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Beyond Technologies of Observation. Accepting Uncertainty in Disaster Risk Management

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Abstract

This short essay examines the current role of technologies of observation in disaster risk management, highlighting the limitations of relying solely on these systems to address extreme natural hazards. While advances in observation and prediction tools, such as seismographs, weather satellites, and early warning systems, have improved societies' capacity to anticipate and mitigate disasters, these technologies are not without challenges. Complex socio-technical systems remain prone to failures, and are difficult to interpret. Overall, uncertainty often prevails during emergencies. Using examples from Chile and Spain, this paper argues that the focus of disaster management should shift from the enhancement of technological precision to empowering decision-makers and communities to act effectively under conditions of uncertainty. I propose focusing on improving situational assessments, by emphasizing the importance of interpretation, translation, and even improvisation.

Keywords: Disasters; observation; uncertainty; risks.

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1 Introduction

Extreme natural hazards are one of the greatest threats to democratic states today. The monopoly of violence is considered a crucial characteristic of the modern state (Weber, 1919). Protecting the population from physical harm, preserving borders, curbing violence, and maintaining internal peace are essential for the legitimacy of state power. While I acknowledge that this perspective was developed with non-state human organizations in mind, the core concept remains that the state should maintain order and protect us from random physical harm. What happens, then, when hurricanes and earthquakes challenge this promise of protection? What if the state not only fails to prevent damage but also responds late and ineffectively?

Almost two decades ago, hurricane Katrina in New Orleans (U.S.) became a symbol of decision-makers' failure to prevent disaster despite having some of the best technoscientific tools and resources to do so (Horowitz, 2020; see NBC News Associated Press, 2006). This event had severe political costs for those officials and administrators responsible for managing the response (Waugh, 2006). Additionally, the American public developed a highly negative impression of governmental performance during disasters, contributing to a widespread perception of political incompetence (Schneider, 2008). In the eyes of the public, Katrina was a human-made disaster (Lemann, 2020; BBC News, 2015). While Katrina was not the first disaster to be understood in the framework of human incompetence, this and other events happening around the same time (particularly the Indian Ocean earthquake and tsunami of 2004) marked a shift towards a new understanding of extreme natural hazards as a challenge that modern states should prepare for (UNISDR, 2005).

Disasters have become an increasing problem for states. Extreme natural hazards today are more common and intense due to the climate crisis and the rapid urbanization and densification of areas where vulnerable populations and infrastructure are exposed (UNISDR, 2015; Hossain et al., 2017; IPCC, 2023). Recently, angry crowds in Valencia threw mud at Spain's Prime Minister, as well as the King and Queen, after an inadequate reaction to a high-impact rainfall event that caused the deaths of at least 231 people and approximately 3.8 billion dollars in damages (Spivey, 2024; Chutel et al., 2024). It is unclear if this event will affect the next Spanish national or regional election, but far-right populist groups have gained attention in its aftermath (Munárriz, 2024; Peñas, 2025). In the two months since the Valencia flooding, monsoon rains have caused widespread flooding in Malaysia and southern Thailand, a 7.3 magnitude earthquake struck Port Vila, the capital of Vanuatu, and Tropical cyclone "Chido" wreaked havoc in Mozambique, among other smaller events (EM-DAT, 2024). As I write this article, raging flames are consuming thousands of homes in Southern California in what looks to be one of the largest wildland-urban interface fires in U.S. history. For many people, this is a reality they see in the never-ending cycle of emergencies and political controversies they consume on their devices. However, as a flooding victim in North Carolina posted recently, "Climate change is what you see on TikTok until you are the one streaming" (original author not found, but several copies remain on X. See e.g., Clennon, 2021).

What we call a disaster, however, is not the extreme natural event itself but a failure in the sociotechnical world of humans. What is disastrous is the loss of lives, infrastructure, livelihoods, and communities. From this, it follows that effective disaster risk management (DRM) involves rethinking how we inhabit different territories, looking to improve resilience and reduce vulnerabilities. Still, the modern expectation of fully controllable and manageable risks associated with natural hazards will most likely remain unattainable, even in the absence of climate change. Volcanoes, earthquakes, landslides, fires, and floods have always been part of human life. The issue is that Earth is not the stable, inert background against which human action unfolds. Recognizing this does not mean slipping into environmental determinism but rather acknowledging that our future depends on how we shape our relationship with a lively planet (Gil, 2024).

Part of this relationship relies on knowledge and observation of natural events in order to recognize those that are potentially hazardous for human communities. As the saying goes, "hindsight is always 20/20". Looking back to any event, it is easy to see the actual threat, to evaluate if human decisions were wrong or data was misconstructed. But in the moment of an acute disaster, uncertainty is usually the norm. During an earthquake, for example, it is important — yet difficult — to know if evacuating to higher ground is necessary. For those with a public responsibility to alert the population in case of a tsunami, it is inevitably a moment of choice — a decision that is simultaneously scientific, political, and even ethical. Making these decisions in the dark or with the best possible evidence about hazards can make a significant difference. This is why technologies of observation (from sensors on the ground to satellites in space) and prediction (statistics and models) are today at the center of DRM strategies.

In the following sections, I will briefly expand on these ideas. I will argue that, no matter how accurate, technologies of observation require important interpretation and translation efforts in order to fulfill our expectations of risk management. This is particularly challenging in the context of a broad "crisis of expertise" (Eyal, 2019), where scientific knowledge is often contested by politics and the media. In this context, I will argue that observing and understanding hazards is indispensable but insufficient for coping with extreme natural hazards. Improving technologies of observation is important, but the real challenge is to educate, enable and empower decision-makers and the population at large on how to make wise, situated decisions in uncertain situations.

2 Observing Hazards, Recognizing Disaster

Since Ulrich Beck (1992) introduced the concept of "risk society" to analyze the modern world, it became customary to distinguish traditional societies, shaped by "external risk", from modern societies, exposed to manufactured risks that emerge "from the very advancement of science and technology" (Giddens, 1999, p. 62). Examples are nuclear power, pesticides, tailings dams, transportation, and various other contemporary threats. However, the rise of manufactured risks has not eliminated natural hazards nor rendered them irrelevant to human societies. Earthquakes and volcanic eruptions continue to occur, while events such as hurricanes and wildfires are rising due to the climate crisis. What has changed is that extreme natural events are no longer viewed as acts of God or fate but as issues primarily driven by human actions and the social, economic, and political conditions that turn hazards into disasters. In other words, we now recognize that all risks are largely manufactured (see Hewitt, 1983; Kelman, 2020; Mileti, 1999; Tierney, 2014; Wisner et al., 2003 for a development of this argument in disaster studies).

Hazards, however, continue to exist and challenge human societies. The "modern dream" — as Zinn (2020) has called it — is that a continuous growth of knowledge and rationalization will enhance our understanding and control over nature to the point that we will be able to anticipate events. But Max Weber (1919) already warned us that "mastering all things by calculation is the modern's worldview but not our experienced reality" (as cited in Zinn, 2020). Earthquakes illustrate this well. Scientists today can estimate the likelihood of a specific earthquake occurring in a particular region within a certain time frame. However, we cannot know

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the precise date, time, location, or magnitude of any given event. We know that some earthquakes can trigger tsunamis, but we cannot prevent this from happening. Even in a highly rationalized society, humans will encounter nature as a source of uncertainty.

Still, solution-driven research and investment in technology and innovation have provided us with new ways to better observe and understand these hazards. Sensors, modeling techniques, and early warning systems look to anticipate, prevent and mitigate the impact of extreme natural events. These technologies of observation are embedded in broader sociotechnical ensembles that we call Early Warning Systems. These complex systems involve multiple entities, protocols, institutions, knowledge, people, and even non-human actors in order to observe the natural world and recognize the possibility of an acute disaster (Farías, 2014).

Although it is generally true that these technologies help societies to reduce risk, they also create new challenges of observation. Complex sociotechnical systems — however well they are managed — are prone to failures (what Perrow, 1984, calls "normal accidents"). If we are used to relying on technologies of observation for evidence-based decision-making, we can find it challenging to decide in their absence (Gil & Undurraga, 2022; Kane et al., 2014). As an example, let us analyze the disaster of February 27, 2010, in central-south Chile. That night, an 8.8 magnitude earthquake triggered a major tsunami that hit about 3,000 kilometers of the Chilean coast. Due to the strong movement, the fiber-optic cables linking tidal gauges in the Pacific to computers at the Chilean Navy's Hydrographic and Oceanographic Service (SHOA) were cut and unable to send information. Facing uncertainty, but having felt the major earthquake, decision-makers at SHOA chose to wait 49 minutes for the GEOS satellite system to provide the data before issuing a tsunami warning. As a result, no official evacuation message was sent to the population. Later, the investigation into the deaths of 181 people due to tsunami concluded that any reasonable analysis would conclude that the risk was greater by not evacuating the population than by doing so (Bonnefoy, 2013). However, navy officials at SHOA failed to recognize this risk or acknowledge that a tsunami was already forming along the Chilean coast with no data to help them model its progression. In his deep analysis of this event, Farías (2014) concluded that the challenge is not how to get more technoscientific certainty but "how to act with uncertainty". I fully agree and will come back to it later.

The recent flash floods in Spain serve as an example of other observation challenges. In the case of Valencia, decision-makers had good information about the natural phenomena threatening to impact their area days ahead but still failed to recognize a disaster in the making. The Agencia Estatal de Meteorología (AEMET), which is the official source of authorized alerts in Spain, issued numerous warnings with a standardized message designed to inform different stakeholders, including the regional emergency offices, about the unusual rainfall. Still, decision-makers could not see the disaster until it was already occurring. The first message to people's mobile phones arrived when many were taking refuge on rooftops (Bordera, 2024). We still do not know all the details about this recent event, but we do know that meteorologists warned Valencia's government about risky flooding (Samaniego, 2024). How did they miss it? There are reasons, besides plain incompetence, that can explain their huge recognition mistake. The accuracy of hazard models depends on the quality of data, the assumptions made by researchers, and the computing capacity at hand. But even in the best conditions, the result is probabilistic, meaning that models hold uncertainty. They can give decision-makers possible scenarios, but it will not tell them precisely what to do. Additionally, communicating scientific information is harder than most people think. Decision-makers may lack the scientific education to understand the information received, or they may feel confused about it. Research shows that if confronted with too much information or if being unable to read data, people often reach for heuristics, also known as mental shortcuts (Brandstätter et al., 2006). The problem is that, without any experience with disasters, heuristics can become a crucial bias towards optimism. As Kane et al. (2014) noted for the case of Chile, repertories are key to coherent decision-making and action in emergencies. In this case, the normalized message posted online and sent to different institutions and the media highlighted the unusual rainfall but did not mention flooding in the lower parts of the riverbeds (which overflowed despite little to no rainfall in these areas). Understanding the risks, then, required not only basic scientific education but also a particular ability to "connect the dots" meaningfully.

Overall, we see that using technologies of observation to identify hazards and predict disaster is important, but not enough for saving lives. Scientific knowledge produced by these technologies must be translated into actionable decisions for a series of actors, some of whom may have problems understanding or trusting expert knowledge. How do we tackle these challenges? While scientists will understandably always want more and better observation capacity, I will argue that the urgent issue is how to empower people and strengthen institutions to act wisely in the context of uncertainty.

3 Interpretation, Translation, and Improvisation

As the examples above show, a key to improving hazard observation is to focus on the moments, places, and tools of translation. Observational data needs to be gathered, interpreted, and described. But this is not all, data also needs to be made sense of. As a scientific modeler told me once during a research interview: data may be quantitative, but its meaning needs to be qualitative (quoted in Gil & Undurraga, 2022). The problem, then, cannot be reduced to the "transmission" of information. We need to think deeply about how science can inform emergency management in practice. The problem, of course, is that it takes time to gain "20/20" vision of an event. In the actual moment of a disaster there may be little time to interpret data, model scenarios, and make evidence-based decisions. This is why learning how to act in the context of uncertainty may be more important for disaster management than improving reaction time or increasing automatization of early warnings.

It is common today in disaster management to face uncertainty under the "precautionary principle" (Harremoës, 2002), which indicates that precautionary measures should be taken even if scientific evidence about the potential harm of a hazard or a situation is not yet fully established. The application of this principle would have led decision-makers in Chile and Valencia to issue evacuation warnings on time. Still, the precautionary principle can lead to false alarms, which can undermine trust in science in general and early warning in particular.

This is why the precautionary principle must be complemented with wise situational assessments. In the case of Chile, officials at SHOA had felt the earthquake and should have been able to assess that a tsunami was very likely in the making. The same can be said for officers at the emergency office in Santiago. In fact, there was at least one official — from the regional emergency office — who acted in accordance with his training as a "human seismograph" and tried to alert the office in Santiago (Farías, 2014). In the case of Valencia, it was harder for decision-makers to establish the possibility of flooding when they were far away from the storm. Still, this situation will become more common as the climate crisis expands through territories that may be politically distinct but are environmentally linked. In this case, the emergency office of the Generalitat of Valencia could have had a crucial role in this assessment, if funded and organized correctly.

To be clear, assessments of hazard development must be informed by the best possible scientific evidence and predictive power. My point here is that — even when available — scientific evidence is not enough to make wise decisions during a rapid-onset disaster (or even a slow-developing one). We also need data interpretation, translation into actionable strategies, and even improvisation.

While improvisation is often seen negatively, particularly in the context of public administration, it can play a crucial role in disaster management (Elkady et al., 2024; Mamédio et al., 2024; Roud, 2021; Kendra & Wachtendorf, 2007; Howitt & Leonard, 2006). Improvisation in this context does not mean a failure to plan, nor "doing my own thing". As Weick (1998) famously defined a long time ago, improvisation is a transformation of some original idea, model, or plan. Kreps (1991), one of the first scholars to study disasters, argues that both preparedness and improvisation play an important role in disaster management. He went to define "improvisation" as organization "during an event" and preparedness as organization "before an event". This means that plans and protocols are a base for action, but since the precise unfolding of events is uncertain and — increasingly — unprecedented, there needs to be situated assessment.

As Stark (2014) stated lately, one cannot plan for the unexpected, but it is possible to be prepared. A wise, situated assessment is not an act of luck or heroism. Just as one can hardly generate instant knowledge without prior study, most people cannot improvise without experience and training. This is why Jazz is so often used as a metaphor for improvisation. A successful Jazz performance results from study, training, practice, and experimentation (Kendra & Wachtendorf, 2007; see also Faulkner & Becker, 2009). These elements serve as repertories for Jazz players to draw upon, in the middle of a show. Disaster risk management, on the contrary, tends to "plan in detail so that we don't have to improvise, knowing that will have to" (Kendra & Wachtendorf, 2007, p. 1).

Finally, it is important to point out that even if decision-makers make the best assessment possible and give appropriate directions to the population, there is no certainty that communities are going to get the message and act accordingly. Uncertainty during emergencies often means that landlines are interrupted and antennas destroyed, which means that people are hard to reach. This is why communities need to be prepared to make their own situated assessments. In Chile, during the 2010 tsunami, most people evacuated to higher ground on their own decision. The lack of an official early warning was irrelevant for most of those who were saved. It worked in their favor that Chile is a country used to earthquakes and although no major tsunami had happened in decades, older people remembered the events of 1960.

4 Final Remarks

The failure to recognize the risks of an extreme event not only amplifies its effects but also transforms the way people interpret those events. Political and technical ineptness became the central concept to interpret the disaster in both Chile and Spain. The disaster was attributed to the failure of the sociotechnical system developed to anticipate these events, and to the people running it. This undermined people's trust in institutions related to disaster risk, as well as political actors in general. I am certain that the Southern California fires will have a similar outcome, considering not only the problems with emergency messages but also the enormous amount of damage.

As a result of this and other failures in communication, several groups have called for better warning systems and clearer communication with communities. Some have even called for the automation of evacuation messages in the case of tsunamis, floods, or fires. While technology is necessary for DRM, I suggest that improving the technoscience associated with early warning systems — both in terms of hazard observation and risk communication — is not the key to facing extreme events today. We already have unprecedented scientific knowledge and prediction accuracy for natural events. What we are missing is training decision-makers to use this information effectively in the context of high uncertainty and high stress. We should educate communities to react quickly to dangerous situations. And we should design organizations and systems that assume uncertainty.

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