The U.S. Geological Survey's Guide to Communicating Aftershock Forecasts: A Primer

Quick Start Guide – What to do if an aftershock forecast has just been released in your area

If a damaging earthquake has just occurred in your area and you are new to the USGS Operational Aftershock Forecast product, here is what you most need to know about communicating related information:

- The main message of the aftershock forecast is to **be prepared for more earthquakes.**
- The forecast product provides guidance on the best ways for people to respond to shaking. When communicating earthquake probabilities, protective action information is important to assist people with actionable steps to improve their safety. Guidance may vary by country and messaging should be consistent across local institutions, if possible.
- The USGS will do its best to communicate the best protective action for your nation, as recommended by local agencies and experts, when practicable. In the USA, the recommended response in most situations is **Drop, Cover, and Hold On**.
- Consider providing additional details from local agencies and experts on safe and non-safe structures, and areas for people to seek out or avoid due to landslide, tsunami, or another hazard.
- A forecast is not a prediction. The forecast provides a general picture of what is likely to happen, not precisely what will happen at a specific time; it is not a prediction of the exact place, time, or location of future earthquakes. Furthermore, forecasts are based on models, and all models have uncertainties. Earthquake sequences vary in activity level based on physical factors, making some more active and others less so. We account for this variability in our forecasts, which is why some information is presented as a range, such as the expected number of aftershocks.
- The USGS uses this message: "No one has yet predicted the exact time, location, and magnitude of a specific earthquake scientifically. The USGS forecast tells us what can happen but not precisely what will happen." To communicate that this is a forecast, not a prediction.
- *Communication types.* There are several ways we communicate our forecasts: through numbers, words, images, tables, and maps. We use different forms of communication to meet the needs of various users. Please pick the communication types that best work for your audiences.

If you need more information, or have any questions, concerns, or suggestions, you can reach out to us directly and we can provide assistance with communication or clarification.

1.0 Introduction: The U.S. Geological Survey Operational Aftershock Forecast Communications Guide

This guide has been developed to assist science communicators and science agencies with communication of USGS Operational Aftershock Forecasts in their country. It is not intended to replace other countries' aftershock forecasting efforts, but rather to complement them by offering an additional model derived from USGS data. Our focus is to provide forecasts for nations that may not otherwise have access to this type of information. If anything in this guide requires clarification OR you require extra communication support for the forecast, please contact the USGS Operational Aftershock Forecasting team directly and we can assist you. There is also an overview of the forecast here: https://earthquake.usgs.gov/data/oaf/overview.php

2.0 About our aftershock forecasts

2.1 What is an aftershock forecast and how does the USGS produce these?

Most large earthquakes are followed by additional earthquakes, called aftershocks, which make up an aftershock sequence. While most aftershocks are smaller than the mainshock, they can still be damaging or deadly. The USGS has developed a statistical model based on the behavior of past aftershock sequences in similar tectonic settings. This model characterizes possibilities for what will happen next, providing what we refer to as an aftershock forecast.

A small fraction of earthquakes are followed by a larger earthquake, in which case the first earthquake is referred to as a foreshock. For example, the 2011 magnitude (M) 9.1 Japan earthquake and tsunami was preceded by a M7.3 foreshock two days before. When the M7.3 earthquake first occurred, it was called the mainshock, and then when the M9.1 earthquake occurred, that larger earthquake became the mainshock. The names "foreshock", "mainshock", and "aftershock" are relational terms to associate earthquakes in space and time, and have no bearing on the physical nature of the individual earthquakes themselves.

The rate of aftershocks usually follows a few general rules:

1. Larger mainshocks trigger more aftershocks than do smaller mainshocks. For example, a magnitude 7 mainshock will trigger, on average, 10 times as many aftershocks as a magnitude 6 mainshock.
2. The average number of aftershocks expected following a mainshock of a given magnitude varies between tectonic regions. For instance, mainshocks within continents generally produce fewer aftershocks than mainshocks of the same magnitude within a subduction zone.
3. The rate of aftershocks decreases with time, such that the earthquake rate is roughly inversely proportional to the time since the mainshock. For example, there are about 10

times as many aftershocks on the first day of an aftershock sequence as on the tenth day.

4. On average, The rate of aftershocks of all magnitudes decreases with time, but aftershocks of all magnitudes are still possible.

After an earthquake occurs, our initial forecast is calculated using parameters developed from analyses of previous earthquakes in that region and similar tectonic regions around the world. As time goes by and we track how many aftershocks are happening in a specific sequence, we update the forecast to better model that sequence. We continue to update the forecast as the sequence progresses using up-to-date aftershock data.

Aftershock forecasts typically include:

- **Probability** of aftershocks of varying magnitudes (e.g., chance of at least one aftershock of magnitude 5 or greater) over specific time frames (next day, week, month, and year).
- **Expected number (and range) of aftershocks** of various magnitudes over specific timeframes (e.g., within the next 24 hours or within the next week).
- **Decay rate** or how the frequency of aftershocks is expected to decrease over time.

2.2 When does the USGS produce an Operational Earthquake Forecast for an earthquake outside the US?

The U.S. Geological Survey may produce Operational Aftershock Forecasts for international earthquakes when a the USGS earthquake damage and loss assessment product, the Prompt Assessment of Global Earthquakes for Response (PAGER), produces a Orange or Red alert for fatalities. An orange level PAGER alert indicates the median estimated number of fatalities exceeds 100. For more information on the USGS PAGER system, please see: https://earthquake.usgs.gov/data/pager/background.php

Below is an explainer of PAGER's different alert level colors:

Alert Level and Color	Estimated Fatalities	Estimated Losses (USD)
Red	1,000+	$1 billion+
Orange	100 - 999	$100 million - $1 billion
Yellow	1 - 99	$1 million - $100 million
Green	0	< $1 million

Table One: PAGER's alert levels and corresponding colors.

2.3 For whom does the USGS produce the Operational Aftershock Forecast?

USGS produces Operational Aftershock Forecasts for a range of stakeholders – engineers, decision makers, emergency managers, search and rescue (SAR) personnel, planners, communities, and anyone who is interested in what could happen next after a large, damaging earthquake.

2.4 Why does the USGS produce Operational Aftershock Forecasts for other countries?

USGS has the capability to produce aftershock forecasts for different countries and we believe access to reliable scientific information is critical to successful emergency response. These forecasts can assist nations in planning and responding to large earthquakes by providing a probabilistic picture of what could happen next.

3.0 Terminology

Some specialized terminology is necessary to communicate aftershock forecasts, and we primarily use terms and language used by geoscientists globally. When possible, it is preferred to use plain language to explain the forecasts, as earthquake response is not the time to introduce complex scientific terms to communities already experiencing trauma.

3.1 Mainshock, aftershock, foreshock, sequences and swarms

An **aftershock** is a nearby earthquake that occurs following a significant earthquake (**mainshock**). These events are common as the Earth adjusts to changes caused by the mainshock. Aftershocks can occur minutes, days, or even years after the initial event.

Most aftershocks are smaller in magnitude than the mainshock. However, while rare, it is possible for an aftershock to be larger than the original mainshock, in which case the aftershock is reclassified as the mainshock, and the original mainshock as a **foreshock**.

Aftershocks form a sequence of earthquakes that happen after a larger mainshock on a fault or faults. Aftershocks occur near the fault zone where the mainshock rupture occurred and are part of the "readjustment process" after the main slip on the fault. Aftershocks are not restricted to the fault on which the mainshock occurred, and may also be located on surrounding faults. Aftershocks become less frequent with time, although they can continue for days, weeks, months, or even years after a very large mainshock. Large aftershocks can generate their own aftershock sequences.

A swarm, on the other hand, is a series of mostly small earthquakes with no clearly identifiable mainshock. Swarms are usually short-lived, but they can continue for days, weeks, months, or sometimes even years. They often recur at the same locations. Unlike aftershocks that are triggered by other earthquakes, swarms are often driven by other processes, such as geothermal or volcanic activity, or human-induced or natural fluid flow.

3.2 Probabilities versus predication (language considerations).

The Operational Aftershock Forecast product from the USGS **is not a prediction, which would imply we know the exact time, location, and size of a future earthquake**. Instead of predictions, we provide probabilities that aftershocks of a given size will occur over specified periods of time, along with estimated ranges for how many aftershocks to expect. This probabilistic approach is the most reliable method available based on current scientific understanding. However, in many languages, "forecast" and "prediction" are considered interchangeable words and concepts. It is thus prudent to be mindful of how you communicate: these forecasts outline what is generally likely to happen in the future, not precisely what will happen.

4.0 Types of USGS aftershock forecast information

4.1 Where is the Operational Aftershock Forecast on a USGS earthquake event page?

Operational Aftershock Forecasts, when available, will be posted and updated on the USGS's earthquake webpage created for the mainshock (the "event page"). Earthquake event pages for recent earthquakes can be found at *earthquake.usgs.gov* under "Latest Earthquakes". (Event pages for older earthquakes can be found using the "Search Earthquake Catalog" feature at *earthquake.usgs.gov)*. From the event page, users can find the Aftershock Forecast for that earthquake by selecting the "card" card titled "Aftershock Forecast" (see the red box below in Figure 1). This card will only appear if an aftershock forecast is available for that event.

The card or aftershock forecast graphic gives a short summary of the probabilities of earthquakes at difference magnitude levels for the next week (or, later in the sequence, for the next month).

Figure 1: USGS Earthquake event page with Operational Aftershock Forecast card highlighted in red.

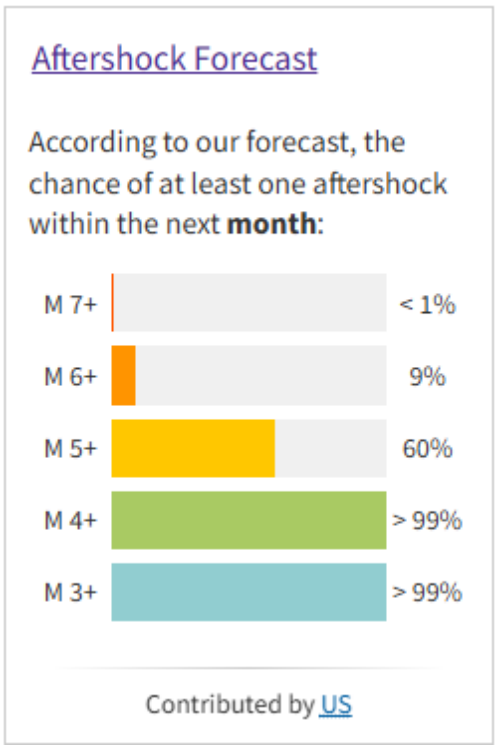


Figure 2: The Operational Aftershock Forecast card.

4.2 Critical messages for the aftershock forecast

Research indicates that when people are in a trauma state or are exposed to a great deal of novel information, like during an earthquake, it is critical to provide simple information related to the future and what they can do to protect themselves. This is why the forecast begins with "**Be ready for more earthquakes**". The banner also includes protective action information and direction to listen to

emergency management authorities as well as a bullet explaining that aftershock forecasts are not precise predictions. Each product tab retains this information as its header.

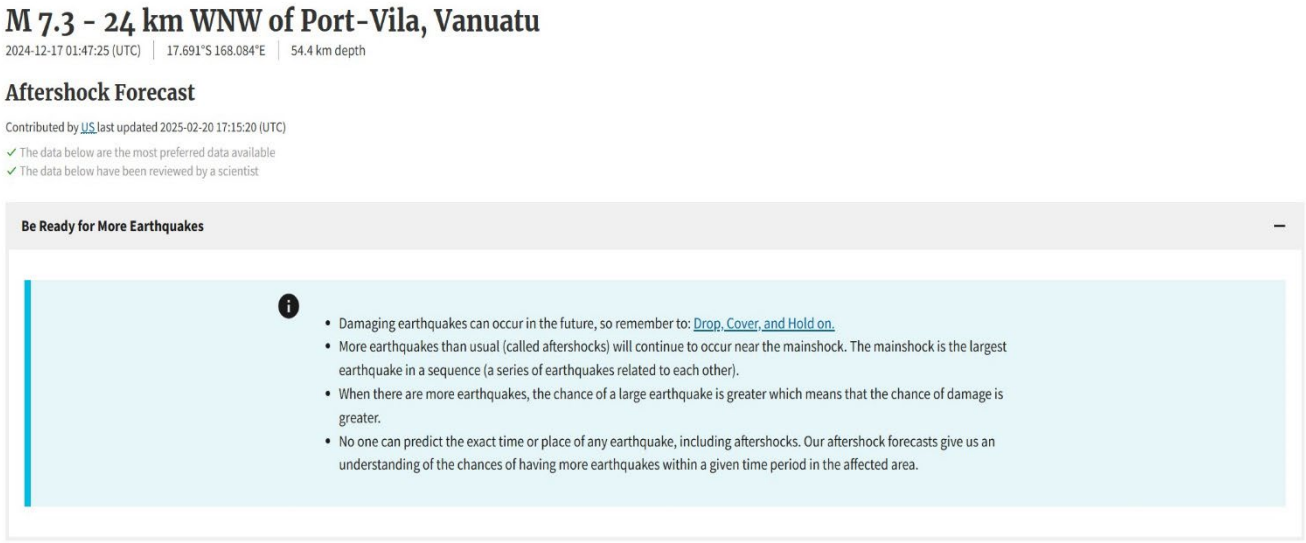


Figure 3: The simple text banner at the top of the aftershock forecasts page.

4.3 Communicating the Forecast with Graphics (Summary Tab)

The landing page for the aftershock forecast is a summary tab. There are several graphics; one is interactive. Users can designate different magnitude levels and different forecast time durations to see illustrations of the aftershock probabilities and expected numbers.

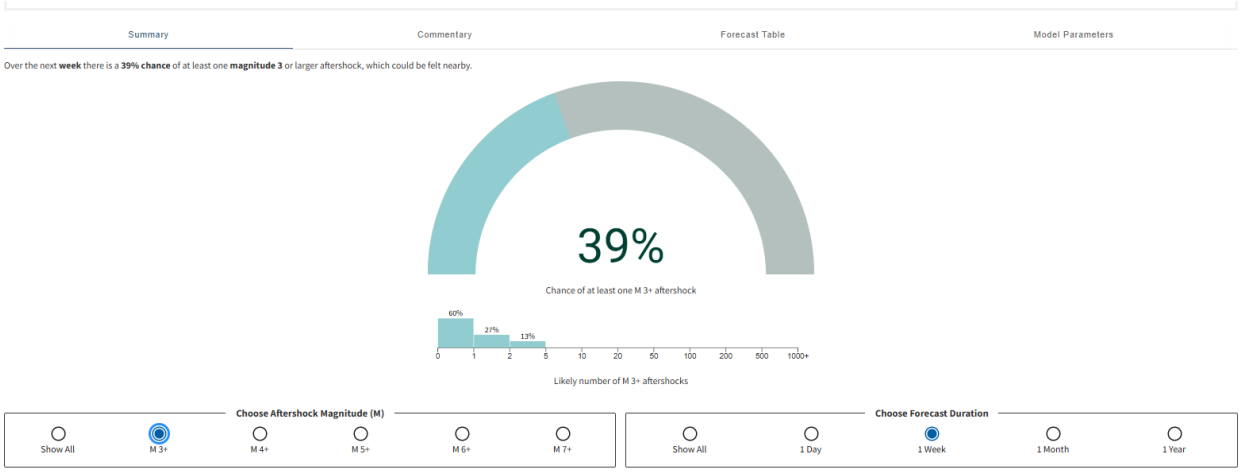


Figure 4: Interactive forecast graphic.

The second image, titled "Aftershock Locations", shows the aftershocks that have occurred to date, colored by how recently they have occurred. The map also shows the region where the forecast is applicable.

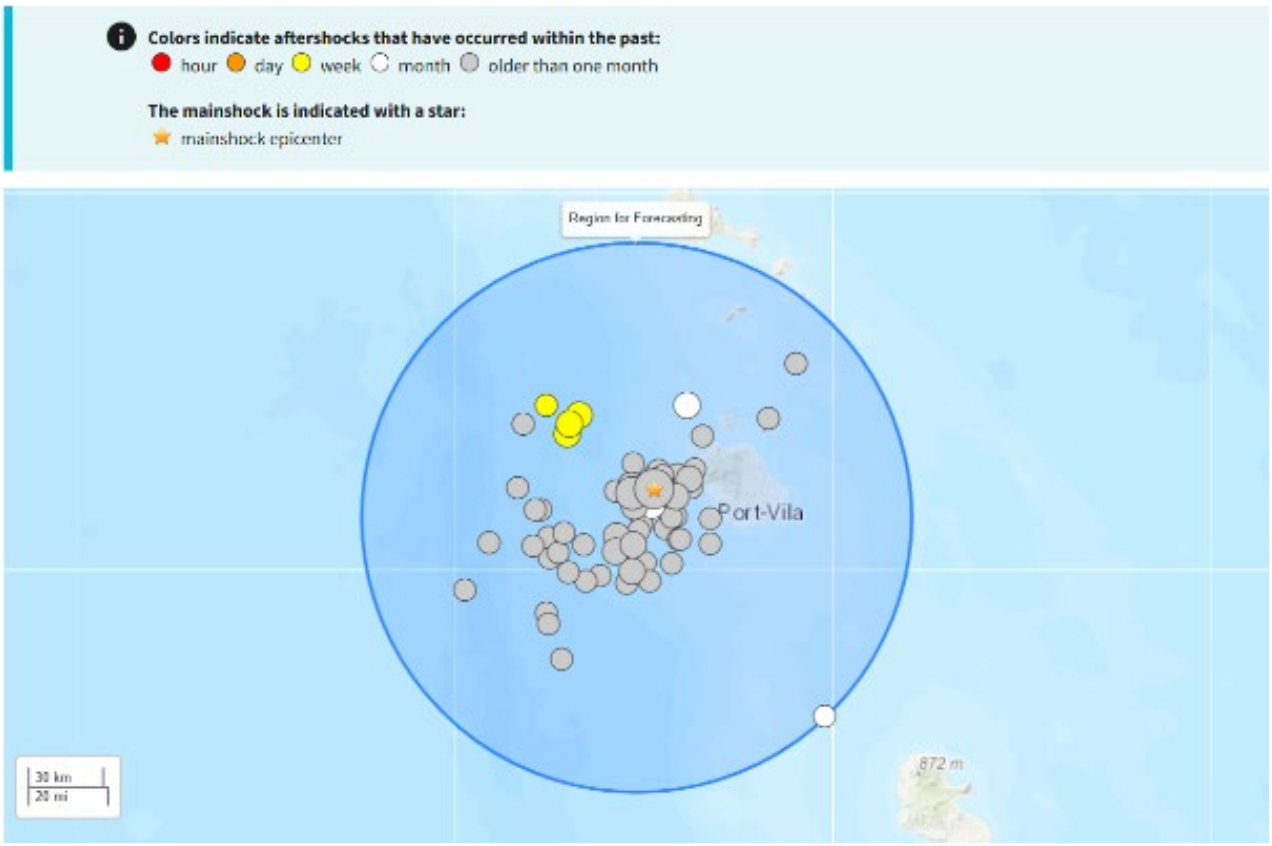


Figure 5: Map of aftershocks that have occurred so far, colored by recency of occurrence. The forecasting region is shown with the blue circle and the mainshock is shown with a orange star.

4.4 Communicating the Forecast with Words (Commentary Tab)

The USGS provides a text commentary that summarizes key points. This may be useful for media or other groups with limited technology access post event – for example via radio, which is frequently used to help keep people informed when power and internet may be inaccessible or damaged. The commentary can also be used to help communicate with people and groups that require or prefer a text explainer.

4.5 Communicating the Forecast with Tables (Forecast Table Tab)

The "Forecast Table", provides information on the chance of at least one of various sized earthquakes for specific timeframes (day, week., month, year). Many cells of the table show the probability of at least one aftershock above a certain magnitude and within a certain time frame. If the probability is high enough that more than one aftershock is likely to occur, the table instead shows the likely number of aftershocks above the given magnitude and within the given time frame.

According to our forecast, the expected number of aftershocks:

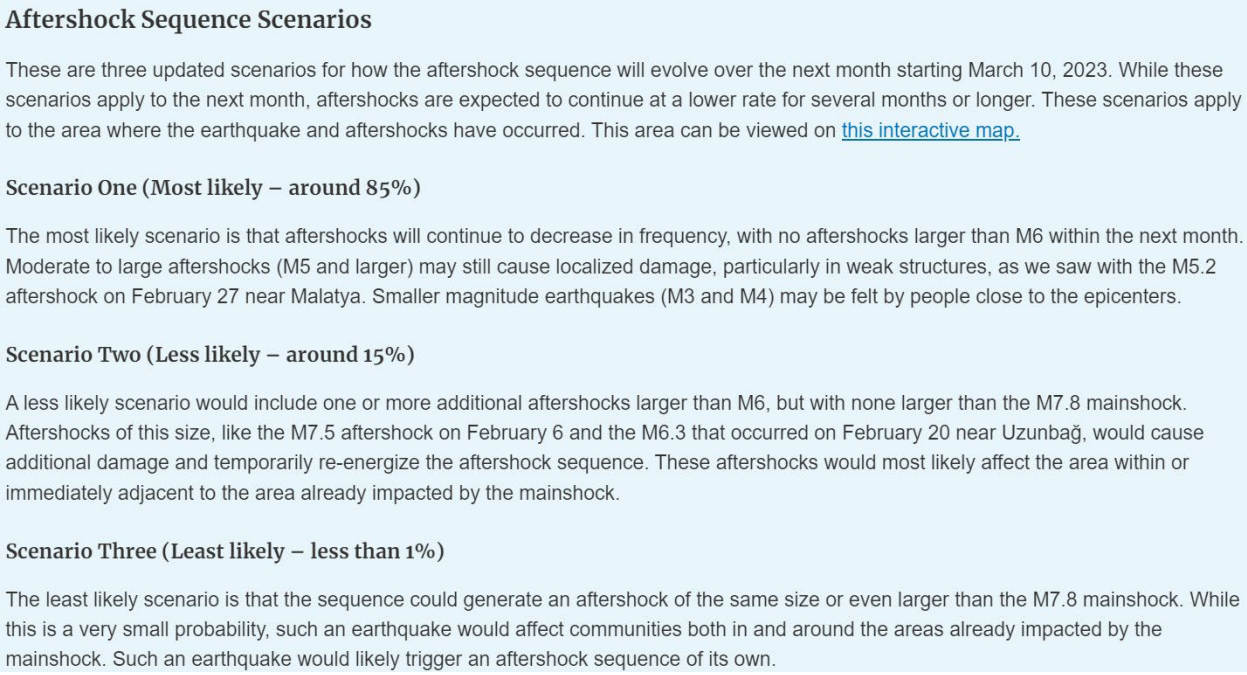
Magnitude (M) of aftershock	within 1 Day	within 1 Week	within 1 Month	within 1 Year
M 7 or higher	1 in 100,000 chance of 1 or more	1 in 20,000 chance of 1 or more	1 in 6,000 chance of 1 or more	1 in 2,000 chance of 1 or more
M 6 or higher	1 in 10,000 chance of 1 or more	1 in 2,000 chance of 1 or more	1 in 600 chance of 1 or more	1 in 200 chance of 1 or more
M 5 or higher	1 in 1,000 chance of 1 or more	1 in 200 chance of 1 or more	2% chance of 1 or more	4% chance of 1 or more
M 4 or higher	1 in 100 chance of 1 or more	5% chance of 1 or more	14% chance of 1 or more	34% chance of 1 or more
M 3 or higher	9% chance of 1 or more	39% chance of 1 or more	67% chance of 1 or more	Expect about 4

The rate of aftershocks is expected to decline with time. However, the probabilities in the longer time windows are higher because the rates are being summed over a longer time period.

Figure 6: Aftershock forecast table.

4.6 Scenarios

The USGS will occasionally produce three aftershock scenarios as a way to explain the possible evolution of the earthquake sequence. These three scenarios are conveyed through relative probability to one another, namely: most likely, less likely, and least likely. The first "most likely" scenario describes evolution of the sequence with only aftershocks smaller than the mainshock, but with events that can still cause additional damage in some places. The second "less likely" scenario is typically illustrative of what could occur if a similarly-sized, or slightly smaller or larger earthquake occurred. Such earthquakes of similar magnitude to the mainshock are more likely than an earthquake larger than the mainshock and, depending on their location, can still be damaging. The third or "least likely" scenario represents the possibility that a much larger and more damaging earthquake than the initial mainshock could occur in the sequence. One of these three scenarios must occur. These aftershock scenarios help to focus on the potential impacts of an earthquake sequence while indicating their relative likelihood.



Aftershock Sequence Scenarios

These are three updated scenarios for how the aftershock sequence will evolve over the next month starting March 10, 2023. While these scenarios apply to the next month, aftershocks are expected to continue at a lower rate for several months or longer. These scenarios apply to the area where the earthquake and aftershocks have occurred. This area can be viewed on this interactive map.

Scenario One (Most likely – around 85%)

The most likely scenario is that aftershocks will continue to decrease in frequency, with no aftershocks larger than M6 within the next month. Moderate to large aftershocks (M5 and larger) may still cause localized damage, particularly in weak structures, as we saw with the M5.2 aftershock on February 27 near Malatya. Smaller magnitude earthquakes (M3 and M4) may be felt by people close to the epicenters.

Scenario Two (Less likely – around 15%)

A less likely scenario would include one or more additional aftershocks larger than M6, but with none larger than the M7.8 mainshock. Aftershocks of this size, like the M7.5 aftershock on February 6 and the M6.3 that occurred on February 20 near Uzunbağ, would cause additional damage and temporarily re-energize the aftershock sequence. These aftershocks would most likely affect the area within or immediately adjacent to the area already impacted by the mainshock.

Scenario Three (Least likely – less than 1%)

The least likely scenario is that the sequence could generate an aftershock of the same size or even larger than the M7.8 mainshock. While this is a very small probability, such an earthquake would affect communities both in and around the areas already impacted by the mainshock. Such an earthquake would likely trigger an aftershock sequence of its own.

Figure 7: Scenarios example from the Türkiye earthquake in 2023.

5.0 Considerations for different audiences and preferred channels

Different user groups require different types of information presented in various formats. For example, some audiences may prefer a technical version of the forecast, while others may benefit more from a simple, compassionate message. Consider the audience as you make your own products or choose which USGS products or statements to provide. Information and product needs vary based on decision-maker roles, their technical expertise, severity of impacts, and the timing within the earthquake sequence.

5.1 Search and Rescue, First responders

First responders makes critical, short-term life-safety decisions, like whether a building is safe to enter or whether a location is safe for community members to return to. This group usually requires a range of products like maps, tables, text, and graphics. Needs may range from awareness of short-term aftershock risk when carrying out response activities to technical information for building safety considerations. This group tends to lean towards requiring more technical and less compassionate messaging.

5.2 Critical infrastructure

This group is largely engineering or engineer-adjacent and has specialty skillsets. As such, they too, want information in many forms and are able to ingest technical information (e.g., probabilistic, uncertainty bounds, measures of shaking intensity). This group may be involved in making longer-term decisions, and probabilities for longer timeframes may be of more interest to them.

5.3 Risk and emergency managers

This group has a combination of needs from the two previous groups as they must typically make decisions about life safety, early recovery, and rebuilding. They will likely want technical information and products.

5.4 Public information professionals and media

Public information management professionals may also want more technical information; however, their role is often to explain the aftershock forecasts simply to their publics. The text is often particularly useful for them, as media is often reliant on more text-based products.

The media will likely want access to all products; however the text will likely be the most used for broadcast forms of media (television and radio) and print, along with either the USGS mainshock ShakeMap or graphical aftershock forecast images.

5.5 Geoscientists

This group will likely be interested in all the products to use in their communications and response (e.g., siting instruments) as well as detailed information on how the USGS develops its forecast. For the latter purpose, model parameters are available in the Model Parameters tab on each Operational Aftershock Forecast product web page.

5.6 Public Health/well-being providers

Empathetic messaging may apply throughout the sequence, especially for traumatized populations. Explanations of earthquake sequence behavior can help people cope with the uncertainty of ongoing aftershocks.

5.7 Community leaders

Community leaders may want some of the technical products; however, given the massive amounts of information that they will be exposed to, they may opt for simpler information to help them make decisions.

5.8 People directly or indirectly impacted by the earthquakes

People who are directly impacted by the earthquake have unique informational needs. When earthquakes strike, the ground shaking and associated damages can induce trauma-like symptoms in people. Trauma responses are expressed differently for everyone; however, there are a few central themes we have noted in the literature describing people's experiences. These symptoms can include irritability, heightened startle responses, tension, difficulty concentrating, falling asleep or staying asleep, and lack of memory or ability to comprehend novel information.

Earthquakes impact people with a wide range of experiences, languages, and technical skills. Therefore, we provide forecast information in different forms of communication, including through numbers, words, images, tables, and maps.

When earthquakes strike, the ground shaking and associated damages can induce trauma-like symptoms in people. Trauma responses are expressed differently for everyone; however, there are a few central themes we have noted in the literature describing people's experiences. These symptoms can include irritability, heightened startle responses, tension, difficulty concentrating, falling asleep or staying asleep, and lack of memory or ability to comprehend novel information.

Simple and empathetic messaging helps people understand that the science agency is communicating the forecast to them because the agency cares about their well-being, and wants to support them to prepare for what is to come. Compassionate messages, including the expression of shared experiences, caring, and concern, may be a useful starting point before more technical information is provided, and can increase the level of trust the community has in the message and the communicator. To support people during stressful times, trauma-informed messaging should prioritize simplicity over complexity. This does not mean restricting access to this information, but rather ensuring that critical messages – such as life safety guidance and the need to prepare for more earthquakes – take precedence.

People outside the impacted area may not be the first concern for responders; however, they likely will be a group wanting to know comprehensive aftershock forecast information to provide to their family members or people they know inside the area.

6.0 Critical key messages

6.1 Advice/reminders on what to do

USGS Operational Aftershock Forecasts start with simple messaging: What people can expect (more shaking) and what to do if an earthquake occurs. While the USGS forecast has some protective action messaging and other safety considerations, it will link to the authoritative science or public safety agency in country if possible.

7.0 Forecasts from multiple science agencies and organizations

7.1Referencing other forecasts

The USGS can link to other forecasts within our text product. However external forecasts that are linked from the USGS Operational Aftershock Forecast product will only be those of the scientific authority in the impacted country.

7.2Responding to alternate theorists or incorrect interpretations of the USGS forecast

During responses, sometimes alternate theorists (those who use methods of prediction or forecasting that have not been validated through normative scientific review processes) can and do communicate their models and forecasts or predictions. Also, USGS Operational Aftershock Forecasts may be misquoted or misunderstood (e.g., the forecast may be erroneously presented as a precise prediction of what is certain to happen).

In cases of misinterpretation or misquoting, we suggest this message:

> "No one has yet predicted the exact time, location, and magnitude of a specific earthquake scientifically. The USGS forecast tells us what can happen but not precisely what will happen."

Any further suggestions or questions can be sent to the USGS for further discussion.

8.0 Communication capacity

8.1 How to seek assistance from the USGS to communicate forecasts

Our team is available, depending on resources, to assist with the communication of our forecasts. We are open to media interviews as well as potentially exploring joint statements or media conferences.

8.2 Considerations and priorities for communicating and coordinating with community leaders

Experience in communicating during aftershock sequences highlights the importance of finding a balance in communicating to all audiences according to community needs, prioritizing communications with emergency mangers, critical infrastructure and community leaders, and being aware of expending available communication resources for different audiences.

8.3 Considerations of communicating over time (years) of an active aftershock sequence

Information needs of various audiences change over time. Audiences also change as people move in and out of impacted areas, and those that experience earthquakes become more sophisticated in their understanding of aftershock forecasts or may be better able to cope. In past aftershock sequences, the basic forecast information has been critical during the first hours of response, and then, over time, more complexity and details have been sought by various audiences.