On the Potential Duration of the Aftershock Sequence of the 2018 Anchorage Earthquake

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Abstract

Currently, an aftershock sequence is ongoing in Alaska after the magnitude 7.0 Anchorage earthquake of November 30, 2018. Using two scenarios, determined with observations as of December 14, 2018, this report estimates that it will take between 2.5 years and 3 decades before the rate of aftershocks decays to the rate of earthquakes that were occurring in this area before the magnitude 7.0 mainshock. All of the time estimates have significant uncertainty owing to different scenarios of how the sequence may decrease over time and could also change if a large aftershock occurs. The report also estimates the amount of time after the mainshock until the annual probability of magnitude 5 or greater and 6 or greater aftershocks—which could cause additional damage—decreases to 50, 25, 10, and 5 percent. For instance, the probability of one or more magnitude 6 or greater aftershocks in the following year decreases to 10 percent between 7 and 250 days after the mainshock. The same probability for magnitude 5 or greater earthquakes is reached between 500 and 7,000 days after the mainshock.

Introduction

This report presents two ways of estimating how long the aftershock sequence, which began after the magnitude 7.0 Anchorage earthquake of November 30, 2018, might last based on the observed earthquake sequence through December 14, 2018. Changes in the behavior of the aftershock sequence, including the occurrence of a large aftershock, could require making new estimates.

Earthquakes are commonly divided into two classes: background earthquakes that occur from stress accumulation in the crust caused by long-term geologic processes versus aftershocks that are triggered (directly or indirectly) by a background earthquake. Background earthquakes are commonly modeled as random, independent occurrences whereas aftershocks cluster in both time and space around the background earthquake, also referred to as the mainshock.

Whereas most aftershocks are smaller than the mainshock, they still have the potential to be damaging or deadly. For example, the devastating 2011 magnitude 6.2 Christchurch earthquake in New Zealand was an aftershock of the less damaging 2010 magnitude 7.1 Darfield earthquake (Kaiser and others, 2012). 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 9.1 Japan earthquake and tsunami was preceded by a magnitude 7.3 foreshock two days before (Hirose and others, 2011).

2018 Anchorage Earthquake Aftershock Sequence and Earlier Earthquakes

Aftershocks are generally located within a radius of 1–2 times the rupture length of the mainshock. That radius can be estimated using equations for rupture length from Wells and Coppersmith (1994). In the 2018 Anchorage earthquake aftershock sequence, the aftershocks are occurring within 41 kilometers (km) of their centroid (appendix 1). From 1992 to the occurrence of the mainshock, magnitude 3 or greater background earthquakes occurred in that region at an average rate of 14 per year, including both the background earthquakes and their aftershocks. The rate is 8 per year if aftershocks are removed using the method of Gardner and Knopoff (1974). The start time in 1992 was chosen because the rate of earthquake occurrence in this area is approximately constant between then and the occurrence of the mainshock.

The lower limit of magnitude 3 was used because the earthquake catalog is complete at that level and including such small earthquakes increases the amount of data, making the rate estimate more robust. This is because most earthquakes are small with approximately 10 times more earthquakes occurring when the magnitude limit is decreased by 1 unit (Gutenberg and Richter, 1944). This pattern is true for both background earthquakes and aftershocks. Hence, small earthquakes can be used to estimate the probabilities of larger earthquakes.

In the 14 days following the mainshock, there were 325 magnitude 3 or greater earthquakes for an average rate of 8,450 earthquakes per year—much greater than the background rate of 8 earthquakes per year. However, the aftershock rate is not constant and decreases with time. The aftershock rate decreases approximately in proportion to 1/time (Omori, 1894). Hence, the rate of aftershocks on the tenth day after the mainshock is generally about 10 percent of what it was on the first day and the rate on the 100th day is about 1 percent of what it was on the first day. Whereas the rate on any given day decreases with time, aftershocks can pose a significant risk to each phase of the disaster recovery process because the phases increase in length as society moves from emergency response, to restoration of services, to reconstruction of damaged buildings, to betterment projects, and onto a return to a long-term normal (Michael, 2012).

Modeling the Aftershock Sequence

The temporal decay of the aftershock sequence can be estimated using the Reasenberg and Jones (1989) model as updated by Page and others (2016). The parameters as of December 14, 2018, are presented in appendix 1. The first set of parameters are the ones being used to compute the operational aftershock forecast for the 2018 Anchorage earthquake shown on the U.S. Geological Survey (USGS) Earthquake Hazards Program website at https://earthquake.usgs.gov/earthquakes/eventpage/ak20419010/oaf/commentary. That forecast, and the parameters used, will be periodically updated. For that set of parameters, the rate at which the aftershocks decrease over time was determined from aftershock sequences in the first 10 days after large earthquakes around the world in similar geological settings. Based on observations through December 14, it is possible that the 2018 Anchorage earthquake aftershock sequence is decreasing at a higher rate than the global average. Hence, a second set of parameters was determined that takes this higher rate of decay into account. These two scenarios provide a range of possibilities for how this earthquake sequence may behave and all results are presented as a range between the two possibilities. As more time passes and data are collected, it may become possible to narrow the range.

Using this model, one can determine the point in time when an earthquake that occurs in the Anchorage area will have an equal probability of being a background earthquake or an aftershock. When the two probabilities are equal, an earthquake cannot confidently be attributed to either category. Before that point, it is more likely that an earthquake is an aftershock; after that point, it is more likely that an earthquake is a background earthquake. This point in time is estimated using the observed rate of magnitude 3 or greater earthquakes prior to November 30, 2018, and the forecast rate of magnitude 3 or greater aftershocks. Using smaller earthquakes makes the rate estimation more stable because there are more observed earthquakes. However, the time at which the background and aftershock probabilities are equal also applies to larger, potentially damaging aftershocks.

The prior rate of 8 background earthquakes per year of magnitude 3 or greater corresponds to a 14 percent probability of 1 or more such earthquakes in a week. By estimating this same probability for aftershocks, one can determine the point at which they are equal. The probability of 1 or more magnitude 3 or greater aftershocks in the next week is shown in table 1 for the two scenarios. For the first scenario, the point when earthquakes in this area are equally likely to be background earthquakes or aftershocks is 30 years in the future—in the year 2048. For the second scenario, this occurs only 2.5 years in the future. While there is a great deal of uncertainty, it should be at least 2.5 years before an earthquake in this area has an equal probability of being either an aftershock or a background earthquake. Until then, and possibly for the next 3 decades, earthquakes in this area are more likely to be aftershocks of the November 30, 2018, mainshock.

Table 1. Probability of 1 or more magnitude 3 or greater earthquakes in the next week

Time after November 30, 2018	Aftershock probability, in percent[1]	Background earthquake probability, in percent
0 days	Greater than 99	14
1 year	32–90	14
2.5 years	14–66	14
5 years	7–46	14
10 years	3–30	14
20 years	2–18	14
30 years	1–14	14

[1] Ranges are based on the two sets of parameters for the aftershock decay (appendix 1).

Next, the times when the probability of aftershocks with magnitudes 5 and 6 or greater occurring in the following year decreases to 50, 25, 10, and 5 percent are calculated. These magnitudes were chosen because a magnitude 5 aftershock could cause light damage whereas a magnitude 6 aftershock could cause moderate damage. If one thought of the aftershock sequence as being over at those times, then the probabilities give the likelihood of being surprised by an aftershock of those magnitudes. The results are shown in table 2. These calculations suggest the probability of 1 or more magnitude 6 or greater aftershocks in the following year decreases to 10 percent between 7 and 250 days after the mainshock. The range from 7 to 250 days represents the two scenarios for how the aftershock sequence decreases over time. The same probability for magnitude 5 or greater earthquakes is reached between 500 and 7,000 days after the mainshock.

Similar to the previous results, these times depend on the decay parameter and a faster estimate of the rate of decay would greatly decrease these times. Thus, the aftershock sequence is unlikely to last longer than the estimates presented in this report, unless a large aftershock occurs and temporarily increases the rate of aftershocks.

Table 2. Time after the mainshock when probabilities of an aftershock in the next year decrease to given values

Probability of 1 or more earthquakes in the next year, in percent	Magnitude 5 or greater aftershock[1]	Magnitude 6 or greater aftershock[1]
50	21–550 days	0 days
25	130–2,000 days	0.5–15 days
10	500–7,000 days	7–250 days
5	1,200–16,000 days	40–775 days

[1] Ranges are based on the two sets of parameters for the aftershock decay (appendix 1).

Conclusions

Earthquakes behave differently from other natural hazards in that these earthquake sequences can last for weeks, years, or decades, rather than one event or season, such as occurs with floods, hurricanes, or wildfires. Our models suggest that aftershocks of the magnitude 7.0 Anchorage earthquake will decrease in frequency as time goes on, but will persist for a long time. It will be years to decades before an earthquake within the current aftershock zone will be considered an independent background earthquake rather than an aftershock. The probabilities of magnitude 5 and 6 or greater aftershocks remain sufficiently high to warrant concern and will for some time into the future. The times when these probabilities reduce to different levels could be used to guide public policy decisions or other actions in concert with additional considerations. The results in this report are based on the current behavior (as of December 14, 2018) of this aftershock sequence and may need to be modified if that behavior changes.

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Appendix 1

This appendix presents the technical parameters for the two scenarios used to estimate aftershock probabilities. These values are presented so that the calculations in this report can be reproduced. For details on parameter definitions see Page and others (2016). All uncertainties are 1 standard deviation.

Table 1.1. Model parameters used for estimates in this report

Parameter	Value(s)
Parameters common to scenarios 1 and 2	
Mainshock magnitude	7.0
Centroid of aftershock sequence	61.42386° N, 150.00277° W
Radius of aftershock sequence	40.7 kilometers
Gutenberg-Richter slope	$b = 1$
Time-dependent magnitude of completeness	$F = 0.5$, $G = 0.25$, $H = 1.0$, $M_{cat} = 3.5$
Scenario 1 parameters (December 14, 2018, forecast)	
Aftershock productivity	$a = -2.408 \pm 0.057$
Aftershock decay	$p = 0.81$, $c = 0.018$
Scenario 2 parameters (higher aftershock decay rate)	
Aftershock productivity	$a = -2.32 \pm 0.058$
Aftershock decay	$p = 1.15 \pm 0.1$, $c = 0.018$

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