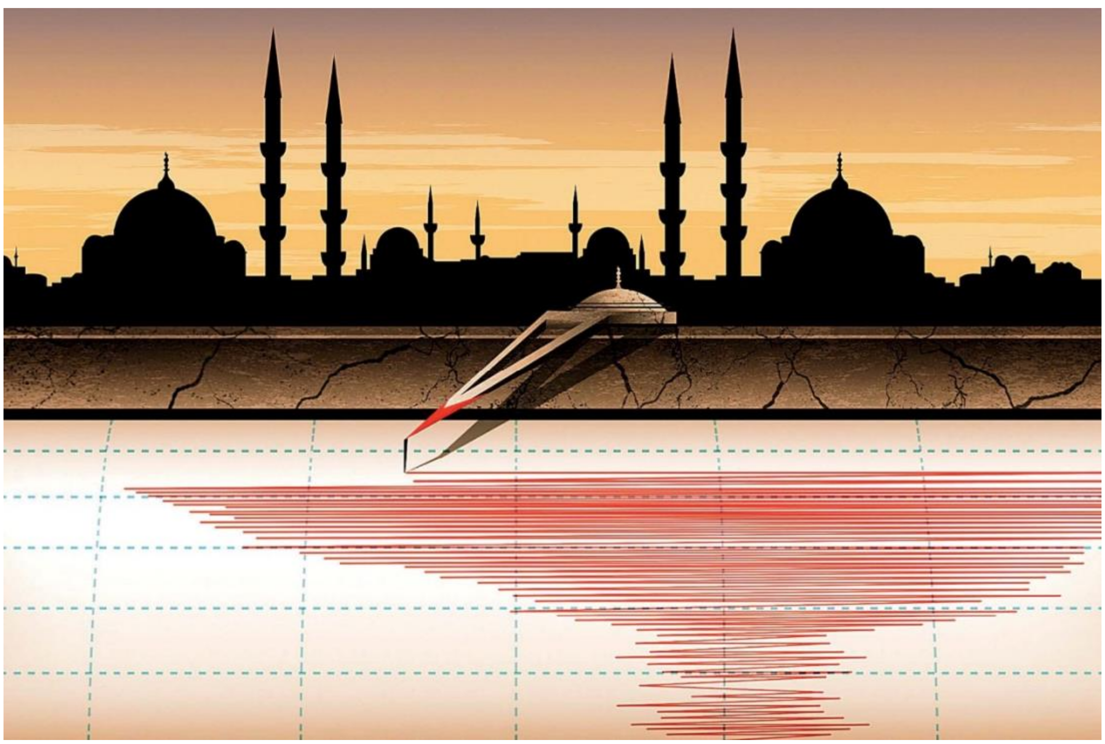
PREDICTING NATURAL DISASTERS

A PRELIMINARY STUDY

MAY 2018



Contents

How to Use the Report

This paper is organized according to XPRIZE's Impact Map development process: Insight, Foresight, Action:

- Insight: hi-fidelity research is conducted, aimed at establishing a baseline, that is, a description of the current state of affairs in a given field (or fields). Establishing this baseline is crucial to identifying gaps, which potential XPRIZEs could solve.
- Foresight: forecasting techniques are employed to determine the baseline scenario (extrapolating the current state into the future), and a preferred future, which will require a series of XPRIZEs in order to be achieved.
- Action: ideation techniques are used in order to identify potential breakthroughs, which could later become XPRIZEs.

Background

Natural disasters affect human and animal lives and properties and flora all around the globe. By definition, the reasons for these natural disasters are not in our control. Meteorologists, Geologists, Ocean Scientists, Computer Scientists, in addition to scientists from various other disciplines have made concerted efforts to predict the time, place, and severity of disasters by using advanced weather and earthquake forecasting models, data assimilation models, and statistical and probabilistic models. A variety of data is collected on a regular basis using in situ sensors, satellites, and remote sensors by national meteorological, geological, and oceanographic agencies, and academic institutions, as well as various other international, government and private bodies, before, during, and after a disaster.

Another line of research, has concentrated on disaster management, the appropriate flow of information beginning prior to a disaster, and then channelizing the relief work and analysis of the needs and concerns of victims. For many decades, local and national governments have worked on establishing robust disaster management plans in the event of an emergency. In recent years, the sources of data for such tasks have also included social media and other internet media as the crowd has reported the situation as and when they are able.

Defining Vulnerability

Vulnerability refers to the way a hazard or disaster will affect human life and property. Vulnerability to a given hazard depends on:

- Proximity to a possible hazardous event;
- Population density in the area proximal to the event;
- Scientific understanding of the hazard;
- Public education and awareness of the hazard;
- Existence or non-existence of early-warning systems and lines of communication;
- Availability and readiness of emergency infrastructure;

- Construction styles and building codes;
- Cultural factors that influence public response to warnings.

In general, less developed countries are more vulnerable to natural hazards than industrialized countries because of a lack of understanding, education, infrastructure, building codes, etc. Poverty also plays a role since poverty leads to poor building structure, increased population density, and general lack of communication and infrastructure.

Economic growth and prosperity can also enhance vulnerability, since increased wealth often contributes to where certain segments of the population decide to live, for example along coastlines.

Destruction Caused by Natural Disasters

More often than not, natural disasters leave in their wake a trail of injury, death, lost livestock, property damage, and enormous economic loss. The single event with the highest death toll since the 1976 “record” earthquake in China[1], was the 2004 Boxing Day tsunami in South East Asia that claimed the lives of 220,000 people. In regard to economic damage, the most destructive natural disaster was the 2011 earthquake and subsequent tsunami in Japan, which caused an estimated economic loss of $360 billion.

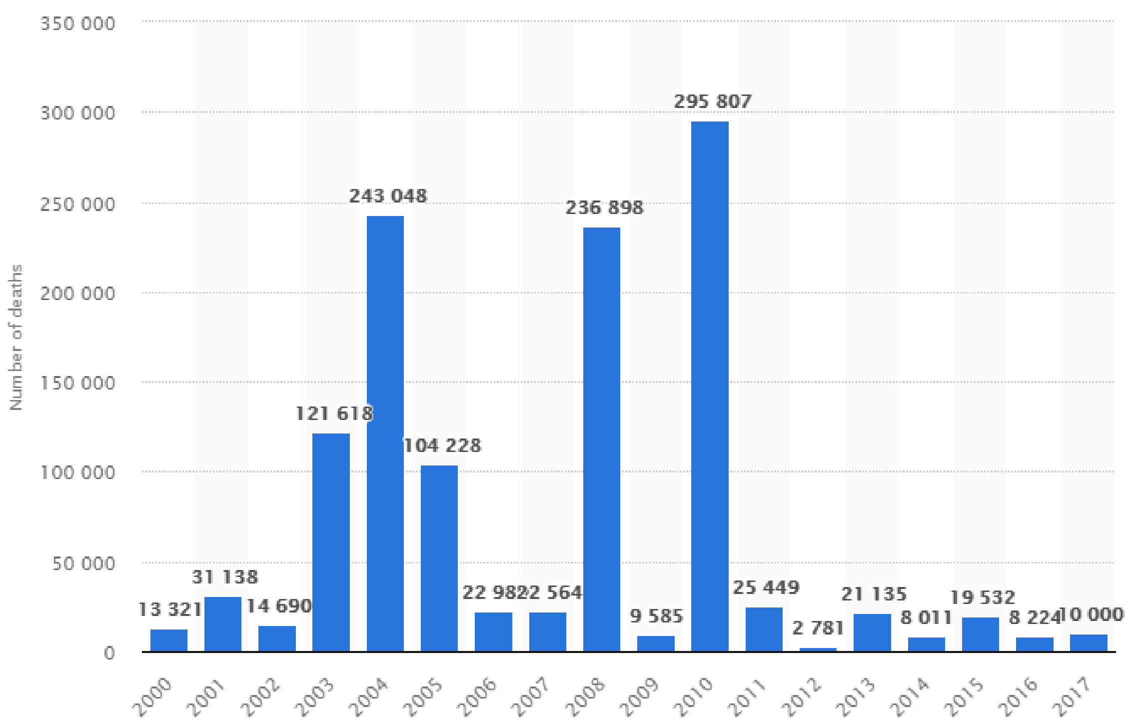
China has experienced a number of the world’s most deadly disasters. In 1976, an earthquake claimed the lives of 242,000 people making it the deadliest earthquake since 1900. The country was also the victim of the most deadly flood since 1900 when 3.7 million people lost their lives in 1931. Although natural disasters are largely seen as outside of human control, human actions are at times responsible for the extremity and impact of such events. Land use can influence the ability of an area to deal with the heavy rains that result in flooding or coastal inundation. On a larger scale, the adverse effects of rising global temperatures, and other phenomena caused by human

[1]The Tangshan earthquake, also known as the Great Tangshan earthquake, was a natural disaster that occurred on July 28, 1976. It is believed to be the largest earthquake of the 20th century in terms of death toll.

intervention, will likely result in stronger and more frequent hurricanes and other extreme weather events in the future.

The chart below, highlights the lethality of natural disasters--particularly from earthquakes, tsunamis and tropical cyclones in the last 17 years at various points around the world[2].

Number of deaths from natural disaster events globally from 2000 to 2017



Prediction and Warning

Vulnerability can usually be reduced if there is an adequate means of predicting a hazardous event.

Prediction involves:

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[2]This statistic displays the annual number of fatalities caused by natural disaster events worldwide from 2000 to 2017. In 2017, there were 10,000 deaths caused by natural disasters worldwide. In 2017, four of the most fatal natural disasters occurred in Asia. (https://www.statista.com/statistics/510952/number-of-deaths-from-natural-disasters-globally/)

- A statement of probability that an event will occur based on scientific observation and understanding.
- Such observation usually involves identifing some kind of precursor event(s)--an anomalous small physical change that may be known to lead to a more devastating event. For example:
    - Hurricanes are known to pass through several stages of development: tropical depression - tropical storm - hurricane. Once an atmospheric wave off Africa is observed to break, forecast models allow meteorologists to predict the likelihood of a tropical depression developing, how long the development into a tropical storm or hurricane might take, and the eventual path of the storm.
    - Volcanic eruptions are usually preceded by a sudden increase in the number of earthquakes immediately below the volcano and changes in the chemical composition of the gases emitted from a volcanic vent. If these are closely monitored, volcanic eruptions can often be predicted, however the accuracy of time of eruption is still very limited.

In the prediction of floods, hurricanes, and other weather-related phenomena the word *forecast* refers to short-term (days) prediction in terms of the magnitude, location, date, and time of an event. Most of us are familiar with weather forecasts. In the prediction of earthquakes, the word *forecast* is used in a much less precise way--referring to a long-term (years) probability that is not specific in terms of the exact time or place that the event will occur.[3] This is mainly because scientists don't have enough data to be able to improve the forecast time.

An "early warning," (a vague term in it of itself) is a statement that a high probability of a hazardous event will occur, based on a forecast. If a warning is issued, it should be interpreted that typical daily routines should be altered to deal with the danger imposed by the imminent event.

[3]For example: Prior to the October 17, 1989 Loma Prieta Earthquake (also known as the World Series Earthquake) the U.S. Geological Survey had forecast a 50% probability that a large earthquake would occur in this area within the next 30 years. Even after the event, the current forecast is for a 63% probability that a major earthquake will occur in this area in the next 30 years.

The effectiveness of a warning depends on:

- The timeliness of the warning;
- Effective communications and public information systems to inform the public of the imminent danger;
- The credibility of the sources from which the warning came.

If warnings are issued too late, or if there is no means of disseminating the information, then there will not be sufficient time or a timely response to the warning. If warnings are issued irresponsibly without credible data or sources, or if they are inaccurate, then they will likely be ignored and a response to the threat will not take place in the future, rendering the warning ineffective.

It is important to understand that natural disasters result from natural processes that affect humans adversely. The three elements that need to be taken into consideration are magnitude, location, and frequency:

- Magnitude - Humans have always coexisted with rivers and benefit from them as a source of water and transportation. Only when the volume of water in the river becomes greater than the capacity of the stream channel is there a resulting disaster. Small earthquakes occur all the time with no adverse effects. Only large earthquakes cause disasters.
- Location - A volcanic eruption on an isolated uninhabited island will not result in a natural disaster. A large earthquake in an unpopulated area will not result in a disaster. A hurricane that makes landfall on a coast where few people live, will not result in a disaster.
- Frequency – A community can be resilient but weakened by one natural disaster, but a second event shortly after may result in increasing the magnitude of the disaster. For example, the Japanese earthquake, followed by the tsunami.

Thus, in studies of natural hazards, it is important to understand the relationship between the frequency, magnitude, and location of an event.

Insight

Description

This study focuses on the convergence of two topics: environmental trends that might affect natural disasters and predictive technology. The current and emerging trends in these two categories are examined further in this report.

Natural Disasters

Environmental and ecological trends can have dire consequences for the planet, causing large-scale natural disasters. Warmer global surface temperatures not only increase the possibility of more droughts, but also enhance the intensity of storms that do occur. As more water vapor is evaporated into the atmosphere it becomes fuel for even more powerful storms to develop. The combination of more water vapor in the atmosphere along with deeper warmer ocean temperatures can lead to increased intensity in tropical cyclones. Rising sea levels will expose locations at higher elevations to the devastating power of the sea and waves, places which haven't experienced this phenomenon previously.

- For example, the coastal areas in the Northeastern U.S. are considered to be facing ecomomic damages due to high property values and built-up coastlines in places like New York City, which could be flooded by 2050. New York City's sea level is expected to increase 79 centimeters (31 in) by 2050, leaving 25% of the city in danger of turning into a floodplain. Around 800,000 people currently live in the target flood zone, and by 2050, 97% of New York City's power plants will be found in this area as well. Because of this, ex–New York mayor Michael Bloomberg proposed a $20 billion flood system in 2013 for New York City before he left office, but his plan was not put into action.

Other factors are less dependent on human behavior, and therefore cannot be controlled.

- For example, the Iquique earthquake (Chile, April 1, 2014) originated from a subduction zone where one tectonic plate, the Nazca Plate, plunged underneath another, the South American Plate. This subduction zone lies within the "Ring of Fire," an arc in the Pacific containing 81% of the world's active volcanoes, causing much of the world's seismic activity.[4] The Iquique earthquake was a "megathrust" earthquake caused by the release of tension from a subduction zone. However, it only relieved 33 percent of the tension on the fault, leaving the remaining tension to be relieved at some point in the future.

Technology

We have better forecasts of many types of natural hazards compared to a few decades ago because of the remarkable progress in weather forecasting, instrumentation, monitoring, and computational technologies. A few decades ago, weather forecasts were rather subjective and found to be invariably at variance with the actual weather across the forecast region. Today, we rarely go wrong in general weather forecasts with a lead time of a day or two across the forecast region. Our ability to making medium- (3-10 days) and longer-term (10+ days) weather predictions which is why we are able to anticipate natural hazards like drought, floods, hurricanes, tornadoes, thunderstorms, and lightning somewhat ahead of their occurrences. [5] About 15 years ago, warning against tornadoes was given for only about 45% of the cases. Today the figure is close to 90%.

Prediction of other types of natural hazards is much more difficult with technological breakthroughs not occurring as rapidly as one would hope. In the case of earthquakes, the continuous tracking of crustal movements, seismic, geoelectric, geomagnetic, geochemical, geothermal observations, geodetic and ground water measurements, and reference to unusual animal behavior are regarded as important indicators. Work is also being done in statistical analysis, chaos physics, sub-surface, ground, and satellite mapping, atmospheric precursors and real-time monitoring to make predictions more

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[4]When a tectonic plate moves under another, the faults can come under severe amounts of stress, and any release of tension causes seismic activity, which results in earthquakes.

[5]For a tornado, there is a few minutes warning (generally 15 minutes over a large area, and until it is seen, it is not guaranteed). For lightning, we can say the general area it will hit within an hour—that's because we know that there is a storm. For a hurricane, last year, Hurricane Irma swerved off its forecasted track just 6 hours before landfall.

reliable. Despite all of this, the prediction of earthquakes (and volcanoes, tsunamis, landslides etc.) remains beyond our capacity at present.

Of the various technologies that have the potential to change disaster prediction, the following three may be considered the most promising:

- Predictive analysis is an advanced branch of data engineering which generally predicts some occurrence or probability based on data. [6] Predictive analytics uses data-mining techniques in order to make predictions about future events, and make recommendations based on these predictions.[7] The process involves an analysis of historic data to predict the future occurrences or events. Predictive analytics is able to not only deal with continuous changes, but discontinuous changes as well. Classification, prediction, and to some extent, affinity analysis constitutes the analytical methods employed in predictive analytics.
- Recent advances in machine learning can be used to solve a tremendous variety of prediction challenges and deep learning is pushing the boundaries even further. In the case of earthquakes for example, machine learning can process and make sense of massive amounts of raw seismic data. Researchers at Los Alamos National Laboratory are able to listen to the acoustic signal emitted by a laboratory-created earthquake; a computer science approach using machine learning can predict the time remaining before the fault fails.
- Finally, the Internet of Things (IoT) combines the previous two and adds another layer. IoT, although it cannot prevent a disaster from happening, it can definitely aid in efficient disaster prediction. It has been found to be useful in predicting the upcoming event and delivering an early warning to communities through smart systems:

[6]There has been many decades of work on: (1) numerical prediction—using data and mathematical models to predict; (2) probabilistic (or stochastic) models—where you add a random variation and look at the probability distribution of the outcomes to determine the most likely scenario; and, (3) statistical models—where historical data is used to get a statistical probability of occurrence.

[7]In the case of large one-off events, this may be the less reliable in terms of refining the exact time and location of an event. We can say "it was a 100-year storm" meaning a storm like this comes along once every 100 years, but there is no exact day/time to such a statement. Numerical prediction models may be the most accurate bet for fine-scale predictions at the moment.

- The first application is, by default, to minimize and possibly prevent the risk of loss of human life and economic loss associated with a natural catastrophic event. With the help of GIS, smart devices, and satellite communication, the IoT technology can be used to design the systems meant for early warning and awareness. For example, remote infrared (IR) satellite sensors can show the rainfall in clouds and be used to predict flooding.
- Conventional media also play a major role. Real-time communication in order to deliver an emergency response is the next potential application of IoT. The most challenging and probably the most exhaustive job that follows any disastrous event is recovery and rescue. The IoT technology can be efficiently used in creating online systems that search for missing people and even manage emergency funds.[8] Moreover, IoT-enabled devices and systems can function as an alternative for communication when the conventional infrastructure for communication is poor, sensitive, or not working. A key challenge here would be to deploy and operate such dvices in areas when there are no means of communication or power.
- IoT-based sensor development is perceived to be an excellent innovation that positions itself as an efficient solution to the lack of foresight which intensifies the adversity of any natural disaster and the resulting emergency. IoT sensors can be installed within a particular area to create a system that ultimately acts as an emergency unit in case of catastrophic events. Enivironmental parameters, such as humidity, temperature, air quality, pressure, water level, and many more are constantly monitored by these sensors and the moment any one or more of them reach a dangerous level, the sensor network grasps it.
- Other notification systems can hardly match the speed of sensor notification, when it comes to alerting emergency responders and message broadcasters. Moreover, sensors anticipate upcoming hazards

[8]This happens already after a natural disaster, but in areas outside the disaster zone usually. Within the disaster zone, there is no communication or power, and that is where this advance is really needed.

well in advance in order to aid decision making regarding the best plan of action.

Additionally, researchers are working on specific IoT sensor types, including infrared and microwave. While the former may be best applied to flood prediction and management, the latter is expected to be a valuable sensor in the realm of earthquakes, by detecting motion close to the earthquake epicenter and transmitting a warning alert to users further away from the epicenter.

What's In, What's Out

Methodological Note

Determining what the Predicting Natural Disasters study entails also means determining what it does not. Therefore, it is important to set boundaries and determine the scope, as it helps focus activities and allows for significant creativity within the defined zone of focus.

Areas of Focus

Natural Hazards and the natural disasters that result can be divided into several different categories:

- Geologic Hazards Include:
    - Earthquakes
    - Volcanic Eruptions
    - Tsunami
    - Landslides
    - Subsidence
    - Impacts with extraterrestrial objects
- Atmospheric Hazards Include:
    - Tropical Cyclones (Hurricanes, Typhoons, Cyclones)
    - Tornadoes
    - Droughts
    - Floods
    - Severe Thunderstorms

    - Snow and Ice storms

Natural Hazards (and the resulting disasters) are the result of naturally occurring processes that have taken place throughout Earth's history.

- Most hazardous processes are also geologic and atmospheric processes.
- Geologic and atmospheric processes affect every human on Earth all the time, but are most noticeable when they cause loss of life or property. If the process that causes the hazard occurs and destroys human life or property, then a natural disaster has occurred.

Risk is a characteristic of the relationship between humans and geologic processes. The risk from natural hazards, while it cannot be eliminated, can, in some cases be understood in a such a way that we can minimize the hazard to humans, and thus minimize the risk. To do this, we need to understand how the process works, and understand the energy required for the process (e.g. for hurricanes, it's the ACE (Accumulated Cyclone Energy). Then we can develop a plan of action to minimize the risk. This minimization of risk is called hazard mitigation.

Natural Hazards can also be divided into rapid onset hazards, such as volcanic eruptions, earthquakes, flash floods, landslides, severe thunderstorms, lightening, and wildfires, which develop with little warning and strike rapidly.

Essential questions to answer for each possible natural disaster are:

- Where is each type of hazard likely to be present and why?
- What scientific principles govern the processes responsible for the disasters?
- How often do these hazards develop into disasters?
- How can each type of disaster be predicted and/or mitigated?

This report will take a closer look at two types of rapid onset hazards--earthquakes and tropical cyclones. These two are chosen because, with the exception of an asteroid impact, they are responsible for the greatest loss of life and economic loss. Given their nature, these disasters are related to other phenomena like, tsunamis, and volcanic eruptions. The vast majority of tsunamis (80 percent) are caused by an earthquake at or below the sea floor. The earthquake causes a large area of the seafloor to either be uplifted or drop down, which results in a tsunami wave on the surface of the ocean which travels out in all directions. Earthquakes can also cause volcanic eruptions. A few historic large regional earthquakes (greater than magnitude 6) are considered by scientists to be related to a subsequent eruption or to some type of unrest at a nearby volcano. Hurricanes, cyclones, and typhoons are the same thing, but they're officially called tropical cyclones. However, they use distinctive terms for a storm in different parts of the world. A tropical cyclone first becomes a tropical storm at 39 mph, and then becomes a Hurricane/Typhoon/Cyclone when it reaches 74 mph. There are five strength categories depending on wind speed and engineering damage. The highest category is five, which is above 155 mph and is defined as total annihilation of property and flora and therefore, by definition, it is not possible to get a higher category.

Although tsunamis and volcanos can be extremely destructive, they are often precipitated by an earthquake. As a result, if a breakthrough in disaster prediction can be achieved for earthquakes, it will benefit millions of people who could potentially be adversely impacted by the resulting tsunami or volcano. Therefore, this report will focus on the following question, "how can each type of disaster (tropical cyclone and earthquakes) be predicted and/or mitigated?"

Who's Doing What? (Benchmark Analysis)

Methodological Note

Benchmarking is a way of discovering the highest level of performance being achieved--whether in a particular company, by a competitor, or by an entirely different industry. This information can then be used to identify gaps in an organization's processes in order to achieve a competitive advantage. However, unlike business-driven benchmark analysis, in the context of XPRIZE prize development, benchmark analysis is aimed at answering the following question: Who (innovators, academics, corporates) is developing solutions to a similar problem? What solutions are they developing? And who is providing funding in this area?

Examples:

- Global initiatives aim to ‘‘provide ready access to global, regional, national and local warning systems, including dissemination of warnings. What has been achieved in this direction is commendable; what further can be achieved is beyond imagination. Advanced geostationary and polar orbit satellites, Doppler radars and wind profiling systems, automated surface observing systems, and interactive information systems have opened up new vistas and mind-boggling possibilities of great potential. Satellites have already been providing reliable, multispectral, multidata, synoptic information and data used for mapping, monitoring, forecasting, surveying of vulnerable and disaster-inflicted areas, and of damaged regions. The UN’s International Decade for Natural Disaster Reduction (IDNDR) infused a new life into a number of local, regional, national, and global networks. For example, many satellite-based networks consisting of digital seismicity and strong motion instruments, located in earthquake prone areas, are fully networked and operational today.
- Hazard-specific warning systems (tornadoes, hurricanes, floods, earthquakes, volcanoes, tsunamis, wildfires, and droughts) have all been perfected to a significant degree but many more new possibilities have opened up because of next generation **weather satellites**[9]. Such satellites provide forecasters more frequent high-quality images and new types of atmospheric soundings leading to advanced information about hurricanes, flashfloods, and other severe weather storms. An example of the seamless integration of seismic monitoring and tide monitoring for tsunamis, or continuous monitoring of cyclones and floods for coastal innundation, are being used to alert communities and save lives and property.
- The effort to put in place a **Global Emergency Observation and Warning Systems**, (GEOWARN), is both significant and laudable. The Institute for Mineralogy and Petrography’s GEOWARN utilizes satellite communications and global high-resolution remote sensing to provide disaster warning and relief

[9]See for example NASAs satellite, carrying the National Oceanic and Atmospheric Administration (NOAA) Geostationary Operational Environmental Satellite, or GOES-S.

support. GEOWARN is primarily designed to combat the effects of floods, hurricanes, earthquakes, droughts, etc., globally. The spinoff benefits include early warning against avalanches, deforestations, dust-storms, landslides, oil fires, tornadoes, tsunamis, volcanic eruptions, wildfires, and scientific applications. An added feature of GEOWARN is the linkage with the global disaster communications networks in order to access the existing sources of remote sensing data and ensure that crucial information reaches its destination in good time. It is also expected that regional centers interconnected with the satellite links and data networks would provide services to the designated parts of the world. Warning Systems are poised to move into much higher orbits of reliability with strengthening of the associated measuring systems such as Satellite Radar Imaging (SAR) and the Global Positioning System (GPS). One might also exploit air-borne system of SAR, Synthetic Aperture Radar, for relief support and damage assessment.

- **AI for Earthquake Response -** While artificial intelligence (AI) is still learning how to best predict earthquakes, it can also be applied in the aftermath of a major earthquake to assist with relief and response efforts. Palo Alta, California based One Concern has developed an algorithm capable of identifying the areas most damaged and in need of aid following an earthquake. The company's algorithm has been taught how earthquakes damage buildings and structures and can be loaded with data in a given area such as the age of buildings and the materials used to construct them. Following an earthquake, all this information can be combined with seismic data, allowing the algorithm to create a heat map that predicts the most damaged areas. As of 2015, One Concern's algorithm has been undergoing beta testing in various areas including San Mateo, Calif.
- **AI for Tsunami Early Warnings -** Resulting from an earthquake in March 2011, a nearly 50-foot tsunami hit the shores of Fukushima, Japan, leading to a series of meltdowns at the Fukushima Daiichi Nuclear Power Plant. Investigators later found that the disaster, the worst nuclear accident since the 1986 meltdown at Chernobyl, could have been prevented with better safety precautions and procedures. The Fukushima incident is an extreme example, but it shows the

devastating effects tsunamis can have. Researchers have been actively working to find ways to improve tsunami warning systems using artificial intelligence. Utilizing fuzzy logic, which analyzes data by the degree to which it is true, as opposed to a Boolean true-false, researchers have been able to pool expert data as well as sensor data from tsunami warning systems to create algorithms that are able to predict the likelihood and severity of a tsunami. A 2010 paper published by the Institute of Electrical and Electronics Engineers (IEEE) demonstrated that it is possible to design an autonomous early warning system for tsunamis that can be deployed in remote areas without the need for human supervision. A 2014 paper published in the *International Journal of Research in Engineering and Technology* further expanded upon this methodology, showing that increasing the number of rule sets and parameters can lead to increased accuracy.

- **Machine Learning to Predict Earthquakes -** Scientists have used a variety of methods to predict earthquakes in the past, but none have yielded the consistency and accuracy the public requires from an earthquake forecast system. But researchers now believe sophisticated machine learning algorithms could be the solution to reliable earthquake prediction. Researchers at Los Alamos National Laboratory have been feeding massive sets of seismic data into a machine learning algorithm, hoping to teach it to find patterns that will allow it to predict earthquakes.
- In February 2017, a team from Cornell University published the results of a study in which they used **machine learning to predict laboratory-simulated earthquakes.** By looking at acoustic and seismic activity that may be precursors to an earthquake, the researchers were able to design an algorithm that could detect earthquakes in a lab-made fault line that consisted of three blocks with a rocky material sandwiched between them. “We show that by listening to the acoustic signal emitted by a laboratory fault, machine learning can predict the time remaining before it fails with great accuracy,” the researchers wrote. “These predictions are based solely on the instantaneous physical characteristics of the acoustical signal, and do not make use of its history.” They also discovered that

the algorithm identified a signal emitted from the fault zone that was thought to only be low-amplitude noise and typically dismissed by seismologists, but the researchers found that it actually improves the accuracy of its predictions. While machine learning has not been applied in any real-world earthquake prediction scenarios yet, the lab results do show promise that it could someday be scaled to do so.

- **Satellites That See Inside Hurricanes -** When Hurricane Maria hit San Juan, Puerto Rico much of the land-based radar used to provide information about the hurricane was destroyed. However, forecasters were able to turn to the National Oceanic and Atmospheric Administration (NOAA) newest Geostationary Operational Environmental Satellite (GOES). The GOES-16, launched in November 2016, uses infrared imaging and is capable of scanning a hurricane as often as every 30 seconds, which allows forecasters to view inside the storm itself to capture detailed data on its intensity, position, and movement. This enabled them to track Maria in real time. According to NOAA, GOES-16 has four times the resolution and a refresh rate five-times faster than previous satellites, allowing for an unprecedented level of detail and accuracy. The GOES-16 is also equipped with a “geostationary lightning mapper” that allows forecasters to view lighting in the storm in real time as well. Beyond hurricanes, the satellite imagery can also be applied to other disasters such as forest fires.
- Together with state and university partners, the U.S. Geological Survey is developing the **ShakeAlert,** which can detect earthquakes and send out an alert up to a few tens of seconds before the shaking starts. The technology will help prevent cars from entering bridges and tunnels, slow down trains and divert planes, if necessary, lowering damages or casualties.
- Researchers from the University of Cambridge have developed a more accurate method of **predicting volcanic eruptions** by measuring the energy moving through a volcano and comparing it with changes in the surrounding rock. According to the team, the pressure changes inside a volcano, caused by an increased presence of magma, can result in the shrinking or bulging of the rock, eventually leading to cracks and faster seismic waves. The strong

correlation between the two could give scientists a new means of predicting eruptions that have had, until now, subtle or imperceptible indicators.

- Scientists from the University of Hawai'i at Manoa School of Ocean and Earth Science and Technology have also developed a system which uses **infrared sensors on satellites to track heat emissions from erupting volcanoes**. The data gathered over the course of nearly 20 years has allowed the researchers to create a prediction model for when eruptions will cease based on the volcanoes' infrared pattern. If the model is accurate, scientists will be able to determine exactly when an eruption has ended, allowing local governments to reduce the time it takes to move evacuated citizens back into their homes.
- Scientists at Oklahoma State University and the universities of Oklahoma, Nebraska and Kentucky are using **unmanned aircraft system (UAS)**, i.e. drone technology, to better understand how tornadoes and other severe weather phenomena develop. The aim is to use new data to improve
  early warning systems, which can increase the advanced warning time from 14 minutes to more than an hour.
- Scientists at Berkley are using the accelerators in smartphones to record earthquakes as they happen. They hope that by turning mobile phones into vast data collection points, they can quickly glean information about the quakes and warn those farther away from the epicenter that shaking is on the way.

Gap Analysis

Methodological Note

Gap analysis involves the comparison of actual performance with potential or desired performance. Simply put, gap analysis addresses three questions:

- "Where are we?" (the present state); and
- "Where do we want to be?" (the target state)
- "What must be addressed to get from today to the target?"

The first question is answered through the previous research components, that is, the insights section and benchmark analysis. These two components are basically a description of the present state and the elements that will shape the future. The second question is answered through the description of the desired end-state. So, if we know where we are (current state), what the desired state is, and who is working on solving related-challenges, we can also identify what areas are being neglected (and for what reason). These areas (and reasons) are the gaps.

Gap Description

While scientific methods may lead us to a reasonably thorough understanding of some phenomenon, that does not always translate into an accurate practical prediction capability that, for example, might help us avoid being killed by a natural disaster. When that is the case, we then find ourselves talking about *risk*, the likelihood that some dangerous event will take place, even though we do not know when.

Risk assessment is necessitated by an inability to predict. That inability to predict may come from some deficiency in our knowledge, or it may be the result of great complexity inherent in the phenomenon (for example, we may not have high-enough-resolution data to represent it, or the process may have a chaotic component that keeps us from determining exactly when it will occur). We are then left only with probabilities.

Let's take a tsunami as an example: The only way that a more advanced tsunami warning could be given is if the earthquake itself could have been predicted. But we cannot predict when an earthquake will strike, not the day, or the month, or the year, or even the decade. All we can do is assign a risk to particular regions. Japan, with its numerous tectonic plates butting up against each other, is known to be a high-risk area; many earthquakes and tsunamis have occurred there before. As a result, some sea walls have been built and some buildings made stronger. Technology contributed to those defenses. But they were not enough, and in fact, can never be enough, without huge sums of money being spent to build 40-foot sea walls along almost the entire Japanese coastline and to make all buildings capable of surviving the very rare 9.0 earthquake.

It would be more effective to pour a small fraction of that cost into additional earthquake prediction research. With the great complexity of the worldwide tectonic environment, understanding what makes two tectonic plates suddenly release each other, much less being able to predict when earthquakes will occur using a detailed geophysical model, is still very far off. But using technology to continuously measure the various signals that the solid Earth provides, until we find signals that only come in advance of an earthquake, may be possible a lot sooner.

Large-scale early warning systems require considerable resources: people, infrastructure, technology, data, and funding. They have to operate continuously. They are complex to manage, needing to integrate multiple actors (scientists, civil authorities, the media, and the public) at different levels (international, national, regional, local). They must also be linked to disaster preparedness and Disaster Risk Reduction (DRR) programs. There must be strong links throughout the system and between its stakeholders: warning system failures often occur when these links are weak or break down.

Institutional arrangements for coordination and communication have to be worked out carefully and agreed upon, and responsibilities defined. Setting up a system can take a long time, depending on its scale and degree of complexity. Systems should always be undergoing testing, practice, review and refinement (warning systems for frequent events tend to be more effective than those for infrequent ones because they are used more regularly). Facilities and equipment have to be maintained and where necessary repaired; staffing and volunteer levels also have to be maintained. However, it is certainly not the case that only wealthy societies can have effective forecasting and warning systems[10].

Large-scale, centralized systems tend to achieve broad geographical coverage but can fade out as they get closer to vulnerable communities and more marginalized groups.

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[10]For example, in 1999 a massive cyclone hit Odisha (India) resulting in almost 10,000 deaths. In 2013, the extremely severe Cyclone Phalin made landfall in almost the same place, but due to the effective warning systems and unprecedented emergency management, over 500,000 people were e evacuated to a safer place and the outcome was that there were only 45 deaths.

Information can be transmitted accurately and effectively through different levels in the system, but may not reach communities at risk (what is often called the ‘last mile’). This problem has been highlighted on a number of occasions. In most systems, the bulk of the effort and expense goes into transmitting detailed, clear information to decision-makers and emergency management services. Less effort and funding go into disseminating this information down to individual communities or households through accessible messages that will warn them and help them make decisions about how to best respond.

Warning systems need to be end-to-end, and connect those who need to receive the message to those who prepare and deliver them. It is particularly important that they reach the most vulnerable and marginalized populations who typically live in rural and often times isolated locations and trigger local evacuation and protection mechanisms. The vulnerabilities, needs, roles and capacities of different groups of society must be taken into account. Messages must be sent/broadcast in a way that all people receive them and in a clear manner so that they are interpreted in the way the message is intended so that the affected respond in an appropriate and timely manner.

Grand Challenges

Methodological Note

Grand Challenges (GCs) are lists of difficult but important problems articulated by the research team to encourage the discovery of (mainly) technological innovation (i.e., breakthroughs) that could potentially solve the main issues. In other words, a GC is one or more specific critical barrier(s) that, if removed, would help solve an important problem with a high likelihood of global impact through widespread implementation.

Articulating important challenges that have the potential to deliver real impact, and allocating significant resources to address these GCs later in the process, allows XPRIZE to bring the best minds to the table by engaging crowds who might not otherwise be engaged in global research.

Key Challenges

What are the primary expectations of early warning alerts against disasters? The foremost expectation is that the warning alert should be *timely* because most disasters are quick to strike and they give very little time to react. The authorities responsible for issuing early warning alerts must be sure of the (a) *reliability* of the hazard detection systems; (b) *clarity* of inflowing alert messages from the automated as well as human-controlled systems; (c) *basic information* on previously established area-specific hazard levels; (d) early warning criteria; and (e) *robustness* of the alert dissemination apparatus at their disposal.

It is expected that early warning systems for specific types of hazards (e.g. hurricanes, earthquakes) will be *closely coupled with a well-coordinated* disaster response apparatus geared to respond to any combination of natural, man-made, or multiple emergencies.

It is expected that early warning alerts are backed by *effective, coordinated, and synergistic* action between the various players for quick decision making. Systems which are quick, dependable (sturdy and reliable), and capable of managing simultaneous wireless communications have helped save lives.

Framing a Grand Challenge—Hurricanes

- **Widely applicable problem…**
  The 2017 North Atlantic hurricane season is currently the most expensive on record, with an initial estimate of $282 billion in economic loss primarily due to the location of landfall and the emergency management reponse. The season had 17 named storms, 10 hurricanes, and 6 major hurricanes. This is well above the 1981-2010 average of 12.1 named storms, 6.4 hurricanes, and 2.7 major hurricanes. This season resulted in over 500 deaths (with some estimates as high as 1500 deaths). Meanwhile, the 2017 Pacific hurricane season had 18 named storms, including 9 hurricanes, 4 of which became major--these are a closer to the average for that basin, which normally sees 16.6 named storms and 8.9 hurricanes. It was also an awful reminder of how vulnerable people are to hurricanes and how unprepared the world is for a potential future where the strongest storms get stronger and push their storm surges inland a top of rising sea levels.

- **for which scientifically sound solutions are imaginable…**
  Scientists are able to observe more of a hurricane now than before, through better satellite surveillance and data-rich aircraft flights through storms. With better computers, meteorologists have improved their simulations of atmospheric processes. Scientists are also better at "initializing" forecast models, which start their forecasts with a vision of reality that's much closer to the real world. These technological advances were key to the improved storm-track models.
- **but not quite at hand…**

Although storm track forecasts have steadily improved over the last 30 years, there's been no tangible improvement in the ability to forecast how strong a storm will be, nor the exact course it will take.

- **with deep societal importance**
  The forecaster's worst nightmare is: There's a storm in the Gulf of Mexico that's 12-24 hours from landfall, and when everyone goes to bed at night it's a tropical storm, but by the morning it's a Category 4 and is veering off the forecast track, taking it from a sparsly populated region towards a major metropolitan area. By then there's just no time to get people out of harm's way. Better prediction models and techniques are needed to warn people of impending disasters.

Framing a Grand Challenge—Earthquakes

- **Widely applicable problem…**
  Currently, it is not possible to predict earthquakes or forecast them with more than a few seconds warning. The United States Geological Survey (USGS) nor any other scientists have ever predicted a major earthquake; Earthquakes can strike any location at any time. But history shows they occur in the same general patterns year after year, principally in three large zones of the earth. The world's greatest earthquake belt is the circum-Pacific seismic belt ("Ring of Fire") found along the rim of the Pacific Ocean, where about 81 percent of the world's largest earthquakes occur. The second belt, the Alpide, extends from Java to Sumatra through the Himalayas, the Mediterranean, and out into the Atlantic. This belt accounts for about 17 percent of the world's largest earthquakes. And the third prominent belt follows the submerged mid-Atlantic ridge. From the years 2000-2015, 801,629 people have died from earthquakes around the world.
- **for which scientifically sound solutions are imaginable…**
  Today's scientists understand earthquakes a lot better than we did even 50 years ago, but they still can't accurately predict when an earthquake will occur.
- **but not quite at hand…**
  It's difficult to figure out when an earthquake will occur since the forces that cause them tend to accumulate slowly over a vast area, but are disbursed rapidly

over a narrow region. Forecasting earthquakes would require high-resolution measurements deep underground over the course of decades, if not longer, coupled with sophisticated simulations. And even then, it’s unlikely to yield an hour’s worth of lead time. There are ultimately too many variables at play and too few tools to analyze them in a meaningful way.

- **with deep societal importance**
  An improvement in earthquake prediction and warning dissemination can save countless lives, not just from massive tremors, but also from the resulting tsunamis and volcanic eruptions.

Notable Grand Challenges in disaster prediction for both tropical cyclones and earthquakes can include the following:

Prediction: Predictions of disasters are not accurate nor consistant globally, and fail to provide enough lead time for complete preparation, resulting in the loss of lives including often substantial economic losses. Some forecasts can also be misleading, which result in unnecessary angst, evacuations, and associated expenses.

Standardization: Warning systems and dissemination of accurate information varies from place to place, resulting in miscommunication and confusion.

Technology: Currently there are insufficient real-time sensors monitoring a natural event that can result in a natural disaster. To improve forecasts, truly real-time data is needed--continuous, instantaneous, and with complete coverage. This is especially important for tropical cyclones.

Genesis: Although considerable research is taking place, the trigger mechanism or precursors to genesis have not yet been identified with any great accuracy. This is especially important for earthquakes.

Communications: Communication of disasters does not give enough lead time for evacuation in some cases, nor is it consistent. There are now apps becoming available which attempt to provide an earthquake alert (of tens of seconds) to those in potential danger. However, many of these apps are still in beta stage. With tropical storms, there is more lead time to provide advance notice and information to those in critical areas, but the accuracy, timeliness, and consistency of this information also needs to be significantly improved.

Reduction: Both earthquakes and tropical cyclones are the Earth's way of releasing energy and in some cases, these disasters are necessary and serve a beneficial purpose (e.g. it is known that without the annual rain from tropical cyclones there will be droughts). These are on such a massive scale that there it would require massive geo-engineering to prevent these, which may have equally massive unintended consequences. However, there may be a path forward where the release of energy can be continuous instead of in large step-functions, thereby lessening the force of natural disasters like tropical cyclones and earthquakes. While there are many ideas and associated solutions in the various patent applications, the primary thrust of the patent application for tropical cyclones is the churning of cold water from deep below the surface to mix with warmer surface water immediately in front of the path of the storm whilst it is far from land. The process is carried out by one or more vessels (which is dangerous, expensive, and unwieldy), and the hope is that using cold water from the depths of the sea could minimize hurricane intensity, potentially saving millions (or billions) of dollars and many lives. For earthquakes, an example of an intervention is to seed the fault line to potentially relieve stress and perhaps reduce the negative effects of an earthquake. These interventions are controversial as there may be unintended consequences from geoengineering, which is the deliberate manipulation of an environmental process that can affect the earth's climate. Many argue that tropical cyclones and earthquakes are a necessary global phenomenon, and if interrupted could negatively impact other parts of the world.

Foresight

Methodological Note

Scenarios inform present-day decision-making by exploring different possible futures. In contrast to forecasting, scenarios examine what is most uncertain and surprising as a mechanism to generate insight and provoke action regarding future-focused risks and opportunities. Scenarios can stretch our thinking about divergent plausible futures. Importantly, the value of scenarios analysis is to examine all of the possible futures identified—rather than focusing on the more desirable ones—with the understanding that any scenario may occur. Thus, scenarios are a tool to uncover blind spots and broaden perspectives about alternative future environments in which today's decisions might play out. The implications drawn from the scenarios are designed to trigger discussion, rather than serving as prescriptive outcomes.

Baseline Scenarios

The future is uncertain. And navigating uncertainty requires thoughtful consideration and contingency planning for unforeseen developments. Scenarios can be a powerful tool to explore potential futures, considering how key trends and uncertainties could lead to different outcomes. They can broaden our perspectives on the possibilities for what the future may hold, and the implications of the choices we make today. Scenarios are also important because they can provoke and challenge leaders to think in new ways about what the future may bring and to motivate action on the key issues that will shape the future.

In the 21st century, many have made predictions of major natural disasters occurring in the near and distant future. Below, are 10 catastrophic natural disasters that, according to scientific evidence, may occur at any time:

- Megathrust Earthquake (Chile, 2015–2065) - the Chilean earthquake of April 2014 opened fissures that could lead to a magnitude 8.5 or larger earthquake in Chile. On April 1, 2014, a magnitude 8.2 earthquake occurred 97 kilometers (60 mi) off the northwest coast of Chile near the city of Iquique, causing landslides and a tsunami to hit the coast. This earthquake created the possibility for an even larger earthquake for Chile in the near future due to the location of the earthquake.

- Twin Earthquake - Masaaki Kimura, a seismologist and emeritus professor of submarine geology at the University of the Ryukyus, is currently predicting that another 9.0 magnitude earthquake, very similar to the 2011 Tohoku earthquake, will occur in Japan after 2017. Occurring March 11, 2011, the magnitude 9.0 Tohoku earthquake struck 372 kilometers (231 mi) off the coast northeast of Tokyo and created a tsunami with 9-meter (30 ft) waves that hit Japan. Dr. Kimura has stated that he predicted the Tohoku earthquake four years before it happened.
- Mt. Fuji Eruption (Japan, 2015–2053) - When the Tohoku earthquake shifted the landmass of Japan, 20 of the 110 active volcanoes in Japan showed increased seismic activity, leading experts to believe one may erupt any given day. The Japan Meteorological Agency (JMA) monitors seismic activity and active volcanoes in Japan. Out of Japan’s 110 volcanoes, 47 are considered “active,” meaning they have erupted in the last 10,000 years or spew gases. Calculations show that Japan should have a major volcanic eruption every 38 years. Currently, 15 “volcanic events” happen annually. On the list of 47 active Japanese volcanoes is Mt. Fuji, Japan’s tallest volcano, standing at 3,773 meters (12,380 ft). In July 2014, a French and Japanese scientific team released a report claiming that Mt. Fuji is among the volcanoes most likely to erupt, causing concern for many Japanese citizens. Mt. Fuji is located only 100 kilometers (62 mi) from Tokyo. If Mt. Fuji erupted, the team predicts that it would necessitate the emergency evacuation of 750,000 people from Tokyo. The city would most likely be covered in ash.
- Earthquake-Tsunami Split (Oregon, 2015-2065) - Through the joint efforts of more than 150 volunteer experts, the Oregon Seismic Safety Policy Advisory Commission predicts that an 8.0–9.0 magnitude earthquake and subsequent tsunami will occur off the coast of Oregon within the next 50 years. The big

questions are: When will it occur, and will Oregon be prepared? The source of this catastrophic earthquake-tsunami split is the Cascadia subduction zone, a 1,287-kilometer (800 mi) crack in the Earth's crust 97 kilometers (60 mi) offshore from Oregon. The Juan de Fuca and North American continental tectonic plates create this subduction zone, which is considered the "quietest subduction zone in the world" but is currently thought to be hiding one of the biggest seismic events of the century. This occurrence has been predicted since 2010; the Commission now states that it will inevitably occur. The predicted earthquake and tsunami will kill over 10,000 people, possibly splitting apart portions of the West Coast and costing the U.S. $32 billion in damage.

- Largest Tsunami Ever (Caribbean, Unknown) - Dr. Simon Day of University College London and Dr. Steven Ward from the University of California Santa Cruz predict that the Cumbre Vieja volcano on the Canary Islands will erupt and create the largest tsunami in recorded history. In their jointly written and released paper on the topic in 2001, Dr. Day and Dr. Ward hypothesize that a rupture in the volcano's structure occurred during its last eruption, causing the left side to have become particularly unstable. If Cumbre Vieja were ever to erupt again, its left side would turn into a landslide that would cause the biggest tsunami in the history of man. They have deduced that the monstrous wave will travel at 800 kilometers per hour (500 mph), be 100 meters (330 ft) tall upon first impact with land, and will reach Florida within nine hours of being created. Dr. Day and Dr. Ward predict that tsunamis will hit faraway places such as England, Florida, and the Caribbean.[11]
- The "Big One" (California, 2015-2045) - The U.S. Geological Survey has increased the probability of the likelihood of a magnitude 8.0 or larger earthquake hitting California within the next few decades. The "Big One" refers to the earthquake that many Californians have been waiting for with bated breath for years. The USGS's Third Uniform California Rupture Forecast (UCERF3) predicts earthquake eruptions and states that a magnitude 8.0 earthquake or

[11]Note that this is a worst-case scenario. If an eruption-caused landslide on Cumbre Vieja were to happen, it's more likely that the entire landmass wouldn't all fall into the sea in one event. A more piecemeal landslide would not cause a record-breaking tsunami.

larger has a 7 percent chance of occurring in the next 30 years. The odds of a magnitude 6.5–7.0 earthquake hitting went up 30 percent. If it were to hit, it would most likely come from the breaking of the San Andreas Fault, spanning the distance in southern California inland from Los Angeles, but there is some speculation as to which fault will be the origin point. No matter where the earthquake comes from, it is predicted to devastate all of California and other parts of the West Coast.

- Indonesia’s forgotten super volcano - The threat posed to the world by the Yellowstone super volcano in the United States is well documented. Less well-known (or acknowledged), however, is that it is just one of many posing a catastrophic threat to the planet. The Lake Toba super volcano, on the Indonesian island of Sumatra, is currently home to the largest volcanic lake on Earth, formed 74,000 years ago when it last blew in the biggest eruption in the last 25 million years. It is estimated that around 2,800 cubic kilometers of volcanic ash and lava were thrown into the atmosphere, 12% more than was ejected by the last Yellowstone eruption 2.2 million years ago. And it may be about to erupt again. As with any super-eruption, the vast quantities of ash and sulphur dioxide produced can have a devastating effect on the global climate. But a number of factors make the prospect of a Toba super-eruption much more intimidating than that of Yellowstone. Toba is located on the densely populated island of Sumatra, home to over 50 million vulnerable people, and is only 40km from the Indian Ocean in which catastrophic tsunamis would certainly be generated. Additionally, in recent months, reports of volcanic gases and heating of the surface have led to suggestions that the sleeping giant may again be waking up.
- The Hilina Slump - Forget the widely-publicized mega tsunami threat that has been attributed to the potential collapse of the Cumbre Vieja volcano on La Palma in the Canary Islands. A far greater danger is posed by the possible collapse of the southern portion of Kilauea Volcano on the Big Island of Hawaii. Termed the Hilina Slump, this could drop 12,000 cubic kilometers of rock into the Pacific Ocean, generating a mega tsunami that would propagate around the

Pacific Ocean and reach the western seaboard of North America in a matter of hours, inundating coastal communities. There is evidence that a similar collapse at nearby Mauna Loa around 120,000 years ago generated a tsunami with a run-up height of over 400m. Even as recently as 1975, movement of the Hilina Slump generated a smaller, yet destructive tsunami that reached California. Given that the slump is continually active and moving, it might only take a jolt from an earthquake in the tectonically active state to set in motion this catastrophic chain of events.

- The North Sea Tsunami - The North Sea may seem an unlikely place for a devastating tsunami but climate change has led to concern that a submarine landslide in the region might lead to just this. There is a precedent. Scientists have suggested that over 6,000 years ago, a sharp sea-level rise, attributed to a changing climate and a rapid melting of ice, added weight to the submarine glacial deposits at the edge of the Norwegian continental shelf, destabilizing them and causing a 300km long landslide. This generated a tsunami that reached heights of up to 20 meters in the Shetland Islands, ten on the Norwegian coast and six meters off the northern and western coast of Scotland.
- A major concern for many is a triple hit year to major metropolitan areas along the East Coast of the United States. The National hurricane Center’s three worst case scenarios are a major hurricane hitting New Orleans, Tampa Bay, and New York City.

Preferred Future

The preferred future is typically captured as a vision. A vision is an image of the future. It creates an attractive mental picture of an outcome that people can strive for. Most people think of the future in ideas rather than images. Attractive ideas are progress, security, enjoyment; unattractive ones include overpopulation, pollution, sickness, and death. None of these are visions, however, because they are not images. What does it look like? How does it feel? What does it taste like, sound like? The vision is something tangible and concrete—something that excites people and enables them to take action in support of reaching the preferred future state.

A future of plenty or a future of scarcity is certainly not a given. It's possible to address system failures to leverage, shift, or even reverse trends—even global mega trends—by enabling and incentivizing bold actions. But to truly think boldly, we cannot start with today. It's imperative to start with a preferred future state. The following is an example of a preferred future.

"By 2035, everyone on the planet will have access to a highly accurate early warning system for both earthquakes and hurricanes, which will allow sufficient time to prepare and respond to an impending disaster."

Action

Methodological Note

Solving grand challenges is complex. XPRIZE only launches the most impactful prizes, those that when launched in conjunction with others will achieve a moonshot and radically transform a given domain. XPRIZE begins this process by developing a Futures Impact Map that maps the full landscape of what is currently happening, what needs to change, and which breakthroughs would not happen unless the crowd was incentivized to develop radical innovations. Once we know which breakthroughs will not be achieved by traditional actors alone, XPRIZE sources brilliant Visioneers in the crowd to vet and evaluate which breakthroughs should become the next XPRIZE.

Principles for Achieving Breakthroughs

Recent decades have seen rapid advances in scientific understanding of natural hazards and ways to monitor them. This has greatly enhanced scientists' ability to forecast the location, timing and severity of events. All forecasting and warning systems rely on scientific knowledge of one kind or another, but scientists' capacity to predict varies with the hazard studied. For example, in the case of geological hazards (earthquakes, volcanic eruptions, landslides, tsunamis), it is possible to identify where events may take place, but it can be very difficult to indicate when. Short-term predictions or forecasts (over days or hours) are generally more successful in the case of landslides, volcanoes and tsunamis than they are for earthquakes. Meteorologists have become very skilled at making short-term forecasts (1-3 days) of tropical cyclones, predicting their timing and movement, but still have a long way to go to get a very accurate 5-day forecast which also includes intensity.

The scientific-technical resource base is the result of many years of investment globally. Knowledge is widely shared among scientific communities. Data from technical devices such as remote-sensing satellites and buoys monitoring ocean temperatures are routinely transmitted to forecasters and disaster planners through established global networks. The World Meteorological Organization, for example, has played a significant role in coordinating the monitoring and forecasting of hydro-meteorological hazards.

Technological sophistication is not necessarily a barrier to small-scale warning systems or community involvement. A wide range of technologies may be appropriate for particular hazards, localities, and needs. Those appropriate at regional or national levels include satellite imagery, GIS maps, computerized networks for receiving and transmitting data, automated gauges and other monitoring devices and radio and television broadcasts. At the community level, one might find participatory mapping of hazards and vulnerable households, manual river level or rainfall gauges, signs marking evacuation routes, and the use of megaphones, bells, and drums to issue warnings. In many cases, vulnerable communities will monitor impending events themselves; for example, communities living close to flood-prone rivers often have people watching water levels at times of severe or prolonged rainfall.

There are 4 components for early-warning systems (remember: a weakness or failure in any one component of the system (technical or human/organizational) can potentially undermine the whole): risk knowledge, monitoring and warning, dissemination and communication, and response capabilities. Here are several points that need to be considered when thinking of potential breakthroughs:

Risk Knowledge - Systematically collect data and undertake risk assessments. Key questions/issues are:

- Are the hazards and the vulnerabilities well known?
- What are the patterns and trends in these factors?
- Are risk maps and data widely available?

Monitoring and Warning Service - Develop hazard monitoring and early warning services. Key questions/issues are:

- Are the right parameters being monitored?
- Is there a sound scientific basis for making forecasts?

- Can accurate and timely warnings be generated in terms of forecast time and location?

Dissemination and Communication - Communicate risk information and early warnings. Key questions/issues are:

- Do warnings reach all of those at risk?
- Are the risks and the warnings understood?
- Is the warning information clear and usable?

Response Capability - Build national and community response capacities. Key questions/issues are:

- Are response plans up-to-date and tested?
- Are local capacities and knowledge being used?
- Are people prepared and ready to react to warnings?

Conclusion

Transformational change is the process of creating a new era. It begins with one or more bold leaders who see that the old era is no longer suitable for the present, much less the future. Bold visionaries must articulate a preferred future for the new era of Disaster Prediction and enroll others in the campaign to bring that future about. These leaders and those that follow face enormous obstacles from the doubts and resistance of the majority to the challenge of leaving behind the old ways of forecasting disasters and forging a new path, even when the way forward isn't entirely apparent. Nevertheless, we are compelled to engage in this work because it must be done sooner or later, and it's best to start today before the terms of change can be dictated.