, 2014; Fearnley, 2019). For several decades, researchers and practitioners have shifted focus increasingly to the importance of the "last mile," the generation and distribution of warnings and the response they motivate, acknowledging the importance of social factors in the success of an EWS. Studies related to the first mile have historically been focused on the physical science and engineering of improving the technical functionality of that part of the system, while research on the last mile is driven by social science fields such as psychology and sociology and pertains to topics such as risk perception, vulnerability, resilience, and capacity and communication (Fearnley, 2019). The research presented here supports Fearnley's (2019) recommendation that more effort be put toward understanding the "first mile," including "how scientists understand volcanoes, how they manage the associated uncertainties

and risks, and how they attempt to manage them both theoretically and practically" (p.9). I argue that this effort should broaden to include civil protection and the relationships between these actors, especially regarding decision-making for issuing warnings, and most importantly, regarding the recommendation to evacuate. As the research presented in this and the previous chapter demonstrates, relationships between stakeholders at both institutional and personal levels, institutional responsibilities, resource allocation, and personal views on relative risks all impact the decisions about whether, when, and where to issue warnings. These same questions that face scrutiny in the 'last mile,' pertaining to at-risk populations, should be examined within the 'first mile' as well.

Models of EWS have shifted from assuming a government-heavy, top-down approach (e.g., Mileti and Sorensen, 1990) to promoting a more localized, grass-roots approach, where in the extreme case the at-risk population holds and controls the capabilities to fully manage their own EWS (Baudoin et al., 2016). Appropriate levels of involvement from government versus local actors depend on the capacities and environment of the at-risk population (Baudoin et al., 2016). In response to the 2004 Boxing Day tsunami, the United Nations governance has taken on the goal of global, multihazard EWS coverage, promoting standardization while also promoting development of 'people-centered early warning systems' (Basher, 2006), in which the system is designed around these capabilities in the local context. While United Nations descriptions of the people-centered EWS acknowledge the importance of the linkages between the four components, these linkages, as pointed out by Fearnley (2019), are not depicted in the model. Garcia and Fearnley (2012) find weaknesses in these linkages are often what cause EWS to fail.

As evident from the case of evacuation processes at Fuego volcano, decision-making for issuing warnings, particularly the call for evacuations, is a crucial component that cannot be glossed over: who makes them and how, as well as through what processes and considering which factors, are critical questions to address in any EWS (Garcia and Fearnley, 2012). While present in earlier EWS models (see Mileti and Sorensen, 1990; Foster, 1980; White and Haas, 1975; and Twiig, 2004) and indicated in Leonard et al.'s (2008) depiction of components of an effective EWS for volcanic risk mitigation, decision-making, and most importantly the decision to evacuate, is not explicitly included in the people-centered EWS, despite its importance and complexity. Presumably this decision-making process is encompassed in the "Detection, observations, monitoring, analysis, and forecasting of hazards" pillar as shown in recent UN documentation (Egerton et al., 2022), though it is unclear. Decision-making, particularly regarding evacuations, should be given the same prominence as each of the components named in that pillar, as it is as if not more important than each, as it describes the use of each of those components.

EWS models tend to present the component representing response to warnings as describing behavior of only the at-risk populations (e.g., "public response," as shown in C. Schlosser's diagram published in Twigg (2004) and reproduced in Fearnley (2019)) and only in response to communication of warnings, without considering the potentially essential role of government or other external actors in the response as well, e.g., mobilizing the resources necessary for appropriate risk-reducing actions. Behavior depends not only on psychological and sociological factors but quite basically also on the material resources available and logistic capacity to take protective action. This applies not only to subsets of a population with limitations in their access

and abilities but to majorities or even entire populations that lack access to resources such as transportation, as is the case for many rural residents around Fuego volcano.

This need for resources calls into question the ideal of a self-sufficient at-risk population that can independently manage its own EWS. This ideal is presented along with ideas of 'empowerment' (Baudoin et al., 2016) and with suggestions that communities either already have the resources needed to reduce their risk (e.g., Kelman and Mather, 2008; Baudoin et al., 2016) or that this capacity can be built through education or collaborative strategy-building (e.g., Baudoin et al., 2016). While I do not deny that this self-sufficiency is the ideal solution, and perhaps the best solution in some real cases, especially as it eliminates the need to rely on potentially weak government systems as noted by Villagrán de León (2011), this EWS ideal is only possible where a population's existing internal material resources meet the resource requirements for appreciate protective action; that is to say, where either the population is resource rich or the appropriate risk-reducing action requires scant resources. Unfortunately, this is not the case in general or in most cases at Fuego volcano, where the vast majority of the at-risk population lives in scarcity of the resources needed for evacuation, most importantly transportation but also shelter and sustenance for the duration of evacuation, at a bare minimum.

Perhaps most importantly, EWS models fail to forefront competing risks. While there is extensive research on what prohibits people from taking protective action, e.g., evacuating, models do not acknowledge the importance of considering these competing risks and costs in the design of the system. Instead, these risks are considered to be ancillary factors. The assumption is that the threat the system is designed around is the most important threat for people to consider, whereas other factors may also be very valid and pressing. Understanding these competing factors should be foundational to the design of the system and designers should consider, account for, and communicate about the risks and costs associated with protective action. For example, residents in rural communities at Fuego volcano may be more willing to participate in evacuations if evacuation shelters are comfortable and this is communicated and understood, ideally long before the crisis happens, to inform their decision-making during the crisis.

In summary, the case of Fuego volcano highlights several potential shortcomings in general EWS models and demonstrates the need for particular attention to factors that can likely not be addressed in a standardized, multi-hazard warning system (in addition to factors already identified by, e.g., Baudoin et al. (2016) and Fearnley (2019)). EWS models should explicitly include understanding and accounting for locally relevant competing risks and costs associated with protective action, and mitigate such competing factors if an effective evacuation is the end goal. This includes the decision-making process for issuing warnings and this process' social, political, and economic drivers, as well as resource allocation to enable at-risk populations to take appropriate protective action. As discussed in Chapter 2, the decision-making processes for issuing warnings must be designed within the limitations of the scientific, technological, economic, and socio-political context in which the EWS operates. Specifically, thresholds for issuing warnings must consider the current understanding of risk as well as detection, communication, and response capabilities and timelines. Matching decision-making processes to context may seem obvious but is complex, especially when the result is costly for all involved.

However, the cost of many successful, safe evacuations that are deemed in hindsight as 'unnecessary' may in the long run far outweigh the cost of one failure to evacuate.

3.7 Conclusions

Current evacuation practices and behavior do not meet the criteria of an EWS that would avert another disaster with characteristics (potential areas exposed, hazard evolution, time scales, etc.) similar to those of the June 2018 paroxysm. The apparent lack of correlation between a community's risk exposure and whether authorities recommend evacuation suggests communities at risk may be overlooked, reminiscent of the case of San Miguel Los Lotes in 2018 where it was a community that was not in the forefront of volcanologists, civil defense officials, and even local population's awareness of risk exposure that ended up being the most impacted by the lethal PDCs. The relatively low levels of evacuations even from towns that evacuate partially is also a cause for concern. Additionally, crucial transportation resources necessary for evacuation are delayed by an inefficient decision-making system; lack of defined thresholds for decision-making of when and where evacuations should occur results in inefficient and inconsistent evacuation decisions; and both government authorities and local community leaders base evacuation decisions and strategies on an inadequate understanding of relative risks. The result is that evacuations are too slow, if they happen; start too late; and are likely too geographically limited to avoid a disaster with a timeline of intensification similar to that of 3 June 2018. Processes can be improved through diverting from the nation-wide, multihazard framework for crisis management and instead developing a system that matches the short timescales and high resource requirements of response at Fuego volcano. Locally relevant evacuation strategies should be co-created between scientists, civil protection staff, and residents within each community to build trust, a localized understanding of risk and a plan that fits local culture and geography.

Deficiencies in evacuation practices at Fuego volcano result in good part from an aversion to providing resources that go unused; aversion or inability to change the highly structured, one-size-fits-all risk reduction system; lack of trust between external authorities and at-risk populations; residents' aversion to the risks and hardships of evacuation; and, most importantly, continued unwillingness of authorities at the highest levels to invest in meaningful risk reduction efforts that meet the needs of the population.

This research demonstrates the importance of explicitly including decision-making processes, resources and infrastructure for taking protective actions, and consideration of competing risks into EWS models.

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4 Children first: Women's perspectives on evacuation at Fuego volcano and implications for disaster risk reduction

4.1 Abstract

As major drivers of behavior, cultural norms influence how disasters differentially affect people of different genders. Cultural gender norms also impact how authorities and at-risk populations approach disaster risk reduction strategies. At Fuego volcano, Guatemala, we applied qualitative methods to investigate women's experiences of the evacuation process after a paroxysmal eruption on 7-8 March, 2022. While participants' experiences and decisions varied, we identified how gender influences evacuation dynamics within communities at Fuego volcano, including who evacuates and who decides at the community and household levels. We find that communities prioritized women for evacuation with the children and elderly in their care, yet prioritized men in the evacuation decision-making; that despite this hierarchy, a woman may override a male partner's decision in order to prioritize the safety and well-being of her children; and that even if she overcomes social barriers to leaving, she may be unable to evacuate in a timely manner because of lack of transportation. This gendered evacuation strategy disproportionately leaves men exposed to the threat and places the burden of evacuation with large families on the women. This study contributes an example of how gendered norms impact disaster risk reduction strategy at an active volcano and how understanding gendered experiences of evacuation can inform future disaster risk reduction efforts.

4.2 Introduction

Researchers have recognized over the past several decades that cultural gender expectations impact vulnerability and resilience to disaster, most commonly negatively impacting women and gender minorities compared with men (Enarson, 1998; Enarson et al., 2018). However, gender is rarely considered in strategies to reduce risk despite an international call to action via both the 2005 Hyogo Framework for Action and the 2015 Sendai Framework for Disaster Risk Reduction (Seager, 2014; Fatouros and Capetola, 2021). Research on gendered experiences in disaster risk reduction (DRR) yields information that may be used to improve preparedness, risk communication, and response capabilities in DRR strategies. Currently, much evacuation research is focused on affluent countries where many residents have access to their own transportation, in particular the United States, and on evacuation from extreme weather (see studies represented in Thompson et al., 2017). Here we focus on the experiences of women faced with short-term evacuation from their homes in small, rural communities on the slopes of Fuego volcano, Guatemala. We hope this research not only informs evacuation strategies at Fuego volcano but contributes meaningfully to the body of research on gender in DRR in various cultural and socioeconomic contexts. We also hope to open more dialogue into gendered experiences of living with active volcanoes.

Evacuation is a necessary risk reduction measure at Fuego volcano. Approximately 63,000 people from more than 30 communities live in areas that have been mapped as potentially exposed to pyroclastic density currents (PDCs), deadly and rapid flows of hot volcanic gasses and debris. While Fuego is one of Central America's most frequently active volcanoes, with daily explosions and frequent short lava flows, PDCs occur only–but not always–during "paroxysms," or larger, explosive eruptive episodes (Naismith et al., 2019). Fuego has entered into multiple paroxysms a year since reawakening in 1999. Most paroxysms last no longer than 48 hours (Naismith et al., 2019), but within that time period can be deadly. PDCs flowing more than 11 km from the volcano's summit reached populated areas on 3 June 2018, resulting in hundreds of deaths and many more casualties. Temporary evacuation from areas potentially subject to PDCs is the only reliable way to reduce risk to this hazard without invoking permanent relocation. However, evacuation numbers remain low despite the recent tragedy of 2018.

Evacuations around Fuego are recommended by authorities during some but not all paroxysms, and for some but not all communities within the mapped hazard zones in each case. Generally, each community then decides whether to evacuate in order to organize and mobilize external resources, but ultimately evacuation decisions are up to each individual or household. The dynamics of the broader evacuation system are complex and outside the scope of this study; we here focus on the experiences of women within that system. A partial evacuation of three communities on the southwestern flank of Fuego on 7 March 2022 in response to a PDC-generating paroxysm yielded an opportunity to investigate women's experiences while the event was still fresh in residents' memories. Only ~20% of the three communities' combined population evacuated (Table 4). Guatemala's national scientific monitoring agency (*Instituto Nacional de Sismología, Vulcanología, Meteorología e Hidrología*, INSIVUMEH) issued bulletins reporting on the evolution of the eruption, while Guatemala's national civil protection agency (*Coordinadora Nacional para la Reducción de Desastres*, CONRED) coordinated buses to transport evacuees to evacuation centers where they were provided with food and shelter for three days (two nights). In this study, we address three primary research questions: 1) How do gendered norms in these three communities impact evacuation dynamics? 2) What do women in these communities perceive as influencing their decisions to evacuate? 3) What barriers do women face to evacuation? We then discuss how we might use this understanding to inform risk reduction practices.

4.3 Methods

While we were in Guatemala collecting data for broader research projects on risk reduction, an increase in activity at Fuego volcano on 7 March 2022 spurred government-supported evacuations in three communities (Morelia, Panimaché 1, and Panimaché 2) on the southwest flank of the volcano (Figure 1). We responded by interviewing residents in these three communities in the week and then month after the evacuation. When people we invited to interview directed us primarily to women to discuss the evacuation, we recognized the opportunity to focus on women's experiences and how gender expectations manifest in evacuation dynamics. We had multiple conversations during this fieldwork on both the informal evacuation strategy at Fuego, where women are prioritized for evacuation with the elderly and

children, and how a community decides whether to evacuate or not. We added questions about agency into our interview guide to better understand how women navigate decision-making to meet their needs in a highly patriarchal culture (e.g., Batthyány, 2011; Ortega Ponce, 2012). This study focuses on an analysis of those interviews and listening sessions. We chose a qualitative design for this study because it allowed us to explore personal aspects of individual women's experiences (e.g., emotion and memory) that would be impossible to capture with quantitative methods such as a survey. Choosing qualitative methods allows us to retain the richness and subtlety of the stories women shared with us. Risk itself is a social construct affected by qualitative factors such as willingness (Jenkin, 2006), so a qualitative design for this study is appropriate. All interviews and observations were conducted under and in accordance with Institutional Review Board (IRB) approval 1760726-2 from Michigan Technological University.

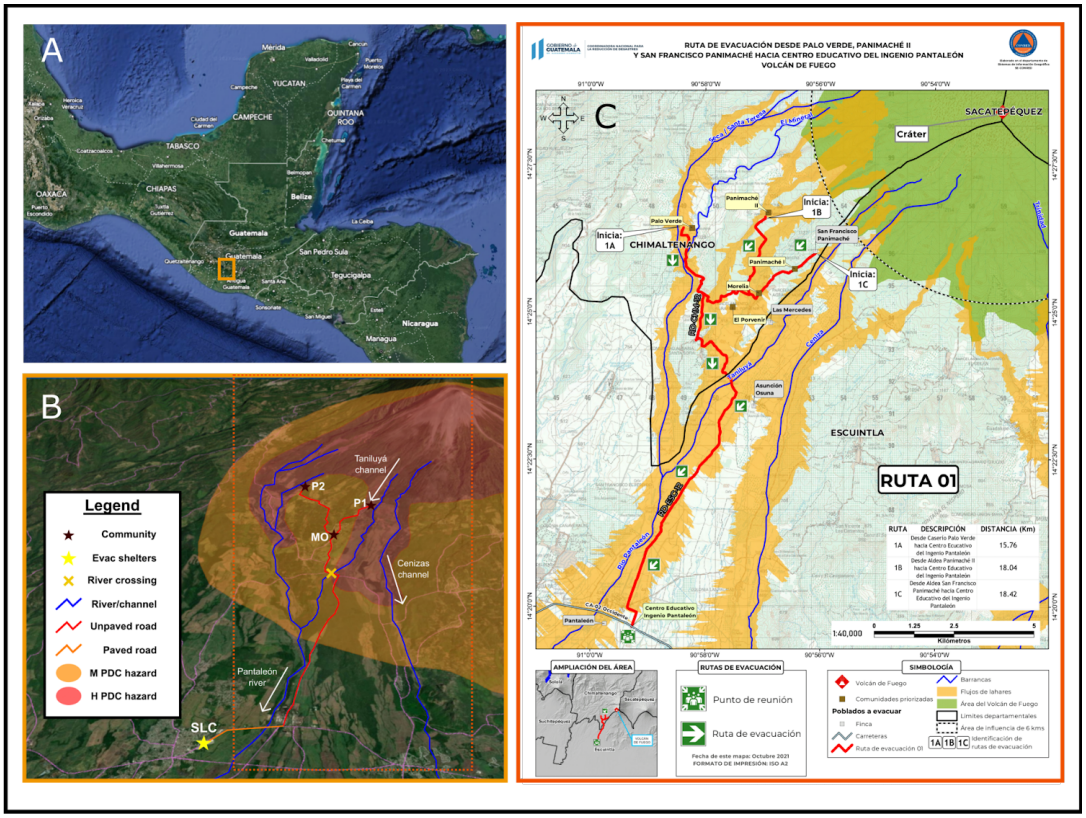

Figure 1: Composite figure of Fuego volcano and locations mentioned in this paper. (A) location of Fuego within Guatemala and Central America, showing extent of (B) in orange box (source: Google Maps). (B) map of Fuego volcano showing communities (MO = Morelia, P1 = Panimaché Uno, P2 = Panimaché Dos, SLC = Santa Lucía Cotzumalguapa), roads, river channels and river crossing point, and extent of (C) in dotted dark orange box (basemap source: INSIVUMEH (2018)). (C) CONRED evacuation map for Morelia, Panimaché 1, Panimaché 2, and the Palo Verde farm (source: CONRED (2021)).

4.3.1 Data collection

We spoke with and listened to the stories of women in a variety of settings: single-participant semi-structured interviews, organized group interviews, and an impromptu listening session. In all, we collected data from approximately 25 women in the three target communities through a total of 11 sessions (interviews and listening sessions, collectively). Because we were already in-country, we were able to respond quickly to conduct these sessions on two different visits to the Observatorio Volcán de Fuego (Fuego Volcano Observatory, OVFGO, operated by INSIVUMEH and located in San Francisco Panimaché or Panimaché 1, Figure 1), one from 12-13 March 2022, just days after the evacuees returned, and the second from 6-8 April 2022, one month after the evacuation. Our goal in these interviews was to document and understand what factors residents consider when making decisions about evacuation during eruptive crises at Fuego volcano, and who makes those decisions at the household level.

4.3.1.1 Approach

We began with single-participant interviews to build a detailed picture of how individuals responded to the evacuation process and then moved toward group interviews to use our own and participants' time efficiently, increase the perspectives represented, and enable participants to discuss details like the timing of the evacuation with each other to triangulate information in real-time. We conducted three interviews together, four interviews independently, and two sets of interviews/listening sessions in parallel:

- Panimaché 1: Four one-on-one interviews at the houses of participants (BAB) and one three-person interview at OVFGO (BAB & AKN)
- Panimaché 2: One single-participant interview at a home (BAB & AKN) and two group interviews conducted in parallel at the same home, one with three participants who evacuated (AKN) and one with four participants who did not (BAB)
- Morelia: One single-participant interview at a public park (BAB & AKM) and two impromptu informal listening sessions conducted in parallel in the street, each of ~15 people with ~5 in each who actively participated while others listened (one AKN, one BAB)

In all sessions, we explained the project and received verbal consent to record audio and use data with names removed from all participants. All sessions were conducted in Spanish and recorded on digital audio recorders for later transcription. Sessions lasted from 20 to 90 minutes. We conducted the interviews and listening sessions alike prioritizing open-ended questions, including "big, expansive questions" (Jacob and Furgerson, 2015, p. 4) that allowed the participant to discuss what they found most relevant, starting most interviews with "Tell me/us about that day. What was it like?" We then asked probing questions considering guidance provided by Lareau (2021) to focus interviewees on factors influencing evacuation decision-making. After an early interviewee shared that she went against her husband's will by evacuating, we modified our interview guide to include a question about who made evacuation decisions within their households. Our interview guide is provided in Supplementary Material.

4.3.1.2 Participants

We selected participants through convenience sampling in each village, relying on existing contacts to gain access to participants in their communities. In Panimaché 1, we were connected with participants through staff at OVFGO. In Panimaché 2, we interviewed a previous contact who then organized a meeting with fellow members of a directive created to liaise with an NGO on a development project for women in their community. In Morelia, our connections were through a colleague in the local civil defense group (known as the *Coordinadora Local para la Reducción de Desastres*, or COLRED). The listening sessions arose when we met her at her house where she had convened women to provide post-evacuation information required by the government; we invited anyone willing to stay and share their experiences, which most did. This is why the groups in Morelia were so large (two groups of ~15 women each) and why our total number of interviewees is approximate rather than exact. While we consider all ~30 women to be participants, it would be misleading to count them as a total number of interviewees, as many listened and talked amongst themselves, perhaps agreeing with others on points made but not sharing out their personal stories. Instead of counting 30, we count 10, the approximate number of women who did share their stories (~5 in each group).

Based on information shared in the interviews, participants ranged in age from mid-20s to mid-70s; most but not all are mothers and many are grandmothers; most grew up in one of these three communities, while some are more recent arrivals; many belong to one of several Evangelical Christian churches, while others stated they believe in God but do not belong to a specific church. We did not systematically collect demographic information. Most participants did evacuate (n=20), while five did not. Table 1 shows the distribution of participants by community, interview type, and evacuation decision.

Table 1: Participant distribution

Village	*Population*	*Evacuated***		*Session type(s)*		*Evacuated*		*Total Participants*
				Single-person interview	Group interview or listening session	Yes	No	
Panimaché I	389	209	54%	4	1 (3pp)	6	1	7
Panimaché II	172	57	33%	1	2 (3pp, 4pp)	3	4	7
Morelia	1994	256	13%	1	2 (~15 pp each, 5 speaking in each)	11	0	11
Total	2555	522	20%	11 interviews		20	5	25

* From 2018 census numbers (INE Guatemala (2018)); populations likely increased between 2018 and 2022, which would imply a lower percentage of evacuation participation than what we calculate here
** From CONRED

4.3.2 Analysis

We transcribed all interviews using a transcription software (Sonix.ai) to automatically generate preliminary transcripts that we then reviewed for accuracy and corrected, maintaining the original language (Spanish). We then coded all transcripts for pre-determined and emergent themes using a qualitative data analysis software (ATLAS.ti). We wanted a pragmatic coding approach: how to "practically go about analyzing large-scale interview data"? (Deterding and Waters, 2021). We

chose the flexible coding approach as described by Deterding and Waters (2021), and followed this three-step process to flexible coding and analysis: first, we identified code groups (e.g., "Social Networks") and subcodes (e.g., "Young children") based on our research questions and our interview notes. Second, we added further codes as themes emerged during coding of the interview data. Finally, we performed a simple review to consolidate similar codes and re-code quotes for codes that may have been missed in earlier coding sessions. Our approach was therefore neither wholly inductive nor deductive, instead best described as "abductive," or "a continuous process of conjecturing about the world that is shaped by the solutions a researcher has 'ready-to-hand'" (Timmermans and Tavory, 2012). Research colleagues at Michigan Technological University checked portions of transcripts and coding to provide external validation (see acknowledgements). All quotes here were translated by the authors after coding.

Based on participant descriptions of their experiences leading up to and, where relevant, during evacuation, we designated six broad code groups with multiple subcodes beneath each (Table 2). The coded groups are Social Networks, Homes and Livelihoods, Information Sources, Structural (government-related processes and resources), Wellbeing, and Evacuation. There is some overlap between all code groups. Codes are provided in Supplementary Material.

Table 2: Example code groups and codes for data analysis

Code group: Social Networks	**Code group: Structural**
Code: Young children	Code: Transportation
Code: Older	Code: Official presence
Code: Spouse or partner	Code: Opportunity to leave
Code: Community	Code: Place to go
Code: Other	Code: Timeliness of outside aid

4.3.3 Supplementary data sources

Because of our previous and continued data collection on Fuego volcano, we have considered data sources outside these interviews and listening sessions to frame the information provided in this rich yet limited data set. We note where our discussions are directly informed by additional sources.

This study is informed by participant observation during these interviews and others conducted from 2018 to present as well as meetings or workshops such as the accreditation of local civil protection groups (COLREDs) by the national-level civil protection staff (SE-CONRED Volcano Prevention Department). Participant observations provide insights into the day-to-day lives of participants and others within these communities; messaging from civil protection groups; and communication during volcanic crises. We recorded these participant observations in written field notes; voice memos recorded either individually or together, in conversation; and in photographs taken while in the field.

We also consider data from government census documents, government evacuation statistics, and news media reports.

4.3.4 Limitations

This study is not intended to be generalizable to all populations around Fuego volcano or even throughout the three communities sampled. We note especially that we spoke with few women who did not evacuate, and in only two of the three villages. Also, because our primary contacts were the OVFGO staff in Panimaché 1 (INSIVUMEH observers) and local civil protection volunteers (COLRED members) in all three villages, our sample is likely skewed toward residents with high levels of civic engagement. Regardless of how soon after the event we spoke with participants, our data may reflect participants' justifications for their evacuation decisions rather than the factors that influenced their decision-making process at the time. On the night of the evacuation, for example, one participant shared with us via text that she was not evacuating because she needed to make cheese. This initially struck us as a bizarre priority. As we suspected, the reality was more complicated, as she described in our interviews with her the following month when we were able to speak in person.

We also acknowledge our positionality as clear outsiders: we are both white women from affluent countries with advanced educational degrees, speaking Spanish as a second language. (Both our degrees focus on case studies in Central America, so we do have relevant experience in the region.) While we spent time in each community on repeated trips, beyond the two reported on here, our time and exposure to village dynamics were limited. Each conversation and observation broadens and deepens our understanding of how people live with Fuego's frequent eruptive activity and we surely would have gained a more nuanced view with more time. Still, despite the limitations, we believe the results we present here are meaningful and reflect both a shared experience of life for women in these rural areas and the diversity in their experiences as individuals faced with the decision to evacuate from their homes on Fuego's slopes.

4.4 Results

We here present the results of our analysis in sections organized by our three primary research questions with the addition of a fourth section that highlights how complex and interdependent people's evacuation decisions are at Fuego, shown here in italics: 1. Impact of gendered norms on evacuation dynamics, *2. Social influences on decision making processes*, 3. Influences on evacuation decisions, and 4. Barriers to evacuation. We use these same categories in the Discussion, incorporating discussion of the additional topic *(2)* into the first research question (1).

4.4.1 Impact of gendered norms on evacuation dynamics

4.4.1.1 Most likely to be home during a crisis

Participants described, and we observed, strong gender norms for distribution of labor within the target communities. In these communities, as elsewhere in Guatemala, women are primarily responsible for household labor while men work in paid labor outside the home. Women's

responsibilities include taking care of a family's basic needs, such as clothing and meals; often they also tend to small, home-based livestock such as chickens, geese, ducks, and rabbits and supplement household income with paid labor or products, e.g., making cheese to sell locally, that are also often based out of the home. By contrast, men typically work outside the community, traveling daily to family land or to coffee or sugar plantations, or to cities for up to several weeks at a time because paid work is scarce locally.

This distribution of household labor and livelihood opportunities has significant implications for evacuations. As shared by participants in Panimaché 2, women are more likely to be home during a volcanic crisis than men in their community:

> *First woman*: There are very few men here because there are no jobs here.
> *Second woman*: It's almost only the old men that are here, the [retired] fathers of the young men.
> (...)
> BAB: Since the eruption was on a Monday, a working day, how..?
> *First woman*: Mostly, it was only us women here.

A video posted by media outlet Prensa Libre during an evacuation process in the town of Ceilán on a Monday in November 2018 shows this holds true for other communities on Fuego as well: the vast majority of the crowd gathered to discuss evacuation are women (Prensa Libre, 2018).

4.4.1.2 Prioritized for evacuation with children and the elderly

Even if men are present, communities prioritize women for evacuation with children and the elderly while men stay behind to take care of property. The reason both male and female residents gave for the gendered evacuation strategy was that women with children move slowly, while men, unencumbered, can run from danger. The implication is that women are responsible for the caretaking of children. Men stay behind to deter looting, feed livestock, and manage ashfall on roofs to prevent collapse. As described by a woman in Morelia, even teenage boys may stay behind with fathers:

> My husband told me to leave because the ash was falling as if it were water, and it stank, so my husband said, 'Go, because we have a lot of kids'… I have five that are still young. The [17-year-old] boy stayed with his father here in Morelia. I took the four little ones. Since they are all small, I left. My husband said, 'Leave, because if it gets worse, how are we going to grab them all since there are so many?'

Like this participant, many households have many children (~22% of women in Yepocapa municipality had five or more living children in 2018 (INE, 2018)), and participants described evacuating not only with children but also with extended family members. Families commonly share land plots, with grown children building houses next to their parents' as they start nuclear families of their own. As one participant in Panimaché 2 said, "there aren't small families here, almost all are big. Where the mom is, the son is too, the daughter-in-law, the grandkids." This

results in multi-generational groups evacuating with one or more middle-aged woman at the hub, as described by a woman in Morelia:

> Since we had to sign up, how many from each family was going, I signed myself up, I signed up my children, I signed up my mom, my dad, my nephew, and I said, 'Okay Mom, I signed you up, let's go.' My husband can flee. He says that if anything happens he can leave running. But me with my children, what am I going to do?

While some shared that men follow later or that only a delegation chosen by local governance stays behind, interviewees in multiple communities expressed that only women, children, and elderly evacuated on 7-8 March, with few exceptions. However, this does not mean that all women, children, and elderly persons evacuated. We estimated the expected number of evacuees from each village if all women, children, and elderly persons left, based on the most recent census data, and compared these estimates to the actual numbers of evacuees provided by CONRED (Table 3, Figure 2). Our estimates show we should expect around 74% of the total population in any of the three communities to evacuate. However, even in Panimaché 1, where residents said 'everyone' evacuated (e.g., "Everyone left. Only the authorities and the men stayed."), CONRED's numbers indicate that only 54% left, or 19% less of the population than expected.

Table 3: Expected evacuation numbers if only and all men stayed behind

Village	***Population****	***Evacuated****		***Estimated expected evacuating population*****		***Discrepancy between expected and actual evacuated population***	
Panimaché I	389	209	54%	283	73%	74	19%
Panimaché II	172	57	33%	132	76%	75	43%
Morelia	1994	256	13%	1466	74%	1210	61%
Total	**2555**	**522**	**20%**	**1881**	**74%**	**1359**	**53%**

* From 2018 census numbers (INE Guatemala (2018)); populations likely increased between 2018 and 2022, which would imply an even lower percentage of evacuation participation than what we calculate here

** From CONRED

***Expected evacuating population estimated by summing all children aged 0-14, all adults aged 60+, and half of adults aged 15-59 (i.e., women); census data showed approximately 50% female and 50% male populations in each location, not disaggregated by age.

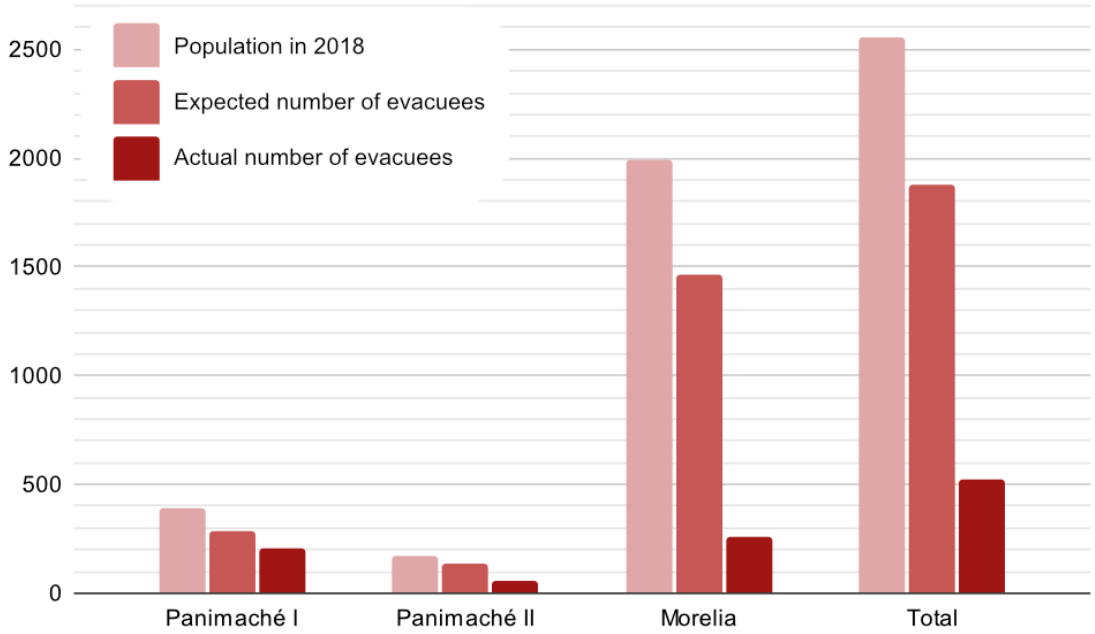

Figure 2: Actual vs. expected evacuation numbers in Panimaché 1, Panimaché 2, and Morelia. Population from 2018 census numbers (INE Guatemala (2018)); populations likely increased between 2018 and 2022, which would imply an even lower percentage of evacuation participation than what we calculate here. Expected number of evacuees estimated by summing all children aged 0-14, all adults aged 60+, and half of adults aged 15-59 (i.e., women); census data showed approximately 50% female and 50% male populations in each location, not disaggregated by age. Actual number of evacuees from CONRED.

It is possible that the evacuation numbers represent only people served by the buses and in the shelters and not those who evacuated to the homes of family away from the volcano, which we know to be non-zero. However, this is not enough to explain the large discrepancies observed in Panimaché 2 and Morelia, where we should expect 43% and 61% more evacuees, respectively. Therefore, while the reported norm may be that women evacuate with children and the elderly, numbers indicate that many did not during this most recent evacuation.

4.4.1.3 Maintaining caretaker responsibilities throughout the evacuation process

Gendered distribution of labor means that women are responsible for multiple aspects of family life throughout the evacuation process, even if men are present. Women we spoke with described preparing their family by gathering important items like documentation, clothing, and diapers, and organizing family members. Thus, the readiness of the family depends primarily on the women in the household. Some women described this responsibility as a burden in a resource-scarce environment; one mother who evacuated from Panimaché 2 explained her feeling of helplessness at maintaining and preparing the "72-hour backpack," a readiness kit promoted by CONRED:

> You throw in important papers for the children. And something that you can give them to eat or ... whatever you think is the most important, you bring. Because they have taught us about these things. But as I said to my friend, the backpack didn't cover the hours that it needed to, because the things were used up. Then you say, 'What can I do?'

Women described taking care of the physical and emotional health of others before and throughout the evacuation process. In Panimaché 1, several participants described sheltering at home to protect themselves and children from ashfall while the men in their family went up to the volcano observatory to get information and discuss evacuation. While several participants described going to the observatory to get information as well, they appear from photos from observatory staff to be the minority. This distribution of labor during a crisis may result in women missing out on opportunities to receive information first-hand and to advocate for themselves and their dependents in negotiating evacuation resources with community leadership and civil defense staff.

Women also described taking on emotional labor and regulating their own feelings in order to manage the feelings of others. For example, this woman in Panimaché 2 shared how she hid her fear while awaiting evacuation decisions to protect the emotional wellbeing of her children:

> Because sometimes, well, we have a knot in our throats, as if, 'This is it.' We wanted to cry and we were already crying with fear. But as mothers, we can't cry because then our children get more scared. So then we endure this knot in our throats.

In evacuation centers, women continued to enact their caretaking responsibilities; they consoled family members, shared resources with others, and problem-solved to keep their children comfortable and clean. A participant from Morelia shared how she found a secluded spot to help her children bathe using containers of drinking water provided in the evacuation center. At night, she concerned herself with her family's safety:

> They were sleeping and I was sitting on the edge of the bed, of the beds they gave us. I looked at my children. And one of them came, a policeman, and told me, 'Go to sleep, daughter, because we are taking care of you here. We are taking care of you and your children and all the families that are here.'

The same woman reflected other participants' concerns about leaving their homes and their other responsibilities, especially in regards to preparing food for their male family members who stayed behind:

> Because like I said, it's hard to leave our belongings, leave our animals, our spouses without meals. It's painful.

Most women we spoke to said they were well-provided for in the evacuation centers, though many had stories of concerns they had addressed for their family or community members: participants described giving medicine to the elderly, consoling young mothers with newborn babies, and borrowing cell phones from other women for calls to check in on family members.

A participant in Panimaché 1's civil protection group who evacuated with her community members advocated for them in the shelters, for instance asking if there would be breakfast coming for restless children when none was provided at a normal mealtime. She and the other two women in Panimaché 1's civil protection group (all three evacuated, and the seven men in the group all stayed back) also kept order among their community members, for which she proudly said they were congratulated–'even though they were women.'

> They congratulated us. They told us that 'Even though you are women, you had your people in good order. All calm.'

This caveat ('even though') indicates both her and the speaker's unfortunately low expectations for women's abilities in civic life.

In summary, gendered divisions of labor mean women are more likely to be home during a crisis, shoulder the burden of preparing households for evacuation, evacuate without their spouses with children in their care, manage and take care of children's physical and emotional health throughout the crisis, and continue much of their caretaking work at the evacuation center even if basic needs are provided for.

4.4.2 Social influences on decision-making

4.4.2.1 Prioritizing men for decision-making

Participants shared a variety of responses when asked who makes the decision to evacuate in their household, though most indicated a clear expectation that men should or do. In Panimaché 2, one woman said, "The husband makes it. If he says to go, they go. Based on how he sees the danger." She and her interview group agreed that in men's absence, they would have to make decisions if they see there is great danger, but that there are always at least some older, retired men in the village. They described how their decision-making is consistent with their caretaking responsibilities: to prepare their families while awaiting the decision to evacuate.

> *First woman*: We can't make the decision, the men do.
> *Second woman*: We did make the decision, but to have things ready, telling the children, "Look, we're ready"... because "Let's see what your dad says." Or see what the authority says.

Men who are absent from the home may still weigh in, as described by a participant in Panimaché 2 whose husband who is gone each week for work elsewhere:

> I was going to go. I was ready to go. Then I talked with him by phone and he told me to only go to Morelia [where my in-laws live] and if it gets worse then you can leave more easily from there.

Relying on men's judgment may significantly hinder both community-wide and household decision-making if men are not accessible. We can see this play out in the same video of

November 2018 evacuation dynamics described in section 3.1.1, when authorities ask a group of mostly women gathered in the street if they will evacuate; one woman responds, “Well, we can't decide anything, ma’am, because our husbands are working in the sugar cane. So maybe when they come we will meet to see what they say” (Prensa Libre, 2018, 00:09:20). In Panimaché 2, interviewees complained that the male head of both their local governance and civil protection groups was away at work on 7 March at a sugar cane plantation and inaccessible until 5 PM.

4.4.2.2 Influencing decisions within and beyond their households

Women’s stories revealed their expectation to rely on men for decision-making but also how they exercise agency in a variety of ways. One participant in Panimaché 1 said she told her husband and eldest son not to go tend to their farmland higher on the mountain on the morning of 7 March because of the heightened volcanic activity; they stayed home. Women faced with evacuation also swayed people’s decisions in other, nearby communities. One participant in Panimaché 2 who did not evacuate described her influence over her adult daughter in Morelia:

> I told her if I go I’m going to bring you with me. Okay, she said, I’m going to get ready and if you go I’ll go too. But since we didn’t leave, she didn’t leave either.

Participants frequently described decision-making as collaborative between family members in other households, such as a widow in Morelia who told how she discussed whether to evacuate with her adult children:

> So, I don't have a husband anymore, he died. But my children... there is a daughter of mine who lives near where I live, and she has a daughter, and they were very worried. So we decided between us to leave. We made the decision between my children and I, and we left.

Making the decision to evacuate can be a source of great stress, especially given the large, tightly connected family groups. A participant in Panimaché 2 described how the decision of whether to evacuate affects not only large nuclear families but an extended family network:

> I would have left with seven children and two daughters-in-law, yes. And the grandchildren. It’s a large group and even one of my sisters and my mother met there at our house to decide and they said, ‘Well, if you leave, so will we.’ So I couldn't figure out what to do, because it wasn't just my life that was in danger, it was my whole family. So it's quite difficult to make the decision that ‘I'm staying today.’

4.4.2.3 Influencing others through civic engagement and example

While women are almost exclusively responsible for housework, they do also participate in civic life within their communities. At least four of our participants were members of their local civil protection groups (COLREDs) during the 7-8 March 2022 evacuation, one in Panimaché 1 and three in Panimaché 2 (not all of which evacuated). Participants in Panimaché 1 explained that a COCODE (*Consejo Comunitario de Desarrollo*, a community’s development council) gathers the

community to make a decision about evacuation and the COLRED then supports evacuation if called for, although this may vary between communities. Participation in the COLREDs is encouraged by national-level civil protection agency staff with the recognition that women are more likely than men to be present in a community during a crisis.

As part of the COLRED, women share information about evacuation and may motivate others in their community to evacuate, as described by a COLRED member in Panimaché 1:

> Here they said 'Well, we're not leaving.' But I said 'Well, that's why we're here and bringing information, we have to get out, let's go! Let's leave now when you can.' Because they're going to want to leave when they can't. 'Right now there's a bus, let's go!'–cheering the people, people who did listen to us and liked what we told them. That's how people left.

In summary, women described prioritizing men, especially their husbands, in the decision-making process, but that the process can be very collaborative between them and their partner, within extended families, and within communities. They also described having influence on other family members and in turn their families–which can be positive but also a burden. In local civil protection groups, they may encourage others to evacuate following official guidance from their community.

4.4.3 Influences on evacuation decisions

We asked our study participants how they decided to evacuate or, in the case of the five who stayed, why they did not.

4.4.3.1 Considering official warnings as guidance

Participants described receiving information from officials about the volcano's activity, alerts to prepare for possible evacuation, and guidance or an order (described differently by different participants) on whether to leave. We heard that these official recommendations can be important but also heard that in some communities (i.e., Panimaché 2) it never arrived, or that there was a large gap in guidance. Some, like this woman in Morelia, expressed that they follow the authorities' guidance as an order:

> I am willing to follow the rules and if they say that we have to go, we have to go.

Others, however, described the decision as up to each household or individual, and most described guidance from authorities as informing, not determining, their decision, as with this woman in Panimaché 2:

> We get together to see what the authorities are going to do. To make the best decision.

As we can see from other descriptions below, while participants may have considered official guidance most deciding factors revolved around protecting children–and the availability of transportation.

4.4.3.2 Motivated by children's fear

As indications that they should evacuate, women described volcanological phenomena including heavy ashfall, dark skies, the occurrence of pyroclastic flows (the most dangerous type of pyroclastic density current), the smell of sulfur, loud and continuous explosions, and ground shaking. However, alongside these descriptions of volcanic phenomena, participants, like this woman in Morelia, almost always also described the fear Fuego caused them and their children:

> … my girls were very scared. From when it got dark. From then, they didn't want to eat, they cried. The same for me, my blood pressure rose, I didn't have lunch, I didn't have dinner, and that's how I left because I get really bad too. And the truth is that I'm afraid of [the volcano]. It does scare me. I'm afraid and my girls … crying that we weren't going and my husband didn't want us to leave and I told him if he wanted he could stay, but I would go with them because they tormented me and I was the same, well, I was too scared because the thunder from the volcano was very loud and it wouldn't calm down.

Another woman in Morelia forewent describing volcanic phenomena and indicated her main motivators to evacuate were her children's fear and the pressure of the last available transportation:

> My kids didn't go to sleep at that time, they couldn't sleep. They cried. And it was the last bus that was going to leave. So, yes, [I had] the decision of either I go or I stay. And in the end my heart couldn't bear to see my kids, the fear of my kids, and I said well, we'd better go. That's how we made the decision to leave, then.

Several women in Panimaché 1 expressed that they were not concerned for their own lives and only evacuated because of the children:

> *First woman*: We did leave voluntarily, always out of fear, for the children. Like I said, we're grown up, we've already lived, but children are what we feel.
> *Second woman*: They have to go first. They get scared.
> *First woman*: The kids get scared.

These women in Morelia shared that they were similarly not concerned about the volcano's activity for themselves, but evacuated out of concern for their children's emotional wellbeing:

> Well, I say nothing is going to happen. As in, this happens normally... But they just get scared...

> What happens is that at that moment the children come to cry. To cry and that–they say they are afraid to die. And all that. And many times that encourages you to go too, you go, because - out of fear for the children. That they can get sick from so much fright.

These stories imply that there are no set criteria or thresholds for evacuations; instead, much of women's evacuation decisions are driven by how uncomfortable they and/or their children are.

We note that families do not have much control over when to evacuate, instead deciding on whether to evacuate given the timing of available transportation. We address this issue in Section 3.4: Barriers to evacuation.

4.4.3.3 Prioritizing children over competing factors

Participants indicated that protecting or calming their children was more important than other factors influencing their evacuation decisions, describing how they overcame economic and social pressures to address children's needs. For a participant in Morelia, the desire to appease her children outweighed the inconvenience of evacuation as well as the potential livelihood losses.

> It's hard because you think first of the children. In my case, I have three. Hauling them around, right? There's the fear of staying, also, because of them. Because in my case, I didn't really want to leave, right? Because of my animals and everything, it pained me to leave. But at the same time, my son was crying and saying, 'Mom, let's go, Mom, let's go!'

Despite saying they prioritized men's word in decision-making (section 3.2.1), multiple women told stories of deciding to evacuate with their children even when their husbands said they should stay. As shared by a woman in Morelia, this unilateral decision-making may cause tension in relationships and be seen as disobedience:

> And I told him, 'Forgive me my love, because what you put on is white, I turned it black. Because I left with my children and you said no, and I said yes.' 'But thank God, now you're all back,' he told me, 'You're all here without any problems.' And everything was like nothing happened.

These women emphasized their responsibilities as mothers to overcome gendered expectations of obedience. We note that it is quite possible that many women did not evacuate because of deferring to their husbands' wishes, given our small sample of non-evacuees; two of the five who stayed back clearly expressed the influence of their husbands in staying.

Two different participants also countered religious arguments to stay home and leave the outcome in the hands of God, arguing like this participant in Panimaché 1 that having faith in God was not contrary to evacuating with their children:

> BAB: Why didn't the people at the church evacuate?

> Because they say they have faith in God. Of course, we all believe in God and that He exists–but not in leaving the burden only to God. We also have to do our part to leave. So, they said they didn't evacuate because they trusted in God and that nothing was going to happen. And I know that God is great because nothing worse happened. But we did it out of concern for our families and to keep them safe.

4.4.3.4 Avoiding regret

One woman in Panimaché 2 described fear not related directly to the volcano's activity but to the potential to regret not taking action. As with many other mothers interviewed, her concerns were tied to the lives of her children:

> I think that we have to be on alert before we have something else to regret. Yes, because sometimes after a tragedy happens, someone will lament, "Why didn't I go, why didn't I get out?" And then more when people have small children, the children do what the mother and father say. And if someone as a parent doesn't think that the life of a child is worth much? And what we think sometimes is that… the children go where the mother goes, and if we have this opportunity to leave in time, it's much better.

In summary, many participants indicated they took the official guidance to evacuate as a consideration rather than an obligation and described the wellbeing of their children–both their lives and emotional health–as a primary motivating factor in their decision to evacuate that could outweigh concerns for their livelihoods, obedience to husbands, and arguments that religious faith deems protective action unnecessary.

4.4.4 Barriers to evacuation

Whether women want to evacuate or not, their ability to do so is challenged by competing factors, including those mentioned above: leaving their homes, leaving their animals, preparing large family groups, and disagreeing on the importance of evacuation with spouses. In previous work and informal interviews, we also heard about concerns that conditions in evacuation centers would be poor or that their families would not be well provided for in them. Some barriers are more surmountable than others; as described above, many of these factors were overcome by the desire to protect children. However, participants also described multiple facets of a single barrier that proved particularly important in their decision to and ability to evacuate: transportation.

4.4.4.1 Availability of vehicles and drivers

Both Panimaché 1 and Panimaché 2 evacuate through Morelia. All three communities evacuate to temporary evacuation shelters such as schools in the small city of Santa Lucía Cotzumalguapa (Figure 1). The evacuation route is mostly on unpaved dirt roads; residents of Panimaché 2 must travel 18.04 km on such roads until they meet the paved highway (RN-14) at the Education Centre of Ingenio Pantaleón (Figure 1C), and a further 2.8 km on the RN-14 to the beginning of Santa Lucía (20.84 km total). Residents of Panimaché 1 travel ~17.4 km on the dirt road (~20.2 km to Santa Lucía), and residents of Morelia ~16.0 km on the dirt road (~18.8 km to Santa

Lucía). According to Guatemala's 2018 census, only 20.2% of households in the municipality of San Pedro Yepocapa had a motorcycle, while fewer–8.8%–had a car or truck (INE Guatemala, 2018). These percentages are likely lower for these three rural communities, as numbers are skewed by urban centers.

Limited vehicle access severely restricts evacuation options for all residents, even after authorities recommend an evacuation. Women in Panimaché 1 and Panimaché 2 shared that authorities expected them to walk to Morelia or further, a task made particularly challenging with small children in tow:

> And they told us to leave. To evacuate. But by foot! By foot from here to, to the main road! (Panimaché 1)

> *First woman:* They've told us that we have to walk. But [the children] don't let us walk.
> AKN: How much time does it take to walk to Morelia from here?
> *First woman:* Walking? With children, almost an hour.
> *Second woman:* Doing this, the eruption will catch us halfway between here in Panimaché and Morelia! So it's almost better that we stay at home. (Panimaché 2)

Even for the few vehicles available in a community, women have less transportation autonomy than men. According to one interviewee in Panimaché 2, "there is a vehicle here but only men drive." She shares that several women in the community, "maybe 4," can drive a motorcycle. This lack of autonomy is reflected in conversations where participants described taking buses or, in the few cases where a household vehicle was described, riding on their sons' motorcycles for non-evacuative transportation. This limitation may be particularly important for people with special needs: a participant in Panimaché 1 shared how she and other family members waited for her father, who owns a truck, to drive them to a safe location because her sister had recently undergone surgery. He was too busy with his duties as COCODE president to do so; they ended up not evacuating.

4.4.4.2 Timeliness, safety, and comfort of vehicles and route

INSIVUMEH issued a first Special Bulletin (BEFGO #006-2022) on the paroxysm at 00:50 on 7 March, and their observer and others noted the first big pyroclastic flows at 12:58 PM (BEFGO #008-2022). The eruption had two peaks in seismic energy and PDCs, one from around 1:00 PM to 3:00 PM with PDCs in the Cenizas channel (BEFGO #010-2022) and a second one from around 7:00 PM to 1:00 AM with greater seismic energy and PDCs in the Cenizas and Las Lajas channels (BEFGO #012-2022). Seismic energy and observed activity remained elevated between the two eruptive peaks. According to interviews, Panimaché 1 began to agree to evacuation support at 4 PM and the first government-coordinated buses arrived at 5 PM, provided by nearby plantations (Azúcar de Guatemala, 2022; Germán Alfaro (ICC), pers. comm.). Therefore, transportation options were available from 5 PM, but only in Panimaché 1 and Morelia. Panimaché 2's first transportation support arrived sometime around or after 9 PM, a volunteer firefighter flatbed truck that made two trips to shuttle interested residents to Morelia. The last bus

left from Morelia with these evacuees plus others from Morelia at 11:20 PM. Military and police support arrived to Panimaché 1 around the same time and was described by Panimaché 1 residents as the reason 'all of' Panimaché 1 evacuated (Table 1). The last transport arrived at evacuation centers well after midnight and possibly as late as 3 AM on 8 March. **Figure 3** is a timeline of the eruption including INSIVUMEH and CONRED bulletins and approximate timings for the arrival of evacuation vehicles at each of the three target communities.

Participants, in particular in Panimaché 1 and Panimaché 2, shared their concern with the timing of transportation. A participant in Panimaché 1 complained that transportation was provided at the height of the eruption, rather than beforehand. The evacuation route requires fording channels prone to lahars, violent mudflows of rainfall and volcanic sediment; because there is no bridge, the route becomes impassable in poor conditions:

> It's scary. Because the worst is when [a flow] starts to come down, in all the rivers, you can't pass. You get stuck. You can't get out. So the buses are afraid to come up here. This should be coordinated ahead of time to evacuate people. But no, when [they] hear that the turmoil is here, then they send the buses. And it shouldn't be like that. I don't think it should be like that. Because it should be beforehand, right?

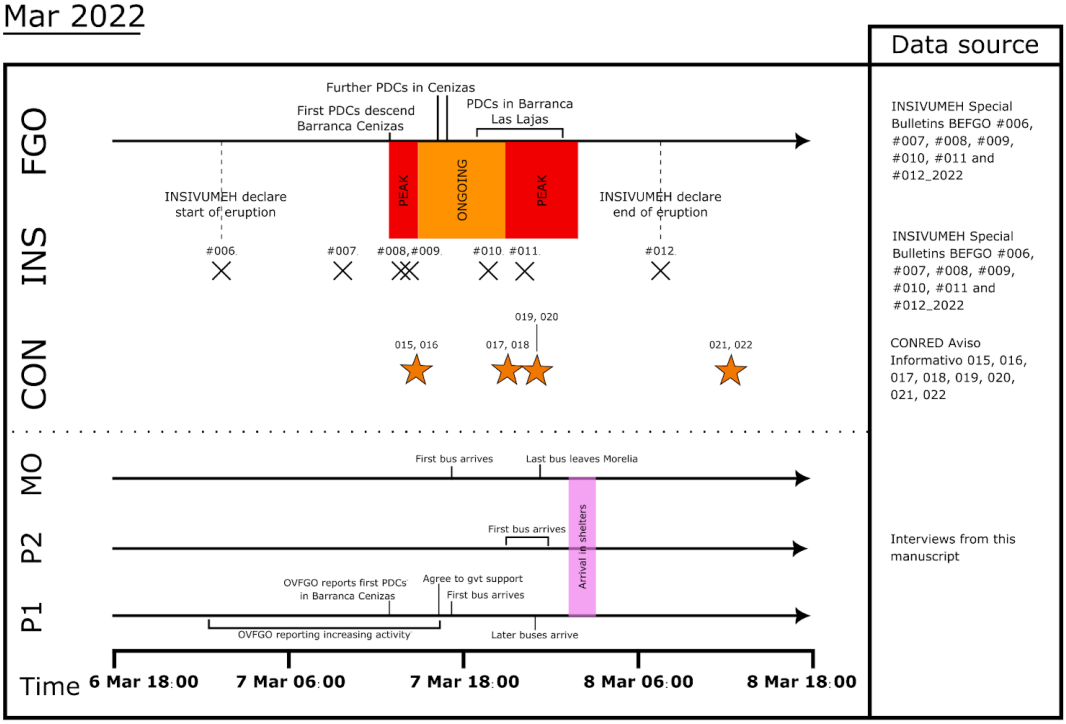

Figure 3: Timeline of events for the 7 March 2022 eruption. (Top - bottom) FGO = activity of Fuego, including timings of pyroclastic density current (PDC) descent; INS = INSIVUMEH Special Bulletins (ID and release time); CON = CONRED Aviso Informativo (they release one for community and one for authorities simultaneously); P1-P2-MO = evacuation timeline for each of the three target communities (Panimaché 1, Panimaché 2, Morelia). Information sources are listed on the right.

A participant in Panimaché 2 complained that the transportation came after she perceived the main threat to have passed:

> [CONRED and the firefighters] arrived at 11 at night. But the worst had already passed, which were the rumbles. And it was dark because there was lots of ash. All this had already happened, and the sound [from the volcano] was slower. So then - it's very late and there was no vehicle to take us, transport us downhill. Only the firefighters.

The same women said she did not evacuate because of the timing of transportation but also because the transportation provided was insufficient for the number of people evacuating and thus unsafe:

> [My husband] saw the danger, that it's very dangerous for me to go hanging onto the truck with everyone all packed in, with suitcases, with children. No. That would have had to be during the day, because at night it's very dangerous. It goes into a ditch, the truck turns over, there's nothing to hold on to. Maybe nothing will happen to me because of the volcano, but something will happen to me because we're all going together, heaped on top of each other.
> BAB: What if there was more transportation?
> If there had been more transportation? One bus, everyone comfortable? Let's go! That wouldn't be dangerous.

A woman in Morelia described her misery and that of the children on the last bus to leave:

> It was hard because the children were going to vomit. Not only because of the heat that gripped them … it's that it was super packed … a taxi. We went in the last bus … it was full of ash. Our skin and hair was white from the ash. I left with a stomach ache, with nausea. And everything was bad. … It took around two hours. We waited for it to fill, then it drove down very badly, we were barely moving.

In summary, women recalled the arduous process of evacuation on 7 March. The rugged and river-woven landscape of Fuego's flanks makes transit to and from these remote communities very difficult even in good conditions; exacerbated by darkness, ash, and heavy loads, evacuating by bus during eruption is a miserable and dangerous experience. Women may still take on this hardship when motivated to by their children's fear. However, we also learned that transportation did not arrive to some communities until after interviewees perceived the eruption as lessened. Despite women's agency and motivations to leave, transportation is a structural barrier to evacuation that they cannot overcome themselves.

4.5 Discussion

4.5.1 Impact of gendered norms on evacuation dynamics

Rural Guatemala has rigid gender norms for women and men (Ortega Ponce, 2012). As in much of Latin America, these norms dictate that women dedicate a majority of their time and effort to

domestic labor and childcare, while men dedicate time and effort towards public life and paid labor (Batthyány, 2011). In 2009, men accounted for 73% of the daily hours worked for paid labor while women accounted for 74% of unpaid labor (Batthyány, 2011). Statistics from 2000 show that women with children in the household spent almost three times as much time on domestic labor per week than men with children. These societal norms imply that women in Guatemala are, as in many cultures worldwide, likely to be responsible for taking care of children during a crisis and more vulnerable than men to economic hardship after a disaster. Consistent with this expectation, we see cultural gender norms impacting behavior before and during evacuation in the three communities represented in this research. We find that gender is a major determinant for who is likely to be in the village during a crisis, who has authority in making decisions about whether to evacuate, and distribution of labor throughout the evacuation process. The results described above have significant implications for risk reduction strategies at Fuego and in other high-risk environments throughout Guatemala.

Women's caretaking responsibilities are the primary drivers for the gendered evacuation dynamics at Fuego volcano, though other patriarchal norms also influence evacuation outcomes. Retrospectives around the world that disaggregate data by gender document a disparity in female vs. male deaths in disasters, most commonly with the deaths of women and girls outnumbering those of men and boys (e.g., Seager, 2014). These disparities are attributed to gender norms such as norms of perceived femininity that dissuade women and girls from learning to swim, norms of virtue that prevent women from leaving a building without a male escort, and norms of labor that place women with vulnerable populations such as children in their care (e.g., Fatouros and Capetola, 2021). Oxfam International (2005) reported that women accounted for up to 77% of deaths resulting from the 2004 Indian Ocean tsunami in some communities and that many women died because they stayed behind to look for their children and other relatives. Women are also often less likely than men to have access to warning information in many locations because of lower levels of literacy, less access to technology such as cell phones, and less access to public spaces (Seager, 2014). These are examples of how gender norms, in the absence of a comprehensive evacuation strategy, can negatively impact specific demographics during a crisis.

The approach to evacuation at Fuego volcano–albeit informal and undocumented–is to prioritize evacuation of women, children, and the elderly, moving vulnerable populations and those who care for them to safety before a rapid escape is necessary. Other places implementing tiered evacuation strategies include Japan (Japan Meteorological Agency, 2022) and Canada (Scharbach and Waldram, 2016), both of which prioritize more vulnerable populations such as those with limited mobility to evacuate first, with the rest of the population to follow at a higher level of warning. However, at Fuego there is no documented strategy for evacuating the remaining population. Instead, men, or a delegation of men, stay behind to protect property from looting and ash accumulation and to tend to livestock, common concerns for evacuees in rural volcanic settings elsewhere in the world as well (Barclay et al., 2019). This gendered division of labor significantly impacts evacuation experiences and has important implications for both short- and long-term outcomes should a disaster occur.

The strategy to leave a delegation behind leaves a significant portion of the population, and specifically the population's workforce, exposed to the threat of PDCs at Fuego volcano. Residents' claim that men will be able to escape if needed likely underestimates the reality of the environment in which they will have to run from PDCs; the flows chart unpredictable pathways at speeds too fast to outrun or outdrive, especially on the poorly maintained roads. At night or in dark conditions it may be difficult to see PDCs, which are mostly silent, coming. Therefore, in the short term, a PDC reaching a village could mean immediate loss of many of the men within the community. The tragedy of this potential loss of lives should not be understated. In addition to this human loss, surviving adult household members in evacuation centers–women–are already the most economically disadvantaged within Guatemalan society, relying on a husband's paid labor. In the long-term, economic recovery may be hampered by scarcity of livelihoods in the high-hazard zone or, conversely, disruption of livelihoods and social networks if relocating (Bowman and Henquinet, 2015), and the new double demand of finding paid labor and undertaking the reproductive labor that women primarily shoulder (Moreno-Walton and Koenig, 2016).

While this strategy of partial evacuation at Fuego may entice people to evacuate who wouldn't otherwise out of concern for their property, it separates family members. In a study of mothers' evacuation behavior during a 2017 hurricane in southern Florida, Brodar et al. (2020) found that keeping their family together was one of respondents' top priorities when deciding whether to evacuate. Mothers in the Florida study were less likely to evacuate if their partners were not evacuating, for instance if the partner was in an emergency response role for which they needed to stay onsite. In Saskatchewan, Canada, the tiered evacuation strategy mentioned above created hardship for already vulnerable family members who were evacuated separately from the rest of their families (Scharbach and Waldram, 2016). Women at Fuego who evacuated indicated that they worried about their male family members left behind, both because of the danger and because they, as their wives and mothers, were not there to prepare meals for them. We also heard from participants that they worked to keep their extended family groups together whether evacuating or sheltering in place. It is possible that more families at Fuego would have evacuated if the norm was for the whole family to leave, including the men.

This gendered evacuation strategy also places the burden of evacuation squarely on the shoulders of women, especially mothers. In Broder et al.'s (2020) study, at least one respondent acknowledged that she did not evacuate because she did not want to have to navigate the chaos of an evacuation with a child and two dogs "alone with them." In our study's three target communities, shouldering the labor of evacuation starts for women before the evacuation does. Women described gendered distribution of pre-evacuation activities, even where both men and women were available. They are primarily responsible for preparing their families for evacuation, including unnecessary work such as preparing a "72-hour backpack" promoted by civil protection while they should have their needs provided for in the evacuation centers. They also take on the emotional labor of maintaining calm within a frightened household and take on the stress of their children who, like them, may be too anxious to eat. Finally, they and possibly their husbands as well concern themselves with the health of their children, though they are more likely to do so from their home while their husband and older sons may be out gathering information and

advocating for their family members. By distributing labor, women may wait with their children; however, they may also be deprived of first-hand information on which to make their own assessments and their opportunity to advocate for themselves and their families, since they are the ones who will evacuate.

Finally, in this pre-evacuation phase, gendered norms give men more authority in decision making, even as women enact those decisions. In an environment where evacuations already lag behind the timeline of the paroxysm, in part due to inefficient decision-making processes (Naismith et al., in prep), decisions (and therefore evacuation) may be further delayed where men responsible for household- and even community-level decisions are out of communication. In 2018, only 54% of the population aged 7 and older in San Pedro Yepocapa were using cell phones, compared with 83% in Guatemala City (INE Guatemala, 2018). Because of the gendered labor distribution, with men likely to be engaged in paid work outside the community while women are at home with children, this is a likely scenario and one we have seen play out at Fuego already, as described in Section 3.1.

This norm of men making household- and community-level evacuation decisions is also problematic if men's risk perception is lower and/or tolerance is higher than that of the women in their community, for example because they are not there and do not have the situational awareness or because they are confident in their abilities to take appropriate action to decrease their risk. Multiple studies point to women as more likely than men to choose to evacuate in other contexts around the world, indirectly implying a higher risk perception or lower risk tolerance. In a literature review of studies on evacuations in multiple natural hazard contexts, Thompson et al. (2017) found that risk perception was a consistent positive predictor of evacuation; in case studies on risk perception, gender is a common differentiator, with women more commonly found to have lower perceptions of preparedness and higher perceptions of risk than men. In regards to volcanic hazards, specifically, researchers have found higher risk perception in women than men in communities in Mexico (Ponce-Pacheco et al., 2021), Ecuador (Jones et al., 2013), and Italy (Barberi et al., 2008). Flynn et al. (1994) suggest sociopolitical factors such as power explain why white men sampled in the U.S. have much lower risk perceptions than white women and all other non-white participants. This may well also be the case in rural Guatemala, a highly patriarchal society (Batthyány, 2011; Ortega Ponce, 2012) where men, as we can see from the decision-making norm, are afforded more power than women. If men do have lower risk perceptions or higher risk tolerances than women around Fuego, this would imply that some women would exceed their threshold for tolerable risk while having to wait for approval from male family members and outside aid.

Still, women around Fuego are not powerless. Despite prioritization of male voices, women described large spheres of influence. They exercise agency by preparing their families and encouraging members of their extended family, neighbors, and broader community to evacuate, through dialogue and through example, including through formal roles in local civil protection groups. In Broder et al.'s (2020) study of mothers in Florida, 80% of evacuees reported that feeling pressure from family and friends impacted their decision to evacuate. They found only about a third of non-evacuees reported this social influence on their decision to stay. At Fuego,

we know women were influenced by and influenced others in decisions both to stay and go, though it's possible that this social influence is particularly important in motivating others to evacuate. Because of tight family structures (Gibbons et al., 2021), it is important to enable extended families and ideally communities to stay together throughout evacuation, for example by designating an evacuation center for a single community. The influence a woman can have within a social network can be leveraged, for example by working closely with the women in the local civil protection groups. Also, and importantly, women overcome gendered household power dynamics–or possibly leverage them–to evacuate for the sake of their children's safety. Women may prioritize their caretaking role over the norm of submissiveness to their husbands to evacuate with their children regardless of their husband's advice.

Other studies on evacuation show how women in shelters assume extra burdens while shouldering more stress (Delica, 1998). Evacuation, if not properly managed, can heavily increase women's responsibilities and isolate them precisely when they may most need their social networks (Tobin and Whiteford, 2002). Evacuation can also require women to assume more responsibility in providing financially for their families (Delica, 1998). Our findings align with this previous research, showing that women in the rural Guatemalan context take their caretaking responsibilities with them throughout the evacuation process. These include looking after the elderly (e.g., giving them medicine) and caring for children (hygiene, health, entertainment). They also take on the emotional labor of addressing their children's fear, concerns, and discomfort both before evacuation and in shelters, while managing their own, in an unfamiliar setting.

4.5.2 Influences on evacuation decisions

Because women do exercise agency in decision making and have influence over others' decisions, it is particularly important to understand what women perceive as motivating their decisions to evacuate or shelter in place. Our interviewees overwhelmingly described children as their primary motivators to evacuate, citing their children's or grandchildren's safety, health, and wellbeing as their reasons to leave. Multiple interviewees described their children's behavior, e.g., crying, as a signal to evacuate, along with or instead of the volcanic activity. Women prioritizing children's needs at Fuego makes sense culturally. Guatemala is a highly collectivist culture, which tends to value family: "Prioritizing family and child well-being [is] … characteristic of Guatemalan culture, labeled as one of the most collectivist societies of the world" (Gibbons et al., 2021). Guatemalan women similarly reported prioritizing their children's development and health through the COVID-19 lockdown, and finding agency in doing so: "...women, despite living in a patriarchal culture, may feel empowered through their ability to care for and protect their children and families" (Gibbons et al., 2021). However, this prioritization of children is not unique to Guatemala and aligns with other research on evacuation decisions worldwide: Thompson et al. (2017) found in their literature review that households with children were more likely to evacuate than those without, and Brodar et al. (2020) found that, in particular, mothers with children under 7 years of age were more likely to evacuate than those with older children. As with the latter study, we found mothers evacuated not only to move their

kids to safety but also to reduce their children's stress even if they felt their lives were not in danger.

Despite many of our participants' strong motivation to protect their children, evacuation numbers for the three target communities were low (Section 3.1.2). Lack of permission from male authority figures in households may be one factor influencing low evacuation numbers, though there are other factors that would compel women to stay home as well. Because women's livelihoods are more likely to be associated with their home, and their home is their domain, evacuation implies a lot at stake for them to leave. Large families with many small children are common in these communities yet difficult to mobilize; Brodar et al. (2020) found families with many children were less likely to evacuate than families with fewer children in her study of mothers in Florida. At Fuego, women with many children face the additional challenge of lack of transportation (see section 4.3, below). Finally, while some participants who evacuated opined that everyone should leave when the authorities say to, many treated the official word as optional and used it to inform, rather than to dictate, their decisions. All five participants who did not evacuate as well as many who did shared a common complaint: that the authorities failed to provide adequate and timely transportation.

4.5.3 Barriers to evacuation

Inadequate transportation was overwhelmingly described as a common barrier to evacuation as shared by research participants. The turmoil the women experienced echoes the conflict of evacuation described at other volcanoes (Tobin and Whiteford, 2002; Goto et al., 2006), and transportation is recognized as a structural barrier to timely evacuation globally (Lazo et al., 2015; Barclay et al., 2019). At Fuego, previous work that surveyed residents about future evacuation behavior found lack of transportation to be a major concern (Escobar Wolf, 2013). As described in section 3.4.1, few households in these three communities have their own vehicles. Private vehicles are most commonly motorcycles, not trucks, and access requires four-wheel drive. In future eruptions of Fuego, people at risk will continue to require outside transportation to evacuate.

Factors affecting interviewees' perceived safety of transportation for the evacuation on 7-8 March included daytime vs nighttime travel, drivers who know the area, and uncrowded vehicles. Some interviewees shared that they were motivated to evacuate on the last bus because they knew it was their last opportunity to leave; they also discussed the discomfort of the overcrowded trip. Despite the hardships of evacuating, for many women this was not the first time they evacuated, and many said they would evacuate again. This speaks to the strength of desire to leave for those who evacuated (e.g., for children, Section 4.2) but also points to the importance of considering needs of safety and comfort for future evacuations. Women we talked with about the March eruption compared their experience with shelter conditions in previous evacuations, on the whole speaking much more favorably about the more recent conditions. Other people we talked with outside this set of interviews conveyed that negative past experiences with evacuation deters them from future evacuations. This concern for evacuation conditions is a common concern for evacuees relying on

government shelters (e.g., Barclay et al., 2019). More families may evacuate if they know shelters will be safe, comfortable, and provide for at least their basic needs.

Outside transportation was slow to arrive on 7 March, arriving after some residents perceived that Fuego had quietened (e.g., Panimaché 2, section 3.4.2). Effective emergency response plans must include the time needed to execute the plan so that evacuees have left a high-hazard zone before eruptive hazards arrive (Marrero et al., 2013). This is particularly pertinent at Fuego: "An evacuation plan should … take into account … the population lacking the means of self-transport and living in areas of difficult access for the evacuation vehicles. The effect of this group on the evacuation time is significant. To minimize the evacuation time, this population must be evacuated in advance of the rest, or at least re-located as early as possible to more accessible areas" (Marrero et al., 2013 (pg. 976)). The women we spoke to are aware of this (section 3.4.2). However, evacuations on 7 March happened at, or after, eruptive climax. This could mean that in future eruptions, evacuation might be undertaken at climax when lahars are already descending channels, with the consequence that evacuees either undertake enormous risk in attempting a crossing or have to turn back (Naismith et al., in prep; this paper, section 3.4.2). The consequences of transportation arriving late in future eruptions of Fuego is that women may be disinclined to evacuate for several reasons: the increased risk from crossing channels, or the belief that an eruption is declining. Pyroclastic flows can descend late in a paroxysm, so the risk of staying at home remains high. Timely arrival of transportation would avoid the "between a rock and a hard place" difficulty that women face in choosing whether to stay or go.

Women's experiences of transportation on 7 March show the hard choices they face between conflicting responsibilities during a crisis. Responsibilities related to local civic groups may conflict with family responsibilities. In Panimaché 1, a family relying on the father to drive them to safety was not able to evacuate because of his role in local governance. Because of a medical issue, they were not able to leave by bus; however, when he came home to drive them he was called back up to lead. This one case highlights multiple issues: That residents are taxed by multiple and sometimes conflicting responsibilities in crisis; families evacuate together, often as all or none; special needs such as medical issues may not be addressed in current evacuation plans; transportation is important and scarce; and that even when private transportation is available, women do not know how to drive the vehicles. These issues impact primarily women and the dependents who evacuate with them.

4.6 Implications

Our findings have critical implications for risk reduction practices at Fuego volcano. Women's responsibility for reproductive labor drives evacuation strategies and determines women's experiences in evacuation, as they act out their caretaking role throughout the evacuation process. The women we talked with prepare their families for evacuation, have networks of influence despite limited agency in evacuation decision-making, are highly driven by the need to protect their children, and look out for their families in evacuation shelters. Communication and evacuation strategies addressing women's concerns and leveraging their strengths can impact up

to ¾ of a community's populations, since women evacuate with the children and elderly in their family networks while men, for the most part, stay behind to protect property.

Because women are more likely than men to be present in a community during the onset of a crisis, information must be assured to reach them through direct channels. We hope the prominent themes identified through this study, most notably concern for the health (e.g., respiratory) and wellbeing (e.g., basic needs and emotional wellbeing) of young children as a primary motivator of women's actions, can serve to inform future messaging about risk reduction. Information about the timing and condition of transportation and evacuation centers is also critical to inform evacuation decisions. We ask whether more of the population would evacuate if women had more autonomy and agency in decision-making processes at both the community and household levels; had adequate and timely transportation; were assured they would be in the same evacuation center as the rest of their community; and knew the government would address their family's needs in the evacuation shelters. Decision-making may be facilitated by encouraging families to discuss how they will decide whether to evacuate if male partners are gone, so that women may enact these decisions on behalf of both parents without threatening household and community dynamics.

We suggest that women's concerns should be prioritized in the development of any early warning system or other evacuation strategies, including any criteria on which evacuation will be based, to assure that the members of these communities most likely to be affected by evacuations and with the most responsibility for others have their needs addressed. Involving women more closely in risk reduction strategy, development, and implementation is an important step toward improving DRR at Fuego and in line with commitments agreed to in the Hyogo and Sendai frameworks. However, this involvement must be approached carefully so as not to impinge on their family responsibilities during a crisis; the same applies for men. Clissold et al. (2020) recommend that DRR efforts that resource women's strengths must also include efforts to improve women's wellbeing, agency, livelihoods, and prospects.

Finally, we note that the norm that men stay behind to protect property and the assumption that they will be able to escape the danger of pyroclastic density currents on foot leaves the male population exposed to a threat that is fast and unpredictable, in turn leaving their evacuated families exposed to long-term hardships as survivors. Future efforts to strengthen DRR at Fuego could recognize more explicitly the dual value of life and livelihood, challenge any norms deterring men from evacuating, and include strategies that more explicitly address livelihood concerns without requiring residents' presence. Examples of this might be emergency personnel that stay throughout the entirety of evacuation, or a local evacuation shelter for each community that can sustain only a small number of residents. Addressing these challenges will require working with a diverse representation of residents to agree on strategies that address their concerns and enable safe evacuations of as much of the population as possible.

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5 Conclusions

At Fuego volcano, Guatemala, temporary evacuation is the de facto risk-reducing risk measure in response to potentially deadly pyroclastic density currents (PDCs) in the absence of permanent relocation programs. Yet despite risk-reduction programs aimed at preparing scientists, civil protection, and residents for response in the face of danger, the research presented here indicates that the 3 June 2018 disaster resulted in great part from authorities' lack of capacities to use the information available to them to enact an effective early warning system (EWS) and that current practices are unlikely to avoid a similar disaster if it were to happen now. Improvements in technological and scientific capabilities, i.e., instrumentation for monitoring and capacity to analyze data, will be important in the future for refining forecasts but of much more immediate importance is defining an evacuation decision-making process with the following characteristics:

- Is understood and agreed-upon by authorities, with roles and responsibilities clearly defined
- Functions within the current capabilities of authorities to obtain and process information
- Considers the short timescales and high resource requirements of evacuation at Fuego volcano
- Is refined through co-creation between authorities and residents in each community to address local cultures, capacities, concerns, and geographies,
- Considers how the system increases or decreases vulnerability of residents, and
- Tolerates ‘false alarms’ or ‘unnecessary evacuations,’ is willing to invest public resources at a greater level to reduce risk, particularly for crisis response, and views these events as successes used to refine the process of early warning and evacuation.

While much of these findings reinforce previous research on efficacy of EWS, this dissertation provides important contributions to ongoing efforts to describe, promote, and apply various EWS models. In particular, this research demonstrates the importance of explicitly including decision-making processes, resources and infrastructure for taking protective actions, and consideration of competing risks into EWS models.

A IRB-approved recruitment scripts and interview guides

The following recruitment scripts and interview guides were approved through Institutional Review Board (IRB) approval 1760726-2 from Michigan Technological University. In practice, scripts and interview questions were modified for each individual depending in part on the goals of the interview with that individual.

A.1 Recruitment Scripts

Interview recruitment – Professionals - English - email

Dear ____,

My name is Beth Bartel and I am a PhD student in Geology at Michigan Technological University. I am researching the human impact of hazards at Fuego volcano. Specifically, I am researching the effectiveness of early warning and how it might be improved. Part of my research includes talking to people who are involved in risk mitigation and volcanic crises, to learn more about your experiences working with hazards and communities around the volcano. This may, but does not have to, include talking about the June 3, 2018 eruption. I understand this topic may be difficult to talk about because of the tragic memories that it may bring back for you, and if you so choose we can discuss other aspects of early warning instead. If we meet, I will let you know when I will ask about the eruption and its aftermath and you can decide whether you are comfortable talking about it.

The interviews last about one hour. Your participation is voluntary and you can end, pause, or postpone the interview at any time. No questions are mandatory. I will record the interview so I can listen to it later and transcribe it, and will use the interview in my analysis, but I will not publish the recording or identify you with the interview content unless you give me permission.

I am hoping this research will be relevant not only to risk reduction at Fuego volcano but at other volcanoes in Guatemala, and around the world.

If you are interested, please let me know and we can schedule a time convenient for you. I am also happy to answer any questions you may have.

Regards,

Beth Bartel

Interview recruitment – Residents - English - verbal

My name is Beth Bartel and I am a PhD student in Geology at Michigan Technological University. I am researching the human impact of hazards at Fuego volcano. Specifically, I am researching the effectiveness of the early warning system. Part of my research includes talking to people in different communities near the volcano, like _____[name of community]___, to learn more about their experiences living with the volcano and what they think about possible future eruptions.

Some of my questions have to do with the eruption on June 3, 2018, but I recognize that this may be a very difficult subject because it may bring back sad or distressing memories for you, and talking about the eruption and its aftermath is completely optional and we don't have to do it if you don't want to. If you are okay talking with me, I will let you know when I will ask about the eruption and you can decide whether you are comfortable talking about it.

The interviews last about one hour. Your participation is voluntary and you can end, pause, or postpone the interview at any time. No questions are mandatory. I will record the interview so I can listen to it later and transcribe it, and will use the interview in my analysis, but I will not publish the recording or identify you with the interview content unless you give me permission. I am hoping this research will help us learn some important things that may help to avoid such tragedies in the future, not only at Fuego volcano but at other volcanoes in Guatemala, and around the world.

Interview recruitment – Professionals - Spanish - email

Estimado/a ____,

Mi nombre es Beth Bartel y soy estudiante de doctorado en Geología en la Universidad Tecnológica de Michigan. Estoy haciendo una investigación sobre el impacto humano de los peligros del volcán de Fuego. Específicamente, estoy investigando la efectividad de la alerta temprana y cómo se lo puede mejorar. Parte de mi investigación incluye hablar con personas que están involucradas en la mitigación de riesgo y las crisis volcánicas, para aprender más sobre sus experiencias trabajando con los peligros y comunidades alrededor del volcán. La entrevista puede tener que ver con la erupción de 3 junio 2018, pero no es necesario. Entiendo que este tema puede ser difícil de hablar debido a los trágicos recuerdos que puede traerle, y si así lo elige, podemos discutir otros aspectos de la alerta temprana en su lugar. Si hablamos, le haré saber cuándo le preguntaré sobre la erupción y sus consecuencias y podrá decidir si se siente cómodo hablando de ello.

Las entrevistas duran aproximadamente una hora. Su participación es voluntaria y puedes finalizar, pausar, o posponer la entrevista en cualquier momento. Ninguna pregunta es obligatoria. Grabaré la entrevista en audio para poder escucharla más tarde y transcribirla, y usaré la entrevista en mi análisis, pero no publicaré la grabación ni le identificaré con el contenido de la entrevista a menos que me des permiso.

Espero que esta investigación sea relevante no solo para la reducción del riesgo en el volcán de Fuego, sino también en otros volcanes en Guatemala y en todo el mundo.

Si está interesado, hágamelo saber y podemos programar un horario conveniente para usted. También me complace responder cualquier pregunta que pueda tener.

Saludos,

Beth Bartel

Interview recruitment – Residents - Spanish - verbal

Mi nombre es Beth Bartel y soy estudiante de doctorado en Geología en la Universidad Tecnológica de Michigan. Estoy haciendo una investigación sobre el impacto humano de los peligros del volcán de Fuego. Específicamente, estoy investigando la efectividad de la alerta temprana. Parte de mi investigación incluye hablar con personas en diferentes

comunidades cercanas al volcán, como [nombre de la comunidad] ___, para aprender más sobre sus experiencias viviendo con el volcán y lo que piensan de posibles erupciones en el futuro.

Algunas de mis preguntas tienen que ver con la erupción del 3 de junio de 2018, pero reconozco que este puede ser un tema muy difícil porque puede traerle recuerdos tristes o angustiantes, y hablar sobre la erupción y sus consecuencias es completamente opcional. No tenemos que hacerlo si no Ud. quiere. Si está de acuerdo en hablar conmigo, le haré saber cuándo le preguntaré sobre la erupción y podrá decidir si se siente cómodo hablando de ello.

Las entrevistas duran aproximadamente una hora. Su participación es voluntaria y puede finalizar, pausar o posponer la entrevista en cualquier momento. Ninguna pregunta es obligatoria. Grabaré la entrevista para poder escucharla más tarde y transcribirla, y usaré la entrevista en mi análisis, pero no publicaré la grabación ni le identificaré a Ud. con el contenido de la entrevista a menos que me de permiso.

Espero que esta investigación nos ayude a aprender algunas cosas importantes que pueden ayudar a evitar tales tragedias en el futuro, no solo en el volcán de Fuego sino en otros volcanes en Guatemala y en todo el mundo.

¿Tiene Ud. alguna pregunta para mi?
¿Está Ud. dispuesto(a) a participar en esta entrevista?

A.2 Consent Script and Interview Guide for professionals (officials and volcano experts)

Instructions

Instructions and explanation of the interview protocol are given in black. The actual set of instructions and questions that the interviewer should give to the interviewee are given in colored text. Spanish is given in red, and will always or almost always be the language used. English translations are given in blue. The **first part of each question is the main point that should be asked (in bold)**, and it is followed by a set of follow-up questions that may be useful to clarify and extend the main question. These follow-up questions can be asked at the discretion of the interviewer. Other related or relevant questions may be asked as well.

Is the participant 18 years of age or older? _____
Gender: _____
Organization: _____

I Introduction

Explain who you are, what you're doing, and what the interview/data are for. Explain to the interviewee that their identity/privacy will be protected and that the interview is confidential. Ask the interviewee for verbal consent to conduct the interview and to record it. The idea of the interview is to get some information on three areas: experiences of people with previous eruptions/evacuations, how people get information about the volcano's activity and warnings, and how people think the warning system *should* be.

If this script is summarized, it **must** include:

- That this is research
- That the conversation will be recorded
- That the conversation will be used only for research purposes
- That the conversation will be kept private and confidential but a risk does exist for a breach of privacy and confidentiality, which I will prevent by removing all names from interview materials
- That the interview will contain questions about the June 3, 2018 eruption but that these are optional and are only part of the interview
- That no question is obligatory
- That the participant may pause or stop the conversation at any time

Mi nombre es Beth Bartel y soy estudiante de doctorado en Geología en la Universidad Tecnológica de Michigan. Estoy haciendo una investigación sobre el impacto humano de los peligros del volcán de Fuego. Específicamente, estoy investigando la efectividad de la alerta temprana y cómo se lo puede mejorar. Parte de mi investigación incluye hablar con personas que están involucradas en la mitigación de riesgo y las crisis volcánicas, para aprender más sobre sus experiencias trabajando con los peligros y comunidades alrededor del volcán. La entrevista puede tener que ver con la erupción de 3 junio 2018, pero no es necesario. Entiendo que este tema puede ser difícil de hablar debido a los trágicos recuerdos que puede traerle, y si así lo elige, podemos discutir otros aspectos de la alerta temprana en su lugar. Si hablamos,

le haré saber cuándo le preguntaré sobre la erupción y sus consecuencias y podrá decidir si se siente cómodo hablando de ello.

Las entrevistas duran aproximadamente una hora. Su participación es voluntaria y puedes finalizar, pausar, o posponer la entrevista en cualquier momento. Ninguna pregunta es obligatoria. Grabaré la entrevista en audio para poder escucharla más tarde y transcribirla, y usaré la entrevista en mi análisis, pero no publicaré la grabación ni le identificaré con el contenido de la entrevista a menos que me des permiso.

Como se mencionó, los riesgos asociados con este proyecto incluyen la posibilidad de causarle angustia emocional debido al tema de discusión. Además, debido a que estoy documentando su nombre, la pérdida de su privacidad o la confidencialidad de sus datos también es un riesgo. Sin embargo, si comenzamos a discutir los eventos del 3 de junio de 2018 y decide que es demasiado difícil continuar, puede pedirme que detenga la entrevista. Para ayudar a proteger su identidad y los datos de investigación que proporcione, le asignaré un código único que se utilizará para documentar cualquier información que me proporcione. Se conservará una clave maestra que vincula su código con su nombre, pero se almacenará por separado de todos los datos de investigación que proporcionó y estará protegida por una contraseña. Seré la única persona con acceso a la llave maestra para volver a identificarle.

Espero que esta investigación sea relevante no solo para la reducción del riesgo en el volcán de Fuego, sino también en otros volcanes en Guatemala y en todo el mundo.
¿Está bien que empecemos la entrevista?

My name is Beth Bartel and I am a PhD student in Geology at Michigan Technological University. I am researching the human impact of hazards at Fuego volcano. Specifically, I am researching the effectiveness of early warning and how it might be improved. Part of my research includes talking to people who are involved in risk mitigation and volcanic crises, to learn more about your experiences working with hazards and communities around the volcano. This may, but does not have to, include talking about the June 3, 2018 eruption. I understand this topic may be difficult to talk about because of the tragic memories that it may bring back for you, and if you so choose we can discuss other aspects of early warning instead. If we meet, I will let you know when I will ask about the eruption and its aftermath and you can decide whether you are comfortable talking about it.

The interviews last about one hour. Your participation is voluntary and you can end, pause, or postpone the interview at any time. No questions are mandatory. I will record the interview so I can listen to it later and transcribe it, and will use the interview in my analysis, but I will not publish the recording or identify you with the interview content unless you give me permission.

As mentioned, the risks associated with this project include the possibility of causing you emotional distress due to the topic of discussion. Additionally, because I am documenting your name, a loss of your privacy or confidentiality of your data is also a risk. However, if we start to discuss the events of June 3, 2018 and you decide it is too difficult to continue you can ask me to stop the interview. To help protect your identity and the research data you provide, I will assign you a unique code that will be used to document any information you provide me. A master key that links your code with your name will be kept but it will be stored separately

from all research data you've provided and protected by a password. I will be the only person with access to the master key to re-identify you.

I am hoping this research will be relevant not only to risk reduction at Fuego volcano but at other volcanoes in Guatemala, and around the world.
Is it okay if we start the interview?

II Icebreaker and background

1) **¿Cuál es el trabajo que usted desarrolla y a qué se dedica en el día a día?**
1) **What's your job, and what does the day-to-day look like?**

2) **¿Cómo se involucró usted en este trabajo?**
2) **How did you get involved in this work?**

3) **¿Cuál es el papel de su institución en reducir el impacto de los desastres en la sociedad?**
3) **What is your institution's role in reducing the societal impact of disasters?**

4) **¿Cuál es su experiencia trabajando en volcanes en general?**
4) **What is your experience working on volcanoes in general?**

III The eruption of June 3, 2018

Tengo unas preguntas que tienen que ver con la erupción del volcán de Fuego de 3 junio 2018. Podemos hablar de eso ahora, o prefiere esperar?

I have several questions that have to do with the Fuego volcano eruption of June 3, 2018. Can we talk about this now, or would you rather wait?

5) **Cuénteme de la erupción del Volcán de Fuego del 3 junio 2018.**

- De lo que usted sabe, puede decirme, ¿qué fue lo que pasó?
- ¿Estuvo usted involucrado de alguna forma en el desastre y la respuesta?
- ¿Por qué murieron las personas en San Miguel Los Lotes?
- ¿Por qué murieron las personas sobre el puente de Las Lajas?
- ¿Qué fue lo que pasó en La Reunión?
- ¿Qué hizo o dijo CONRED respecto de la erupción ese día, antes de que San Miguel Los Lotes fuera destruido?
    - ¿Publicaron alertas o comunicaron información sobre el riesgo?
- ¿Qué hizo o dijo INSIVUMEH respecto de la erupción ese día, antes de que San Miguel Los Lotes fuera destruido?
    - ¿Publicaron alertas o comunicaron información sobre el riesgo?

- ¿Que hicieron las autoridades locales (municipalidad, etc.) ese día en respecto a la seguridad pública?
- ¿Hubo alertas para que las personas de las comunidades evacuaran?
    - Porque sí o porque no?
- Evacuaron las personas de las comunidades?
    - ¿Por qué sí o por qué no?
- ¿Cree usted que CONRED hizo todo lo que pudo haber hecho?
- ¿Cree usted que INSIVUMEH hizo todo lo que pudo haber hecho?
- ¿Cree usted que las comunidades alrededor del volcán hicieron todo lo que pudieron haber hecho?
- En su opinión, en retrospectiva, ¿qué debería haber sucedido ese día?
- ¿Pensó que algo como esto podía suceder?
- ¿Podría una mejor comunicación haber mejorado el resultado?
- Por curiosidad, ¿las redes sociales jugaron un papel en la comunicación ese día?
- ¿Hay algo más que quiera comentar sobre lo que pasó ese día?

5) **Tell me about the June 3, 2018 eruption of Fuego volcano.**

- From what you know, can you tell me what happened?
- Were you involved in any way in the disaster and response?
- Why did the people in San Miguel Los Lotes die?
- Why did the people at the Las Lajas bridge die?
- What happened at La Reunión?
- What did CONRED do with respect to the eruption this day, before San Miguel Los Lotes was destroyed?
    - Did they publish alerts or communication about the risk?
- What did INSIVUMEH do with respect to the eruption this day, before San Miguel Los Lotes was destroyed?
    - Did they publish alerts or communication about the risk?
- What did local authorities (municipalities, etc.) do with respect to public safety?
- Were there alerts/warnings for people in the communities to evacuate?
    - Why or why not?
- Did people from the communities evacuate?
    - Why or why not?
- Do you think CONRED did everything they could?
- Do you think INSIVUMEH did everything they could?
- Do you think the communities around the volcano did everything they could?
- In your opinion, in retrospect, what should have happened this day?
- Did you think that something like this could happen?
- Could better communication have improved the outcome?
- Out of curiosity, did social media play a role in communication that day?
- Is there something in particular that stands out to you from that day?

IV Early warning

Ahora hablemos del estado actual de alerta temprana en Fuego. Idealmente un sistema de alerta temprana permitiría a las personas expuestas al riesgo volcánico evacuar antes de que

una erupción volcánica pueda causar su muerte.

Now let's talk about the current state of early warning at Fuego. Ideally, an early warning system will allow people exposed to volcanic hazards to evacuate before any life-threatening danger.

6) **¿Cree que la alerta temprana en el volcán de Fuego es posible en las condiciones actuales? Es decir, si ocurriera una crisis volcánica hoy en día, ¿sería posible la alerta temprana? ¿Por qué sí o por qué no?**

Conocimiento y información

- ¿Tienen las autoridades como INSIVUMEH y CONRED, la capacidad (expertos, equipo, recursos, etc.) para monitorear y pronosticar las amenazas volcánicas, es decir saber en qué momento el volcán se vuelve muy peligroso?
    - ¿Por qué sí o por qué no?
- ¿Tienen las personas en las poblaciones, o las autoridades locales (por ejemplo las municipalidades), la capacidad y el conocimiento para saber si el volcán se está volviendo muy peligroso?
- ¿Tienen las autoridades como INSIVUMEH o CONRED los criterios y la información suficiente para recomendar u ordenar una evacuación de la población durante una crisis volcánica?
- ¿Tienen las autoridades locales como las municipalidades los criterios y la información suficiente para recomendar u ordenar una evacuación de la población durante una crisis volcánica?
- ¿Tienen las personas en las comunidades los criterios y la información suficiente para decidir que van a evacuar durante una crisis volcánica?
- ¿Pueden las personas de las comunidades contribuir (o realizar por sí mismas) al monitoreo y pronóstico de las amenazas volcánicas durante una crisis?
- Al saber que deben evacuar, ¿sabe la gente en las comunidades que hacer para poder evacuar? ¿Hay planes de cómo se puede hacer esto como comunidad o como familia?

Capacidad

- Al haber decidido que deben evacuar, ¿tienen las personas en las comunidades los medios materiales y logísticos (albergues a donde ir, transporte para poder ir, etc.) para poder evacuar?
- ¿Cómo debería ser el proceso de toma de decisiones para decidir que la población debe evacuar durante una crisis?
    - ¿Qué información es necesaria?
    - ¿Qué criterios deben usarse para decidir cuando el riesgo volcánico es demasiado alto y se vuelve inaceptable, y por lo tanto debe evacuarse?
    - ¿Quiénes deben tomar esas decisiones?
    - ¿De qué forma afecta la disponibilidad de recursos y apoyo logístico, como albergues, transporte, seguridad, etc., en la toma de estas decisiones?
- La CONRED frecuentemente menciona el término "autoevacuación" en relación a que las comunidades deben evacuar por sí mismas cuando así lo consideren necesario. ¿Cree que los habitantes de las comunidades están adecuadamente preparados para autoevacuarse?

    - Si no es así, ¿qué necesitan?
    - Tienen el conocimiento para monitorear la actividad volcánica por sí mismos y saber cuando esta es demasiado peligrosa?
    - Tienen los criterios para decidir por sí mismos en qué momento deben evacuar?
    - Tienen los recursos (albergues a donde ir, transporte para trasladarse rápidamente a los albergues, etc.) para de hecho evacuar durante una crisis?
- ¿Cuáles podrían ser las principales razones por las que la gente de las comunidades decidiría no evacuar durante una crisis?
- ¿Cómo sería un sistema de alerta y evacuación ideal?

Comunicación

- En el caso de que sean las autoridades como INSIVUMEH y CONRED, o incluso si fueran las municipalidades, las que deben alertar a las comunidades y recomendarles evacuar, podrían comunicar la recomendación u orden de evacuación con suficiente rapidez antes de que amenazas, como flujos piroclásticos, lleguen a las comunidades? ¿Cómo podrían comunicarse de forma rápida y eficiente?
- ¿Es la información o las alertas que autoridades como INSIVUMEH y CONRED comunican a las poblaciones o a las autoridades locales (como municipalidades) suficientemente informativas y entendibles para tomar la decisión de evacuar?
- ¿Cree que la comunicación entre autoridades a nivel nacional como INSIVUMEH y CONRED, autoridades locales como las municipalidades y los habitantes de las comunidades alrededor del volcán de Fuego es adecuada durante una crisis?
    - Si no es así, ¿cuáles son los mayores problemas?, y ¿cómo los mejoraría?
    - ¿Cuáles deberían ser los canales de comunicación? Por ejemplo los boletines de algunas de estas instituciones se publican en las redes sociales, pero es ese el mejor canal de comunicación?

Confianza

- ¿Confía o cree la gente de las comunidades en la información sobre el riesgo, o las recomendaciones u órdenes de evacuar que autoridades como INSIVUMEH y CONRED hacen?
    - ¿Por qué sí o por qué no?
- ¿Confía o cree la gente de las comunidades en la información sobre el riesgo, o las recomendaciones u órdenes de evacuar que autoridades locales como las municipalidades hacen?

6) **Do you believe an early warning at Fuego is possible given current conditions? That is to say, if a volcanic crisis happened today, would early warning be possible? Why or why not?**

Knowledge and information

- Do the authorities like INSIVUMEH and CONRED have the capacity--experts,

equipment, resources, etc.--to monitor and forecast volcanic hazards, that is to say, know when a volcano becomes dangerous?
    - Why or why not?
- Do people living around the volcano, or local authorities (such as municipalities), have the capacity and knowledge to know if the volcano is becoming dangerous?
- Do the authorities like INSIVUMEH and CONRED have sufficient criteria and information to recommend or order an evacuation during a volcanic crisis?
- Do the local authorities like municipalities have sufficient criteria and information to recommend or order an evacuation during a volcanic crisis?
- Do people in the communities have sufficient criteria and information to decide whether to evacuate during a volcanic crisis?
- Can people in the communities contribute to or actualize their own monitoring and forecasting of volcanic hazards during a crisis?
- On knowing they should evacuate, do people know what to do? Are there plans for how to evacuate as a community or family?

Capacity

- Having decided that they should evacuate, do the people in the communities have the material and logistical means (shelters to go to, transportation to go, etc.) to be able to evacuate?
- What should the decision-making process look like to decide whether the population should evacuate during a crisis?
    - What information is necessary?
    - What criteria should be used to decide when the volcanic risk is too high and becomes unacceptable, and therefore people should evacuate?
    - Who should make those decisions?
    - How does the availability of resources and logistical support, such as shelters, transportation, security, etc., affect the making of these decisions?
- CONRED frequently mentions the term "self-evacuation" in relation to the fact that communities must evacuate themselves when they deem it necessary. Do you think that the inhabitants of the communities are adequately prepared to evacuate themselves?
    - If not, what do they need?
    - Do they have the knowledge to monitor volcanic activity themselves and know when it is too dangerous?
    - Do they have the criteria to decide for themselves when to evacuate?
    - Do they have the resources (shelters to go to, transportation to get to shelters quickly, etc.) to actually evacuate during a crisis?
- What could be the main reasons why people in communities would decide not to evacuate during a crisis?
- What would an ideal evacuation and alert system look like?

Communication

- In the case that authorities such as INSIVUMEH and CONRED, or municipalities, are the ones who should alert communities and recommend evacuation, could they communicate the recommendation or order to evacuate quickly enough before hazards such as pyroclastic flows reach the communities?
    - How could they communicate this rapidly and efficiently?

- Is the information or alerts that authorities such as INSIVUMEH and CONRED communicate to the populations or local authorities (such as municipalities) sufficiently informative and understandable for them to make the decision to evacuate?
- Do you think that communication between authorities at the national level such as INSIVUMEH and CONRED, local authorities such as municipalities, and the inhabitants of the communities around the Fuego volcano is adequate during a crisis?
    - If not, what are the biggest problems, and how would you improve them?
    - What should the communication channels be? For example, the bulletins of some of these institutions are published on social networks, but is that the best communication channel?

Trust

- Do the people of the communities trust or believe in the information about the risk, or the recommendations or orders to evacuate that authorities such as INSIVUMEH and CONRED make?
    - Why or why not?
- Do the people of the communities trust or believe in the information about the risk, or the recommendations or orders to evacuate that local authorities such as municipalities make?

V Final section and additional comments

Casi hemos terminado. Solo tengo algunas preguntas más que son más generales.

We're almost through. I just have a few more questions that are more general.

8. **¿Hay algo que le gustaría entender mejor sobre el volcán o sobre las evacuaciones de las poblaciones cercanas al volcán?**

8. **Is there something you wish you understood better about the volcano or about evacuations of the populations around the volcano?**

9. **¿Qué consejo daría a otros profesionales que intentan reducir el riesgo alrededor de un volcán activo?**

9. **What advice do you have for other professionals trying to reduce risk around an active volcano?**

10. **¿Hay algo más que le gustaría compartir, algo de lo que no hemos hablado, pero que cree que es interesante o importante que yo sepa?**

10. **Is there anything else you would like to share--something that we missed talking about, but that you think is interesting, or important for me to know?**

Muchas gracias por tu tiempo. ¿Tienes alguna pregunta para mí?

Thank you very much for your time. Do you have any questions for me?

Give contact information if desired.

A.3 Consent Script and Interview Guide for Residents

Instructions

Instructions and explanation of the interview protocol are given in black. The actual set of instructions and questions that the interviewer should give to the interviewee are given in colored text. Spanish is given in red, and will always or almost always be the language used. English translations are given in blue. The **first part of each question is the main point that should be asked (in bold)**, and it is followed by a set of follow-up questions that may be useful to clarify and extend the main question. These follow-up questions can be asked at the discretion of the interviewer. Other related or relevant questions may be asked as well.

Is the participant 18 years of age or older? _____
Gender: _____
Organization: _____

I Introduction

Explain who you are, what you're doing, and what the interview/data are for. Explain to the interviewee that their identity/privacy will be protected and that the interview is confidential. Ask the interviewee for verbal consent to conduct the interview and to record it. The idea of the interview is to get some information on three areas: experiences of people with previous eruptions/evacuations, how people get information about the volcano's activity and warnings, and how people think the warning system *should* be.

If this script is summarized, it **must** include:

- This this is research
- That the conversation will be recorded
- That the conversation will be used only for research purposes
- That the conversation will be kept private and confidential but a risk does exist for a breach of privacy and confidentiality, which we will prevent by removing names from all interview materials
- That the interview will contain questions about the June 3, 2018 eruption but that these are optional and are only part of the interview
- That no question is obligatory
- That the participant may pause or stop the conversation at any time

Mi nombre es Beth Bartel y soy estudiante de doctorado en Geología en la Universidad Tecnológica de Michigan. Estoy haciendo una investigación sobre el impacto humano de los peligros del volcán de Fuego. Específicamente, estoy investigando la efectividad de la alerta temprana. Parte de mi investigación incluye hablar con personas en diferentes comunidades cercanas al volcán, como [nombre de la comunidad] ___, para aprender más sobre sus experiencias viviendo con el volcán y lo que piensan de posibles erupciones en el futuro. Espero que esta investigación nos ayude a aprender algunas cosas importantes que pueden ayudar a evitar tales tragedias en el futuro, no solo en el volcán de Fuego sino en otros volcanes en Guatemala.

Algunas de mis preguntas tienen que ver con la erupción del 3 de junio de 2018, pero reconozco que este puede ser un tema muy difícil porque puede traerle recuerdos tristes o angustiantes, y hablar sobre la erupción y sus consecuencias es completamente opcional. No tenemos que hacerlo si no Ud. quiere. Si está de acuerdo en hablar conmigo, le haré saber cuándo le preguntaré sobre la erupción y podrá decidir si se siente cómodo hablando de ello.

Como se mencionó, los riesgos asociados con este proyecto incluyen la posibilidad de hacer que se sienta triste o angustiado debido al tema de discusión. Además, debido a que estoy documentando su nombre, la pérdida de su privacidad o la confidencialidad de sus datos también es un riesgo. Sin embargo, si comenzamos a discutir los eventos del 3 de junio de 2018 y decide que es demasiado difícil continuar, puede pedirme que detenga la entrevista. Para ayudar a proteger su identidad y los datos de investigación que proporcione, mantendré su nombre separado de la información de la entrevista y seré la única persona que podrá identificar que esta entrevista es con usted.

Grabaré la entrevista para poder escucharla más tarde y transcribirla, y usaré la entrevista en mi análisis, pero no publicaré la grabación ni le identificaré a Ud. con el contenido de la entrevista a menos que me de permiso. Ud. puede finalizar, pausar o posponer la entrevista en cualquier momento. Ninguna pregunta es obligatoria.

¿Le parece bien?

My name is Beth Bartel and I am a PhD student in Geology at Michigan Technological University. I am researching the human impact of hazards at Fuego volcano. Specifically, I am researching the effectiveness of the early warning system. Part of my research includes talking to people in different communities near the volcano, like _____[name of community]___, to learn more about their experiences living with the volcano and what they think about possible future eruptions. I am hoping this research will help us learn some important things that may help to avoid tragedies in the future, not only at Fuego volcano but at other volcanoes in Guatemala.

Some of my questions have to do with the eruption on June 3, 2018, but I recognize that this may be a very difficult subject because it may bring back sad or distressing memories for you, and talking about the eruption and its aftermath is completely optional and we don't have to do it if you don't want to. I will let you know when I will ask about the eruption and you can decide whether you are comfortable talking about it.

As mentioned, the risks associated with this project include the possibility of causing you to feel sad or distressed due to the topic of discussion. Additionally, because I am documenting your name, a loss of your privacy or confidentiality of your data is also a risk. However, if we start to discuss the events of June 3, 2018 and you decide it is too difficult to continue you can ask me to stop the interview. To help protect your identity and the research data you provide, I will keep your name separate from the interview information and will be the only person who will be able to identify that this interview is with you.

I will record our conversation so I can listen to it later and transcribe it, and will use the interview in my analysis, but I will not publish the recording or identify you unless you give me

permission. You can end, pause, or postpone our conversation at any time. No questions are mandatory.

Is that okay with you?

II Icebreaker and background

These questions should engage the interviewee in a topic that they like and may open the interview to a more pleasant and fluid conversation.

1) **¿Cuánto tiempo tiene usted de vivir en esta comunidad?**
- ¿Es usted de esta comunidad?
- ¿Cómo llegó a vivir aquí?

1) **How long have you been living in this community?**
- Are you from this community?
- How did you come to live here?

2) **¿A qué se dedica en el día a día?**

2) **What is a typical day like for you?**

3) **¿Espera que sus hijos se queden y vivan aquí?**

3) **Do you hope your kids will stay and make their lives here?**

III Living with the volcano

4) **¿En qué medida el volcán forma parte de su vida diaria?**
- ¿Cómo ves el volcán? ¿Es un amigo, un enemigo, un vecino…?

4) **How much is the volcano a part of your daily life?**
- How do you see the volcano? Is it a friend, an enemy, a neighbor…?

5) **¿Qué peligros presenta el volcán?**
- ¿Hay algo que puedas hacer al respecto?

5) **What hazards does the volcano pose?**
- Is there anything you can do about them?

IV The eruption of June 3, 2018

Tengo unas preguntas que tienen que ver con la erupción del volcán de Fuego de

3 junio 2018. Podemos hablar de eso ahora, o prefiere esperar?

I have several questions that have to do with the Fuego volcano eruption of June 3, 2018. Can we talk about this now, or would you rather wait?

6) **Cuénteme lo que sabe sobre la erupción del 3 de junio de 2018 y su experiencia personal.**

- ¿Dónde estaba Ud. cuando fue la erupción?
- ¿Cuál fue su experiencia personal y la de su familia?
- ¿Tuvieron Uds. que evacuar durante la erupción?

Si evacuaron:

- ¿Cómo tomaron la decisión de evacuar?
  - ¿Por qué decidieron evacuar?
  - ¿Qué fue lo que escucharon o vieron que los hizo evacuar?
  - ¿A qué hora decidieron evacuar?
- El INSIVUMEH o la CONRED, o alguna otra autoridad (por ejemplo la municipalidad) les dijeron que evacuaran, o Uds. decidieron evacuar por su propia cuenta?
- Si evacuaron por su propia cuenta, le avisaron a CONRED u otra autoridad (la muni, etc.) que iban a evacuar?
- La decisión de evacuar la tomaron como familia o como comunidad?

A todos:

- ¿Cuántas personas de su comunidad evacuaron? Todos? Casi todos? La mayoría? La mitad? Menos de la mitad? Solo algunos pocos?
- ¿Le hablaron a otros familiares, amigos o conocidos para que ellos también evacuaran, en su comunidad o en otras comunidades?

Si evacuaron:

- ¿A dónde evacuaron?
- ¿Cómo se transportaron de la comunidad hacia donde evacuaron?
- En el momento de la evacuación, ¿recibieron ayuda (transporte, etc.) de la CONRED o alguna otra autoridad (la muni, etc.)?
- ¿Cuánto tiempo permanecieron evacuados?
- ¿Se quedó alguien cuidando sus casas o cosas en la comunidad mientras permanecieron evacuados?
- ¿Cómo fue su experiencia en el lugar al que evacuaron?
- ¿Cómo o por qué decidieron regresar a su comunidad y ya no permanecer evacuados?

Si no evacuaron:

- Trató Ud. de evacuar pero no pudo? ¿Por qué?

A todos:

- ¿Tiene usted familiares, o amigos o conocidos que evacuaron durante la erupción?
- ¿Tiene usted familiares, o amigos o conocidos que murieron en la erupción?
- ¿En su opinión qué fue lo que pasó en San Miguel Los Lotes?
- ¿Por qué murieron las personas en San Miguel Los Lotes?
- ¿Por qué murieron las personas sobre el puente de Las Lajas?
- ¿Qué fue lo que pasó en La Reunión?
- ¿Qué hizo la CONRED ese día?
- ¿Qué hizo el INSIVUMEH ese día?
- ¿Qué hicieron las autoridades locales (municipalidad, etc.) ese dia?

- ¿Hubieron alertas para que las personas de las comunidades evacuaran?
    - ¿Porque sí o porque no?
- ¿Evacuaron las personas de las comunidades?
    - ¿Por qué sí o por qué no?
- ¿Cree Ud. que CONRED hizo todo lo que pudo haber hecho?
- ¿Cree Ud. que INSIVUMEH hizo todo lo que pudo haber hecho?
- ¿Cree usted que las comunidades alrededor del volcán hicieron todo lo que pudieron haber hecho?
- En su opinión, en retrospectiva, ¿qué debería haber sucedido ese día?
- ¿Pensó que algo como esto podía suceder?
- ¿Hay algo más que quiera comentar sobre lo que pasó en particular que te llame la atención de ese día?

6) **Tell me what you know about the June 3, 2018 eruption and your personal experience.**

- Where were you when the eruption occurred?
- What was your personal experience and that of your family?
- Did you have to evacuate during the eruption?

If they evacuated:

- How did you make the decision to evacuate?
- Why did you decide to evacuate?
- What did you hear or see that made you evacuate?
- What time did you decide to evacuate?
- Did INSIVUMEH or CONRED, or some other authority (for example the municipality) tell you to evacuate, or did you decide to evacuate on your own?
- If you evacuated on your own, did you notify CONRED or another authority (the municipality, etc.) that you were going to evacuate?
- Was the decision to evacuate made as a family or as a community?

To all:

- How many people from your community evacuated? Everyone? Almost every? The majority? Half? Less than half? Just a few?
- Did you talk to other family members, friends or acquaintances so that they too could evacuate, in your community or in other communities?

If they evacuated:

- Where did you evacuate?
- How did you get from the community to where you evacuated?
- At the time of evacuation, did you receive help (transportation, etc.) from CONRED or some other authority (the municipality, etc.)?
- How long did you remain evacuated?
- Did someone take care of your homes or things in the community while you were evacuated?
- How was your experience in the place where you evacuated?
- How or why did you decide to return to your community and no longer remain evacuated?

If they did not evacuate:

- Did you try to evacuate but could not? Why?

To all:

- Do you have family members or friends or acquaintances who evacuated during the

eruption?

- Do you have relatives, or friends or acquaintances who suffered in the eruption?
- In your opinion, what happened in San Miguel Los Lotes?
- Why did the people in San Miguel Los Lotes die?
- Why did people die on the Las Lajas bridge?
- What happened in La Reunión?
- What did CONRED do that day?
- What did INSIVUMEH do that day?
- What did the local authorities (municipality, etc.) do that day?
- Were there alerts for people in the communities to evacuate?
    - Why or why not?
- Did people evacuate from the communities?
    - Why or why not?
- Do you think that CONRED did everything they could have done?
- Do you believe that INSIVUMEH did everything they could have done?
- Do you think the communities around the volcano did everything they could have done?
- In your opinion, in hindsight, what should have happened that day?
- Did you think something like this could happen?
- Is there anything else you want to say about what happened in particular that caught your attention that day?

7) **¿Qué otras erupciones ha vivido?**

- ¿Ha evacuado o intentado evacuar para las erupciones anteriores? Recuerda en qué fechas fueron esas erupciones?
- ¿Por qué decidió evacuar o intentó evacuar en erupciones anteriores? ¿Qué fue lo que escucharon o vieron que los hizo evacuar?

7) **What other eruptions have you experienced?**

- Have you evacuated or attempted to evacuate for previous eruptions? Do you remember what dates were those eruptions?
- Why did you decide to evacuate or did you try to evacuate in previous eruptions? What did they hear or see that made them evacuate?

V Early warning and communication

8) **Piensa Usted que las erupciones grandes del Volcán de fuego se puede pronosticar o predecir?**

- Piensa que el Volcán de Fuego da signos o señales de que va a hacer una erupción grande antes de que esta ocurra?
- Qué tipos de signos o señales podría dar el Volcán de Fuego antes de una erupción grande?
- Quien podría ver esos signos o señales para analizarlos y pronosticar o predecir que puede haber una erupción grande del Volcán de Fuego?

- Aparte de los signos o señales que los científicos o vulcanólogos o el INSIVUMEH pueden detectar, hay signos o señales que la gente en las comunidades también podría detectar?

8) **Do you think that the large eruptions of Volcán de Fuego could be forecasted or predicted?**
- Do you think the Volcán de Fuego gives signs or signals before producing a large eruption?
- What kind of signs or signals could the Volcán de Fuego give before a big eruption?
- Who could see these signs to analyze them and give a forecast or prediction that a larger eruption at Volcán de Fuego will happen?
- Other than the signs that the scientists or volcanologists of INSIVUMEH can detect, are there other signs or signals that the people in the communities could also detect?

9) **Que tendrá que hacer la gente para evitar el peligro de una erupción grande?**
- Qué acciones tendría que tomar la gente si se fuera a dar una erupción grande?

9) **What do people need to do to avoid the danger during a large eruption?**
- What actions would the people have to take if a large eruption happens?

10) **Piensa usted que sería posible alertar a la gente antes de que se de una erupción grande para que la gente pueda evacuar y salir del área de peligro?**
- ¿Quién debe dar esa alerta a la gente?

10) **Do you think that it would be possible to warn people in the villages before a large eruption happens, so that they can leave the area under threat?**
- Who should give this warning?

11) **Cuando necesite información sobre el volcán, ¿qué información necesita?**
- ¿Tiene lugares donde puede obtener esa información?
- ¿A dónde va usted para obtener información sobre el volcán?
- ¿La información a la que tiene acceso es confiable? ¿Por qué sí o no?
- ¿Es útil la información a la que tiene acceso? ¿Por qué sí o no?
- ¿Comparte información con sus amigos o vecinos? Si es así, ¿qué tipo de información comparte?
- ¿Obtiene alguna información de las redes sociales?
    - ¿Sigue usted las cuentas INSIVUMEH o CONRED?
    - ¿Usó las redes sociales para obtener información sobre la erupción de junio de 2018?
- ¿Cuál es la mejor manera para que las autoridades compartan información con usted sobre el volcán de Fuego?

11) **When you need information about the volcano, what information do you need?**
- Do you have places you can get that information?
- Where do you go to get information about the volcano?

- Is the information you have access to trustworthy? Why/why not?
- Is the information you have access to helpful? Why/why not?
- Do you share information with your friends or neighbors? If so, what kind of information do you share?
- Do you get any information from social media?
    - Do you follow INSIVUMEH or CONRED accounts?
    - Did you use social media for information about the June 2018 eruption?
- What is the best way for authorities to share information with you about Fuego volcano?

VI Evacuation today

12) **Si el volcán entrara en erupción hoy, ¿qué haría usted?**

- ¿Cuándo o en qué momento cree usted que deberían de evacuar las comunidades?
- ¿Quién debe de tomar la decisión para que las comunidades evacuen? ¿Quién es el que decide el momento en el que la gente va a salir de las comunidades?
- ¿Tendría usted transporte para evacuar?
- ¿Dónde se evacuaría?
- ¿Se evacuaría como hogar o como comunidad? Barrio, familia, amigos, ciudad entera…?
- ¿Ha coordinado o coordinaría su evacuación con vecinos u otras personas dentro de su comunidad?
- ¿Se evacuarían sus vecinos?
- ¿Tendrían ellos transporte?
- ¿Se evacuarían al mismo lugar que usted?

12) **If the volcano erupted today, what would you do?**

- When or under what circumstances do you think that the communities should be evacuated?
- Who should make the decision that the communities have to evacuate? Who decides the moment at which the communities evacuate?
- Would you have transportation to evacuate?
- Where would you evacuate?
- Would you evacuate as a household or as a community? Neighborhood, family, friends, whole town…?
- Have you, or would you, coordinate your evacuation with neighbors or others within your community?
- Tell me about your neighbors. Would they evacuate?
- Would they have transportation?
- Would they evacuate to the same place as you?

13) **En general, cómo cree usted que se debería de dar la evacuación?**

- ¿Quién es responsable de la evacuación?
- ¿Cómo debería de apoyarse a las comunidades en el momento de una evacuación?

13) **In general, how do you think the evacuation should happen?**

- Who is responsible for the evacuation?
- What support should the communities get during the evacuation?

14) **¿Están las autoridades haciendo lo suficiente para garantizar la seguridad alrededor del volcán?**

14) **Are authorities doing enough to ensure safety around the volcano?**

VI Final section and additional comments

Wind down the conversation and thank the interviewee for their time.

Casi hemos terminado. Solo tengo algunas preguntas más que son más generales.

We're almost through. I just have a few more questions that are more general.

6. **¿Hay algo que le gustaría entender mejor sobre el volcán?**

6. **Is there something you wish you understood better about the volcano?**

7. **¿Qué consejo daría a otras comunidades que viven alrededor de un volcán activo?**

7. **What advice do you have for other communities that live around an active volcano?**

8. **¿Hay algo más que le gustaría compartir, algo de lo que no hemos hablado, pero que cree que es interesante o importante que yo sepa?**

8. **Is there anything else you would like to share--something that we missed talking about, but that you think is interesting, or important for me to know?**

Ask the following questions dependent on the comfort level of interviewer and participant.

Y unas preguntas cortas.

And some short questions.

9. **¿Habla Ud. idiomas aparte del español?**
¿Cuáles?

9. **Do you speak languages other than Spanish?**
Which ones?

11. **¿Cuál es su nivel más alto de educación?**

- No escuela
- Escuela primaria
- Escuela secundaria (colegio)
- Universidad
- Más

11. **What is your highest level of education?**

- No school
- Primary school
- Secondary school (high school)
- University
- More

Muchas gracias por su tiempo. ¿Tiene alguna pregunta para mí?

Thank you very much for your time. Do you have any questions for me?

Give contact information if desired.

A.4 Interview guide for Chapter 4 as submitted for publication with manuscript

Most of the questions below were addressed in a natural flow and many without prompts from the warm-up question. We let the content of the interview be guided in part by what the interviewee found most important to share; because of this, and because group interviews were not conducive to soliciting answers to all questions from each participant, not all questions were addressed by each interviewee. Also, not all questions are addressed in detail in the manuscript because of the breadth of topics covered and our desire to focus the manuscript on the issues we believe to be most relevant to the gendered experiences of the women interviewed.

Warm up/overview:

1. Tell me about the day of the eruption. What was it like?

Evacuation behavior and process:

If they evacuated

2. How did you decide to evacuate?
3. How was the evacuation process? How was the evacuation center? How was the transportation?
4. Would you evacuate again in the future?

If they did not evacuate

2. Did you consider evacuating?

3. Why didn't you evacuate?

4. Is there a case in which you would evacuate?

Information and influence

5. Where did you get information during the crisis?
6. Who makes the decision to evacuate in your household?

Risk

7. What is the greatest danger to your community from the volcano?
8. Do you think something like what happened in San Miguel Los Lotes could happen here?

Demographics

9. How long have you lived in this community?
10. How many people are in your household?

Closing

11. Is there anything else you would like to add?

A.5 Thank-you handout for interviewees

Muchas gracias por compartir sus experiencias!

Mi nombre es Beth Bartel, soy una estudiante e investigadora de la Universidad Tecnológica de Michigan (Michigan Tech) en los Estados Unidos. Estoy haciendo un estudio sobre cómo las personas alrededor del volcán de Fuego se adaptan a vivir con un volcán activo, con un enfoque en las evacuaciones.

Le agradezco mucho por su tiempo y por la confianza en contarme y compartir conmigo su historia. Mantendré lo que usted ha compartido conmigo en confidencialidad. No voy a publicar los nombres de las personas con las que hablo, en los informes y presentaciones que resulten de este trabajo, así que su identidad no va a ser conocida por quienes lean mis informes.

Por cualquier duda o comentario, se puede comunicar conmigo por:

WhatsApp: +1 303 717 2225

Teléfono (solo mientras estoy en Guatemala hasta finales de mayo): 5589 5894

Correo electrónico: bbartel@mtu.edu

Si tiene alguna duda sobre mi trabajo también puede contactar a mi asesor, que es guatemalteco y conoce bien el volcán de Fuego y las comunidades cercanas, su nombre es Rüdiger Escobar Wolf y su correo electrónico es rpescoba@mtu.edu

English translation:

Thank you very much for sharing your experiences!

My name is Beth Bartel, I am a student and researcher at Michigan Technological University (Michigan Tech) in the United States. I am doing a study on how people around the Fuego volcano adjust to living with an active volcano, with a focus on evacuations.

I thank you very much for your time and for trusting me in telling and sharing your story with me. I will keep what you have shared with me confidential. I will not publish the names of the people I speak to in the reports and presentations that result from this work, so their identity will not be known to those who read my reports.

For any questions or comments, you can contact me at:

WhatsApp: +1 303 717 2225

Phone (only while I am in Guatemala until the end of May): 5589 5894

Email: bbartel@mtu.edu

If you have any questions about my work, you can also contact my advisor, who is Guatemalan and knows Fuego volcano and the nearby communities well, his name is Rüdiger Escobar Wolf and his email is rpescoba@mtu.edu

B Code structure

B.1 Chapter 2 codes and subcodes

Timeline
- volcanic activity
- key communication
- evacuation
- other

Real-time information
- observations
  - indications of elevated activity
- interpretations
- warning or guidance

Assessment of risk
- indications of concern
- other (uncategorized)

Understanding of risk

Previous experience

System for response

Risk-reducing action

PDC description

B.2 Chapter 3 codes and subcodes

Location
- Panimaché II
- Panimaché I
- Escuintla
- La Rochela
- Guadalupe
- La Trinidad
- Santa Rosa
- San Miguel Los Lotes

Event
- 7 March 2022
- 8 June 2018

Evacuation decisions
- communication
- roles
- decision processes
- decision factors
- evacuation strategy
- logistical process
- attitude
- experience
- risk perception
- improvements

B.3 Chapter 4 codes and subcodes

Social Networks
- young children
- older (parents, grandparents)
- spouse or partner
- community
- other family or social connections

Homes and Livelihoods
- livestock
- security and looting
- environment
- money
- other
- work / income

Information Sources
- direct volcanic observations
- example of others
- news media
- official sources
- other
- past experiences
- understanding of hazard or risk

Structural
- transportation
- official presence
- opportunity to leave
- place to go
- timeliness of outside aid
- responsibilities
- dependence on others
- safety

Wellbeing
- decision difficulty
- fear (personal)
- health
- regret and avoidance

Evacuation
- basic needs (e.g., food and water)
- benefits
- comfort
- environment
- losses associated with
- other
- resistance to
- responsibilities during
- safety/security

C Information sources and timelines of information availability, 3 June 2018

C.1 Stakeholder information sources

Stakeholder group	Open information networks (publicly accessible)	Closed information networks (not publicly accessible)	Primary information sources
INSIVUMEH volcanology staff	News media (radio, TV, internet) Social media Open remote sensing data (expertise needed for discovery and interpretation)	Observer on duty at the observatory on the west side of the volcano (OVFGO) Seismic data from station FG3 after 10:21 am Personal contacts, incl. staff from SE-CONRED and La Reunión	Direct observations of volcanic activity from observer Observations and data reported through social media Open remote sensing data Personal contacts (phone calls and direct messaging) Radio and TV news
SE-CONRED response staff		Radio base operators in 4 communities close to the volcano Mobile field staff onsite at the volcano, primarily south and southeast sides Broader CONRED network (reports from related staff and volunteers outside the agency) Personal contacts, incl. staff from INSIVUMEH and La Reunión, residents in many communities	Direct observations of volcanic activity from staff and radio base operators INSIVUMEH bulletins Personal contacts (phone calls and direct messaging) Social cues
La Reunión management		WhatsApp group for security staff and management Personal contacts, incl. staff from INSIVUMEH, SE-CONRED	Direct observations of volcanic activity INSIVUMEH bulletins
San Miguel Los Lotes residents		Personal contacts, primarily family members	Direct observations of volcanic activity Personal contacts (phone calls and direct messaging) Social cues

C.2 Information pertaining to PDCs in INSIVUMEH's bulletins

Time and bulletin #	Description of activity	Interpretations and guidance
6:00 BEFGO 27-2018	This eruption is generating Pyroclastic Flows in the direction of the Seca or Santa Teresa ravine and possibly in other ravines such as Cenizas. At the moment, due to the cloudiness, its length cannot be observed. The ash from the columns of the Pyroclastic flows moves over the Aldea Sangre de Cristo and the municipality of San Pedro Yepocapa, estimating that the column moves more than 40 kilometers in this direction	Appropriate precautions must be taken, since the pyroclastic flows of the Seca ravine can fill the ravines again. Take into account that this eruption is just beginning, so the descent of Pyroclastic flows in any ravine around the Fuego volcano cannot be ruled out.
10:05 BEFGO 28-2018	Moderate Pyroclastic Flows continue to be generated in the direction of the Seca or Santa Teresa ravine, with pulses also being observed in the Ceniza ravine. The volcanic edifice is still poorly visible, so the length of the flows is not observed.	This eruption maintains the energy, so Pyroclastic flows can be generated in any ravine around the Fuego volcano you should not stay inside or near ravines due to the eruption
13:45 BEFGO 29-2018	Generating strong Pyroclastic flows, in the Seca, Cenizas, Mineral, Taniluya, Las Lajas, and Honda ravines	To SE-CONRED: Raise the state of alert that it deems necessary due to the energy of the eruption and consider the evacuation of the people from Sangre de Cristo due to the descent of Pyroclastic Flows. As well as maintaining monitoring on the south, southwest and southeast flanks.
13:55 BEFGO 30-2018	Strong Pyroclastic flows, in the Seca, Cenizas, Mineral, Taniluya, Las Lajas, and Honda ravines	To SE-CONRED: Raise the state of alert that it deems necessary due to the energy of the eruption and consider the evacuation of the people of Sangre de Cristo due to the descent of Pyroclastic Flows. As well as maintaining monitoring on the south, southwest and southeast flanks.
16:55 BEFGO 31-2018	Moderate Pyroclastic flows continue to descend the Seca, Cenizas, Mineral, Taniluya, Las Lajas, and Honda ravines	The communities of Sangre de Cristo, Fca. Palo Verde, Panimache and others have been evacuated by CONRED to shelters. *Note: Interviewees from Panimaché I and II say they were unable to evacuate because of lahars.*
19:20 BEFGO 32-2018	Some Pyroclastic flows are still reported, which can travel further since the ravines are full and continue to overflow.	There is still the probability of increasing again, so you should not stay near or within the ravines.
22:00 BEFGO 33-2018	The FG3 seismic station recorded a last Pyroclastic Flow at 6:45 pm hours	It must also be taken into account that there is a probability of a reactivation, so one should not stay near or within the ravines affected by today's flows. To SE-CONRED: continue with the current state of alert, stay in safe places at night

C.3 INSIVUMEH information timeline, 3 June 2018

Local time	Bulletin number	Observations: eruption intensity	Observations: PDCs	Guidance: for CONRED	Guidance: for airport	Guidance: for tourism
1:00-3:00 AM	*Increase in seismic energy and likely PDCs recorded by seismometer FG8; data not available until after the paroxysm*					
3:30 AM	*Observer texts central to report incrementing explosions*					
5:00 AM	*Observer calls central to report PFs and lava flows on west side*					
6:00 AM	Bulletin 27	Ash at 6000 m	PFs on west side	Implement alert mainly on west side	Take precautions with air traffic	Don't stay or camp on Meseta
10:05 AM	Bulletin 28	Ash at 6000 m	Moderate PFs on west side	Maintain alert mainly on west side	Take precautions with air traffic	Don't stay or camp on Meseta
10:21 AM	*Seismometer FG3 back online; see Bulletin 33*					
12:30-1:00 PM	*Observer calls central to report large PFs on west side; Facebook posts from residents show ashfall ~50 km from volcano; satellite data show ash reaching 10,000 m*					
1:30 PM	*External scientist sees images on social media of PDCs directly hitting La Reunión; is unable to communicate with INSIVUMEH central after midday*					
1:45 PM	Bulletin 29	Ash at 10,000 m; "the eruption is the strongest in recent years"	Strong PFs on west and east sides	Raise the alert level and consider evacuating Sangre de Cristo	Take precautions with air traffic	Climbing the volcano is prohibited
1:55 PM	Bulletin 30	"	"	"	Close the airport	"
2:36 PM	First ashfall map posted on Twitter					
2:40 PM	Did You Know? about ashfall posted on Twitter					
2:57 PM	What to do in the case of a volcanic eruption (responding to ashfall) posted on Twitter					
3:00 PM	*SE-CONRED DPV staff calls central to share that PDCs reached La Reunión*					

Exact time not known	*INSIVUMEH central staff learns flows have reached the Las Lajas bridge with fatalities by calling a contact at La Reunión for an update on the flows at the resort; the contact answers from near Las Lajas bridge where he is helping people evacuate*					
4:55 PM	Bulletin 31	Ash at 10,000 m	Moderate PFs on west and east sides	Maintain alert level	Keep airport closed for a few more hours	Climbing the volcano is prohibited
6:00 PM	Second ashfall map posted on Twitter					
7:20 PM	Bulletin 32	Ash at 6000	Some PFs	Maintain alert levels; don't go in or near ravines	Maintain closure	Climbing the volcano is prohibited
10:00 PM	Bulletin 33	Ash at 4500 m; eruption is ending	Seismic station recorded last PF at 6:45 pm	Maintain alert levels; don't go in or near ravines	Unclear	Climbing the volcano is prohibited

Sources: Twitter, six interviews, INSIVUMEH special bulletins

C.4 CONRED information timeline, 3 June 2018

Local time	Text from Twitter post (denoted by gray highlight in time column; author's emphases; translated from Spanish; posts with recommendations highlighted in light gray) or description of activity from interviews (*italics*) or official records
6:55 AM	INSIVUMEH bulletin 27 (1st): #VolcánDeFuego The second eruption of Fuego volcano in 2018 is beginning, accompanied by strong explosions raising thick columns of ash at 6,000 meters above sea level, moving for the moment in a West, Southwest direction. Source: INSIVUMEH
8:00 AM	*SE-CONRED staff already deployed for an unrelated search-and-rescue mission and CONRED volunteer radio base operators in multiple communities close to the volcano report PDCs and ash toward the direction of Sangre de Cristo and/or Yepocapa (west side of Fuego); SE-CONRED staff based in Escuintla deploy to opposite side of the volcano, starting at the Las Lajas bridge (southeast) and heading west from there to visit communities near the volcano (south)*
8:13 AM	The Volcano Prevention Unit of the CONRED Executive Secretariat is constantly monitoring the activity of the #VolcánDeFuego. At this time, the column of ash is dispersing in a Southwest direction, continuous explosions are heard, some strong and sporadic.
8:50 AM	Following the eruption of the #VolcánDeFuego, monitoring is being carried out in Barranca Las Lajas, there are no pyroclastic flows descending towards this sector nor fall of material, moderate explosions are heard. Source: Wotzbely Suárez, Field Technician of the CONRED Executive Secretariat.
9:21 AM	#VolcánDeFuego Monitoring is carried out in the village of El Rodeo and the community of La Reina with personnel from the Local Coordinator for Disaster Reduction -COLRED- of La Reina, no ash fall was recorded. Source: Wotzbely Suárez, Field Technician of the CONRED Executive Secretariat.
9:51 AM	#VolcánDeFuego Following the eruption of Fuego volcano, ash fall and dispersion is recorded per the predominant wind direction in La Soledad Acatenango.
10:10 AM	IMPORTANT RECOMMENDATIONS. We share the following recommendations with you regarding the possible fall of ash from the eruption of Fuego volcano. #PrevenirParaVivir #TodosSomosResponsables
10:45 AM	#VolcánDeFuego After monitoring carried out in the village of Guadalupe, El Zapote, no ash fall was recorded pertaining to the eruption of Fuego volcano. Source: Wotzbely Suarez, Field Technician of the CONRED Executive Secretariat.
11:01 AM	Fuego volcano began its second eruption this year, with explosions that are raising columns of ash to 6,000 meters above sea level, pyroclastic flows in ravines. **At the moment it is not necessary to carry out evacuations.** Video: Armando Pineda, Speleologist.
11:10 AM	#VolcánDeFuego In the San Andrés Osuna community, no ash falls were recorded during the monitoring carried out by Wotzbely Suárez, Field Technician of the CONRED Executive Secretariat, only rumblings are heard. #PrevenirParaVivir #TodosSomosResponsables
11:59 AM	RECOMMENDATIONS: It is important that you know what measures to take when registering a volcanic eruption, especially if you live near the area of the volcano.

	#PrevenirParaVivir #TodosSomosResponsables *Attached:* Gif of what to do in an eruption: alert authorities of changes in the volcano, stay informed by listening to the radio, know where to go
12:13 PM	#VolcánDeFuego Small avalanches and pyroclastic flows are observed descending through the Las Lajas and Onda ravines, while moderate rain is starting to fall in the same area. Source: Mario Ovalle, Volcano Prevention Unit -UPV- of the CONRED Executive Secretariat.
12:30 PM	*Informed that PFs were coming down the Ceniza ravine; started giving warning information to Las Palmas and La Reina*
12:30+ PM	*La Reina COLRED head rides road past southeastern communities in a tuc-tuc warning residents*
12:41 PM	#VolcánDeFuego Due to the presence of ash in communities around Fuego volcano, it is important to cover food and containers where water is stored for human consumption, follow our recommendations. #PreventParaVivir #TodosSomosResponsables.
12:45 PM	*Has recognized that activity is stronger than usual; started to send messages of alarm to the authorities and colleagues asking that they get involved*
1:08 PM	#VolcánDeFuego After the monitoring carried out in the town of Las Palmas and the Ceniza river, no ash falls were recorded, activities are normal in said community and the ford across the Ceniza river is passible.
1:30 PM	*Governor called to confirm that the activity was strong; SE-CONRED staff member asked him to activate the COE and declare a red alert; governor instead came to Las Lajas for situational awareness*
1:49 PM	The general population is recommended to wear a mask in the event of ash fall from the eruption of Fuego volcano and follow the recommendations issued by the authorities. #PrevenirParaVivir #TodosSomosResponsables
1:58 PM	#VolcánDeFuego Due to the eruption of Fuego volcano, ash fall is reported in some sectors of San Juan Sacatepéquez and Chimaltenango. #PrevenirParaVivir #TodosSomosResponsables
2:00 PM	Departmental red alert declared in Sacatapéquez
2:11 PM	La Aurora Airport closed
2:12 PM	INSIVUMEH bulletin 29 (3rd): #VolcánDeFuego The eruption of Fuego volcano is the strongest recorded in recent years, generating strong pyroclastic flows in the Seca, Cenizas, Mineral, Taniluya, Las Lajas, and Barranca Honda ravines, raising thick columns of ash to a height of 10,000 meters above sea level.
2:15 PM	Municipal red alert declared and COE activated in Escuintla

2:22 PM	#VolcánDeFuego Ash fall is recorded in San Miguel Dueñas Sacatepéquez, it is recommended to clean the roofs of their homes after the end of the eruption. #PrevenirParaVivir #TodosSomosResponsables
2:29 PM	The eruption of the #VolcánDeFuego is currently registering ash fall in the municipalities of San Antonio Aguas Calientes, Santa Catarina Barahona, San Miguel Dueñas, Ciudad Vieja, Alotenango and Antigua Guatemala Source: Oscar López, UGAM San Antonio
2:30 PM	*Municipal officials leave the Las Lajas bridge by 2:30 PM*
2:34 PM	CONRED INFORMS: La Aurora International Airport closes its runway due to the presence of coarse volcanic ash after the eruption of Fuego volcano in order to safeguard people's lives. Source: Juan Gabriel, Emergency Operations Center -COE-
2:45 PM	*First PDC reaches Las Lajas bridge; SE-CONRED 3 flees to west and stops at the entrance to San Miguel Los Lotes to warn residents, continues along the RN-14 warning people along the road; takes La Reina COLRED head back to La Reina to warn their community.* *SE-CONRED 4 flees to east, presumably warns people nearby to evacuate, returns to bridge. [Warns Fuego 5 to evacuate?]*
2:48 PM	#VolcánDeFuego Currently, ash fall is no longer reported in the municipalities of Acatenango, San Andrés Itzapa, Chimaltenango, Patzicia, Saragoza, Patzún and Tecpán Guatemala. Source: Aroldo Santelel, Departmental Delegate of the CONRED Executive Secretariat.
2:49 PM	RN-14 from Alotenango to the El Rodeo junction closed by this time
2:57 PM	#VolcánDeFuego In the central valley of Baja Verapaz and Rabinal there is light rain accompanied by ash. Source: Roberto Recinos, CONRED Regional Delegate.
3:07 PM	Due to the activity of Fuego volcano, **SE-CONRED recommends that the population living in areas near the #VolcánDeFuego evacuate to safe areas if indicated** and avoid being near ravines or in danger. #PrevenirParaVivir #TodosSomosResponsables
3:11 PM	*PDC destroys Las Lajas bridge and San Miguel Los Lotes. SE-CONRED 4 is unable to escape. Fuego 5 and his family have not evacuated; their home is destroyed as well.*
3:20 PM	*SE-CONRED 3 returns to go into San Miguel Los Lotes to warn them but the flows have already come down and he is unable to make it to the main entry; people are fleeing into the road; he makes eight trips evacuating survivors from near San Miguel Los Lotes to El Rodeo, each time with fewer people.*
3:24 PM	r#VolcánDeFuego Due to the accumulation of material in the ravines of Fuego volcano and the rains in the sector, the descent of a lahar increasing the flow of the Pantaleon River is reported.
3:30 PM	Municipal red alert declared and COE activated in Alotenango

3:41 PM	#VolcánDeFuego The Departmental Delegate of the CONRED Executive Secretariat will hold a meeting at the Escuintla Departmental Emergency Operations Center -COE- with the presence of the Departmental Governor.
4:18 PM	Institutional orange alert declared by SE-CONRED
4:25 PM	Departmental red alert declared and COE activated in Escuintla; municipal red alert declared and COE activated in San Pedro Yepocapa
4:49 PM	Shelters and morgue available in Escuintla
5:23 PM	INSIVUMEH bulletin 31 (5th): #VolcánDeFuego The eruption of Fuego volcano maintains the same energy, moderate pyroclastic flows continue to descend through the Seca, Cenizas, Mineral, Taniluya, Las Lajas, and Honda ravines, raising columns of ash to a height of 10,000 meters above sea level.
5:34 PM	RECOMMENDATIONS: Due to the activity of Fuego volcano, SE-CONRED recommends to the population living in areas close to the volcano: avoid rumors and avoid approaching the area where lahars descend. https://conred.gob.gt/site/Boletin-Informativo-952018 *(Link to the only CONRED special bulletin)*
5:42 PM	It is important for the general population to be attentive to the information that authorities share and to be careful in the area. Like and Share our recommendations. #PrevenirParaVivir #TodosSomosResponsables *jpg images of recommendations for what to do in ashfall*
6:01 PM	CONRED INFORMS: After the eruption of Fuego volcano, the shelters located in the Municipal Hall, Escuintla, Simón Bergaño y Villegas Institute, Escuintla and Municipal Hall, Santa Lucía Cotzumalguapa, Escuintla, are now open. #TodosSomosResponsibles
6:40 PM	Press conference begins to provide a report on the situation due to the eruption of Fuego volcano. Follow our live broadcast
6:41 PM	CONRED INFORMS. To the population in areas around Fuego volcano, the eruptive activity continues, we recommend moving to safe places and not approaching areas of risk. #PreventParaVivir #TodosSomosResponsables.
6:45 PM	"From early on we have monitored the situation of the eruption of Fuego volcano" Sergio García Cabañas, Executive Secretary of CONRED
6:49 PM	"We have the activation of departmental delegates of SE-CONRED and declaration of Institutional Orange Alert" Sergio García Cabañas, Executive Secretary of CONRED. Press conference: "We've activated the SE-CONRED departmental delegates and declared an Institutional Orange Alert"
6:49 PM	⚠Caution⚠ Stay away from the ravines and areas surrounding the #VolcánDeFuego, take refuge in a safe place. #PreventToLive "Precaution: Get away from gullies and areas around Fuego Volcano, protect yourself in a safe place."

6:53 PM	"As of 11:30 a.m., bulletins began to be generated to report the situation of Fuego volcano" Eddy Sánchez, Director of INSIVUMEH
6:55 PM	"Currently the volcano continues to rumble and there is a greater potential for mudslides" Eddy Sánchez, Director of INSIVUMEH
7:02 PM	"It is a call to the population to attend to the recommendations that are offered in the situation of Fuego volcano" Jimmy Morales, President of the Republic.
7:04 PM	"We thank the Government of Mexico, Honduras and El Salvador for the shows of support." Jimmy Morales, President of the Republic.
7:08 PM	These are our recommendations for the eruption of Volcán de Fuego. Visit this link: https://conred.gob.gt/site/Boletin-Informativo-952018
8:15 PM	#VolcánDeFuego Coordination is carried out at the Command Post -PC- in Alotenango with the Immediate Response Team -ERI- of the Executive Secretariat of CONRED.
8:40 PM	#VolcánDeFuego The Immediate Response Team -ERI- of the CONRED Executive Secretariat carry out the systematization and coordination of the actions before the activity of Fuego volcano in the communities surrounding the volcano.
9:14 PM	#VolcánDeFuego An inter-institutional meeting is held to prepare the action plan to be carried out due to the activity of Fuego volcano.
10:21 PM	As of 6:00 a.m. this Sunday, June 3, a total of 637 public servants from entities that make up the CONRED System are working on various actions due to the increase in eruptive activity of Fuego volcano.
10:34 PM	INSIVUMEH bulletin 33 (7th): #VolcánDeFuego The eruption of Fuego volcano, after 16 and a half hours of having started, is ending with ash at 4,500 meters above sea level with weak and moderate explosions, with incandescence in the crater. #TodosSomosResponsibles Fountain: @insivumehgt

Sources: Twitter, four interviews

D Timeline for the 7-9 March 2022 paroxysm and evacuation

Date and time	Document if applicable	Key content
7 March 2022 00:50	1st INSIVUMEH bulletin (BEFGO 006-2022)	"Review the action and mitigation protocols in the towns near the volcano, especially in the direction of the Ceniza ravine, where the activity of lava flows and block avalanches can last several hours or days, and can also intensify and/or spread to other ravines of the Fuego volcano. Be aware of special bulletins that may be generated in the coming hours or days."
7 March 2022 09:10	2nd INSIVUMEH bulletin (BEFGO 007-2022)	"Implement the state of alert that you deem necessary, taking into account that the activity that is currently being recorded can generate pyroclastic flows towards any of the canyons of the Fuego volcano, so it is recommended to be alert to this activity."
7 March 2022	CONRED avisos 11 & 12	Summary of BEFGO 007-2022
7 March 2022 ~12:00		*Shortly after 12:00 seismic energy (represented by RSAM) increases sharply*
7 March 2022 12:58		*Large PDCs descend Ceniza channel*
7 March 2022 13:10	3rd INSIVUMEH bulletin (BEFGO 008-2022)	Descent of moderate to strong PFs in Ceniza at 1:00 PM; "Implement the state of alert that you deem necessary, taking into account that the descent of these pyroclastic flows can cause ash falls in the areas close to the ravines where they occur, as well as interrupt the passage through them."
7 March 2022	CONRED avisos 13 & 14	Summary of BEFGO 008-2022
7 March 2022 13:15-13:45		*Largest PDCs of paroxysm descend Ceniza channel, seem to include an ash cloud surge overbanking the channel*
7 March 2022 13:45	4th INSIVUMEH bulletin (BEFGO 009-2022)	Much larger PFs in Ceniza in the past half hour, with waves beginning to overflow the banks; eruption energy continues to increase; "Implement the state of alert and take the actions deemed necessary in the communities located in the vicinity of the volcano ravines, especially the Ceniza, Trinidad and Taniluyá ravines, taking into consideration that the descent of these pyroclastic flows can produce ash falls in the areas close to the ravines where they occur, as well as interrupting the passage through them."
7 March 2022 14:00	CONRED avisos 15 & 16	Summary of BEFGO 009-2022
7 March 2022 ~14:00		*SE-CONRED DPV staff encourage Panimaché I to evacuate in person at the INSIVUMEH volcano observatory in Panimaché I*
7 March 2022 14:30		*Local authorities convene to decide on evacuation*

7 March 2022 15:15		*Activity appears to lessen; local authorities decide to wait an hour*
7 March 2022 16:00		*Panimaché I decide to evacuate; SE-CONRED DPV coordinates transportation*
7 March 2022 16:11, 16:52		*Smaller PDCs in Ceniza channel*
7 March 2022 17:00		*First plantation bus arrives to Panimaché I, departs an hour later (18:00)*
7 March 2022 19:10	5th INSIVUMEH bulletin (BEFGO 010-2022)	"Continue with the state of alert and the actions it deems necessary in the communities located in the vicinity of the volcano ravines, especially the Ceniza, Trinidad and Taniluyá ravines, taking into consideration that the descent of these pyroclastic flows can produce ash falls in the areas close to the ravines where they occur, as well as interrupting the passage through them."
7 March 2022 20:00	CONRED avisos 17 & 18	Summary of BEFGO 010-2022
7 March 2022 21:40	6th INSIVUMEH bulletin (BEFGO 011-2022)	"Continue with the state of alert and the actions it deems necessary in the communities located in the vicinity of the volcano ravines, especially the Ceniza, Trinidad and Taniluyá ravines, taking into consideration that the descent of these pyroclastic flows can produce ash falls in the areas close to the ravines where they occur, as well as interrupting the passage through them."
7 March 2022 22:00	CONRED avisos 19 & 20	Summary of BEFGO 011-2022
7 March 2022 24:20		*Last bus leaves Morelia*
8 March 2022 07:00	7th INSIVUMEH bulletin (BEFGO 012-2022)	"Continue with the state of alert and the actions it deems necessary in the communities located in the vicinity of the ravines of the volcano, especially the Ceniza, Trinidad, Las Lajas and Santa Teresa ravines, taking into consideration that in the face of the possible descent of weak avalanches, moderate or even strong, ash falls can still occur in the areas near the volcano."
8 March 2022 10:30	8th INSIVUMEH bulletin (BEFGO 013-2022)	
8 March 2022 11:20	CONRED avisos 21 & 22	Summary of BEFGO 013-2022