2021 Alaska Seismicity Summary

Technical Report

Natalia A. Ruppert and Lea Gardine

February, 2022

2156 Koyukuk Drive · Geophysical Institute · Fairbanks, Alaska 99775
earthquake.alaska.edu · (907)474-7320

Contents

1. Abstract

The Alaska Earthquake Center reported 49,120 seismic events in Alaska and neighboring regions in 2021. The largest earthquake was a magnitude 8.2 event that occurred on July 29 southwest of Kodiak Island. It was followed by about 1,300 aftershocks including two magnitude 6.9 events on August 14 and October 11. Other active spots include sequences near Harding Lake in Interior Alaska in July-September and near Yakutat Bay in September. The largest earthquake in mainland Alaska was the M6.1 Chickaloon Earthquake on May 31. We continued to monitor ongoing activity within the 2018 M7.1 Anchorage, 2018 M6.4 Kaktovik, and 2018 M7.9 Offshore Kodiak aftershock sequences, the Purcell Mountains earthquake swarm, and the Wright Glacier cluster northeast of Juneau.

2. Introduction

The Earthquake Center reported 49,120 seismic events in Alaska and nearby regions in 2021 (Figure 2.1), making it the state's fourth largest year, after 2018 (about 55,000 seismic events), 2019 (about 50,000 seismic events), and 2020 (about 49,250 seismic events) (Figure 2.2) (*Ruppert & Gardine, February 2021*). AEC data analysts picked and cataloged 1,583,292 seismic phases, the second largest number after 2018 (Figure 2.3). The largest event was the magnitude 8.2 Chignik Earthquake that occurred on July 29 southwest of Kodiak Island. It was the largest worldwide earthquake in 2021, and the largest earthquake in the United States in over 50 years. Five earthquakes had magnitudes between 6.0 and 6.9, two of which were Chignik aftershocks. There were no earthquakes in the magnitude 7.0-8.1 range.

Due to various seismic sequences that occurred throughout the year, earthquake rates varied from week to week, with the highest peak in late July - early August associated with the M8.2 Chignik aftershock sequence, followed by the early September sequence near Yakutat Bay, and the third highest peak in late May - early June from the M6.1 Chickaloon Earthquake sequence in central Alaska (Figure 2.4). Throughout the year we averaged 942 reported earthquakes per week, which is slightly less than in the previous 2 years. Between 14 and 25 earthquakes per month were reported felt in Alaskan communities (Figure 2.5), with magnitudes of these events ranging from as small as 1.8 to as large as 8.2. The largest earthquakes each month ranged from 4.8 in March to 8.2 in July (Figure 2.5).

We continued monitoring several ongoing aftershock sequences such as the 2018 M7.9 Offshore Kodiak, 2018 M6.4 Kaktovik, 2018 M7.1 Anchorage earthquakes, and earthquake swarms in the Purcell Mountains and northeast Brooks Range. In addition to tectonic earthquakes, we recorded 2,184 other seismic sources: 1,399 glacial quakes and small rock/ice avalanches; 426 volcanic events; and 329 quarry blasts, the majority of which were located in the vicinity of Fort Knox and Usibelli mines in Interior Alaska.

See details on notable sequences in the following sections and in Table 1.

3. Notable earthquakes and sequences of 2021

3.1. January 3 and September 24 M6.1 earthquakes in Andreanof Islands

Two M6.1 earthquakes occurred in the Andreanof Islands region: One on January 3 located at 21 km depth, 230 km WSW of Adak and another on September 24 located at 18 km depth, 187 km WSW of Adak (Figure 2.1). The source mechanisms for both earthquakes indicate underthrusting, consistent with the fault movement along the Aleutian megathrust. The January 3 earthquake was felt in Adak with a reported intensity of shaking of III, weak.

3.2. May 31 M6.1 Chickaloon Earthquake

A magnitude 6.1 earthquake on May 31 near Chickaloon in central Alaska generated an active aftershock sequence with 522 aftershocks between magnitudes 0.6 and 4.6 recorded within the month (*Ruppert et al., August 2021*). This earthquake occurred at a depth of 45 km and was widely felt across Interior and southern Alaska. This was in an intraslab, normal faulting earthquake, the typical location and mechanism for this region (Figure 3.1). However, it was the

largest intraslab earthquake in this region in about 50 years. Since this earthquake occurred in the middle of the regional network, aftershocks with magnitudes as small as 1.0 were reliably detected and located.

3.3. July 29 M8.2 Chignik Earthquake

A magnitude 8.2 earthquake struck offshore of the Alaska Peninsula on July 29, the largest earthquake in the U.S. in 50 years (*Ruppert et al., November 2021*). Perryville and Chignik were the nearest communities to the epicenter and the fault rupture zone, and felt the highest intensity of shaking. The earthquake did not produce a damaging tsunami, however. The M8.2 epicenter was located immediately east of the M7.8 July 21, 2020 Simeonof Earthquake and the fault rupture propagated for about 200 km towards Kodiak Island along a 100 km wide fault (Figures 3.2, 3.3). This earthquake ruptured the subduction zone interface; previously this part of the Aleutian megathrust ruptured in a M8.3 earthquake in 1932. We recorded about 1,370 aftershocks with magnitudes ranging between 1.3 and 6.9 through the end of the year (Figure 3.4). Due to the offshore location of this sequence, only aftershocks with magnitudes 2.5 and above can be reliably detected and located (Figures 3.4-right, 3.5-left).

The largest aftershocks, both M6.9, occurred on August 14 and October 11 (Figure 3.3). The August 14 aftershock was located on the main rupture patch and had the same underthrusting focal mechanism as the mainshock. The October 11 magnitude 6.9 aftershock, however, was an intraslab earthquake located inside the subducted plate rather than on the plate interface that was ruptured in the M8.2 earthquake. It is not uncommon for aftershocks to be triggered on neighboring faults as the stresses around the main ruptured fault adjust with time.

The Chignik aftershock rate decreased rapidly after the initial few weeks, making it less active than the longer-lasting Simeonof sequence to the southwest (*Ruppert & Gardine, February 2021*). Frequency-magnitude (or b-value) plots for the M8.2 Chignik (Figure 3.5-left) and July 22, 2020 M7.8 Simeonof (Figure 3.5-right) earthquakes show distinct differences between the two sequences. The magnitude of completeness (the value above which we are most likely detecting all earthquakes and below which we lose detection ability) for the M7.8 is Mc=2.2 as compared to Mc=2.5 for the M8.2 event. Comparisons of the cumulative number of events and subsequent b-values (a ratio of the number of small earthquakes to the number of larger earthquakes) demonstrate how much more vigorous the M7.8 has been than the M8.2. Some researchers explain the difference between the two sequences by the different megathrust properties that they ruptured: locked vs. creeping portions of the subducting interface.

3.4. July 23 M4.7 and September 14 M4.9 Harding Lake earthquakes

Another interesting earthquake sequence was recorded east of Harding Lake in Interior Alaska (Figures 3.6, 3.7) (*Ruppert et al., November 2021*). It began with a M4.7 earthquake on July 23 and culminated in a M4.9 earthquake on September 14. Both events were followed by aftershocks, with the M4.9 aftershock sequence being about 4 times as active as the M4.7 sequence. These events and some of the larger aftershocks were widely felt in the Interior. Both earthquakes indicate strike-slip faulting, typical of the crustal faulting in Interior Alaska, and

occurred within the so-called Salcha Seismic Zone. This fault zone produced a M7 earthquake on July 22, 1937. While the aftershock rate decreased with time, the activity level remained above background through the end of 2021. Since this earthquake occurred within a well-instrumented part of the regional network, aftershocks with magnitudes as small as 0.5 were reliably detected and located. The estimated magnitude of completeness for this sequence is 0.8.

3.5. September 5-6 M4.0 and M4.1 Yakutat earthquakes

An earthquake sequence west of Yakutat Bay began on September 5 with a M4.0 earthquake followed by a M4.1 earthquake on September 6 (Figure 3.8). The sequence produced the second highest number of aftershocks after the Chignik Earthquake sequence (Figures 3.9 vs 3.4) (*Ruppert et al., November 2021*). We recorded more than 760 events in this sequence through the end of October with magnitudes ranging between 0.8 and 3.4, with a magnitude of completeness of 1.1. This area is characterized by complex faulting as the strike-slip Fairweather fault coming from the east bends and merges into the Chugach - St. Elias thrust-and-fold belt in the west. Both the M4.0 and M4.1 earthquakes indicate reverse faulting on a SW-NE trending fault resulting from the strong compressional stresses created around the Fairweather fault bend. The very high level of aftershock activity, however, was unexpected for such a sequence.

4. Ongoing aftershock sequences and swarms

4.1. 2020 M7.8 Simeonof aftershock sequence

The Simeonof Earthquake continued to produce the most active ongoing aftershock sequence with about 3,013 reported aftershocks between magnitude 1.0 and 5.4, continuing the 2020 trend. A total of 27 aftershocks had magnitudes greater than 4.0. The largest aftershock, magnitude 5.4, occurred on October 31. The M7.6 aftershock cluster continues to be more active than the larger M7.8 patch (Figure 4.1) (*Ruppert & Gardine, February 2021*). Estimated magnitude of completeness remains at 2.2, similar to the 2020 observations (Figure 3.4-right). While the rate of the aftershocks continued to decline through 2021, we expect the Simeonof aftershock sequence to extend through 2022.

4.2. 2018 M7.1 Anchorage aftershock sequence

Aftershocks from the November 30, 2018 M7.1 Anchorage Earthquake continued into their third year at an average pace of about 17 earthquakes per week, which is about 30% less than the 2020 rate (*Ruppert & Gardine, February 2021*). The largest aftershock, magnitude 5.3, occurred on February 27, with the second largest aftershock of magnitude 4.8 on April 27. Approximately 900 aftershocks were reported in 2021 (Figure 4.2) with a magnitude of completeness of Mc=1.1, bringing the total count for the sequence to more than 13,500 aftershocks. About 27 of these aftershocks were reported as felt in 2021. While the original estimates for the duration of this aftershock sequence were on the order of 2-2.5 years

(*Michaels et al*., 2019), the seismicity rate remains elevated compared to the background rate prior to the M7.1 earthquake. We expect this sequence to continue at a decreasing rate in 2022.

4.3. 2018 M6.4 Kaktovik aftershock sequence

We continued to record aftershocks of the 2018 M6.4 Kaktovik Earthquake, the largest earthquake ever recorded on the North Slope. During 2021, we reported about 325 aftershocks (Figure 4.3) at a magnitude of completeness of Mc=1.1, bringing the sequence up to approximately 7,225. A slightly higher rate and lower magnitude of detection were observed in summer months when seismic stations were in a continuous recording mode. To conserve power, northern Alaska stations operate in an on/off regime during winter months, resulting in smaller events (less than M1.5) not being routinely detected. The largest aftershock was a M3.6 on November 7. While the 2021 aftershock rate remained at a low rate of about 6 events per week, which is half of the 2020 rate (*Ruppert & Gardine, February 2021)*, it is still above background level and we expect this sequence to continue in 2022 at a decreasing rate.

4.4. 2018 M7.9 Offshore Kodiak aftershock sequence

We continued to record aftershocks of the 2018 M7.9 Offshore Kodiak Earthquake, a complex strike-slip rupture on a series of conjugate faults and fractures. During 2021, we reported only about 254 earthquakes (Figure 4.4), bringing the sequence up to approximately 5,450. Due to its offshore location, about 200 km from the nearest on-land seismic stations, the magnitude of completeness for this sequence remains rather high at Mc=2.5. The largest aftershock was a M4.5 on May 18, with the rest of the aftershocks below M4.0. A slightly higher rate and lower magnitude of detection were observed in summer months, perhaps due to more seismic stations being in operation. The aftershock rate in 2021 remained at nearly the same level as in 2020 at about 5 events per week (*Ruppert & Gardine, February 2021)*, however it is still above the background level and we expect this sequence to continue in 2022.

4.5. Purcell Mountains earthquake swarm

The Purcell Mountains Swarm, which began in March 2019, had about 709 events, which is less than half of what was recorded in 2020 (*Ruppert & Gardine, February 2021)*. The activity rate continued at an average pace of about 14 earthquakes per week, with some periods of increased activity (Figure 4.5), bringing the sequence total to more than 9,100 events. The largest event in the swarm during 2021 was a M3.4 on September 17, with only two other earthquakes larger than M3.0. We maintained a low completeness level for this sequence at Mc=1.1. A new feature a short distance north of the main cluster became active between April 9-23 (Figures 4.5 and 4.6); the largest earthquake within this new cluster was a M2.1. This particular area did not exhibit much activity prior to this period of activation.

4.6. Northeast Brooks Range earthquake sequence

We continued to monitor seismicity in the northeastern Brooks Range region of Alaska. This region piqued our interest in 2018 and 2019 with energetic swarm-like activity in late summer–early fall months. We recorded about 200 earthquakes in this region in 2021, with a

low magnitude of completeness of Mc=1.2 (Figure 4.7). The largest earthquake of M4.0 occurred on July 8 (Figure 4.8). The 2021 earthquake rate was much lower than in the previous three years, with the exception of several days in mid-late July when about 100 events occurred in a concentrated area, including a M4.0 earthquake. The nature of this swarm-like behavior is still unknown and we will continue to monitor this region in 2022.

5. Glacial seismicity and Wright Glacier cluster

Glacial seismicity is being recorded and studied globally; Alaska is no exception due to its large expanse of glaciated areas. In 2021, we reported about 1,400 glacial quakes, ranging in magnitudes up to M3.1. We normally record the majority of glacial activity near the termini of tidewater glaciers such as in the Prince William Sound region, Icy Bay, and Yakutat Bay (Figure 5.1). This activity follows seasonal variability and peaks at different times in different areas, with most glacial quakes occurring between April and October (Figure 5.2). Glacial seismic activity in Prince William Sound and Yakutat Bay peaked in April, while in Icy Bay most activity was observed in late summer - early fall.

This year we continued to record events in a cluster under Wright Glacier, which is about 40 miles northeast of Juneau. A few of these events reached magnitudes between 2.9-3.0 and were felt in Juneau. The 2021 activity picked up in June and continued at elevated levels through the rest of summer and early fall. All activity ceased in late September (Figure 5.3). Periodic seismicity in this area has been observed since the 1970s, with event rates usually peaking in summer and early fall. These quakes tend to cluster near the Speel River, where it drains glaciated areas of Mt. Ogden. The levels of activity, however, are not the same every year. Seismicity rates observed in 2020 and 2021, for example, have not been observed since 2011-2012.

6. Acknowledgments

We would like to acknowledge the center’s seismic data analysts who analyzed and cataloged thousands of events and seismic phases in 2021: Kenneth Becker, Shila Cotton, Natalia Kozyreva, Heather McFarlin, Danielle Molisee, and Richard Ranft.

This material is based upon work supported by the U.S. Geological Survey under Grants No. G15AC00047, Modification No. 0005 to award G15AC00047, and G19AC00008. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the opinions or policies of the U.S. Geological Survey. Mention of trade names or commercial products does not constitute their endorsement by the U.S. Geological Survey.

7. References

Michael, A. J., et al., Statistical Seismology and Communication of the USGS Operational Aftershock Forecasts for the 30 November 2018 Mw 7.1 Anchorage, Alaska, Earthquake, *Seism. Res. Lett. 91(1)*, doi:10.1785/0220190196, 2019.

Ruppert, N. A., and L. Gardine (February 2021). 2020 Alaska seismicity summary, ScholarWorks@UA, 16 pp., http://hdl.handle.net/11122/11865.

Ruppert, N. A., S. Dalton, L. Gardine, M. Gardine, B. Grassi, S. G. Holtkamp, H. McFarlin, and M. E. West (May 2021). Alaska Earthquake Center Quarterly Technical Report January-March 2021. ScholarWorks@UA, 38 pp., http://hdl.handle.net/11122/11966.

Ruppert, N. A., S. Dalton, L. Gardine, M. Gardine, B. Grassi, S. G. Holtkamp, H. McFarlin, and M. E. West (August 2021). Alaska Earthquake Center Quarterly Technical Report April-June 2021. ScholarWorks@UA, 43pp, http://hdl.handle.net/11122/12243.

Ruppert, N. A., L. Gardine, M. Gardine, B. Grassi, S. G. Holtkamp, H. McFarlin, M. E. West, and S. Wiser (November 2021). Alaska Earthquake Center Quarterly Technical Report July-September 2021. ScholarWorks@UA, 44pp, http://hdl.handle.net/11122/12527

Ruppert, N. A., L. Gardine, M. Gardine, B. Grassi, S. G. Holtkamp, H. McFarlin, M. E. West, and S. Wiser (February 2022). Alaska Earthquake Center Quarterly Technical Report October-December 2021. ScholarWorks@UA, 42pp, http://hdl.handle.net/11122/12677

Table 1. *Notable Alaska seismic sequences in 2021.*

Name (start date)	**Total number of events in 2021**	**Magnitude of the largest aftershock**	**Magnitude of completeness (Mc)**	**Rate of events per week**
Notable sequences in 2021 (in order of decreasing activity)				
July 29 M8.2 Chignik Earthquake	1,370	Two 6.9	2.5	N/A
Sept 5 M4.0 Sept 6 M4.1 Yakutat Bay	760	3.4	1.1	N/A
May 31 M6.1 Chickaloon Earthquake	522	4.6	1.1	N/A
July 23 M4.7 Sept 14 M4.9 Harding Lake	196	3.2	0.8	N/A
Continuing sequences from past years (in order of decreasing activity)				
Simeonof Earthquake (7/22/2020)	3,013	5.4	2.2	58
Anchorage Earthquake (11/30/2018)	898	5.3	1.1	17
Purcell Swarm (March 2019)	709	3.4	1.1	14
Kaktovik Earthquake (8/12/2018)	325	3.6	1.1	6
Offshore Kodiak Earthquake (1/23/2018)	254	4.5	2.5	5
Northeast Brooks Range Swarm (July 2018)	147	4.0	1.2	3

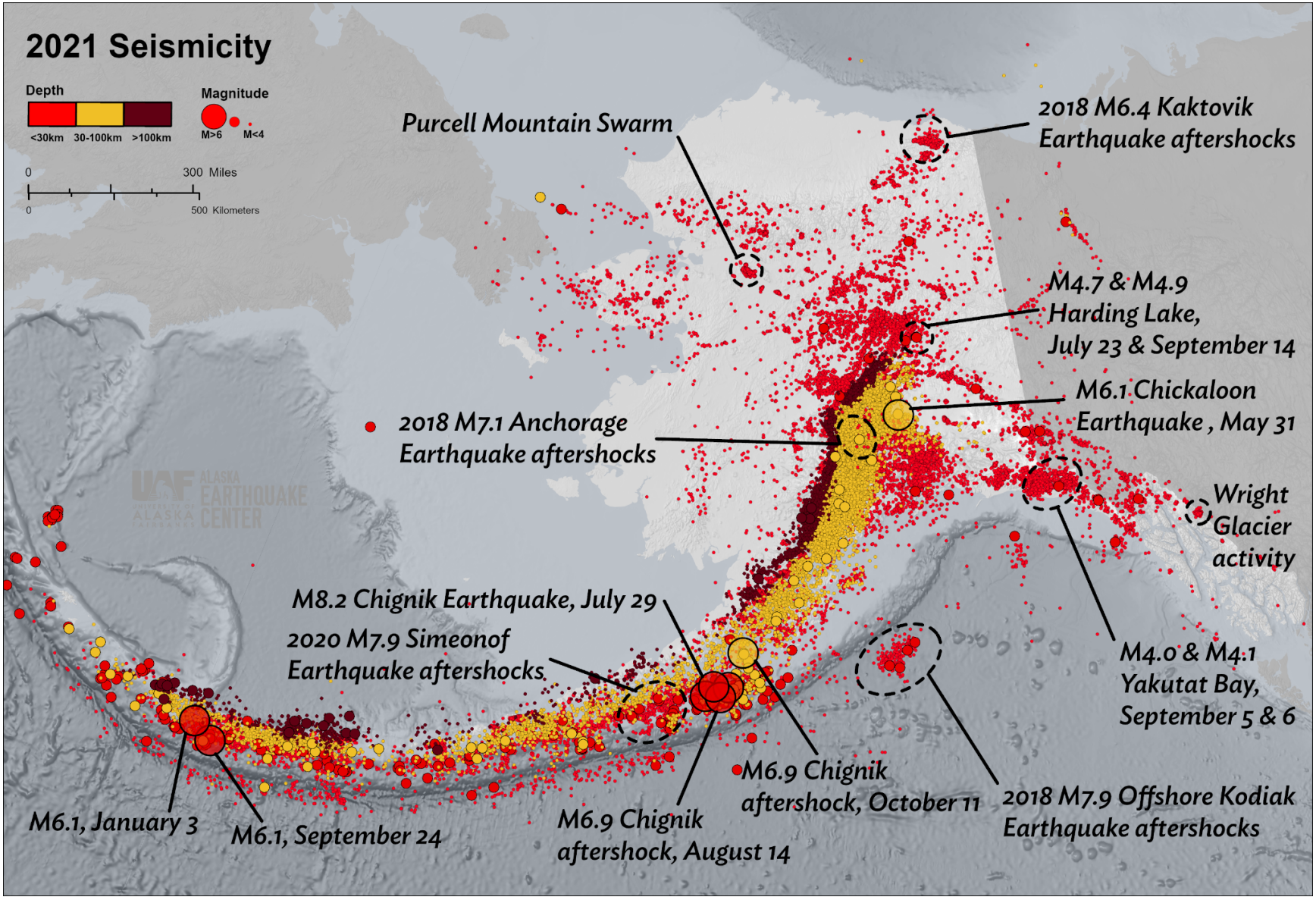

Figure 2.1. *2021 seismicity map for Alaska and the neighboring regions.*

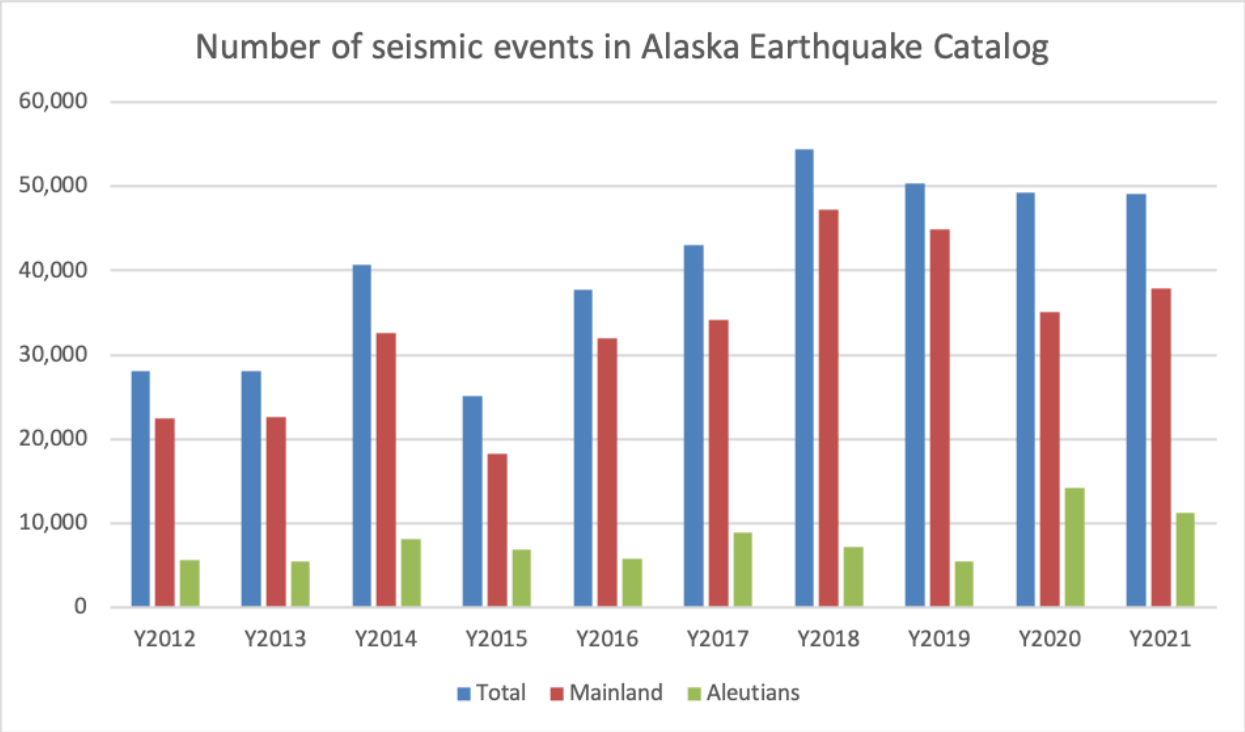

Figure 2.2. *Earthquakes reported in the Alaska earthquake catalog each year between 2012 and 2021. The total number of events, as well as the number of events in the Aleutians and mainland Alaska, are shown. 2018 was the highest year, with about 55,000 events; 2021 is in 4th place, with about 49,100 events.*

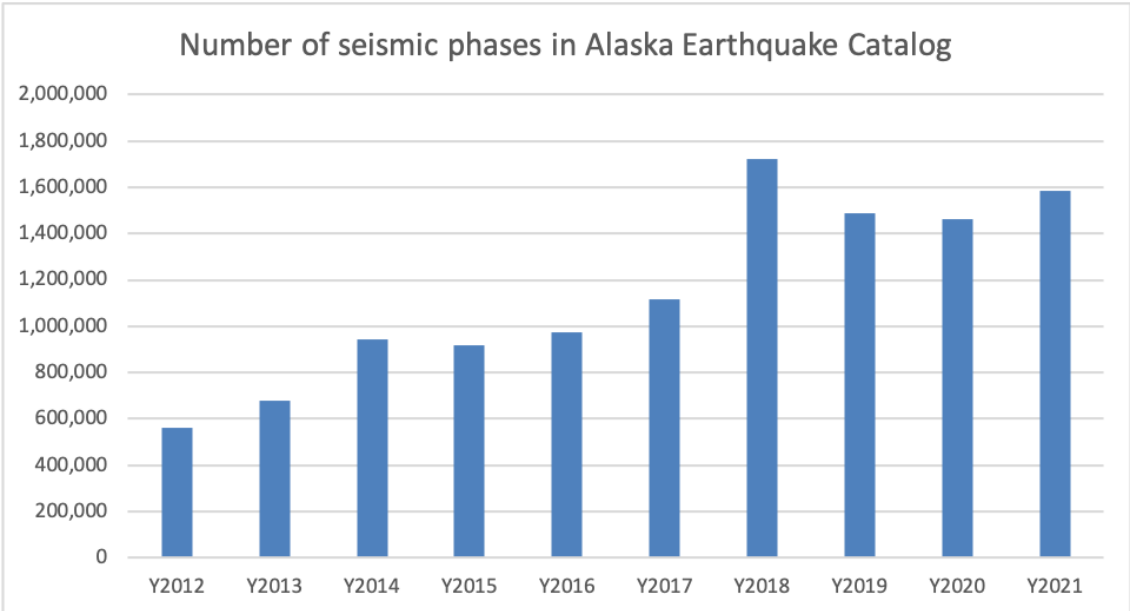

Figure 2.3. *Seismic phases reported in the Alaska earthquake catalog each year between 2012 and 2021. 2018 was the highest year, followed by 2021 in 2nd place.*

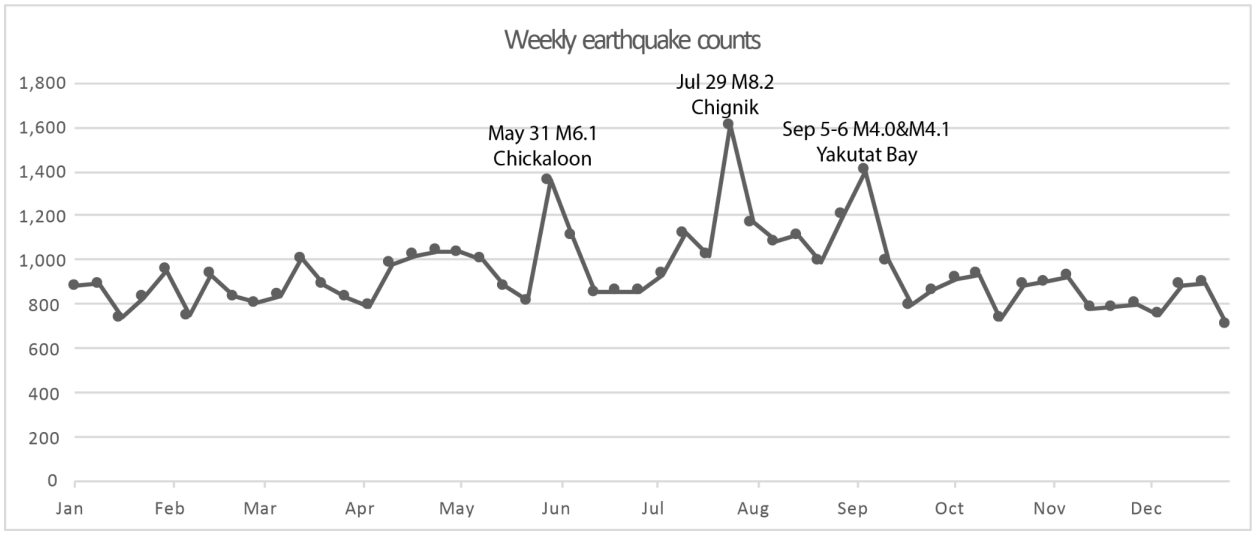

Figure 2.4. *Weekly earthquake reporting in 2021. Peaks of activity are labeled with a corresponding earthquake sequence.*

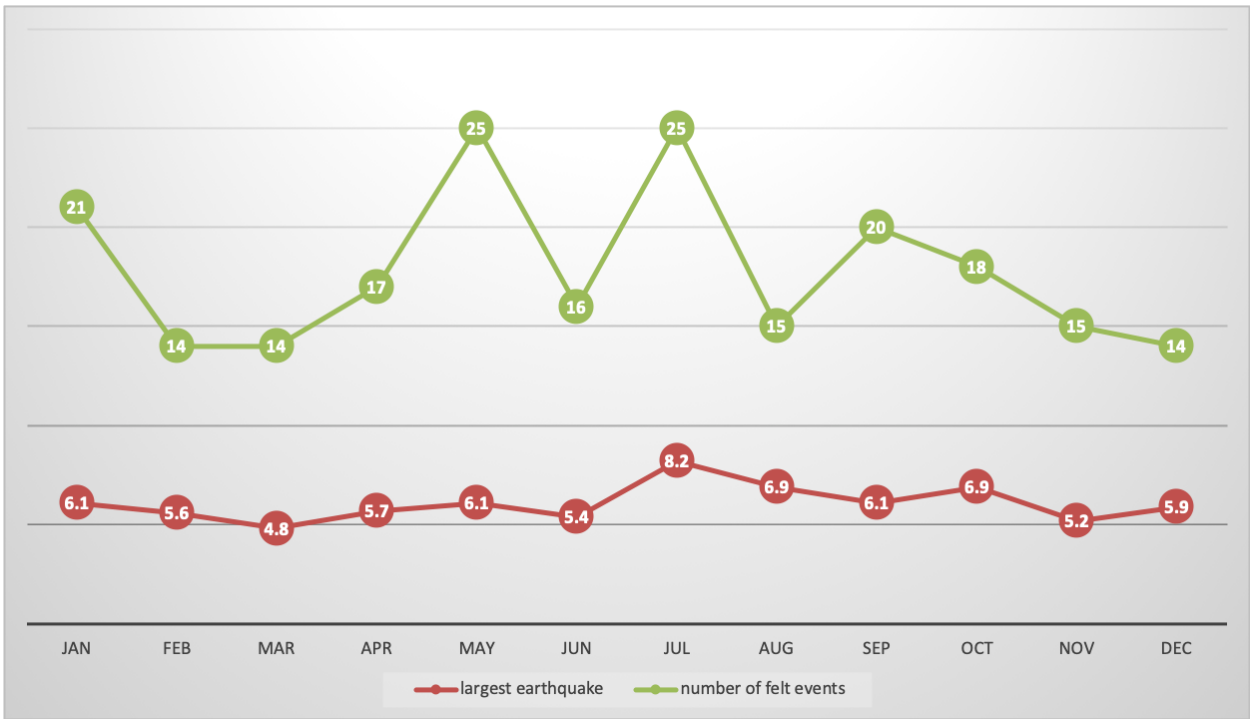

Figure 2.5. *Largest earthquake recorded (red line, with magnitude denoted inside a circle) and number of felt events (green line) each month in 2021.*

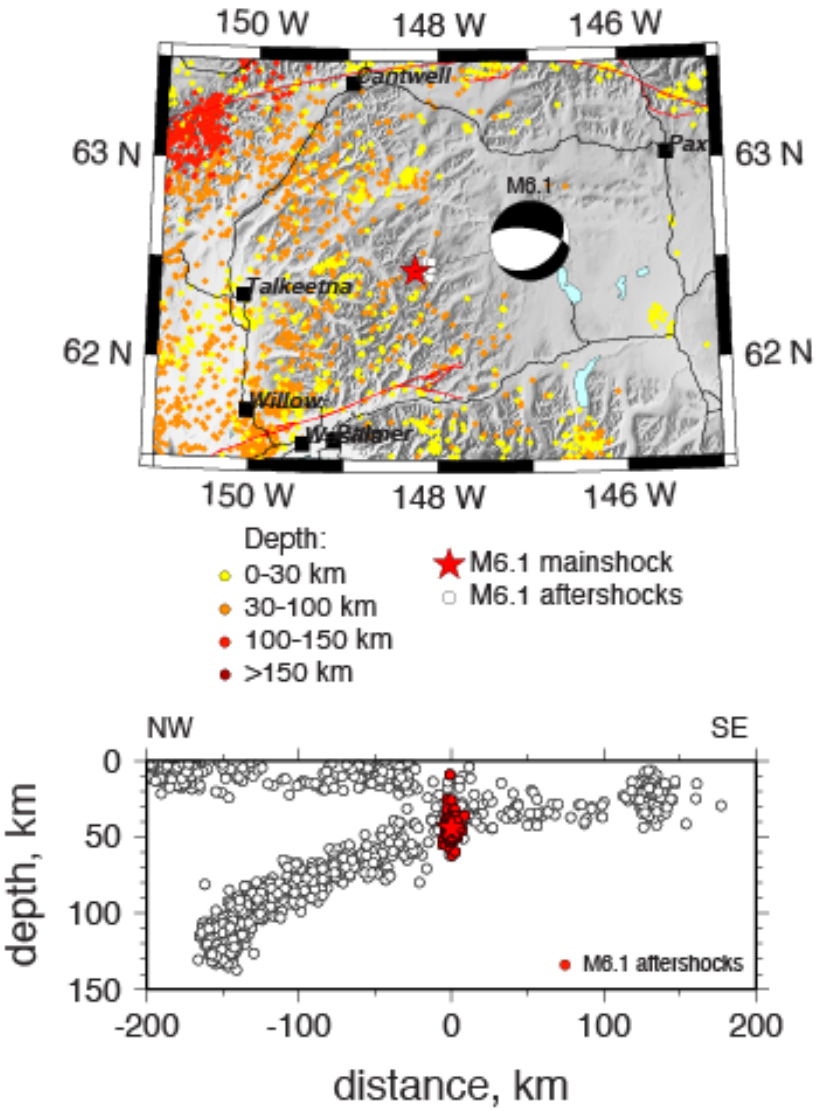

Figure 3.1. *Location map and cross-section for the May 31, 2021 M6.1 Chickaloon Earthquake. Cross-section trends from southeast to northwest across the M6.1 epicenter.*

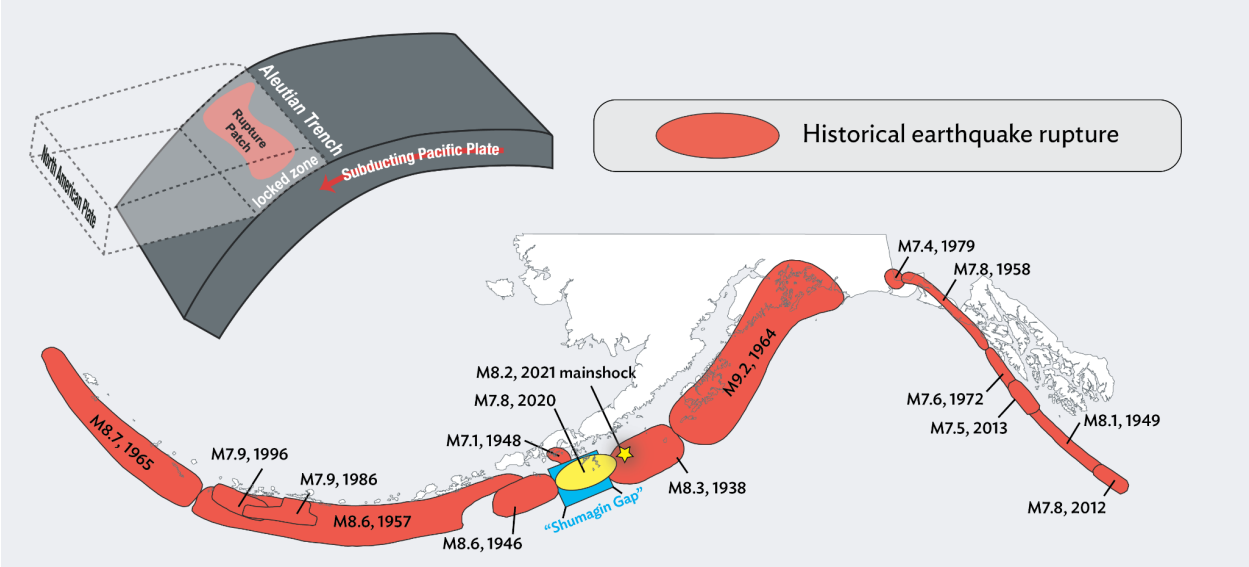

Figure 3.2. *Major earthquake ruptures along the Alaska-Aleutian subduction zone and the Fairweather-Queen Charlotte fault system. The Shumagin seismic gap was partially filled by the July 22, 2020 M7.8 Simeonof Earthquake. The July 29 M8.2 Chignik Earthquake occurred within the 1938 M8.3 rupture area.*

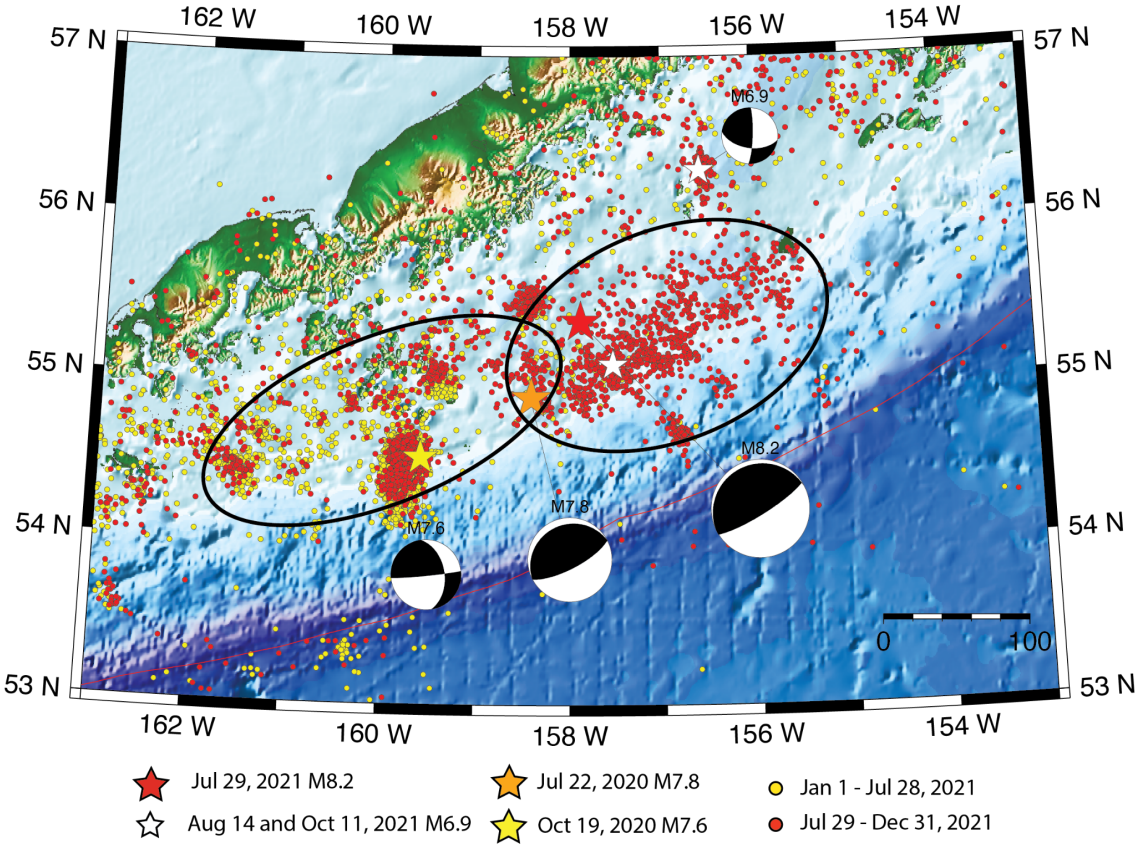

Figure 3.3. *Map of the July 22, 2020 M7.8 Simeonof and the July 29, 2021 Chignik earthquakes, their aftershocks, and nearby regional seismicity recorded in 2021. Approximate rupture areas of the two earthquakes are outlined by the ovals.*

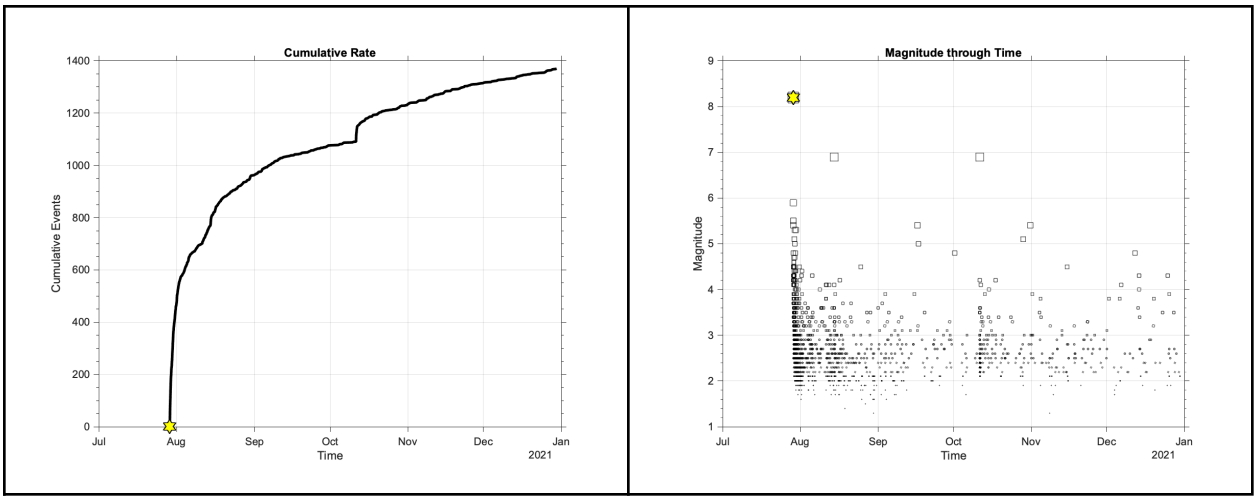

Figure 3.4. *Cumulative number (left) and time-magnitude (right) plots for the M8.2 Chignik Earthquake (yellow star) sequence. Note increase in activity following the October 11 M6.9 aftershock.*

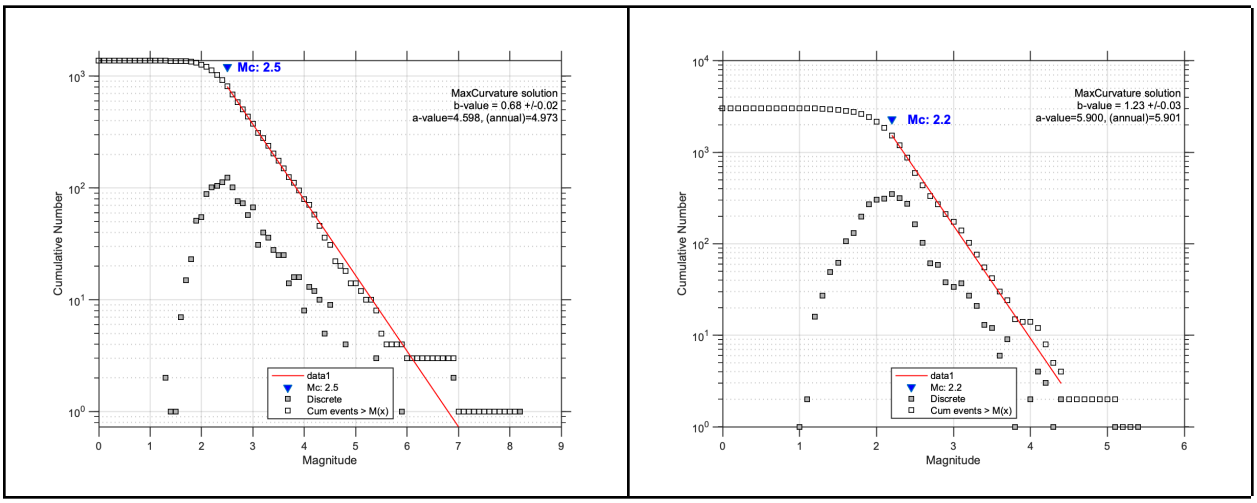

Figure 3.5. *Frequency-magnitude (or b-value) plots for the July 29, 2021 M8.2 (left) and July 22, 2020 M7.8 (right) earthquakes. Both plots include 2021 data only. Note lower magnitude of completeness Mc=2.2 for the M7.8 earthquake compared to Mc=2.5 for the M8.2 event.*

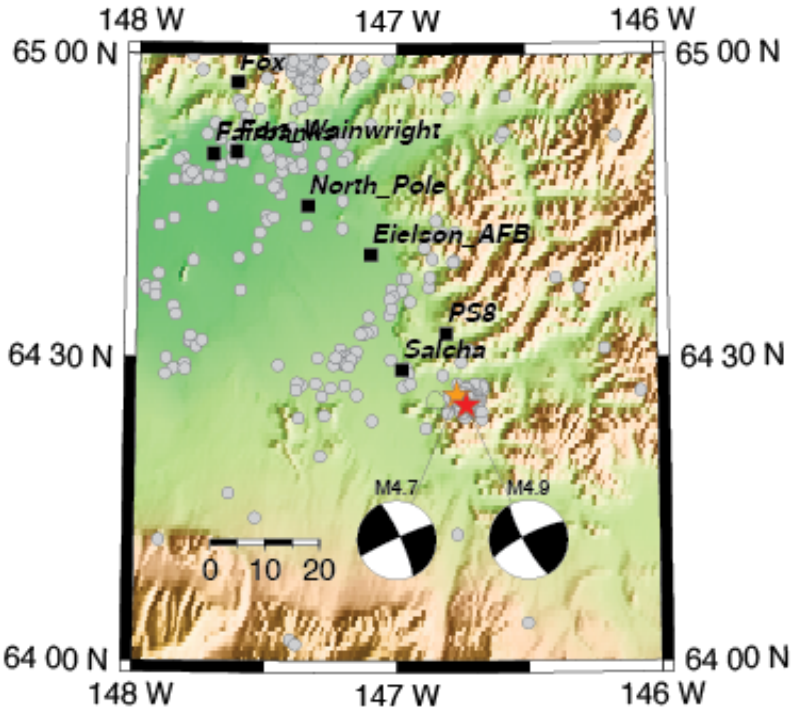

Figure 3.6*. M4.7 July 23 and M4.9 September 14, 2021 Harding Lake earthquakes location map. Gray circles are all earthquakes reported between July 1 - December 31, 2021. Red and orange stars are the M4.9 and M4.7 epicenters, respectively. Focal mechanisms are from the Comcat catalog.*

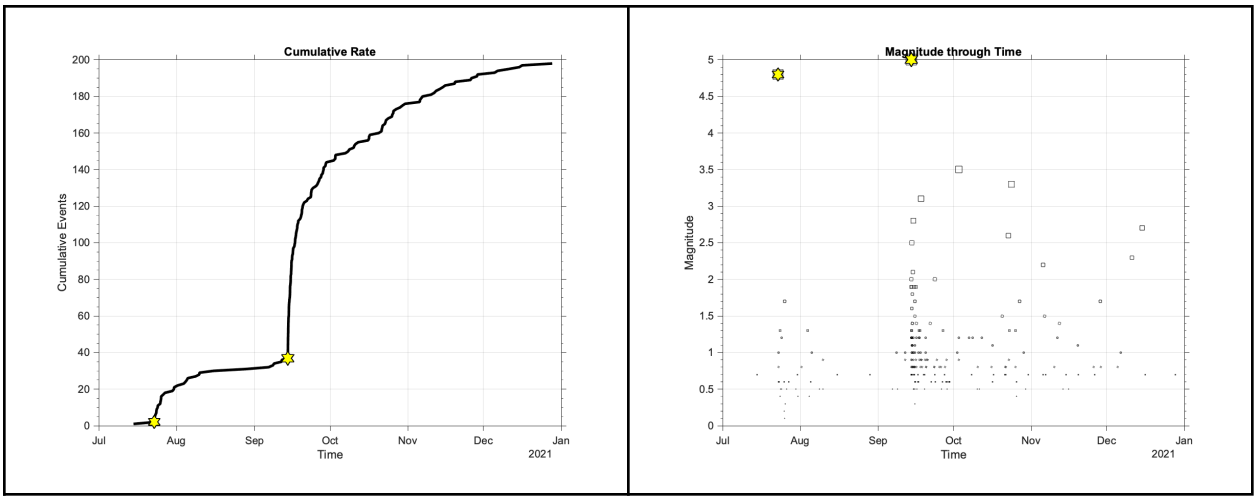

Figure 3.7. *Cumulative number (left) and time-magnitude (right) plots for the Harding Lake earthquakes (yellow stars) sequence.*

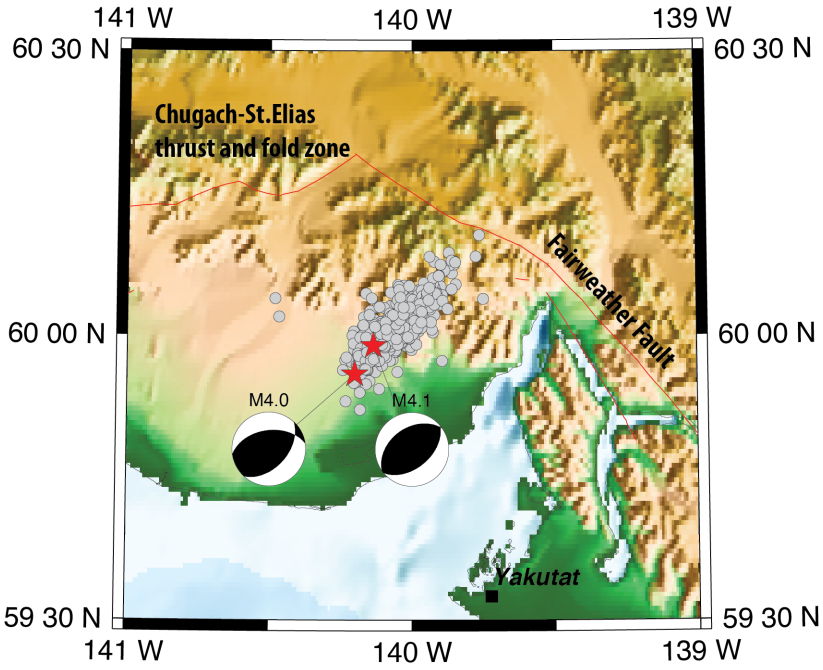

***Figure 3.8**. M4.0 September 5 and M4.1 September 6, 2021 Yakutat Bay earthquakes location map. Gray circles are all earthquakes reported between September 5-30, 2021. Red stars are M4.0 and M4.1 epicenters. Focal mechanisms are from the Comcat catalog.*

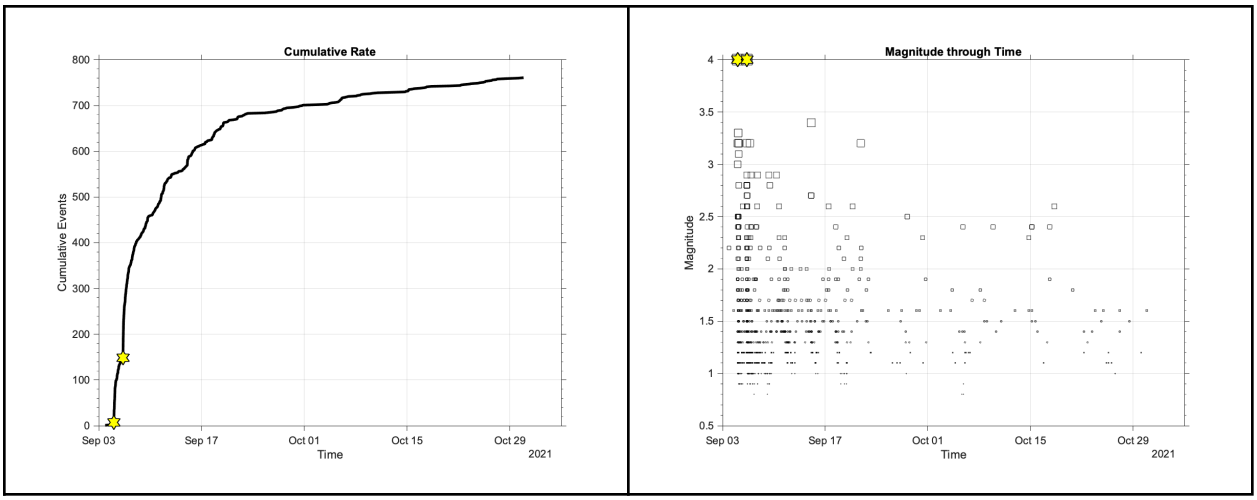

***Figure 3.9.** Cumulative number (left) and time-magnitude (right) plots for the Yakutat Bay earthquake (yellow stars) sequence.*

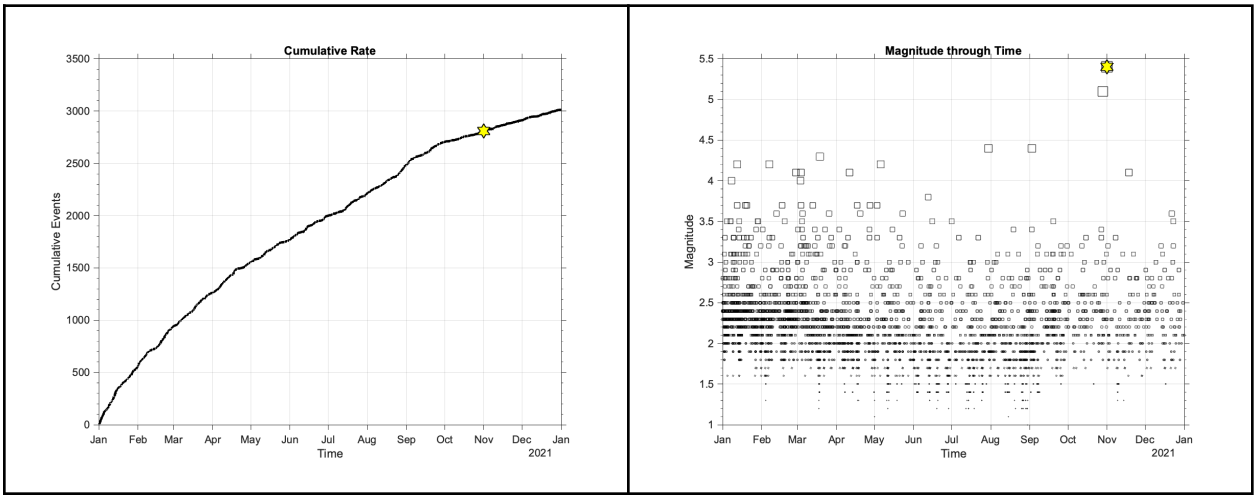

Figure 4.1. *Cumulative number (left) and time-magnitude (right) plots for the M7.8 Simeonof earthquake sequence in 2021. Note the gradual flattening of the cumulative curve, indicating a decreasing rate of activity. The yellow star indicates the largest aftershock: M5.4* on October 31.

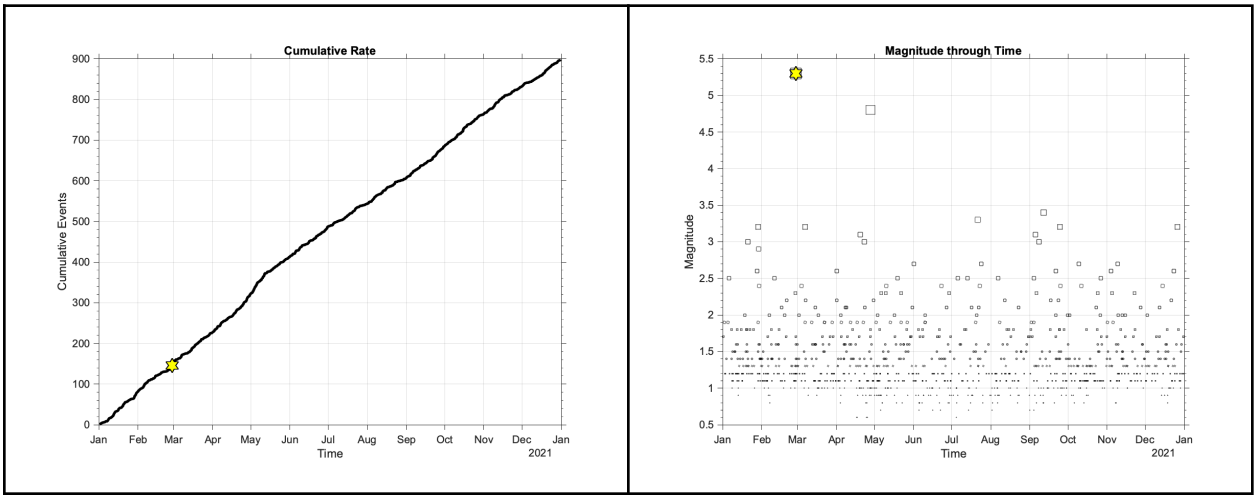

Figure 4.2. *Cumulative number (left) and time-magnitude (right) plots for the November 30, 2018 M7.1 Anchorage aftershock sequence in 2021. The yellow star indicates the largest aftershock: M5.3 on February 27.*

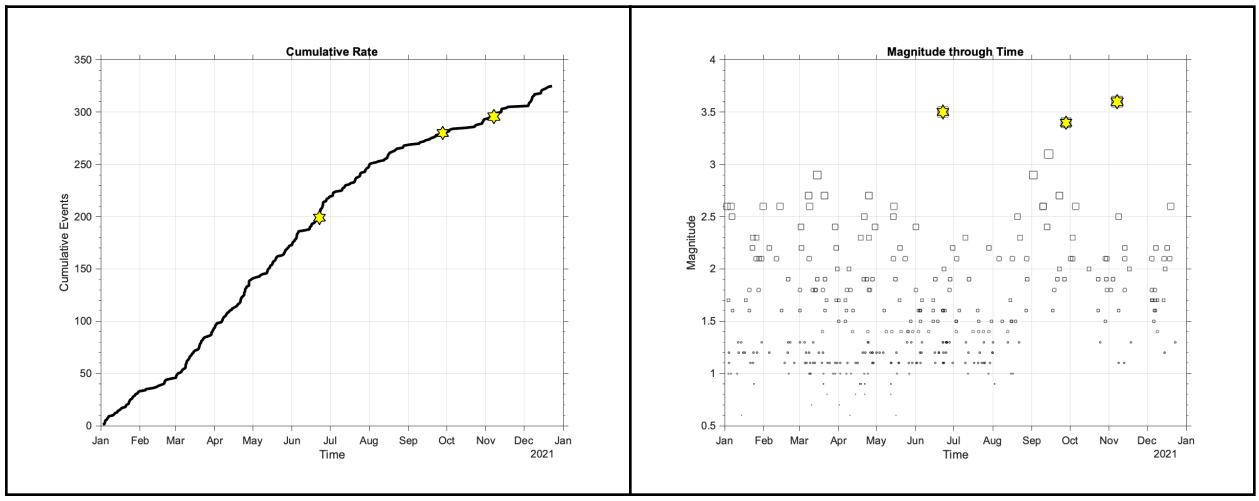

Figure 4.3. *Cumulative number (left) and time-magnitude (right) plots for the August 12, 2018 Kaktovik aftershock sequence in 2021. The higher rate of recorded aftershocks in the first half of the year is most likely due to smaller earthquakes being detected. Loss of real-time data from some stations hindered detection of smaller earthquakes starting in the fall when stations returned to power-cycling modes.*

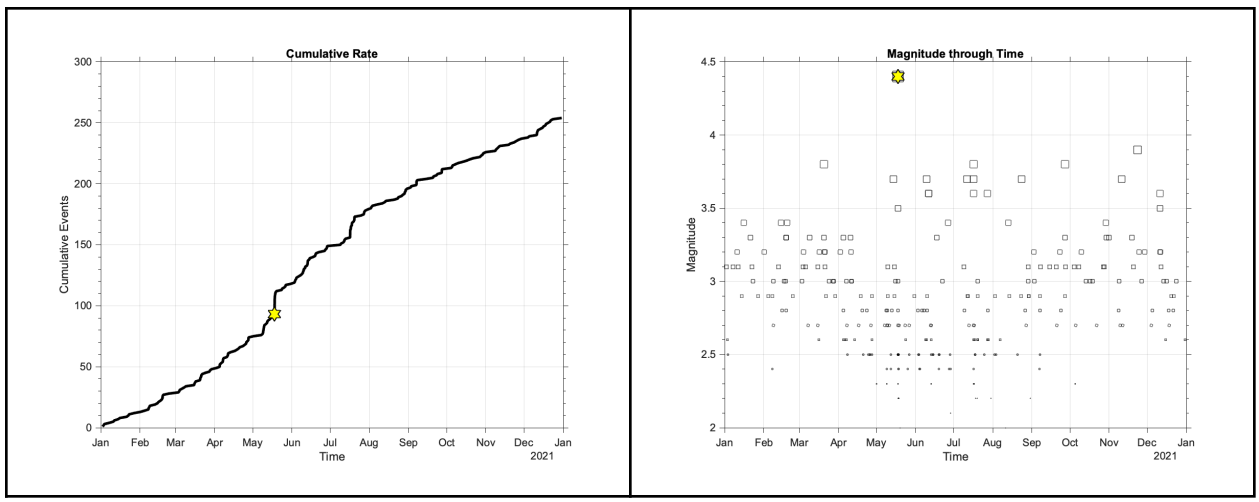

Figure 4.4. *Cumulative number (left) and time-magnitude (right) plots for the January 23, 2018 M7.9 Offshore Kodiak aftershock sequence in 2021. The higher rate of recorded aftershocks in the summer is most likely due to smaller earthquakes being detected, potentially related to increased station functionality.*

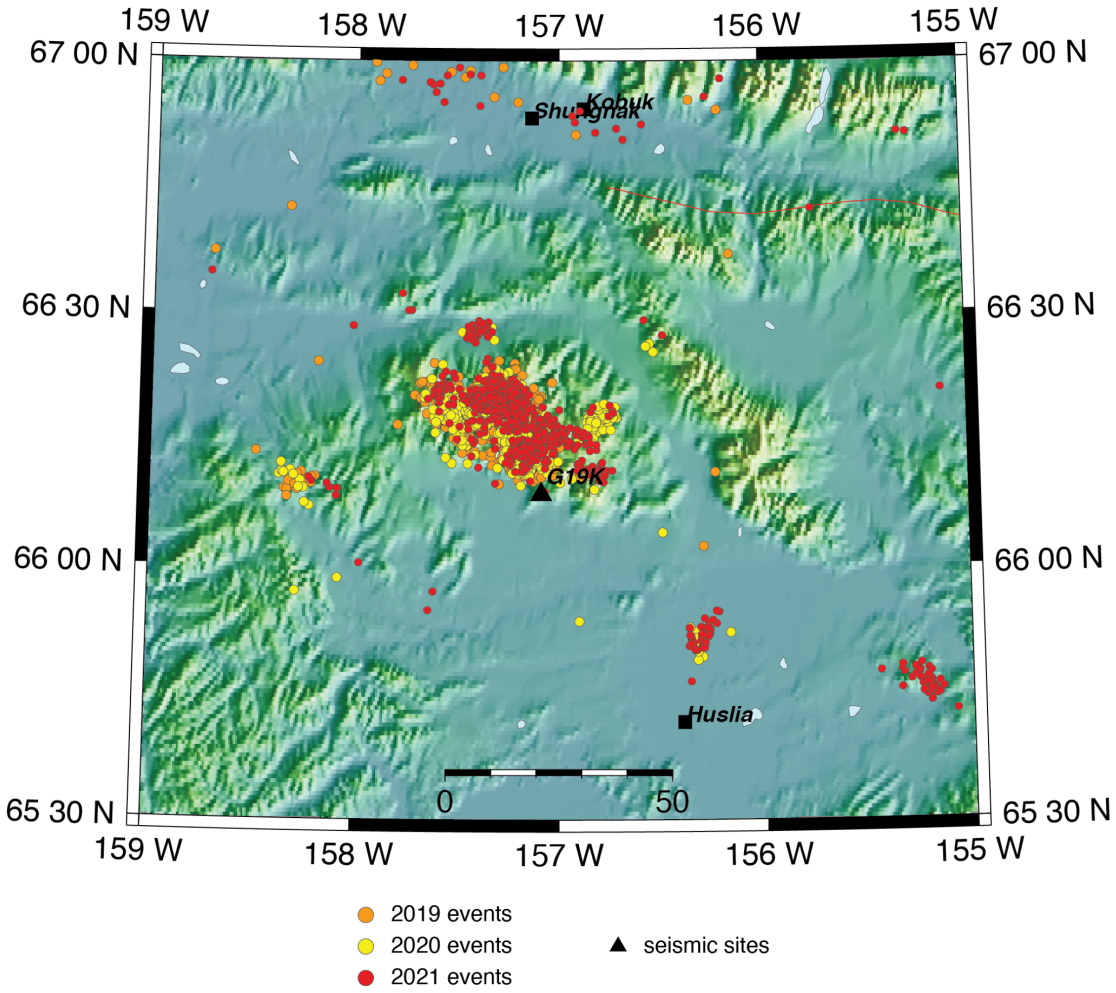

Figure 4.5*. Purcell Mountains Swarm location map. Events are color-coded by year of occurrence. Note the red cluster just north of the main swarm location, which was a new, short-lived feature that appeared in April 2021.*

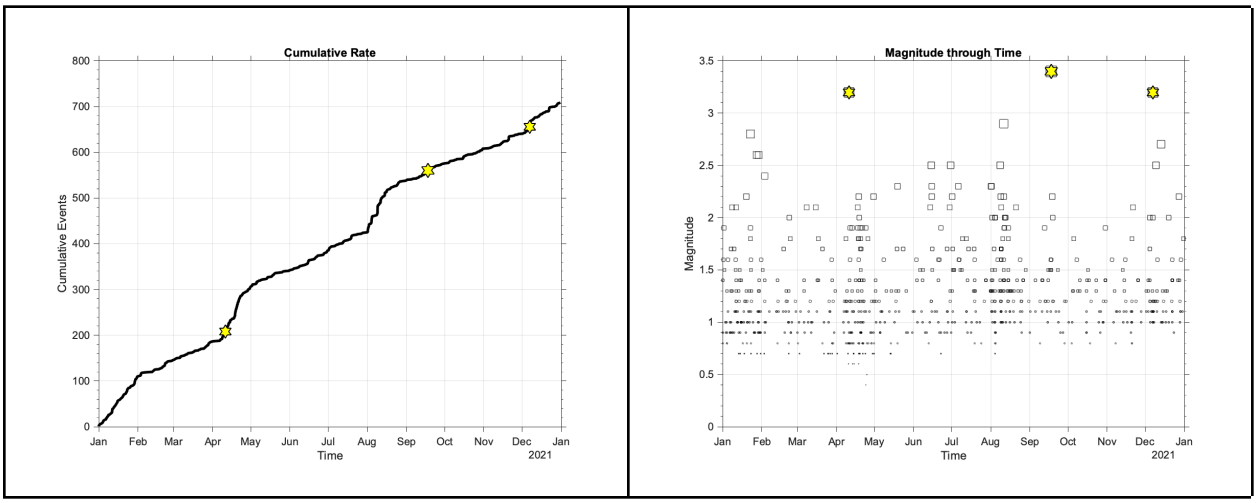

Figure 4.6. *Cumulative number (left) and time-magnitude (right) plots for the Purcell Mountains Swarm in 2021. The three largest earthquakes are shown by yellow stars.*

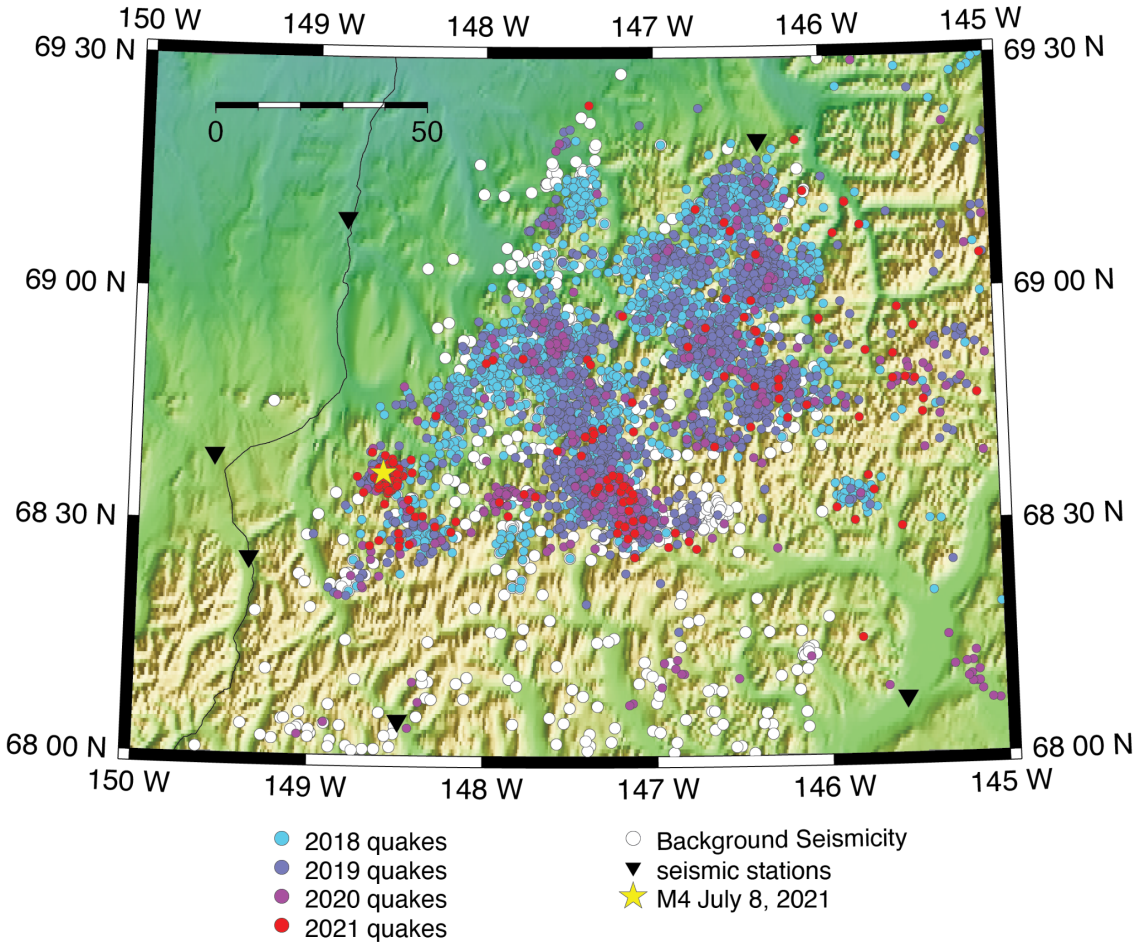

Figure 4.7. *Location map of the Northeast Brooks Range sequence. It was less active in 2021 than in previous years.*

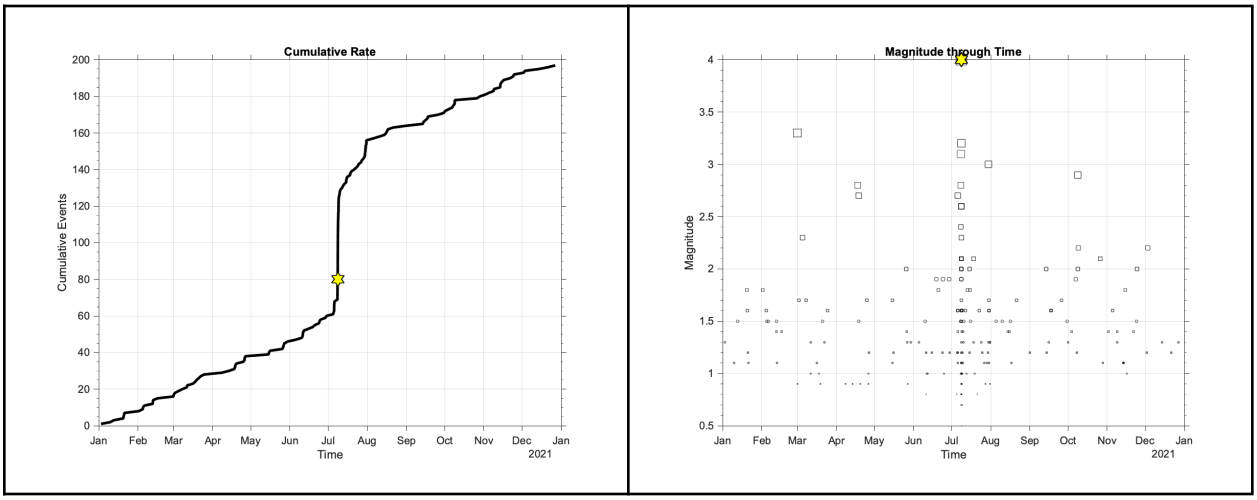

Figure 4.8. *Cumulative number (left) and time-magnitude (right) plots for the Northeast Brooks Range sequence in 2021. Note increased rate in July due to a localized swarm. Yellow star is the M4.0 July 8 earthquake.*

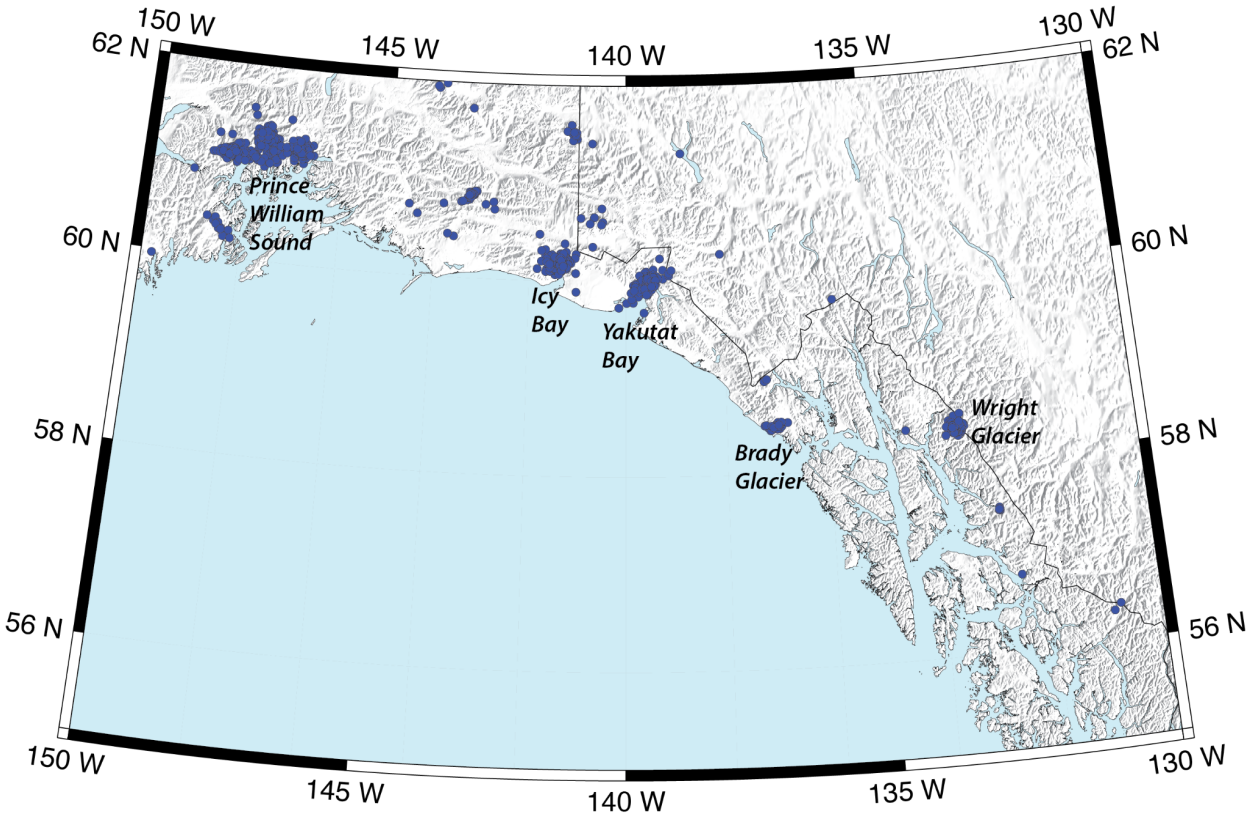

Figure 5.1. *Glacial events reported in 2021, with the most active areas labeled.*

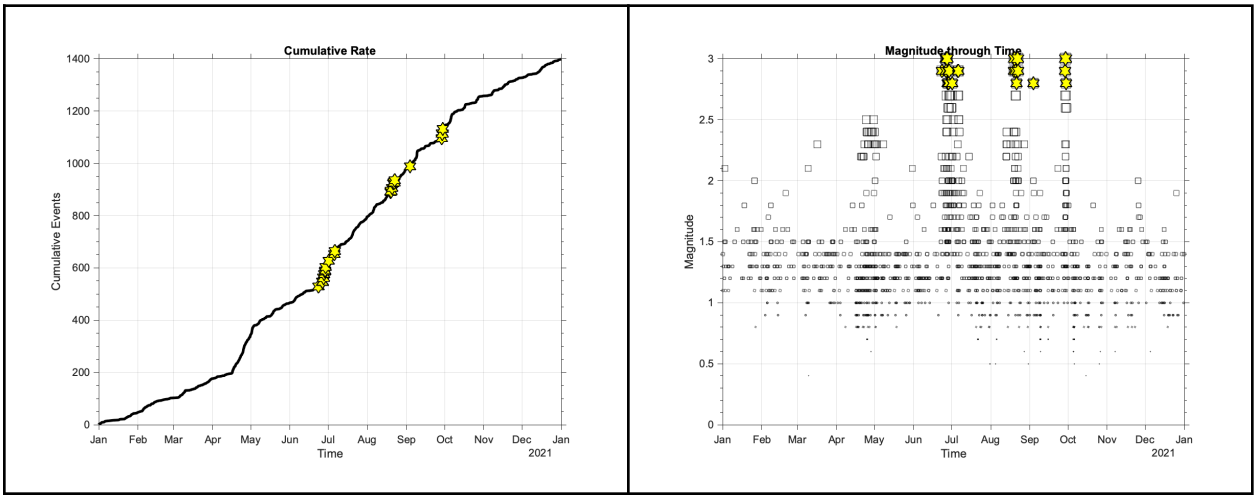

Figure 5.2. *Cumulative number (left) and time-magnitude (right) plots for glacial seismicity in 2021. Note the increased rate between April-October. Events with magnitudes 2.8 and greater are shown by yellow stars.*

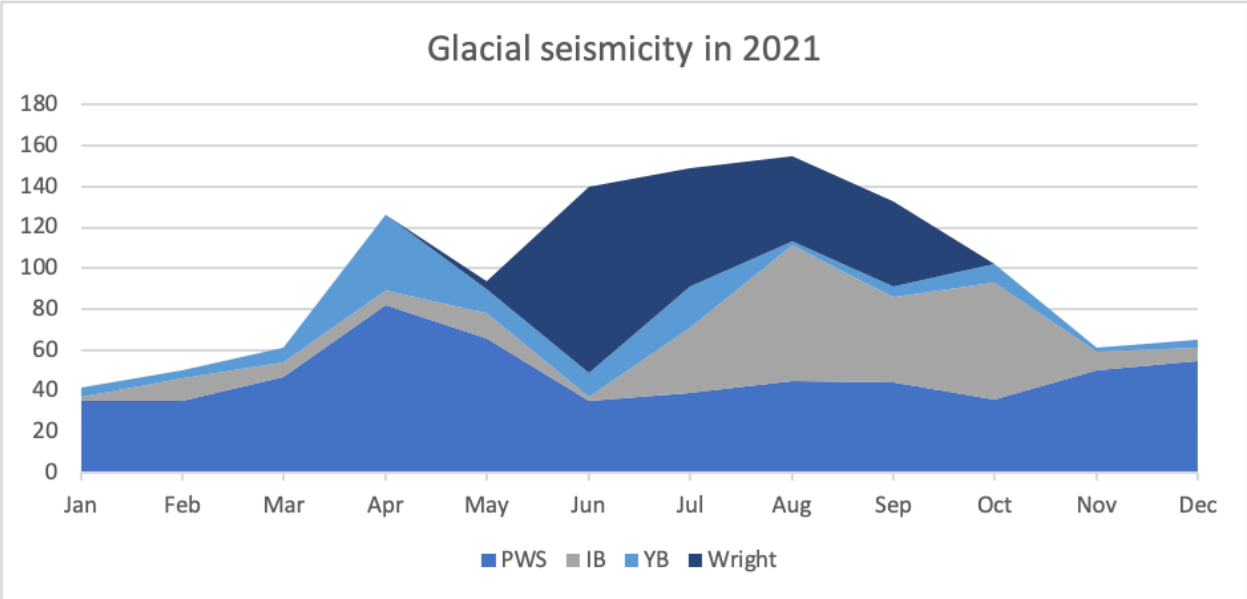

Figure 5.3. *Monthly counts of reported glacial events broken into the four main regions of activity. Note that the glacial activity peaked in the April-October time frame. PWS - Prince William Sound; IB - Icy Bay; YB - Yakutat Bay; Wright - Wright Glacier in Southeast Alaska.*