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Transforming Earthquake Detection and Science Through Citizen Seismology

by Jason C. Young,
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TRANSFORMING EARTHQUAKE DETECTION AND SCIENCE THROUGH CITIZEN SEISMOLOGY

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COMMONS LAB

The Commons Lab advances research and non-partisan policy analysis on emerging technologies that facilitate collaborative, science based and citizen-driven decision-making. New tools like social media and crowdsourcing methods are empowering average people to monitor their environment, collectively generate actionable scientific data, and support disaster response.

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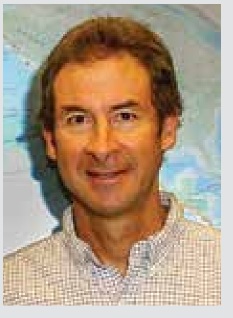

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David earned his B.S. in physics and geology at St. Lawrence University in New York, his M.S. in geophysics at the University of Arizona, and his Ph.D. in geophysics at the California Institute of Technology. At the California Institute of Technology and the Colorado School of Mines, David has advised dozens of postdoctoral, graduate, and undergraduate students on their research projects. His scientific interests include the estimation of rupture process from complex modern and historic earthquakes using combined geodetic, teleseismic, and strong motion data; waveform modeling and inversion; analysis of their ground motion hazards; and earthquake source physics and earthquake loss modeling.

David has been a Distinguished Lecturer for the Seismological Society of America (SSA) and serves on the Society's Board of Directors. He was awarded SSA's Frank Press Public Service Award in 2009 and a Department of the Interior Superior Service Award in 2010.

Paul S. Earle is the Director of Operations for the U.S. Geological Survey National Earthquake Information Center (NEIC). Paul's primary responsibility is oversight of 24/7 earthquake monitoring. He guides the development and implementation of new policies and procedures used during earthquake response and catalog production. He also serves in the rotating role of NEIC event coordinator, overseeing the production of near-real-time products following earthquake disasters around the globe.

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Lea A. Shanley directs the Commons Lab (within the Science and Technology Innovation Program of the Woodrow Wilson International Center for Scholars). Prior to this, Lea was a postdoctoral fellow on the Mapping Science Committee of the National Academy of Sciences, where she co-directed two reports: *Precise Geodetic Infrastructure: National Requirements for a Shared Resource*; and *New Research Directions for the National Geospatial-Intelligence Agency*. These reports recommended strategic science and technology priorities for geodesy, hazards monitoring, and national security.

In 2009, Lea was an American Association for the Advancement of Science/Agronomy Society of America-Crop Science Society of America-Soil Science Society of America Congressional Science Fellow and primary science adviser to the Chair of the Senate Subcommittee on Science and Space. She managed priorities for federal research and development, and she crafted and negotiated legislation addressing earth observation, oceans issues, and hazards research and mitigation. Previously, she had conducted community-based participatory action research in geographic information science at the University of Wisconsin–Madison. This research engaged local and tribal communities in the development and use of decision support systems based on geographic information science, enabling collaborative decision-making for improved emergency management, resource management, and land use planning.

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Contents

Foreword

In the last few years, we have received regular reminders of the terrifying effects of earthquakes. Events in China, Haiti, and Japan had enormous human and economic costs. Despite improved seismic monitoring, there is still an information gap in the immediate aftermath of an earthquake. However, new social media, technology, and communications are rapidly changing the process of post-earthquake information flow.

Sensing capabilities, computing power, and data storage have grown rapidly and become increasingly ubiquitous. In 2012, the number of smartphones worldwide topped one billion, and it is expected to double by 2015. A growing section of the population has the ability to send and receive information instantly. We have seen exciting uses of mobile technology to assist with humanitarian crises after earthquakes. Volunteers have collaboratively built maps to enhance situational awareness.

This report describes a groundbreaking system of citizen science projects initiated by the U.S. Geological Survey (USGS) and other scientific institutions. These citizen seismology tools can provide a more robust alert network and generate more real-time motion data. For example, the USGS project Did You Feel It? (DYFI?) solicits input from citizens after seismic events, asking where they were, what they observed, and what they experienced during the earthquake. The USGS uses an algorithm to process these data, translating them into quantitative measures of the earthquake's intensity. This initiative is particularly exciting for two reasons. First, it produces fairly accurate data with a wide range of uses very quickly and in a cost-effective manner. In this time of budgetary constraints, projects that can produce useful data with minimal expenditure are worth highlighting. Second, it offers a wonderful opportunity for citizens to participate in the work of government

Projects like DYFI do not happen by accident. The USGS had to navigate a web of practical, legal, and policy considerations to make it a reality.

and in rigorous scientific research. Citizen seismology is a powerful resource that the USGS has embraced by supporting these efforts.

Projects like DYFI? do not happen by accident. The USGS had to navigate a web of practical, legal, and policy considerations to make it a reality. First, the program had to take into account the limitations of the Privacy Act, advising citizens on how their information might be used and respecting fair information practices. Second, the project obeyed the Paperwork Reduction Act, receiving Office of Management and Budget approval before beginning information collection. These and other choices by the USGS allowed this useful project to fit within the administrative realities of agency operations.

Our hope is that agencies will read and consider how lessons learned in this initiative might apply to their unique missions. The opportunity for large-scale citizen input is greater than ever before. With planning and support, it could improve our scientific enterprise, facilitate greater public awareness and understanding of scientific issues, and forever change how citizens interact with government and the scientific community.

David Rejeski

Director, Science and Technology Innovation Program, Woodrow Wilson Center

January 2013

Executive Summary

Over the past decade, the Internet has dramatically changed the ways in which citizens collaborate to produce and share information. With increasing ubiquity, citizens use the Web to do everything from sharing reviews of local restaurants with friends to contributing to international aid efforts through the construction of global maps. In fact, the practice of tasking a number of loosely coordinated volunteers with data production, data processing, and problem solving (referred to as crowdsourcing) is garnering attention from many government agencies, from the local to the federal level. Recently, agencies charged with monitoring earthquakes around the globe, including the U.S. Geological Survey (USGS), have begun to ask how citizens might best contribute to the detection of and response to earthquakes. Such contributions, broadly termed citizen seismology, have shown the potential to augment more traditional forms of earthquake science.

In 2008, for example, a magnitude 7.9 earthquake wracked the city of Wenchuan, China. Although many foreign nations and international organizations quickly responded to this humanitarian disaster, individual citizens were actually the first to send out alerts about the earthquake—using social networking tools. Given the speed of this response, as well as the high accessibility and visibility of social networking tools, the USGS has shown that citizen seismology can supplement three of their goals: rapid detection, information gathering for emergency response, and information dissemination. Scientists have had great success both at using automated tools to quickly find earthquake information that citizens are already posting on the Web and at providing citizens with interactive tools that they can use to provide more detailed information about their earthquake experiences. Just as important, these same tools can be used to send information to citizens during disasters so that those citizens can better respond to dangerous situations.

Most obviously, then, citizen seismology has the potential to greatly enhance emergency response to earthquakes. Citizens are more likely to survive earthquakes if they are armed with knowledge, and first responders can more effectively aid these survivors

For crowdsourcing projects to be effective, the agencies leading these projects must carefully plan how they divide and assign tasks to citizens, how they motivate their user bases, and how they combine citizen responses to produce actionable information.

when on-the-ground, citizen-generated information is readily available. More broadly, citizen seismology is advancing earthquake science, because it allows scientists to collect data about earthquakes even in locations where sensors are sparse or even absent altogether. Similarly, the human element in many of these projects also grants scientists valuable insights into the ways in which individuals perceive and respond to earthquakes, which can help to advance studies in the sociology of risk and risk management.

Naturally, the path to citizen seismology has not always been easy, and those involved have learned many lessons along the way. For crowdsourcing projects to be effective, the agencies leading these projects must carefully plan how they divide and assign tasks to citizens, how they motivate their user bases, and how they combine citizen responses to produce actionable information. If any of these stages are planned poorly, it is likely that the entire project will fail or, potentially worse, produce inaccurate information. The citizen seismology projects described in this report provide important lessons learned for those wanting to develop their own successful and accurate crowdsourcing projects.

Successful projects also require a political and legal environment conducive to the high levels of government–citizen collaboration that are intrinsic to crowdsourcing techniques. Unfamiliarity with the complex system of policies and laws at the federal level can produce great frustration, particularly when policies were not created with citizen-based science in mind. Greater dialogue is needed between scientists and policymakers on issues from privacy to democratic participation. This report therefore attempts to give both scientists and policymakers the knowledge necessary to begin such a dialogue. Citizen seismology is an exciting new example of government–citizen collaboration. As a collaborative process, it is up to all actors involved to continue working together to produce more effective and more powerful results.

Introduction

On March 12, 2008, a magnitude 7.9 earthquake wracked the city of Wenchuan, China, leaving more than 87,000 people dead or missing and another 375,000 people injured.[1] This was the most devastating earthquake to affect China since 1976, and the rescue attempts made by the Chinese government, foreign nations, and international organizations were swift and massive.[2] Yet, despite this outpouring of support from around the world, neither national governments nor powerful international organizations were the first to respond to the earthquake. Individual citizens, using social networking tools on the Internet, were actually the first to send alerts to others about the severity of the earthquake. As Scoble, a technology blogger, said, "I reported the major quake to my followers on Twitter before the USGS website had a report up and about an hour before CNN or major press started talking about it."[3] After the earthquake, many other bloggers continued to comment that alerts by the USGS lagged behind first-hand accounts of the earthquake circulating on the Internet.

Naturally, it is difficult to directly compare information circulating within social media to the verified and authoritative information that the USGS shares with the public. Even Scoble freely admits that, for him, "Twitter is just the signal to look at the USGS Web site for more info."[4] Nevertheless, this was not the first example of citizens using the Internet to generate data that are traditionally provided by more authoritative sources. Over the past decade, the practice of tasking a number of loosely coordinated volunteers with data production, data processing, and problem solving (often referred to as crowdsourcing) has been used for such purposes as the production of global maps, disease surveillance, emergency response, improved provision of city services, and much more.[5] Additionally, through efforts labeled citizen science, organizations from the Audubon Society to The Globe Program have begun harnessing crowdsourcing techniques to engage the public in the collection of data for scientific research.[6] Based on these many successes, as well as the preexisting evidence that citizens could quickly detect earthquakes, the USGS and others began exploring the possibility of another form of citizen science—that of citizen seismology.[7]

In this paper, we describe the concept of citizen seismology, explore current citizen seismology initiatives, and discuss the potential benefits and impacts of likely future developments. Following suggestions put forth at the recent 2012 International Open Government Data Conference,[8] we find that a systems approach offers the best methodology for designing and describing technological solutions to complex problems.[9] A systems approach requires researchers to examine problems as a whole rather than in a piecemeal fashion, meaning that analysis must holistically address the processes, goals, people, tools, and environment that compose the system.[10] Thus, this report describes not only current citizen seismology projects, but also the technical, legal, and political environment that make these projects possible.

In the first section, Description of Citizen Seismology, we give a broad overview of the many different processes that organizations are using to carry out citizen seismology. We take a broad view of citizen seismology and include in our analysis projects with varying levels of collaboration between government seismologists and citizens.[11] The goal is to showcase the many different ways in which citizens are becoming more involved in earthquake science and disaster response rather than to build a strict definition of citizen seismology. This section also describes some of the goals that these initiatives have allowed seismologists to achieve.

The second section, Recommendations for Implementation Based on Lessons Learned, looks at the more technical lessons that researchers have learned through their implementation of citizen seismology. These include lessons about the people and technologies needed to produce effective projects. This section is aimed at agencies interested in implementing their own citizen science project so that they can learn from the experiences of others.

The third section, Policy and Legal Issues, explores the current legislative environment and the ways in which it both enables and constrains citizen seismology efforts. It includes a discussion of the ethics of citizen seismology, with a particular focus on its implications, both positive and negative, for citizen empowerment and democratic participation. We end the report with the section entitled Conclusion, a general discussion of the opportunities presented by citizen seismology.

Citizen Seismology

1

Both the public and emergency response teams must quickly mobilize after an earthquake in order to save lives and money. Traditionally, many national agencies have relied on a system of sophisticated sensors to detect an earthquake and to determine the attributes of the earthquake that have implications for disaster follow-up, such as the type of earthquake and its magnitude, depth, and epicenter (i.e., location on the earth's surface). In the United States, for example, the National Earthquake Hazards Reduction Program (NEHRP) was established to reduce the risks associated with future earthquakes.[12] To accomplish this mission, the NEHRP operates and maintains the USGS Advanced National Seismic System (ANSS), a nationwide network of more than 7,000 sensors that provide real-time earthquake information.[13] This network includes nearly 100 backbone stations and 15 regional seismic networks, in addition to the National Earthquake Information Center (NEIC) and the National Strong Motion Project.

In addition to the goals of quickly detecting earthquakes and recording detailed scientific data about those earthquakes, the ANSS also seeks to broadcast information about significant earthquakes to scientists, emergency responders, and the public at large.[14] Their data thus go into many USGS earthquake products, including ShakeMaps[15] and National Seismic Hazard Maps.[16] At a global scale, the ANSS is supplemented by the more than 150 sensors of the Global Seismographic Network (GSN).[17]

Although the ANSS has been effective in monitoring and responding to earthquakes, citizen seismology is changing and supplementing the organization's efforts to meet three of its goals: rapid detection of earthquakes, information gathering for emergency response teams, and information dissemination.[18]

Rapid Detection

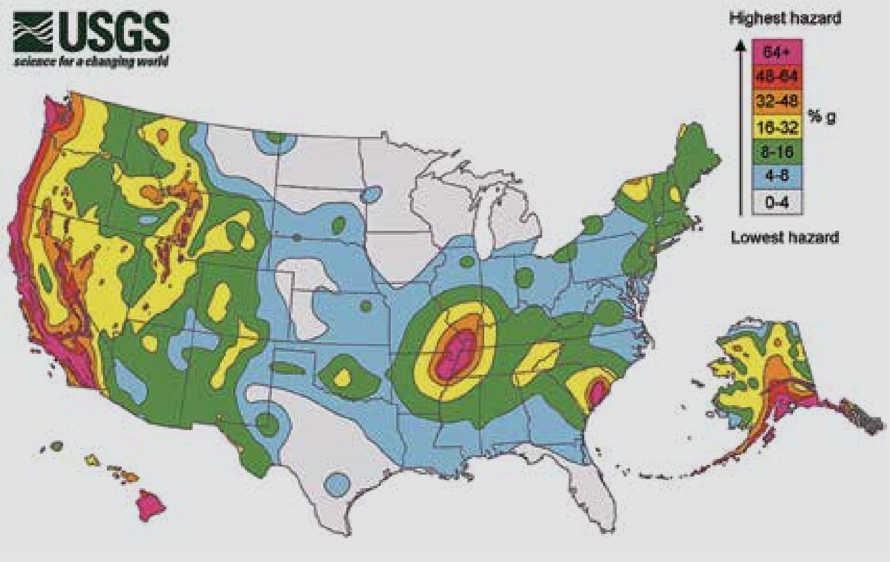
Modern earthquake sensors are capable of detecting earthquakes from across the globe.[19] Among other things, seismologists use complex algorithms to transform the seismic data collected by these sensors into information such as an earthquake's

Box 1. The National Seismic Hazard Mapping Project

The goal of the National Seismic Hazard Mapping Project (NSHMP) produces maps depicting the ground-shaking hazard from future earthquakes (see below). Although earthquakes produce many different hazards, including landslides, rockfalls, and ground ruptures, the NSHMP focuses on ground shaking because it tends to produce the most widespread damage and greatest loss of life. By understanding the potential ground shaking through hazard maps, scientists and others can better plan for those earthquakes. To produce these hazard maps, the USGS follows several steps:

1. Historical seismic activity over a range of magnitudes is cataloged. Even information about small earthquakes can help scientists model future damaging earthquakes.
2. Hazardous faults differ in their rates of seismic activity, and many have not generated significant earthquakes in the past. Geological and geophysical data, including trenching and other "paleoseismic" studies, can be used to characterize fault behavior.
3. The maximum earthquake size in a region is estimated with consideration of both the local seismic history and global analogs (i.e., earthquakes that have occurred worldwide in similar tectonic settings).
4. Finally, estimates of shaking for hypothetical future earthquakes are combined with ground-shaking patterns from past earthquakes in software that maps the future probabilities of different levels of ground shaking.

These hazard maps, produced since the 1970s, are currently used for a wide variety of purposes. These include the assignment of building codes and insurance rates, construction standards for waste disposal facilities, emergency planning and the allocation of assistance funds by the Federal Emergency Management Agency (FEMA), and business and land use planning. For more information, see http://earthquake.usgs.gov/hazards/about/basics/.



Box 2. ShakeMaps

In the event of a significant earthquake (magnitude 3.5 or higher), the USGS Earthquake Hazards Program (EHP) produces a ShakeMap, which depicts the ground shaking produced by that earthquake. This information is different from the magnitude of the earthquake—although every earthquake has a single magnitude and a single hypocenter (originating point), each earthquake nevertheless produces ground shaking of many different levels throughout the surrounding area (USGS 2012b). Several types of ShakeMaps are produced for each earthquake. These maps represent ground shaking through measurements of peak acceleration, peak velocity, and intensity. They are used for post-earthquake response, earthquake science, disaster planning, and much more. The map below represents the intensities of the Wenchuan, China, earthquake. For more on ShakeMaps, see http://earthquake.usgs.gov/research/shakemap/.

magnitude, depth, and epicenter. The more data the seismologists have, the more quickly and accurately they can produce this information. In certain locations, such as California, the regional networks that make up the ANSS are sufficiently dense and sophisticated to provide such information quickly.[20] Unfortunately, these dense networks are the exception rather than the rule—many areas of the world have only sparse networks of sensors, and other areas contain none at all. Thus, it can take the USGS up to 20 minutes to issue alerts about an earthquake, particularly when the earthquake occurs in remote or offshore locations.[21] In some cases, the public would like information faster.

As a result, many seismological agencies are investigating other mechanisms for rapid detection. The idea is not to replace current procedures, which have great merit and produce the most accurate results, but rather to augment them with less expensive procedures that can produce quicker results. The USGS, for example, is investigating the use of social networking tools for rapid detection. These tools are web-based services designed to help users build and maintain social relationships with other users.[22] Many allow users to follow one another's daily activities and communicate with one another; examples include Facebook,[23] Google,[24] Twitter,[25] and LinkedIn,[26] among others.

Box 3. Magnitude vs. Intensity

Many different projects use different techniques to describe earthquakes and their effects. Seismologists use different measures to describe the actual amount of energy released by an earthquake, or earthquake magnitude, and the felt effects of an earthquake on the earth's surface, or the intensity of an earthquake. The relationship between magnitude and intensity can be quite complex. Higher magnitude earthquakes have the potential to produce more ground shaking (and therefore higher intensities) because they release more energy, but the depth of an earthquake (as well as a host of other geological factors) mediates how much of that energy actually reaches the earth's surface. Therefore, it is possible for a low-magnitude earthquake that occurs close to the earth's surface to have a higher intensity than a high-magnitude earthquake that occurs deep in the earth.

Additionally, magnitude is related to the energy released by an earthquake on the rupturing fault, while intensity is a measure of the strength of shaking at a particular location on the earth's surface. Although an earthquake has only one magnitude, it produces differing levels of shaking intensity at different locations. Both magnitude and intensity measures can be important for emergency response purposes. For a more in-depth discussion of magnitude and intensity, see the following:

- For a comparison of magnitude and intensity: http://earthquake.usgs.gov/learn/topics/mag_vs_int.php
- For more information on measurements of intensity: http://earthquake.usgs.gov/learn/topics/mercalli.php or http://en.wikipedia.org/wiki/Mercalli_intensity_scale

Thus far, the USGS has focused much of its own analysis on Twitter, although researchers have also expressed interest in exploring other tools.[27] Twitter allows users to post 140-character messages, called "tweets." These tweets can be made private and directed at particular individuals, or they can be made public so that anyone can view them. Increasingly, a geographic location is being attached to many tweets to indicate the city or exact location of the individual tweeting, but this information is not always accurate or available.[28] Users can also now tweet using a variety of devices, including computers, tablets, and mobile devices.[29]

As a result, Twitter has become a popular service across the globe, with more than 500 million registered users employing it for everything from communicating with friends to publicly documenting their everyday lives.[30] Seismologists at the USGS have also found that users turn to Twitter for situational awareness during earthquakes.[31] For example, it was Twitter that quickly alerted blogger Robert Scoble about the 2008 earthquake in Wenchuan, China, as described earlier. Scoble found that individuals experiencing the earthquake were quickly reporting their experience via Twitter and that others were spreading the word (by repeating, or "retweeting," the original tweets) or verifying the earthquake with their own experience.[32] Thus, the frequency of tweets that include the word *earthquake* increases dramatically just after an earthquake. Moreover, this increase occurs quickly—in the case of a 2009 earthquake in Morgan Hill, California, the first tweet about the earthquake was sent within 19 seconds of the actual earthquake.[33]

These observations led the USGS to conduct a number of experiments to test the effectiveness of Twitter at detecting earthquakes. For example, Paul Earle and his team at the NEIC have developed algorithms that automatically detect large increases in the usage of the term *earthquake*, in multiple languages, on Twitter.[34] When they tested the Tweet Earthquake Dispatch (TED) algorithm using Twitter data collected between August and November 2009, they found that TED often detected earthquakes in less than 1 minute; in fact, 75 percent of all detections occurred within 2 minutes, which is much faster than the time period of 2 to 20 minutes that traditional sensing methods require.[35] Only a few regions of the world can produce seismically based alerts more quickly. Once the TED application detects an earthquake, it automatically produces alerts that are sent internally to the USGS duty seismologists and cooperating response agencies so that the NEIC can turn to more scientific data sources for confirmation of the earthquake.[36]

The earthquakes that TED detected tended to come from regions of potentially high impact, as Twitter is used the most in areas with large populations.[37] Academic researchers, including those at George Mason University who examined data from the 2011 earthquake in Mineral, Virginia, have reported similar results of earthquake detection.[38] Nevertheless, there remain deficiencies to this approach. The 4-month TED experiment was able to catch only 48 earthquakes, which is quite limited compared with the 5,175 earthquakes officially reported during that same period.[39]

Although it is likely that many of the earthquakes that went undetected by TED were either very small or far from human populations, others may have gone undetected simply because Twitter is not widely used by the populations affected by the earthquake. For example, 28 percent of all users on Twitter are in the United States, with far smaller numbers of users in other countries.[40] Additionally, TED analyzes Twitter using only a handful of languages, meaning that it cannot detect earthquakes from tweets written in a non-supported character set. For instance, although Japanese is the second most used language on Twitter, TED does not support analysis using Japanese.[41] Combined, these factors mean that the current version of TED is unlikely to detect earthquakes in many areas of the world.

To overcome some of these limitations, seismologists can use similar methods with other social media tools or even with other forms of technology. For example, the European–Mediterranean Seismological Centre (EMSC), an international nonprofit association that provides seismic alerts for Europe, is currently performing an earthquake

Box 4. Emergency Response

One of the greatest advantages of citizen seismology is the speed at which it is capable of providing situational awareness to scientists and the general public. Automatic processes like TED are capable of detecting earthquakes from around the world and sending out alerts, all via Twitter, in less than 1 minute. Most traditional methods can take 2 to 20 minutes to do the same thing, depending on the location of the earthquakes.[a] The time saved by utilizing rapid detection tools can potentially help emergency response teams form plans more quickly and provide citizens with important situational awareness in the immediate aftermath of the earthquake. The extension of alerts to mobile devices makes it even more likely that information will be readily available, even in emergency conditions.

Social networking tools like Twitter also provide first-hand, qualitative accounts of ground conditions that can be important for first responders. In the case of the 2010 earthquake in Haiti, these same types of social networking tools were used not only to determine ground conditions, but also to locate survivors in need of rescue.[b] For example, Ushahidi was a crowdsourcing application that allowed survivors of the earthquake to use their mobile phones to text emergency responders for help.[c] Volunteers were then set up to translate text messages from Creole and map the location of the survivor so that emergency response teams could quickly respond.[d] Similar efforts, from OpenStreetMap (OSM)[e] to GeoCommons,[f] allowed volunteers to produce maps of Haiti that emergency responders could use for logistical purposes.[g] For instance, in a matter of weeks, more than 640 OSM volunteers performed more than 10,000 edits or additions to the mapped streets, buildings, and important sites of Port-au-Prince.[h] In sum, citizen seismology and other crowdsourcing applications allow emergency response teams to react to earthquakes more quickly and more effectively.[i]

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a. P. Earle et al., "OMG Earthquake! Can Twitter Improve Earthquake Response?" The Electronic Seismologist, Seismological Research Letters vol 81, no. 2 (2010): 246-51.
b. M. Zook et al., "Volunteered Geographic Information and Crowdsourcing Disaster Relief: A Case Study of the Haitian Earthquake," World Medical & Health Policy 2, no. 2 (2010):7–33.
c. See http://ushahidi.com/.
d. Zook et al., "Volunteered Geographic Information."
e. http://www.openstreetmap.org/.
f. See http://geocommons.com/.
g. Harvard Humanitarian Initiative. The Future of Information Sharing in Humanitarian Emergencies, (Washington, DC: U.N. Foundation & Vodafone Foundation Technology Partnership, 2011).
h. Zook et al., "Volunteered Geographic Information;" Crowley and Chan, The Future of Information Sharing.
i. For some of the limitations to crowdsourcing in the response to the Haitian earthquake, see Crowley and Chan, The Future of Information Sharing.

detection project with its own website.[42] In addition to providing earthquake guidance to the Secretariat of the EUR-OPA Major Hazards Agreement, the EMSC also publishes earthquake alerts for the general public on its website. As a result, the EMSC website is a primary source of earthquake information for European citizens, and it is heavily visited just after an earthquake as those citizens seek situational awareness.

Having observed that the website experiences a sharp surge in traffic just following an earthquake, EMSC scientists posited that they could use this website traffic data to detect when an earthquake occurred. Furthermore, they noted that, when someone visits their website, the site records the Internet protocol (IP) address of the visitor.[43] An IP address is simply a unique number assigned to every device (computer, smartphone, etc.) participating in a computer network of some kind, such as the Internet. This number is used essentially like a name so that the devices on the network can communicate with one another. Furthermore, like a more traditional address, it is sometimes possible to use an IP address to determine the general geographic location of the device to which that IP address belongs.

Based on these observations, EMSC scientists designed a mathematical algorithm capable of (1) detecting surges in activity on their website and (2) plotting the locations of the visitors participating in this surge. The algorithm is also capable of filtering certain types of visitors out of the calculations, such as visitors from other seismological institutes, visitors being linked to the site from some external site (such as a news article discussing historical earthquakes), and Web crawlers.[44] This feature reduces the possibility of false alerts. For example, if a news article about personal preparations for earthquakes links people to the EMSC website, the popularity of this article will not set off an alert. On the other hand, if there is a surge of regular visitors to the website and those visitors all come from the same region of Europe, the EMSC algorithm plots an earthquake alert for that region.[45] The scientists found that this approach was effective at identifying earthquakes of felt magnitude 2.1 and larger. Additionally, it also detects the effects of earthquakes in less than 5 minutes, which makes it the fastest tool available at EMSC.[46]

Many problems remain with this approach to citizen seismology, however. For example, there remains the possibility of false alerts; the website may stop working; and earthquake victims may not naturally converge on the EMSC website.[47] Additionally, both the EMSC website project and the USGS Twitter project suffer other disadvantages—Twitter maps are primarily subjective and entirely general, meaning that scientists cannot derive in-depth information from them; that is, they do not provide information about an earthquake's magnitude, nor do they provide a quantitative measure of an earthquake's intensity in different locations. The main advantage of these projects is that they offer a cheap and very fast method for detecting earthquakes that have affected large populations. Seismologists have developed more enhanced crowdsourcing methods to obtain more quantitative information for first responders.

The results of the DYFI system have been impressive to date. Citizen response rates are high and increasing—DYFI has received more than 2,790,000 total responses since its inception.

Information Gathering

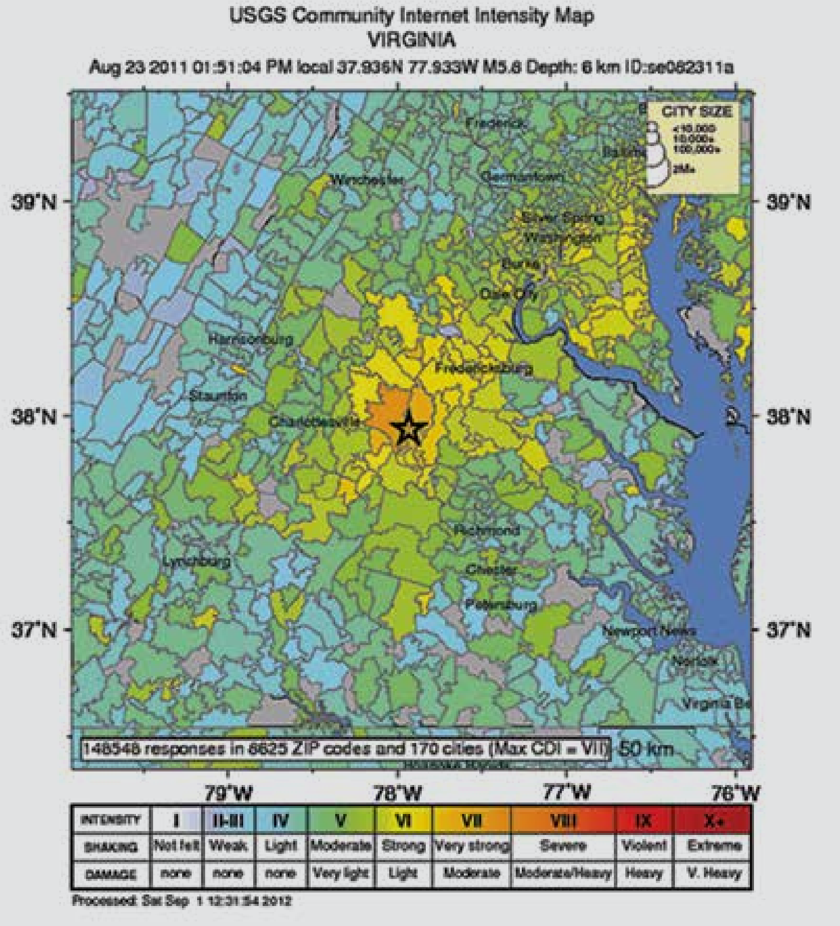
Social media tools, from Twitter to Facebook to photo-sharing sites, offer much more than quantitative information about the number of times a user has written the word *earthquake*. Every message posted also contains a qualitative description of the on-the-ground experiences of users. Thus, social media sites may contain first-hand accounts of the earthquake, which can potentially provide situational awareness to first responders and earthquake survivors.[48] Precisely because they are qualitative and unstructured, it is often cumbersome to exploit these accounts. Therefore, the USGS has developed a number of other applications that provide more rigorous and structured first-hand accounts. These narratives can then be combined with other scientific data to help first responders.

Did You Feel It? (DYFI?) is one of the longest standing, and most successful, examples of citizen-based science on the Web.[49] This program, which began under the name Community Internet Intensity Maps (CIIM), informally went online in California in 1997, was extended to all of the United States in 2000, and became global in 2004. Essentially, it was an attempt to use the Internet to broaden the scope of citizen surveys traditionally carried out via telephone and the postal service.[50] These surveys asked individuals about their experiences of earthquakes, and its implementation online allowed citizens to visit the USGS website after an earthquake and fill out a questionnaire. The questionnaire asks where users were during the earthquake, what sounds they heard during the earthquake, and what the earthquake did to the building they were in. For example, did books fall off shelves? Did free-hanging objects swing? Did you hear creaking noises?[51] The USGS then uses an algorithm to translate the aggregated results of these questionnaires into a quantitative measure of the macroseismic intensity of the earthquake.

The results of the DYFI? system have been impressive to date. Citizen response rates are high and increasing— DYFI? has received more than 2,790,000 total responses since its inception, with instances of 78 entries in 1 second in 2010 and of 2,594 entries

Box 5. Citizen Responses to Did You Feel It?

On August 23, 2011, approximately 148,000 individuals used DYFI? to describe their experience of a magnitude 5.8 earthquake affecting the Washington, D.C., area.[a] Additionally, because high-magnitude earthquakes are fairly rare along the East Coast, only a handful of nearby seismometers recorded the main shock of this earthquake. Thus, much of the preliminary data about the extent and level of shaking of this earthquake came from DYFI? Because similar sensor conditions exist in most of the country outside of California, DYFI? continues to offer invaluable benefits.



a. U.S. Geological Survey, "One Year Anniversary: Magnitude 5.8 Virginia Earthquake," USGS website, 2012, accessed September 4, 2012, http://www.usgs.gov/blogs/features/usgs_top_story/one-year-anniversary-magnitude-5-8-virginia-earthquake/.

Box 6. Earthquake Science

People have thought about and reacted to earthquakes for centuries, but seismology has really coalesced into a science only in the past 100 years, since the invention of the first seismometer.[a] Since the invention of this device, seismologists have discovered a great deal about earthquakes, but many questions remain. Additional detailed measurement of earthquake distribution and the shaking produced by earthquakes around the world can help to advance earthquake science.

Unfortunately, although the USGS sensors can provide very rich datasets describing earthquakes, these sensor networks do not exist in equal density throughout the world or even throughout the United States (Figure 1). As a result, sensors and the algorithms used to document the data that they collect may not fully document earthquakes that are of a small magnitude and are located in remote areas.[b] Citizen seismology demonstrates important promise in supplementing traditional datasets with missed or insufficiently documented earthquake events. For example, DYFI? has proven its ability to detect earthquakes of magnitudes of less than 2.0 in even remote areas. As Wald notes, DYFI? "represents something we have never been able to show before: the actual distribution of shaking intensity over the entire nation for a decade."[c] Since 2004, the project has also greatly advanced its international coverage; it has now gathered more than 145,000 entries covering 192 different countries.

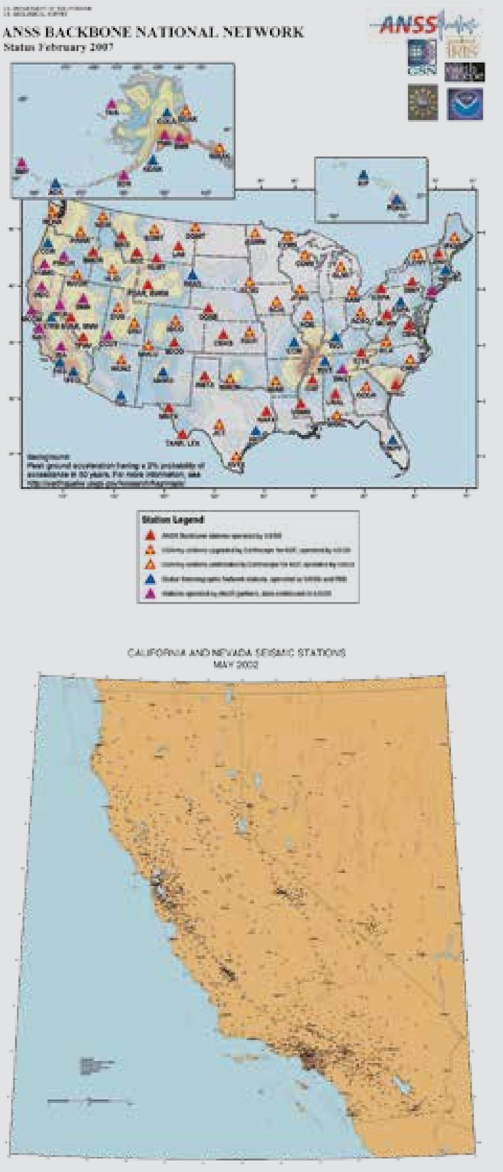


Figure 1. The Advanced National Seismic System (ANSS) appears on the top. The California Integrated Seismic Network (CISN), bottom, makes up the California portion of the ANSS, but is a much denser network of sensors than those in the other ANSS regions of the United States. For more information, see http://earthquake.usgs.gov/monitoring/anss/backbone.php and http://www.cisn.org/.

a. Seismological Society of America, "Careers in Seismology," SSA website, 2008, accessed August 10, 2012, http://www.seismosoc.org/society/education/careers/php.

b. D. Wald et al., "USGS Did You Feel It? Internet-Based Macroseismic Intensity Maps," *Annals of Geophysics* 54, no. 6 (2011):688–707.

c. Ibid., 694.

in 1 minute in 2009.[52] Furthermore, the results are surprisingly accurate; citizens tend to report very similar experiences, thereby producing a remarkable consensus about the intensity of the earthquake very quickly. These intensities are actually calculated down to one decimal point, which gives scientists and first responders a more detailed description of the intensity than the traditional scales that report only integer intensities.[53] Finally, some of the earthquakes detected by DYFI? are of less than magnitude 2.0, which are difficult to detect using distant traditional sensors.

DYFI? is even capable of distinguishing earthquakes from other shaking sources that might trigger citizen contributions, thereby allowing the USGS to provide citizens with information about non-earthquake events. For instance, citizens sometimes report sonic booms or distant thunder storms. DYFI? can now rapidly determine that these events are not earthquakes. In other cases, deliberately false reports are submitted, or typos make submissions less useful. Even these events can be filtered out or are not widespread enough to bias the data.[54] In all, DYFI? has developed into the world's number one source of citizen-based earthquake data, with more than a decade of results that have been tested robustly.

DYFI? contributes to a number of other USGS products to provide citizens and first responders with more effective situational awareness. For instance, the Prompt Assessment of Global Earthquakes for Response (PAGER)[55] system combines DYFI? data with traditional seismic and population data to provide population exposure maps to first responders.[56] Population exposure data can actually be more valuable than information on the magnitude of the earthquake, the true impact of major events, in both lives and money, is generally determined by the geographic extent and severity of the shaking, the population exposed to the shaking, and that population's vulnerability. As PAGER produces maps that take each of these factors into account, it gives first responders a much more detailed representation of the situation on the ground.[57] It can also help to distinguish which earthquakes are of the most societal importance.[58]

Other citizen seismology projects attempt to provide citizens with sensors to contribute scientific data rather than translate their experiences into scientific data. The Quake-Catcher Network (QCN)[59] is a joint initiative of Stanford University and the USGS that attempts to produce a sensor-based version of DYFI?.[60] QCN researchers argue that traditional networks of sensors are often not dense enough to provide an optimal level of information and that citizen-provided data are not always reliable enough to provide correct information after a devastating event like an earthquake. To remedy this situation, QCN supplies citizens with two different kinds of sensors—those attached to mobile devices and those installed in USB drives.[61] In either case, the sensor is composed of a newly developed, low-cost micro-electro-mechanical systems (MEMS) accelerometer.

These sensors are incredibly cheap compared with traditional sensors. Because they cost as little as $50 per person, they can be distributed

Box 7. Crowdsourced Data Accuracy

People have thought about and reacted to earthquakes for centuries, but seismology has really coalesced into a science only in the past 100 years, since the invention of the first seismometer.[a] Since the invention of this device, seismologists have discovered a great deal about earthquakes, but many questions remain. Additional detailed measurement of earthquake distribution and the shaking produced by earthquakes around the world can help to advance earthquake science.

In general, crowdsourcing is based on the idea that, when aggregated, the opinions or observations of large numbers of individuals will gravitate toward the truth. In the case of citizen seismology, this appears to hold true—individual observations of an earthquake, when combined with other individual observations, tend to produce a very accurate representation of where the earthquake occurred and how strong the earthquake was. For example, results from DYFI? tend to correspond very closely to the authoritative data present in ShakeMaps.[a] Even more impressive, DYFI? may actually be more accurate than traditional data sources in certain respects. Seismometers collect ground-shaking data from particular points, and seismologists then use complex algorithms to calculate felt intensity for a much wider area. If more sensors detect the earthquake, scientists have more data points to put into these algorithms. They thus cut down on sampling bias, or inaccuracy, in the resulting information. Unfortunately, if an earthquake is small, it is unlikely that many instruments will capture ground-shaking measurements. However, citizens often contribute a number of DYFI? questionnaires for even small earthquakes, resulting in more accurate data.[b]

Nevertheless, there exists some uncertainty when trying to ascertain the exact time and place of an earthquake from crowdsourced data. For instance, with the Tweet Earthquake Dispatch (TED) system, the detection time is not the same as the origin time of an earthquake, nor is it the time when the first people started tweeting about the earthquake; it is the time when the algorithm detects a spike in the number of tweets with the word *earthquake* in them.[c] It can take time for people to feel the shaking and go to Twitter, and even more time for the tweets to reach a critical mass. Nevertheless, approximately 75 percent of earthquakes detected by TED are detected in less than 2 minutes.

It can be even more difficult to determine the location of an earthquake. In the case of DYFI?, citizens have the option to provide their ZIP code (or city for non–U.S.

observations) and street address. However, they do not always do so. Even when ZIP codes or cities are provided, the resulting maps can be imprecise because these geographic bodies can cover large areas.[d] Twitter can be even more unreliable. Tweets are given a location, or geo-located, in several ways. Most reliably, users who are tweeting from a device with a global positioning system (GPS), such as some mobile phones, can voluntarily attach their exact geographic location to the tweet. If their device does not have GPS capabilities, users can add a location manually to their Twitter profile. This can be unreliable, because users might manually enter one location but then travel elsewhere, thereby producing tweets that are incorrectly geo-located. As a result, TED relies on spatial averaging to improve the reliability of manually entered locations.

The availability of exact geographic information varies wildly, based on both the availability of GPS-enabled mobile phones and the cultural acceptance of the use of applications that share one's location.[e] In USGS experiments, no location information could be found for approximately half of the tweets.[f] In some cases, though, the number of geo-located tweets available may be even lower. One study of Twitter use in the United States found the use of geo-located tweets to be as low as 5 percent.[g] However, considerably more users provide less accurate geographic data, such as their home city. Low participation rates can pose problems for citizen seismology. Nevertheless, location data obtained during the TED experiments were able to detect events in areas with poor instrumentation and did have a global reach, making the filtering strategy somewhat effective. More research is needed to determine the relative geographic effectiveness of Twitter detection around the world.

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a. D. Wald et al., "USGS Did You Feel It? Internet-Based Macroseismic Intensity Maps," Annals of Geophysics 54, no. 6 (2011):688–707.

b. Ibid.

c. P. Earle, D.C. Bowden, and M. Guy, "Twitter Earthquake Detection: Earthquake Monitoring in a Social World," Annals of Geophysics 54, no. 6 (2011):708–715.

d. D. Wald et al., "USGS Did You Feel It? Internet-Based Macroseismic Intensity Maps."

e. A. Croitoru, A. Stefanidis, J. Radzikowski, et al., "Towards a Collaborative GeoSocial Analysis," Workbench, COM.Geo '12, Washington, D.C. (article #18).

f. Earle et al., "Twitter Earthquake Detection."

g. Z. Cheng, J. Caverlee, and K. Lee, "You Are Where You Tweet: A Content-Based Approach to Geo-Locating Twitter Users," *Proceedings of the 2010 ACM Conference on Information and Knowledge Management*, Toronto, Canada, accessed August 28, 2012, http://infolab.cse.tamu.edu/static/papers/cikm1184c-cheng.pdf; A. Crooks, A. Croitoru, A. Stefanidis, and J. Radzikowski, "# Earthquake Twitter as a Distributed Sensor System," *Transactions in GIS* vol 17, no 1 (2012): 124-47.

Figure 2. Left. The USGS NetQuake sensor (U.S. Geological Survey). **Right.** The USB version of the Quake-Catcher Network micro-electro-mechanical systems (MEMS) accelerometer (Courtesy of Stanford University: http://stanford.qcn.edu).

widely for a low cost overall. (In contrast, USGS NetQuake[62] sensors cost $6,000 per unit [Figure 2].[63]) Once citizens have installed the QCN sensors in their homes or mobile devices, they provide seismologists with a dense network of sensors that has a number of advantages over traditional seismological techniques, including increased spatial accuracy, easier computer processing, and less complicated calculations (i.e., less interpolation). Furthermore, tests have proven that "QCN installations provide adequate sensor performance and coupling to ground motion."[64]

Owing to the success of the QCN, a number of other institutions are exploring similar solutions to citizen seismology. The Community Seismic Network (CSN)[65] is a recent initiative by the California Institute of Technology to produce similar dense networks of citizen sensors.[66] CSN provides citizens with low-cost sensors that are attached to the citizens' home and connected to their computer. The sensor then records ground-shaking data and transmits these data using each citizen's own Internet connection.

Another project, iShake Cal,[67] makes use of the motion sensors that citizens already own in their iPhones. iShake Cal is a small iPhone application offered by the University of California–Berkeley.[68] If users turn the application on at night, the application will capture any ground shaking that occurs throughout the course of the night. In this way, seismologist could obtain detailed information without ever purchasing or deploying new sensors; however, this system is still in the development stage.

All of the programs discussed thus far have targeted citizens who are experiencing, or have recently experienced, an earthquake. Another

Box 8. Citizen Responses to Did You Feel It?

Citizen seismology cannot replace observations made by cutting-edge instrumentation and real-time seismic systems. Such systems provide fundamental data for designing earthquake-resilient buildings, rapidly assessing earthquake impact, and describing physical details of the earthquake process. Yet, the comparatively low cost of citizen seismology allows the collection of data in extended areas that would be cost-prohibitive using traditional high-quality sensors. These initiatives take advantage of both preexisting infrastructure and the voluntary contributions of citizens, which are dramatically less expensive than cutting-edge sensors and the time of trained seismologists.

Even sensor-based forms of citizen seismology, such as the Community Seismic Network (CSN) and the Quake-Catcher Network (QCN), cost much less than traditional sensors. The micro-electro-mechanical systems (MEMS) sensors used by each of these networks cost only about $50[a]—while the cost of a single high-quality seismometer installation can be as high as about $200,000, in addition to the costs of maintaining it. Therefore, a network of 4,000 MEMS sensors could be deployed for the same cost as installing a single high-quality sensor. Furthermore, programs like TED and DYFI? have been much less expensive to implement and maintain; DYFI?, for example, is run by less than one full-time equivalent per year.

Naturally, the low-cost sensors produce very different results from traditional sensors and cannot fully replace them. Nevertheless, their low cost does make them very attractive supplements to the current system, and more rigorous forms of cost–benefit analysis should be performed to ascertain the true value of citizen seismology.

Furthermore, the Federal Emergency Management Agency estimates that earthquakes produce an average of $5 billion in costs to the United States every year.[b] Even more troubling, large earthquakes in California have the potential to cost much more in lives and damage—studies suggest that a large earthquake along the San Andreas Fault could produce as much as $200 billion in damage and 1,800 casualties.[c] Following these projections, the National Research Council finds that the potential benefits to improved seismic monitoring and earthquake response far outweigh the costs.[d] According to the Council, improved monitoring has the potential to save the United States hundreds of millions of dollars a year, in addition to saved lives. The savings are even greater given the very low costs of citizen seismology.

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a. R.W. Clayton, T. Heaton, M. Chandy, et al., “Community Seismic Network,” *Annals of Geophysics* 54, no. 6 (2011):738–747; E.S. Cochran, J.F. Lawrence, A. Kaiser, et al., “Comparison Between Low-Cost and Traditional MEMS Accelerometers: A Case Study from the M7.1 Darfield, New Zealand, Aftershock Deployment,” *Annals of Geophysics* 54, no. 6 (2011): 728–737.

b. P. Folger, *Earthquakes: Risk, Detection, Warning, and Research*, Congressional Research Service Report for Congress, 2011.

c. Ibid.

d. National Research Council, *Improved Seismic Monitoring—Improved Decision-Making: Assessing the Value of Reduced Uncertainty* (Washington, DC: National Academies Press, 2006).

Box 9. Sociology of Risk and Risk Management

Although much of the focus on citizen seismology has been on data about the physical effects of earthquakes, other scientists are interested in these data because they provide rich descriptions of the reactions and behaviors of citizens. This type of information allows scientists to predict how survivors will react to earthquakes in the future and thus to produce better long-term plans for earthquake response. For instance, Twitter provides space for citizens to describe how they are reacting to an earthquake.[a] Further advances, such as detailed geographic information from mobile devices, could give scientists additional insights into how and where citizens move during earthquakes.[b]

DYFI? also provides insights into risk perception among earthquake survivors. Seismologists have found that individuals tend to use their own earthquake experiences to estimate their risk during subsequent earthquakes.[c] They also tend to misunderstand scientific scales describing earthquake intensity. As a result, they mistranslate their past experience and, in most cases, end up underestimating the intensity of new earthquakes as well as their own risk during those earthquakes.[d] However, DYFI? as a process allows earthquake survivors to input their experience of an earthquake into the Web application and see how those experiences translate into a felt intensity. This allows them to continuously learn how their experiences relate to their risk during an earthquake. Seismologists hope that this will help these same citizens to better prepare for and respond to earthquakes in the future.[e]

a. M. Guy, P. Earle, K. Ostrum, et al., "Integration and Dissemination of Citizen Reported and Seismically Derived Earthquake Information Via Social Network Technologies," in *Advances in Intelligent Data Analysis*, ed. P.R. Cohen, N. M. Adams, and M.R. Berthold (Berlin-Heidelberg: Springer, 2010), 42–53.

b. R. Bossu, S. Gilles, G. Mazet-Rouxand, and F. Roussel, "Citizen Seismology: How to Involve the Public in Earthquake Response," in *Comparative Emergency Management: Examining Global and Regional Responses to Disasters*, ed. J.D. Rivera (New York: CRC Press, 2011), 237-60.

c. R. Celsi, M. Wolfinbarger, and D. Wald, "The Effects of Earthquake Measurement Concepts and Magnitude Anchoring on Individuals' Perceptions of Earthquake Risk," *Earthquake Spectra* 21, no. 4 (2005):987–1008.

d. Ibid.

e. Ibid.

international consortium, the Global Earth Observation Catastrophe Assessment Network (GEO-CAN), allows citizens[69] from around the world to aid emergency relief efforts after an earthquake.[70] GEO-CAN has its roots in the Wenchuan, China, earthquake described earlier. During this earthquake, Image Cat, Inc., and the Earthquake Engineering Research Institute (EERI) developed the Virtual Disaster Viewer (VDV), a social networking tool that allowed earthquake experts from around the world to view satellite imagery taken of Wenchuan both before and after the earthquake. They used this imagery to perform earthquake impact and damage assessment.[71] For instance, users could log into the VDV and notate changes in the imagery, including damage to buildings, damage to bridges and other infrastructure, landslides, road obstructions, and the existence of humanitarian relief operations.

Based on the success of the VDV, GEO-CAN was formed during the 2010 earthquake in Haiti; it brought more than 600 volunteers from 23 different countries together to produce earthquake information.[72] These volunteers used Google Earth, a three-dimensional viewing application for maps and satellite imagery, to mark differences in imagery, notate those differences with damage grades, and then share the information with other volunteers and emergency responders. However, the project suffered from a number of problems, including difficulty of use by both contributors and emergency responders, lack of institutionalization, lack of training, and reliance on experts.[73] Thus, since the Haiti earthquake, GEO-CAN has been working to make its collaborative process faster, easier to use, and more accurate. Most notably, they have produced a more user-friendly application, as well as a basic training module, to open the process up to citizens with less technological expertise. The improved process was used to analyze more than 77 square kilometers of Christchurch, New Zealand, after a 2011 earthquake.[74] This initiative shows the potential for actively involving citizens around the world in disaster characterization.

Information Dissemination

In many instances, the information generated during an earthquake moves through traditional circuits to the public or to emergency response teams. For example, a great deal of information can be found on the EMSC or USGS websites. However, these dissemination strategies are based on the assumption that the public will naturally—and quickly—gravitate toward these resources during an earthquake. Because this is not always the case, earthquake authorities are seeking enhanced methods of information dissemination, which often involve increased networking and collaboration with citizens. Sometimes agencies use the same social networking tools popular with citizens; other times, agencies develop new dissemination tools.

The USGS, for instance, has begun using social media sites for alerts and outreach following earthquakes. Once the USGS has detected an earthquake, it can then automatically post alerts using various social media tools; this streamlined process takes only seconds. The availability of many social media tools on mobile devices can result in higher dissemination rates to those individuals who use social media. Overall, this process demonstrates a high level of interaction between the USGS and citizens—the citizens demonstrate their need for information about the earthquake via Twitter, and then the USGS quickly verifies the existence of an earthquake and provides additional information.[75] This is also a very cheap dissemination strategy, as the USGS can use Twitter's already existing infrastructure.

Social media have some disadvantages in terms of information dissemination. First, not all citizens use social media sites, nor do all citizens who do use them immediately turn to these sites for situational awareness during emergencies. Thus, not all individuals will benefit equally from this dissemination strategy. Second, like many other

Box 10. Citizen Education and Empowerment

In addition to providing benefits to scientists and emergency responders, citizen seismology helps to empower individuals and communities by helping them to help themselves and one another.[a] Just like earthquake information gathered in traditional ways, the warnings and information resulting from citizen seismology can help to give individuals situational awareness during hazardous situations, which can help these individuals to make good decisions.

Citizen seismology has some advantages over traditional methods of communication during earthquakes. First, projects like DYFI? provide a direct connection between citizens and government agencies. Thus, citizens can use these applications to express their needs directly to agencies like the USGS, and the USGS can then prioritize the information that it disseminates about an earthquake based on those needs.[b] In the most extreme cases, social networking tools allow citizens to request aid directly from first-response teams during emergencies.[c] Some citizens are even using the power of social networking tools and crowdsourcing methods to assist one another in the aftermath of natural disasters.[d] Citizens are now using social networking tools both to organize themselves and to seek aid from neighbors in the immediate aftermath of an earthquake, thereby averting crises before emergency responders can get to them. Even if citizens do not directly help one another, they can still provide one another with detailed information about on-the-ground conditions, including the location of safe and dangerous areas.[e]

In many cases, citizen seismology projects also motivate individuals to further educate themselves about earthquakes and earthquake safety. Because the information produced by these projects is tailored to their own situations, citizens are more likely to explore and retain the information given to them.[f] Seismologists hope that this will help citizens to better react to the situations produced by earthquakes.

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a. D. Wald, V. Quitoriano, B. Worden, et al., "USGS Did You Feel It? Internet-Based Macroseismic Intensity Maps," *Annals of Geophysics* 54, no 6 (2011):688–707.

b. R. Bossu and P.S. Earle, "On the Use of the Internet to Collect Earthquake Information," *Annals of Geophysics* 54, no. 6 (2011):672; D. Wald et al., "USGS Did You Feel It? Internet-Based Macroseismic Intensity Maps."

c. M. Zook, M. Graham, T. Shelton, and S. Gorman, "Volunteered Geographic Information and Crowdsourcing Disaster Relief: A Case Study of the Haitian Earthquake," *World Medical & Health Policy* 2, no 2 (2010):7–33.

d. R. Bossu, S. Gilles, G. Mazet-Rouxand, and F. Roussel, "Citizen Seismology: How to Involve the Public in Earthquake Response," in *Comparative Emergency Management: Examining Global and Regional Responses to Disasters*, ed. D.S. Miller and J.D. Rivera (New York: CRC Press, 2011), 237-60; K. Torgovnick, "Hit by a Natural Disaster? The First 6 Things to Do for Your Community's Relief Effort," TED Blog, 2012, accessed August 24, 2012, http://blog.ted.com/2012/08/14/hit-by-a-natural-disaster-the-first-6-things-to-do-for-your-communitys-relief-effort.

e. L. Palen and S. Liu, "Citizen Communications in Crisis: Anticipating a Future of ICT-Supported Participation," *Proceedings of the ACM Conference on Human Factors in Computing Systems* (CHI 2007, San Jose, CA, April 28–May 3, 2007), 727–736; M. Crutcher and M. Zook, "Placemarks and Waterlines: Racialized Cyberscapes in post-Katrina Google Earth," *GeoForum* 40, no 4 (2009):523–534; C. Wardell III and Y.S. Su, *Social Media + Emergency Management Camp Report: Transforming the Response Enterprise* (Alexandria, VA: CNA Analysis & Solutions, 2011).

f. R. Celsi, M. Wolfinbarger, and D. Wald, "The Effects of Earthquake Measurement Concepts and Magnitude Anchoring on Individuals' Perceptions of Earthquake Risk," *Earthquake Spectra* 21, no 4 (2005):987–1008; M. Guy, P. Earle, C. Ostrum, et al., "Integration and Dissemination of Citizen Reported and Seismically Derived Earthquake Information via Social Network Technologies," in *Advances in Intelligent Data Analysis IX*, ed. P. Cohen, N. Adams, and M. Berthold (New York:Springer, 2010), 42–53; L. Barrington, S. Ghosh, M. Greene, et al., "Crowdsourcing Earthquake Damage Assessment Using Remote Sensing Imagery," *Annals of Geophysics* 54, no. 6 (2011):680–687; D. Wald et al., "USGS Did You Feel It? Internet-Based Macroseismic Intensity Maps;" R. Allen, "Transforming Earthquake Detection?" Science 335, no 6066 (2012):297–298.

alert strategies, the USGS must rely on the availability and serviceability of communication infrastructure in the disaster areas to send alerts via social media. If telephone towers are not operational, or if they are flooded with too much activity, earthquake survivors will not be able to access the alerts. Finally, the survivors cannot customize USGS social media alerts to specific areas or magnitude ranges. When the USGS posts a public message on a social media site, it generally becomes the responsibility of citizens at large to seek out that social media site and read the alert. All citizens viewing the site will then see the same information, regardless of their location or need.

For a more personalized experience, citizens can turn to the USGS Earthquake Notification Service (ENS).[76] The USGS Earthquake Hazards Program[77] introduced the ENS in 2006, when the system replaced several other national and regional dissemination systems.[78] ENS is a subscription-based service, meaning that users must go online and create profiles that specify their alert needs. During the sign-up process, users can customize the types of alerts that they want to receive. For example, they can specify what magnitude earthquake should trigger an alert, what times of the day or night they want the system to send alerts, and from where an earthquake should emanate in order to trigger an alert.[79] Users can also choose to receive alerts via email or on their mobile phone or pager. The alerts themselves offer users not only basic information about the size and location of the earthquake, but also links to the USGS website for more information. As a whole, the ENS has proven to be quite popular, and it currently attracts about 50 new users each day. The system also sends out about 188,000 messages covering 35 earthquake events each day. In the future, the USGS hopes to enhance the alerts with additional information, such as PAGER loss estimates.

For the time being, though, users must turn to ShakeMap and ShakeMap Broadcast (ShakeCast)[80] for detailed information on earthquakes. ShakeMap is a fairly traditional source of earthquake information; it consists of data about the extent and severity of earthquake shaking. For example, ShakeMap includes high-resolution imagery, maps for publication and television, data from geographic information systems (GIS) for scientific programs like Hazards United States (HAZUS), and more.[81]

ShakeCast is an innovative add-on to the ShakeMap system. A fully automated system, ShakeCast allows advanced users, such as power plant or other utility operators, to input data about their own facilities into the system. For example, these users might input data about the vulnerability of their facilities. Then they will receive customized alerts about earthquakes that affect or endanger their facilities and can even automatically send personalized alerts to the mobile devices of key operators, if warranted by the expected effects of the earthquake on the facility.[82] The system can also use more generalized data for those who do not have full information about their own facilities. All of this can be critical to ensure that advanced users have the necessary knowledge to plan for and respond to earthquakes.

These applications give users access to many different types of alerts, from quick and basic to advanced and detailed. The intent of all these alerts is to increase the situational awareness of users at the time of an earthquake. However, through the use of different crowdsourcing techniques, the USGS has identified another effect of information dissemination—that of long-term education and engagement of citizens. Educators have even adopted DYFI? as a tool to teach children about earthquakes, and the National Geographic Society and the State of California Education Standards currently reference it as an educational resource.[83] Ideally, this increased information will empower citizens to make better decisions in the event of a future earthquake and to continue utilizing USGS resources to further educate themselves.

Lessons Learned

2

Citizen seismology can achieve a number of important goals when executed appropriately. The execution, however, must take into account a wide spectrum of factors in order to produce the desired results.

Microtasking

To properly understand what roles citizens must play, organizations implementing citizen seismology projects must first decide the purposes for which they want to use crowdsourced data. Otherwise, their crowdsourcing will simply produce data redundant with those of traditional methods, leading citizens to believe their contributions are meaningless and leading scientists to disregard potentially valuable data sources. Thus, organizations must assign certain appropriate tasks to citizens and reserve others for their own experts.

In nearly all of the cases discussed within this paper, citizen seismology was most valuable for providing data quickly in time-sensitive cases, for providing data in poorly monitored locations, or for providing scientists with data about human elements related to earthquakes. As the need for more rigorous scientific information increases, more organizational influence is necessary. Thus, for example, TED utilizes Twitter accounts of earthquakes primarily because Twitter provides a very rapid response and reasonably global coverage.

However, these data tend not to be quantitative or scientifically rigorous because the USGS has very little control over how users report earthquakes via Twitter. DYFI? increases USGS control of information gathering by asking users specific questions, thereby producing more quantitative, rigorous results. Programs like QCN and CSN, which actually provide citizens with sensors to use, further increase seismologists' control over the type of information gathered and its scientific rigor, but fewer citizens end up participating in these projects. The most scientific data, and thus those that drive earthquake science the most heavily, generally remain in the hands of scientists within organizations like the USGS.

In addition to the division of tasks between citizens and experts, the division of different tasks among actively engaged citizens can be important. The key to an appropriate division of citizen efforts is in deciding how much redundancy is needed for the project to produce accurate information. Many crowdsourcing projects rely on redundant responses to eliminate data outliers and to confirm the accuracy of information. TED, for example, is triggered when the number of earthquake tweets rises significantly above the noise.[84] This allows scientists to separate accurate information from all of the noise on Twitter without ever training participants.

In contrast, projects like GEO-CAN require participants to have some training in earthquake damage assessment and to commit greater amounts of time to the project.[85] As a result, individual responses tend to be more accurate, but also take more time. GEO-CAN assigns each participant a different area affected by an earthquake to ensure that all areas are mapped by at least one participant. This approach allows each citizen to spend a large amount of time producing detailed and accurate information about a single area. Organizations should choose the microtasking strategy that best fits their own information needs.

Citizen or Volunteer Motivation

In general, citizen seismology projects tend to fall into one of two categories; they either repurpose preexisting data found on the Internet, or they actively engage the public to produce new information. Projects like TED fall into the first category, because they simply mine information that others have already shared on Twitter. These projects are convenient in that they do not require the sponsoring agency to motivate a user base to participate. The data already exist and are being constantly produced by citizens. These projects have a disadvantage, however, in that citizens are producing data without any knowledge of the ways in which seismologists plan to repurpose it, meaning that these data may not perfectly fit the purposes of the seismologists. Scientists must therefore be careful to manipulate the data in such a way as to filter out nonpertinent information.

To overcome this limitation, other projects actively engage users to provide the specific types of information that are most useful for seismologists. A key challenge for this type of project is to motivate users to participate. Motivational techniques have varied widely; they have included rewards, the inclusion of fun games in the application, an emphasis on the participants' contribution to science ("science altruism") and the public good, and access to services, among others.[86] These different motivational techniques may attract different types of users and even different types of contributions. More research is needed to understand the advantages of different forms of motivation.

In addition to motivating citizens to begin participating in citizen seismology, organizations must also maintain participants' interest to make their projects successful. Scientists have noted a number of techniques for maintaining citizen interest.[87] First, it is very important that the applications are intuitive and easy to use so that users do not become frustrated with them.[88] Not only should the technology itself be easy to use, but also the tasks that the organization is assigning citizens should be clear.[89] Such an understanding will also help to prevent frustration from causing citizens to cease participating in the project.

Second, the organization controlling the application must build a relationship with the users of the application.[90] The organization should cultivate a clear and consistent voice to communicate with the public so that citizens feel they are interacting with and helping a real person. Also, the organization should give users instant feedback and routinely answer any questions posed by those users.[91] This approach will help to make users feel that they are being listened to, that their experiences are being validated, and that their needs are being met. Also, as the Wenchuan, China, example demonstrates, Internet users are very critical of slow responses in this digital age.[92]

Third, even when users are asked to fill out specific questionnaires, it is important to provide them with open text spaces so that they can discuss any first-hand experiences not covered by the questionnaire.[93] Once again, this ensures that users feel a validation of their personal experiences. Fourth, it is important to institutionalize the participants' interactions with the project in such a way that they have regular contact with the project so that they do not forget about it or lose interest.[94] However, the amount of contact should not be so great that participants feel overwhelmed or frustrated because the project is filling their inbox with emails. Finally, organizations must also ensure that they do not forget the "social" in social media.[95] Because the fun- and community-oriented aspects of social media are critical for motivating participation, organizations must ensure that these aspects do not dissipate over time.

System Robustness and Usability

Regardless of the type of microtasking or the motivational technique used, all crowdsourcing projects rely on computer systems to transform citizen input into actionable information. Therefore, the robustness and usability of these systems are critical concerns. These systems must be capable of handling a variety of events, including large spikes in web traffic, poor Internet coverage, power outages, and severe damage to infrastructure.

Different programs have adopted different strategies to control for these events. The USGS, for example, has put a great deal of work into making DYFI? capable of managing high levels of Web traffic. The system can currently handle large amounts of traffic; after a recent magnitude 5.7 earthquake in California, it captured 78 questionnaire submissions in 1 second.[96] However, DYFI? is not able to handle power outages or severe damage to infrastructure in the affected region—if individuals cannot use the Internet to contribute questionnaires, then DYFI? will not detect the earthquake. In contrast, EMSC's Web traffic detection strategy can better handle power outages; it will detect a sudden

It is not enough for citizen data to be available through robust systems. If citizen seismology is to translate into an improved emergency response, emergency responders themselves must know about the data and trust the information enough to use it to make decisions on the ground.

large decrease in the number of users viewing their website, and the organization can make assumptions about power outages based on this.

It is not enough for citizen data to be available through robust systems. If citizen seismology is to translate into an improved emergency response, emergency responders themselves must know about the data and trust the information enough to use it to make decisions on the ground. In particular, those involved in the GEO-CAN initiative found that emergency responders needed to know the advantages and disadvantages of citizen-based systems so that they could make appropriate decisions about the use of these data. Additionally, to make the information easier to analyze, it is recommended that organizations develop a single web portal through which both analysts and data contributors can interact with the crowdsourcing platform.[97]

Policy and Legal Issues

3

Given the appropriate mix of technologies and participants, citizen seismology can produce powerful results. However, achieving that correct mix is not always enough; organizations must also consider the policy and legal environment that shapes and constrains their activities. Many scientists who create and maintain citizen seismology projects do have no training in working with human subjects, nor do they have experience with policies regarding government–citizen interaction. Unfamiliarity with the complex system of policies and laws at the Federal level can produce great frustration, particularly when policies were not created and laws were not enacted with citizen-based science in mind. In this section we review some of the policy and legal issues that have affected citizen-seismology efforts, with a particular focus on current federal laws that have affected USGS citizen seismology projects. We do not focus heavily on laws pertaining to the states or private industry, nor do we focus on legislation pending in the House and Senate. The intent is thus simply to give Federal agencies considering the implementation of citizen seismology projects a basic introduction to the legal and policy issues that they are most likely to encounter in the status quo. It is important for organizations to take these issues into account when developing projects and for policymakers to understand how they affect citizen science.

Federal Privacy Act

The Privacy Act of 1974 establishes policies and procedures for the federal government's collection, protection, maintenance, utilization, and dissemination of records of personally identifiable information (PII) of individuals.[98] Congress enacted the Privacy Act in response to citizen concerns about the government's creation of large databases and accessibility of personal data.[99]

The Act created four procedural and substantive rights governing records of PII. Agencies (1) must share with an individual any records kept on them, (2) must follow fair information practices, (3) must obey restrictions on sharing PII with other individuals and agencies, and (4) can be sued by individuals if they violate the Privacy Act.[100] According to the Act, PII includes information such as an individual's name, an identifying number or symbol unique to the individual (such as a Social Security number), or any "other identifying particular assigned to the individual, such as a finger or voice print or a photograph."[101] The Privacy Act governs only databases that retrieve information by the name, identifying number, symbol, or other identifying particular of an individual.[102] Record systems that do not retrieve information in this way are exempt from the Privacy Act.

Federal agencies implementing citizen seismology projects have two options to comply with the Privacy Act. First, they can choose not to collect PII about participating individuals or not to produce a system of records that retrieves data based on PII. In other words, their project does not involve a database that can be searched based on PII. In the case of TED, scientists use technological solutions to eliminate PII from their systems of record. An individual's tweets are associated with a username, a unique name that the individual uses to represent himself or herself. If users opt to include their real name in addition to a username, then tweets can be tied to them. However, when collecting tweets, the USGS system uses a one-way encryption technique to irreversibly hide usernames; they replace the username with a new, unique identifier that cannot be retraced. Neither the USGS, nor anyone with whom the USGS shares their data, is able to use the encrypted identifier to access any form of PII.

In contrast, DYFI? invites users to contribute PII in the form of contact information and location, so the project must comply with the Privacy Act. First, to inform users that the USGS is storing records based on the DYFI? information, researchers must provide a Privacy Act Statement along with the questionnaire. This statement must inform users of their rights regarding PII and must describe the planned use and storage of any contributed PII. For example, the statement currently attached to the DYFI? questionnaire reads as follows:

> **Privacy Act Statement** You are not required to provide your personal contact information in order to submit your survey. However, if you do not provide contact information, we may be unable to contact you for additional information to verify your responses. If you do provide contact information, this information will only be used to initiate follow-up communications with you. The records for this collection will be maintained in the appropriate Privacy Act System of Records identified as Earthquake Hazards Program Earthquake Information.[103]

Furthermore, the USGS must follow fair information practices to protect these data, as set out in the agency's System of Records Notice.[104] The procedures and restrictions set out for DYFI? prevent the USGS from redistributing PII or user's comments, which restricts the ways the USGS can share DYFI? data with other researchers or organizations.[105] Although they cannot provide raw data to other researchers, they can produce a sanitized version that does not contain PII, but is valuable in its description of an earthquake. This produces a trade-off

The rapid emergence of new technologies, such as location-based services is changing the ways in which technology and privacy affect one another. Policy continues to lag behind technology with dangerous implications for the privacy of contributing citizens.

between privacy and the specificity of data that can be shared.

The rapid emergence of new technologies, such as location-based services (i.e., applications capable of determining a user's location and then offering that user customized services based upon that location), is changing the ways in which technology and privacy affect one another.[106] Policy continues to lag behind technology with dangerous implications for the privacy of contributing citizens.[107]

Although the Privacy Act protects PII held by federal agencies, there exists no comprehensive federal law that protects PII held by both the public and private sectors.[108] In fact, much of the legislation protecting the privacy of data held by the private sector has been implemented piecemeal across different sectors and at both the state and federal level. Federal agencies' use of social media services like Twitter may encourage more citizens to share their personal information with the companies providing these services. Even if those data are safeguarded once they enter federal hands, they may be less protected within the companies' own databases. Federal scientists must ensure they are doing their best to protect the privacy of participants and that they consider the wide range of effects that their projects might have on privacy.

Policy changes are inevitable, and researchers must keep abreast of these changes. There is a great deal of discussion surrounding the protection of online personal information, and PII legislation is currently pending in both the House and the Senate. If passed, this legislation could make important changes to the Privacy Act of 1974. Scientists and policymakers must work together to ensure that these changes both protect and empower citizens to the greatest extent possible.

Dissemination and Access: Freedom of Information Act

Enacted in 1966 on principles of government openness and transparency, the Freedom of Information Act (FOIA) guarantees citizens' access to records kept by the federal government. [109] The goals of the FOIA are (1) to prevent the federal government from creating secret laws and (2) to open their activities and information to public scrutiny. Citizens can use the FOIA to request much of the information collected through citizen seismology. Also, many citizen seismology projects are founded on collaboration and transparency, and promote the same information sharing valued by the FOIA. However, the FOIA includes several exemptions and exclusions that could hinder the widespread dissemination of citizen seismology data.

Like the Privacy Act, the FOIA protects personal information; it does so by exempting such information from public requests. Thus, only TED and DYFI? data that have been sanitized of personal information can be released to the public. However, this exemption may not entirely protect the privacy of individuals using applications that provide geographic information about their daily lives. As many geographers point out, emerging geospatial technologies share real-time information about individuals' exact locations over long periods of time. By providing their location while tweeting, individuals often share daily information about their routines.[110] If an individual tweets about activities at home and includes the location, others can deduce the location of that individual's home. This information could be used to discover the identity of the individual and infringe his or her privacy. Thus, individuals need to fully understand what types of information they are providing to the public when they use location-based services.

Exemptions also exist to protect classified matters of national defense or foreign policy. Although these exemptions protect secrets, they have produced institutional environments in which information is not freely shared. Some agencies may classify information that does not need to be classified, as when they add unclassified information to a classified system; other agencies are used to dealing with classified information and may choose not to trust unclassified information. These factors affected the use of crowdsourcing methods during the response to the 2010 earthquake in Haiti, as relief efforts required coordination between military and civilian organizations. In many cases, information did not flow, hindering the speed and effectiveness of emergency responders.[111] As a result of this experience, many organizations advocated open-architecture portals through which all participants could share information and emphasized the need for agencies and first responders to better understand the benefits and limitations of citizen science.[112]

Other forms of information are also exempt from the FOIA, including certain data collected by law enforcement, geological information about wells, and trade secrets. These types of information are less likely to affect the sharing of citizen seismology data.

Paperwork Reduction Act

The Paperwork Reduction Act (PRA) was enacted in 1980 to grant the Office of Management and Budget (OMB) the authority to regulate and establish federal information policies.[113] It seeks to reduce paperwork in both federal agencies and the general public. Under the PRA, agencies are required to obtain a control number from the OMB before initiating new information collections from the public. In order to acquire this control number, agencies must go through an approval process that lasts a minimum of 90 days.[114]

First, the agency must solicit public comments on their new information collection by publishing a 60-day notice in the *Federal Register*. The notice must include a description of the collection method and ask the public to evaluate the proposed collection based on how valuable the resulting data will be and how great of a burden the collection of the data imposes on the public. Once this 60-day Federal Register notice has expired, the agency can consider any public comments internally. They must then submit their proposed collection to the OMB while simultaneously publishing a 30-day Federal Register notice announcing the start of OMB review.[115] This second notice describes how members of the public can submit comments directly to the OMB. At the conclusion of their review, the OMB can either return necessary changes to the agency or approve the collection.[116]

If the OMB approves the new information collection, they assign a control number that the collecting agency must display on the information collection instrument, such as the questionnaire or the survey.[117] Along with the OMB control number and a notice that the number is required for the collection to be valid, the collecting agency must provide the public with information about the collection, including why the information is being collected, how it will be used, what the estimated time burden on the public produced by the collection will be, and whether responses are voluntary.[118] This constitutes the PRA Burden Statement.

In 2009, President Barack Obama issued a memorandum requiring that the OMB issue an Open Government Directive to promote increased transparency, participation, and collaboration within the federal government.[119] The resulting Directive called for the review of the way in which existing OMB policies affect government transparency and the use of emerging technologies, including social media. Therefore, in 2010, the Office of Information and Regulatory Affairs of the OMB released a memorandum that clarifies how and when the PRA applies to the federal use of social media.[120] It creates several exceptions whereby agencies can use social media outside of the mandates of the PRA.[121]

The OMB specifies that information contained in general solicitations, public meetings, and like items do not count as information under the PRA. Each of these exclusions has implications for the use of social media. By excluding general solicitations, the memorandum allows agencies to ask for unstructured comments from the general public. An agency may include a suggestion box for feedback on their web page without obtaining a control number from the OMB. The box may also include a request for users' name and email address without invoking the PRA, but not for other specific data. In a similar vein, the memorandum allows users to sign up for agency notifications to their email address without invoking the PRA. The exclusion of

When deciding to implement a citizen seismology project, agencies should consider if and how they wish to deal with PRA requirements and then develop their application appropriately.

public meetings allows agencies to use a number of social media tools for public collaboration, including discussion boards, forums, blogs, social networks, and online communities.

However, the agency cannot use the meetings to carry out certain activities, such as interviews or surveys. Of particular importance to citizen seismology, asking identical questions of 10 or more attendees at these meetings will trigger the PRA. Other activities exempted from the PRA include the creation of user accounts or profiles for agency websites, the collection of information to allow users to customize website content, the rating or ranking of information, the collection of information to facilitate a commercial transaction, or the collection of information for a contest.[122]

As a result of this memorandum, some forms of citizen seismology are exempt from the PRA. For example, because Twitter takes a form much like a public meeting, applications like TED do not fall under the PRA. Similarly, notification systems, including the ENS, are exempt. In contrast, many crowdsourcing approaches require many different individuals to answer the same set of questions, thereby increasing the reliability of the resulting data. These applications do fall under the PRA. Because DYFI? collects specific information using an online survey, it must follow all PRA guidelines. Therefore, DYFI? had to obtain OMB approval before implementation and is required to prominently display a tailored PRA Burden Statement on the application. At the bottom of the DYFI? questionnaire, users will find the following statement:

> **Paperwork Reduction Act Statement** The Paperwork Reduction Act of 1995 (44 U.S.C. 3501 et seq.) requires us to inform you that this information is being collected to supplement instrumental data and to promote public safety through better understanding of earthquakes. Response to this request is voluntary. Public reporting for this form is estimated to average 6 minutes per response, including the time for reviewing instructions and completing the form. A Federal agency may not conduct or sponsor, and a person is not required to respond to, a collection of information

unless it displays a currently valid OMB Control Number. Comments regarding this collection of information should be directed to: Bureau Clearance officer, U.S. Geological Survey, 807 National Center, Reston, VA 20192.

When deciding to implement a citizen seismology project, agencies should consider if and how they wish to deal with PRA requirements and then develop their application appropriately. An organization that would like to avoid triggering the PRA cannot ask participants for specific forms of information, including their demographic background. These types of applications should not ask surveylike questions, but should give participants the space to make their own contributions. If an agency wants to ask many citizens the same set of questions as part of a citizen seismology effort, then it is important for them to consider the implications of the PRA. Because many crowdsourcing applications require many individuals to provide redundant responses, it is likely that the PRA places a higher burden on federal agencies' abilities to implement these types of crowdsourcing projects.

Potential Liabilities

In the case of emergency management where lives are in danger, there are liabilities for those participating in citizen seismology efforts. Unfortunately, because of the relative youth of crowdsourcing approaches for emergency response, many of these liabilities have not yet been adjudicated. Thus, it is not yet possible to know how the courts might react to future cases involving crowdsourcing.

Box 11. Crowdsourcing and Misinformation

Although data produced through citizen seismology can offer many benefits, they can also be quite dangerous if they contain misinformation. As crowdsourcing often allows any citizen to contribute information, there exists the possibility of a number of intentional and unintentional outliers, or events that trigger an alert but are not really earthquakes. Fortunately, because these systems rely on large spikes in reports before producing an earthquake alert, the effects of intentional outliers tend to be minimal. The USGS has not yet documented a case in which large groups of individuals have attempted to flood their applications with misinformation in order to trigger a false alert. Unintentional outliers, sparked by non-earthquake events, are more probable. In the case of the TED system, scientists found that an algorithm with a moderately high threshold for producing an alert detected two false triggers—one related to the Great California ShakeOut earthquake drill and the other related to the sonic boom associated with a space shuttle landing.[a] Once again, though, advances in computer science will continue to minimize even these false alerts— DYFI?, for example, can now differentiate earthquakes from sonic booms and other shaking events.

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a. P. Earle, D.C. Bowden, and M. Guy, "Twitter Earthquake Detection: Earthquake Monitoring in a Social World," *Annals of Geophysics* 54, no. 6 (2011):708–715.

Box 12. Liability in the 2009 L'Aquila Earthquake

In April 2009, an earthquake killed more than 300 people in the city of L'Aquila, Italy.[a] Just prior to the main shock, the city had experienced many minor tremors, and the Civil Protection Agency of L'Aquila had invited several scientists to speak at a meeting about seismic risks to the city. At this meeting, the seismologists stated that a major earthquake was unlikely, but not impossible, and a government official of the Civil Protection Agency subsequently went on to tell the press that the "scientific community tells us there is no danger, because there is an ongoing discharge of energy."[b]

After the earthquake, six scientists and the government official were charged with manslaughter for giving "inexact, incomplete and contradictory information about the dangers" to the city.[c] The prosecution argued that the assurances offered by the panel of scientists led some individuals to stay in L'Aquila when they had planned on leaving owing to a fear of a larger earthquake. The defendants were later sentenced to 6 years in prison and $10.2 million in damages and court costs.[d]

The exact implications of this decision for seismologists remain unclear. Some have argued that the court's decision was a result of public pressure and an indication of the lack of science's political clout in Italy and therefore that a similar situation would not play out in other countries.[e] Others fear that this decision will lead scientists to withdraw from the domain of public policy. Regardless, this case presents an important example of why it is important for seismologists to think carefully about how they communicate with the public.

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a. J. Mullen, "Italian Scientists Resign Over L'Aquila Quake Verdicts," CNN website, 2012, accessed January 6, 2013, http://www.cnn.com/2012/10/23/world/europe/italy-quake-scientists-guilty/index.html.
b. D. Ropiek, "The L'Aquila Verdict: A Judgment Not Against Science, But Against a Failure of Science Communication," Guest blog, 2012, accessed on January 6, 2013, http://blogs.scientificamerican.com/guest-blog/2012/10/22/the-laquila-verdict-a-judgment-not-against-science-but-against-a-failure-of-science-communication.
c. Mullen, "Italian Scientists Resign."
d. M. Fisher, "The Deeper Issues Behind Italy's Conviction of Earthquake Scientists," WorldViews blog, *The Washington Post*, 2012, accessed January 6, 2013, http://www.washingtonpost.com/blogs/worldviews/wp/2012/10/24/the-deeper-issues-behind-italys-conviction-of -earthquake-scientists.
e. "Shock and Law," Editorial, *Nature,* 2012, accessed January 6, 2013, http://www.nature.com/news/shock-and-law-1.11643.

Robson argues that crowdsourcing participants may become liable for injuries to others in three particular cases. He notes that U.S. law requires one individual to rescue another (1) if the individual begins a rescue attempt, (2) if the individual put the other in a dangerous situation, or (3) if a special relationship exists between the individual and the other.[123]

Crowdsourcing could produce each of these situations. If an organization designs an application that allows individuals to request rescue following an earthquake, the courts may perceive this as the first step in a rescue attempt. The organization may thus become liable for the safety of those individuals who used their application. Citizen seismology applications may put individuals in danger if they provide those individuals with false or misleading information. Any of the applications that release information publicly have the potential to provide inaccurate information and therefore have the potential to place earthquake survivors in greater danger.

Finally, it is unclear whether a court may find a special relationship exists between crowdsourcing participants and aid workers or victims who consistently rely on those participants. Robson argues that organizations sponsoring crowdsourcing applications can preemptively respond to some of these potential liabilities through the use of disclaimers. At the very least, both organizations and individuals should be aware of the risks.[124]

Democratic Participation

Many of the organizations exploring crowdsourcing argue that it ushers in a new stage of democratic participation, as it offers citizens a venue in which they can be heard by government. Applications from DYFI? to Twitter are capable of producing two-way dialogue between citizens and government agencies, and both sides can benefit greatly.[125] Crowdsourcing projects have empowered citizens in a wide range of activities, from cleaning up their city to helping fight forest fires.[126]

However, crowdsourcing is not always empowering, nor does participation in crowdsourcing automatically equate to benefits for citizens. In most cases, crowdsourcing techniques are used to get citizens to produce data that the government has traditionally produced on its own for citizens, meaning that it allows the government to outsource work to citizens. Some citizens may simply perceive this as an increased burden rather than an opportunity to participate in data collection.[127] Some citizens prefer lower levels of participation.[128] Organizations must examine their crowdsourcing techniques and qualitatively evaluate their effect on citizens' lives instead of simply assuming that they are empowering because they allow citizen participation.[129]

The literature increasingly describes the ways in which crowdsourcing produces uneven opportunities for citizen participation. Some researchers have found that the individuals who use the Internet to participate in governance processes are those who have good technical skills and a predisposition to participate in non-Internet forms of the same processes.[130] Individuals without these traits, who also tend to belong to marginalized demographic groups, remain marginalized within crowdsourcing applications. Following Hurricane Katrina in New Orleans, crowdsourcing applications were used to describe conditions on the ground throughout affected areas. When geographers analyzed the areas from which these descriptions were coming, they found an uneven distribution of participation.[131] Traditionally low-income, African American neighborhoods were described far less than other neighborhoods. In addition, the type of language used in contributions to crowdsourcing applications revealed that different demographic groups were participating much more than others.[132]

These potential inequalities are evident in the types of participation being

Box 13. Citizen Seismology, Cultural Bias, and Data Standardization

It is likely that a number of biases are built into citizen seismology systems through cultural, technological, and language assumptions made by the organizations that designed the systems. For example, thus far Twitter algorithms have based their analysis on only a handful of languages, and DYFI? is available only in English and Spanish. This makes it more difficult for individuals who do not speak these languages to effectively report an earthquake using these systems. More broadly, geographic web applications generally seem to be more highly populated by English contributions from the United States and Western Europe, which hints at potential inequalities in accessibility to these types of applications.[a] In fact, many researchers have noted a growing digital divide that affects who has access to newer information and communications technologies.[b] These researchers argue that many factors, including demographic background, interest, social networks, and technological ability, all affect the ability and likelihood that different social groups will participate in crowdsourcing projects. These different factors thus affect the probability that any particular population group will report an earthquake.

As citizen seismology approaches become more popular around the globe, it becomes increasingly important both to understand different cultural contexts and to standardize the questionnaires, macroseismic scales, and approaches used by international groups. To further minimize the likelihood that data will be misinterpreted, it is helpful if scientists adopt international standards for citizen seismology. Currently, many projects ask different questions or use a slightly different macroseismic scale. If these data are shared without a full understanding of the differences, future analysis based on the data can be highly skewed. As a result, the 2008 General Assembly of the European Seismological Commission established the ESC Working Group for International Macroseismology, which seeks to develop common citizen seismology efforts.[c] Already the USGS shares DYFI? data in many different formats, including XML, to increase the potential for collaboration with others.

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a. M. Graham and M. Zook, "Augmented Realities and Uneven Geographies: Exploring the Geo-Linguistic Contours of the Web," *Environment and Planning*, forthcoming.

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In view of the constrained nature of resources, agencies must be careful to ensure that all citizens are able to obtain aid, and not only those citizens advantaged enough to have access to citizen seismology projects.

valued within citizen seismology. Nearly all of the applications require users to have a decent grasp of technology, from knowledge of specific earthquake websites to the use of Twitter. These technical skills vary dramatically around the world and within the United States.[133] Users also require access to necessary hardware and software, which is not universal. Furthermore, ease of participation varies largely by language. The Twitter algorithms used by the USGS detect events based on only a handful of languages, while DYFI? questionnaires are available only in English and Spanish.[134] Given these limitations and inequalities, it is important to fund research into the interactions among citizen seismology, democratic participation, inequality, and emergency response.

Citizen seismology is often simply a supplement to traditional forms of seismology. Seismological organizations continue to offer the same services that they did prior to the advent of crowdsourcing technologies. However, emergency responders will be able to offer better and quicker services to those individuals who can feed them situational awareness after crisis events. In view of the constrained nature of resources, agencies must be careful to ensure that all citizens are able to obtain aid, and not only those citizens advantaged enough to have access to citizen seismology projects.

Conclusion

Citizen seismology is a powerful process precisely because it allows many citizens to work together to respond to earthquakes. Although these citizens may not be trained in seismology themselves, crowdsourcing applications developed by trained scientists can help transform citizen observations into valuable scientific data. Furthermore, these data have the advantages of being fast and cheap, and they provide valuable insights into survivors' reactions to earthquake events. If citizen science projects are to achieve these benefits, however, a number of variables have to fall into place. Organizations must design effective and robust applications; those applications must attract a reliable user base; and the policy environment must be conducive to the use of the resulting data.

Naturally, given the youth of these projects, there remains much to do. From a scientific perspective, many of the projects attempted thus far have been tested or deployed only to a limited degree; more testing is needed. For instance, TED has been deployed only as an internal system to the USGS, and both the QCN and the CSN are still evolving into robust operational systems. Additionally, as technology advances, the science behind citizen seismology is likely to improve dramatically. Scientists will be better able to eliminate non-pertinent data from crowdsourcing datasets, resulting in more accurate and more reliable data. The increasing prevalence of mobile devices and the use of location-based services will also improve scientists' knowledge of the location and movement of individuals contributing to citizen seismology efforts.

Outside of the seismology itself, additional research is needed into the sociology of crowdsourcing, as well as the impact of policy on citizen science and vice versa. Researchers still understand fairly little about who is participating in citizen science efforts, why they are participating, and how others might be drawn into the efforts in a fair and equitable manner. Despite important steps forward, such as the memorandum Social Media, Web-Based Interactive Technologies, and the Paperwork Reduction Act,[135] policy continues to play catch-up to advances in technology. Policy analysts and policymakers need to rigorously examine the ways in which current policy affects citizen seismology and find ways to improve the policy environment in order to take full advantage of these new practices. Citizen seismology is certainly an exciting new example of government–citizen collaboration. As a collaborative process, it is up to all the actors involved to continue to work together to produce more effective and more empowering results.

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