Developing earthquake forecast templates for fast and effective communication

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ABSTRACT

In the immediate aftermath of a damaging earthquake, evidence shows that people respond positively to receiving basic earthquake information quickly by science authorities[1]. This evidence, gathered from numerous aftershock sequences in New Zealand from 2010-2016, indicates that earthquake forecasts, while complex, can also be a critical component of emergency response[1-3]. Research conducted during these sequences indicates that people value aftershock forecasts for a variety of reasons, from informing important response and recovery decisions to psychologically preparing for more earthquakes.

Currently, the USGS is expanding its aftershock forecasting from California [4] to the nation, improving the scientific methods used to provide immediate estimates of potential seismic behavior after large earthquakes [5], and updating the communication methods. Similar activities are underway in New Zealand, Japan, and Italy. To assist with fast and effective USGS response to earthquakes, an earthquake forecast communication template is being developed. The purpose of the template is to:

-Establish an authoritative and trustworthy scientific voice,
- Provide information about earthquake sequences and forecasts,

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- Psychologically prepare people for continued seismic activity and link them to preparedness information,
- Engage with stakeholders and members of the public during the template development process to understand their needs for information and develop relationships between them and USGS Scientists.

Communication research, best-practice literature, and experience with forecasts in the U.S., Nepal, and New Zealand was used to inform the development of the templates. Revisions were based on consultation with emergency managers, government agencies, businesses, and social scientists, as well as lessons learned using the template during the 2016 M5.8 Pawnee, Oklahoma and 2017 Soda Springs, Idaho earthquake sequences.

The earthquake forecast communication template is envisioned to be only for early response (within the first hour of a major earthquake); communication will be tailored to specific earthquakes, and possibly audiences, as the sequence continues and as required. In addition to the OEF communication template, the USGS is developing new tools to allow users to customize spatiotemporal forecasts to their specific needs and access advanced information such as hazard curves.

Introduction

Earthquakes strike without notice, causing shock and confusion among people closely impacted. Audiences directly impacted are largely not able to process information the same during times of crisis as they are during times of non-crisis due to heightened levels of stress and tiredness [6, 7]. During the initial phase of response, the need for scientific information increases, particularly in regards to the likelihood of large aftershocks. Seismologists have developed operational earthquake forecasting, which can provide a probabilistic understanding of how large and frequent aftershocks can be post the initial earthquake. This information has been used in New Zealand, to varying degrees of success, depending on the particular audience. The purpose of this research is to combine best-practice communication techniques with the New Zealand experience to develop a fast and effective communication response for the United States of America.

About Operational Earthquake Forecasting

Operational Earthquake Forecasting (OEF) “is the dissemination of authoritative information about these time-dependent probabilities to help communities prepare for potentially destructive earthquakes” [8]. In New Zealand, OEF has been communicated in a variety of ways including maps, tables, and scenarios [1].

OEF presents a variety of communication challenges, e.g. time frames in which to frame probabilities, and the complexity of communicating probabilities. Not only is OEF communicated during times of crisis but also as a reassessment of risk in recovery. An OEF was communicated during the Canterbury Earthquake Sequence (2010-present) with regular updates, but this was not without complications [2]. For example, there were mixed responses to the forecast probabilities. Some people utilized such information to inform practical response and recovery-related tasks and to help make meaning of the likelihood earthquakes for their own wellbeing. While others did not want to know about the forecasts as it caused anxiety [3]. Given the complexities, is necessary to think about how to communicate the OEF before an event.

Reasoning for the development of communication templates

Historically, the California Integrated Seismic Network produced Operational Aftershock Forecasts (for earthquakes M≥5) in the early 1990s. However, over time, these aftershock forecasts were found to be too difficult to find and there was overall lack of public attention to the forecasts.

To communicate forecasts, the USGS has produced information about forecasts for several sequences, including the M7.0 Haiti Earthquake (2010)[9], M5.8 Mineral Earthquake, VA (2011)[10], M6.0 Napa Earthquake, CA (2014)[11], M7.8 Nepal Earthquake (2015)[12], Oklahoma earthquakes (ongoing)[13], Bombay Beach swarm (2016), and the M5.3 Soda Springs, Idaho Sequence (2017). These forecasts in the past have been manually crafted and disseminated to various audiences, with different formats each time. Opinions among the scientists has varied wildly on grammar, structure, hierarchy, tone, and language. Further, the process described above is time consuming and stressful. Information is critical during the early hours of a major earthquake [1], so the process requires streamlining, which is why the templates would be valuable resources for the science community.

The concept of templates for OEF is not novel; many people at the USGS have worked on this project, with some success. Further, templates are used in earthquake response at the U.S.G.S's National Earthquake Information Center (NEIC)[14]. However, for various reasons, the templates for OEF have not been finalized. This project aims to complete the work already started and operationalize templates. The reasoning for this project is now explored further.

Establishing an authoritative and trustworthy scientific voice

Communication is not without challenges by scientific experts to various audiences. In the last three generations, there is evidence to suggest that authority and expert perspectives are increasingly challenged and held with skepticism by audiences [15]. One-way communication and exclusionary social structures of science (e.g. if a person is not a scientist, then scientists will not listen or respect the person) have also contributed to this erosion of trust [16]. In Christchurch, distrust appeared to manifest around the time earthquake probabilities jumped up due to a model change [3]. Some people reported that they stopped listening. Workshop participants who were geology students at the university suggested that the distrust in scientists stemmed from a lack of understanding the scientific process [3].

By sharing science information in a transparent and timely manner, it may create and sustain more trust among various publics and the scientists at the USGS.

Template development

Engaging with stakeholders and members of the public during the template development process helps to support relationships with USGS Scientists. *Figure 1* represents an earlier iteration from August 2017 that was developed combining theory, practice and research.

DRAFT - THIS EARTHQUAKE AND ITS STATISTICS ARE MADE UP AS AN EXAMPLE

[Name of Earthquake] Aftershock advisory from the United States Geological Survey (USGS)

Be ready for more earthquakes

- Due to an earthquake of magnitude [mainshock magnitude] at [mainshock time] on [mainshock date] near [nearest city to mainshock], more earthquakes than usual will continue to occur approximately within [two times Wells and Coppersmith length of mainshock rupture] of the mainshock.
- When there are more earthquakes, the chance of a large earthquake is greater which means that the chance of damage is greater. The USGS advises everyone to be aware of the possibility of aftershocks, especially when in or around vulnerable structures such as unreinforced masonry buildings.
- Because of the increased probability of damaging earthquakes, we strongly advise people to listen to the advice of your (State/County/City) emergency management office.
- This sequence may have damaging earthquakes in the future, so remember to: Drop, Cover, and Hold on. Earthquakes can be scary for a lot of people and we encourage everyone to look after each other during this time.

What we think will happen next

With earthquakes of this size, we often experience an increase in the number of earthquakes (called aftershocks) in the area. We do know that the number of aftershocks will drop off over time, but a large aftershock can increase the numbers again, temporarily.

According to our forecast, over the next week there is a [forecast: probability of M≥ magnitude of the mainshock in next week] chance of one or more aftershocks that are larger than the magnitude [mainshock magnitude]. It more likely that there will smaller earthquakes, with [forecast: range of number M≥3 earthquakes in next week] magnitude 3 or higher aftershocks, which are large enough to be felt, and there is a [forecast: probability of M≥ 5 in next week] chance of one or more magnitude 5 or higher aftershocks, which can cause damage.

More detail about the forecast is provided in the section "Our detailed aftershock forecast".

About this earthquake
(more specific info about the earthquake)
So far in this sequence there have been [number M≥3 earthquakes] magnitude 3 or higher earthquakes, which are large enough to be felt, and [number M≥5 earthquakes] magnitude 5 or higher earthquakes, which are large enough to do damage.

Our detailed aftershock forecast
The USGS estimates the chance of more aftershocks as follows:

Figure 1. Draft template as of August 2017.

The bulleted list in the template contains the basic information regarding the magnitude, date, location, time and relevance (nearest city) for earthquake. The second bullet focuses on the concept that larger earthquakes could follow and that aftershocks will be continuing for some time, with some building safety information included. The third bullet focuses on where people can get more information, specifically their emergency management office [17, 18]. Finally, the last bullet point provides personal safety advice and acknowledging the distressing nature of earthquakes (empathetic message) [19]. The next section (what we think will happen next) focuses is a simple summary of the forecasts and re-enforces safety messages [20]. The next section (about this earthquake) provides contextual information about the current state of the sequence.

Soda Springs, Idaho Sequence: Template in action

On September 2, 2017, there was a M5.3 earthquake east of Soda Springs, Idaho. The earthquake caused moderate shaking over a broad area of southeastern Idaho, northern Utah, and western Wyoming. After the initial M5.3, there was a sustained and active sequence of smaller earthquakes. Given this, it was decided to use the template to determine its utility in a real-time event. Application of the template (Figure 1) was problematic for several reasons. The M5.3 Idaho Springs sequence behaved more like a swarm than a typical mainshock/aftershock sequence. Also, the M5.3 was not immediately damaging to a large number of structures, so preparedness and empathetic messages were not as in demand as they were in New Zealand, where earthquakes were much larger and damaging [1]. The template was put aside for a handcrafted response, which took some time to reconcile a variety of internal and key stakeholder input. The experience has led to a renewed call for templates to be available for a crisis. The template needs to satisfy USGS standards, and provide speedier and clearer delivery of key information to various audiences during times of heightened seismicity.

Earthquake Forecast

The M5.3 Soda Springs Sequence is particularly active, producing more aftershocks on average than other earthquakes of this magnitude. In terms of future larger earthquakes in this area:

- When there are more earthquakes, the chance of a large earthquake is greater, which means that the chance of damage is greater.
- Idaho and Montana experience earthquakes. While earthquakes are not that common, it is also not surprising to see earthquakes in these areas.
- This sequence may have damaging earthquakes in the future, so remember to: Drop, Cover, and Hold on if you feel the ground shaking.

Due to the active and ongoing nature of this sequence, we have developed an earthquake forecast for continuing seismicity. No one can predict the exact time or place of any earthquake, including aftershocks. What our earthquake forecasts do is give us an understanding of the chances of having more earthquakes within a given time period. We calculate this earthquake forecast using a statistical analysis based on past earthquakes in similar tectonic environments, as well as the aftershocks recorded to date for this sequence.

Our forecast changes as time passes due to the decay in the frequency of aftershocks, larger aftershocks that reinvigorate the sequence, and changes in forecast modeling based on the earthquake data collected. Similar to weather models, our models will also change with more data and information. The longer this sequence goes on, the more we learn about what it will do in the future.

We have taken a detailed forecast and developed three scenarios that we consider to be the most likely. These scenarios are for the following month, but earthquakes will continue to be possible at later times. The forecast was last updated on Sept. 28, 2017. We will continue to update the forecast as more information becomes available.

Here are the three scenarios or possibilities for the month starting Sept. 28, 2017, based on earthquake forecast models:

1. **Scenario #1 (most likely: 90-95% chance):**
   The sequence will continue to decay over the next month, which means there will be fewer earthquakes. Earthquakes above M3 may be felt by those in the area, and occasional spikes in activity may be accompanied by additional M4 or larger earthquakes, but with none larger than the M5.3 mainshock. While all earthquake sequences decay over time, there are several other possible outcomes, which are listed next.
   Scenario #2 (less likely than Scenario #1 but possible with 5-10% chance):
   A similar sized or larger earthquake than the M5.3 mainshock may occur. This situation is often referred to as a "doublet" when a similar sized earthquake follows the original earthquake that kicked off the sequence. Doublets have occurred in places around the world, but they are not very common.
   Scenario #3 (the least likely scenario but still possible with less than 1% chance):
   A much larger earthquake than M5.3 could occur, up to and including the M7 range, in which case we would call what has happened prior to any larger earthquake a foreshock sequence. We have seen this happen in other places around the world, with the most notable being L'Aquila, Italy in 2009. It is important to understand that this is a highly unlikely scenario, but we cannot ignore the possibility of this occurring.

Figure 2. Text from earthquake forecast developed for the Soda Springs, Idaho sequence[21].

Conclusions

Prepared communication templates, based on research, may aid scientists in a fast and clear response to various publics regarding earthquake forecasts. Fast response combined with empathetic and science-focused messages may aid in increased trust between the science community and the publics they seek to serve. A shared agreement among scientists about style, tone, and verbiage could assist the speed of communication. Further development is required regarding the templates to ensure preparedness and empathetic messages are effective and that science information is sufficient and trusted.

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