Alaska Earthquake Center Quarterly Technical Report October-December 2023

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Contents

1. Introduction

This series of technical quarterly reports from the Alaska Earthquake Center (AEC) includes detailed summaries and updates on Alaska seismicity, the AEC seismic network and stations, field work, our social media presence, and lists publications and presentations by AEC staff. Multiple AEC staff members contribute to this report. It is issued in the following month after the completion of each quarter Q1: January-March, Q2: April-June, Q3: July-September, and Q4: October-December. The first report was published for January-March, 2021.

2. Seismicity

Between October 1 and December 31, 2023, we reported 10,160 seismic events in the state and the neighboring regions (Figures 2.1, 2.2), with magnitudes ranging between 0.5 and 6.4 and depths between 0 and 254 km (Figures 2.3, 2.4). The largest earthquake of Mw=6.4 occurred on October 16 at 11:35:31 UTC, 4.8 km west of Adak in the Andreanof Islands region of the Aleutian Islands. There was one other earthquake with a magnitude greater than 6, an Mw=6.1, 87 km south of Atka Pass, also in the Andreanof Islands. There were eight earthquakes with magnitudes 5.0-5.6. Overall, we reported about 110 events per day, or one event every 13 minutes on average. This is slightly less than in the previous quarter (Ruppert et al., December 2023).

The seismicity rate remained steady (Figures 2.2, 2.3), even with the two M6+ events and their aftershocks. This period's overall magnitude of completeness was Mc=1.4 (Figure 2.5), ranging from Mc=1.3 in mainland Alaska to Mc=2.0 in the Alaska Peninsula and the Aleutians (Figure 2.6).

AEC data analysts picked and cataloged 386,378 seismic phases, 246,927 of which were P-phase and 139,457 S-phase arrival picks. Fewer phase arrivals per event were cataloged for the Aleutian earthquakes due to sparser station coverage compared to mainland Alaska (Figure 2.7).

We reported 657 seismic sources that were classified as something other than regional tectonic earthquakes (Figure 2.8). Of these, 98 were suspected quarry blasts (magnitudes M=0.7-2.2), all located near either Fort Knox or Usibelli mines in Interior Alaska. The reported events included 361 glacial events (magnitudes M=0.8-2.9), primarily located in the Prince William Sound, Icy Bay, and Yakutat Bay areas, as well as at Wright Glacier (Figure 2.9). Glacial activity was at a higher rate than in the previous quarter, by about 13%. This is a typical seasonal behavior, with glacial seismicity increasing in the summer and through the fall. We characterized 193 quakes as seismic events associated with volcanic activity (M=0.8-3.2). This is approximately 43% lower than the previous quarter. Seismic activity decreased substantially since the last quarter at the volcanoes in the Katmai group, with a total of 90 events (Figure 2.10). We continued to process Katmai volcanic events with M>0.9 due to the continued large volume of events. Alaska Volcano Observatory (AVO) reports these events in their earthquake catalogs. We have reported 2 suspected landslides (M=1.1-1.8), one near the Mt. Foraker area in Denali National Park on October 11, 2023, at 06:41:39 UTC, and one near Mt. Sandford in Wrangell-St. Elias National Park and Preserve on November 1, 2023, at 08:14:35 UTC. The suspected Mt. Sandford slide has an estimated volume of approximately 700,000 m^3. Both suspected landslides have yet to be ground-truthed. The remaining 3 events were classified as “other” type (M=1.0-2.1).

There were 63 earthquakes reported as felt (magnitudes M=1.8-6.4), two of which were located in Southeast Alaska near Glacier Bay (along with a few of their aftershocks), eight in the Interior (including an M4 near Kantishna), eight in the Aleutian Islands and the Alaska Peninsula, and the remainder in the Southcentral region of Alaska (Figure 2.11). The largest number of DYFI (Did You Feel It) responses, 827, came from the M4.2 earthquake that occurred October 6 at 14:01:18 UTC, 3 miles north of Anchorage in the Cook Inlet region of Alaska (https://earthquake.usgs.gov/earthquakes/eventpage/ak023ctna5d5/dyfi/intensity).

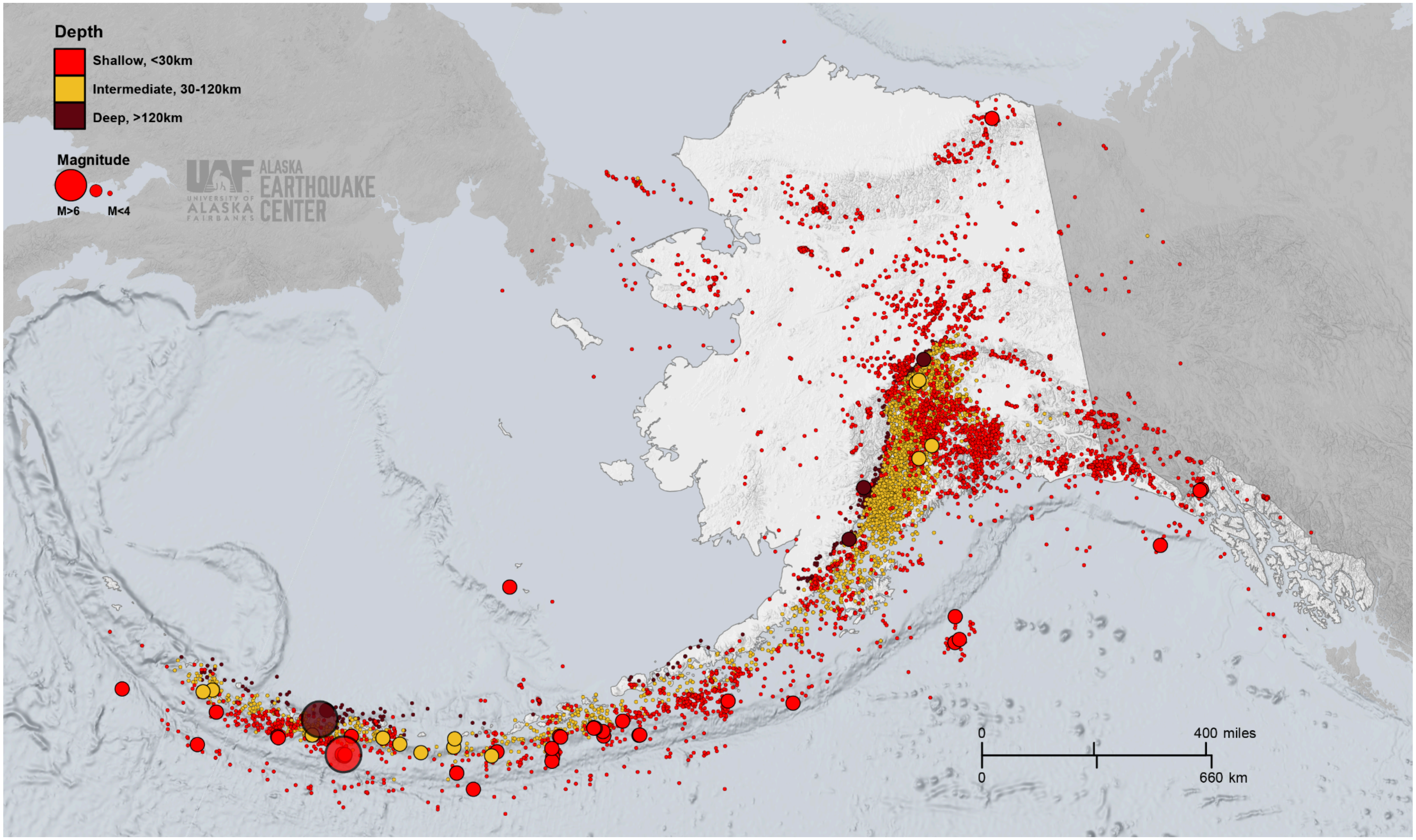
We continued recording above the background activity for the following sequences: 2023 M7.2 Sand Point Earthquake, 2023 Point Hope Earthquake Swarm, 2023 Katmai Volcanic Swarm, 2020 M7.8 Simeonof Earthquake, and 2018 M7.1 Anchorage Earthquake. The 2018 M6.4 Kaktovik and Northeastern Brooks Range sequences decreased this quarter, with approximately 1 event per week for each. For the remaining sequences, see Table 2.1 for a summary.

This quarter we eliminated from analyst processing any autodetected events smaller than M=0.8. We also eliminated any autodetected Katmai volcanic swarm events smaller than M=0.9. We maintained our processing backlog of approximately 14 days.

Table 2.1. *Notable Alaska seismic sequences for October 1-December 31, 2023.*

Earthquake	**Number of events**	**Magnitude range**	**Magnitude of completeness (Mc)**	**Number of events per week**
New sequences this quarter				
October 16, 2023 M6.4 earthquake	1	6.4	N/A	N/A
December 21, 2023 M6.1 earthquake	42	1.9-6.1	2.3	N/A
October 28, 2023 M5.1 & 5.3 Glacier Bay earthquakes	127	1.0-5.3	1.6	10
Continuing sequences (in order of decreasing activity)				
2020 M7.8 Simeonof Earthquake	289	1.5-4.5	2.0	22
2018 M7.1 Anchorage Earthquake	165	0.9-4.2	1.3	13
Katmai Volcanic Swarm	90	0.9-3.2	1.1	7
Point Hope Earthquake Swarm	27	1.3-3.6	2.7	2

Figure 2.1. *Earthquake map for Alaska and neighboring regions for October 1–December 31, 2023.*



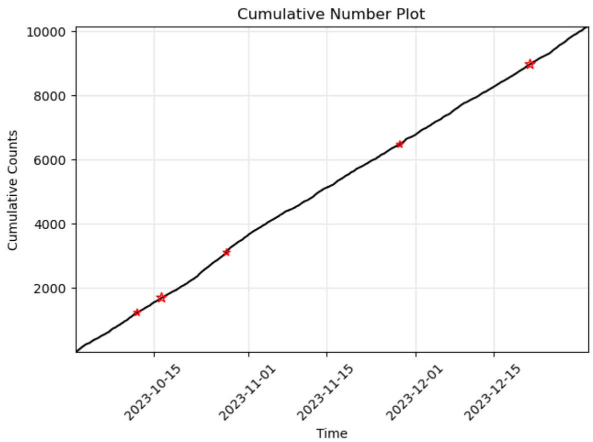


Figure 2.2. *Cumulative number of events for October 1-December 31, 2023. Red stars indicate the five largest earthquakes.*

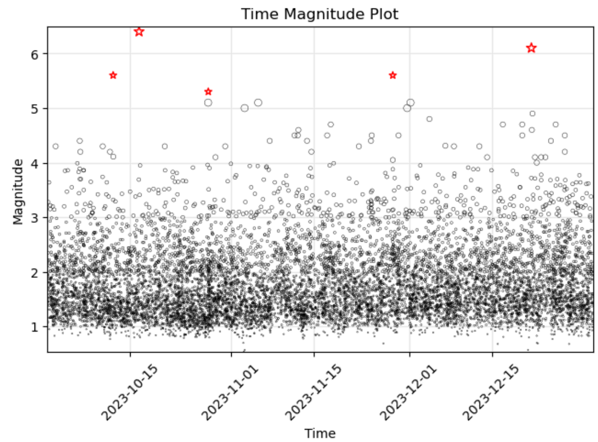


Figure 2.3*. Time-magnitude plot of events for October 1-December 31, 2023. Red stars indicate the five largest earthquakes.*

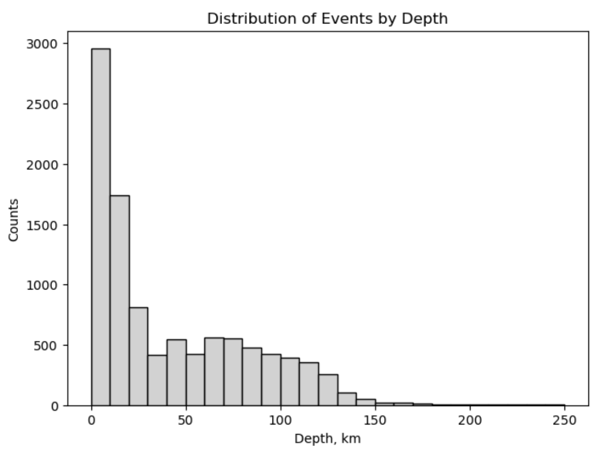


Figure 2.4*. Depth distribution of all events for October 1-December 31, 2023.*

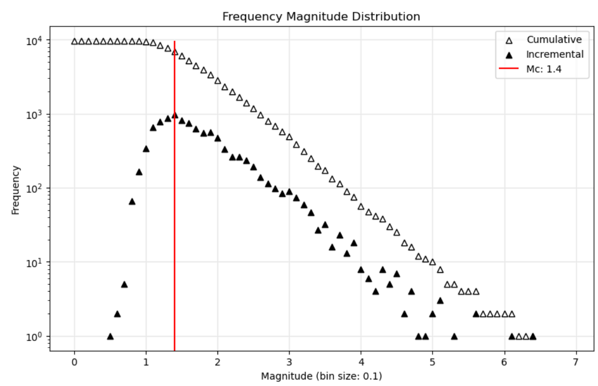


Figure 2.5*. Frequency-magnitude distribution of events for October 1-December 31, 2023 (glacial, landslide, unknown, and quarry blast types are not included).*

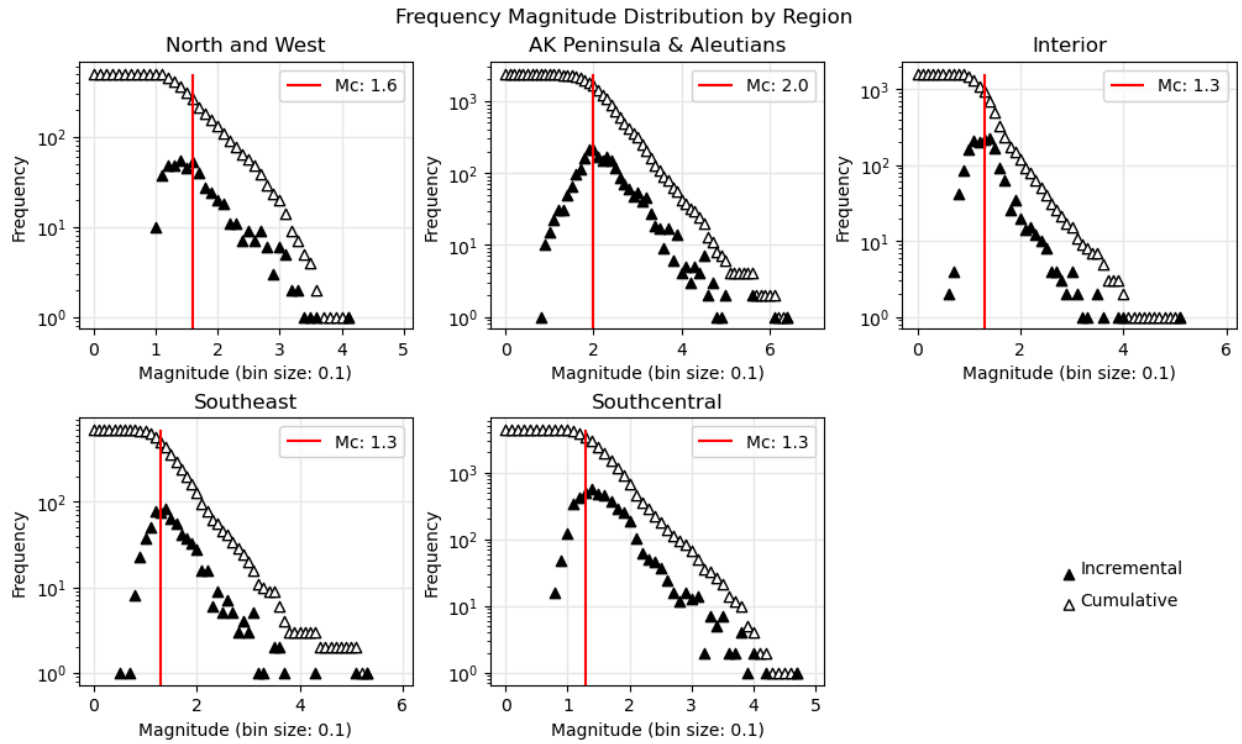


Figure 2.6. *Frequency-magnitude distribution of events for October 1-December 31, 2023 grouped by geographic region (glacial, landslide, unknown, and quarry blast types are not included).*

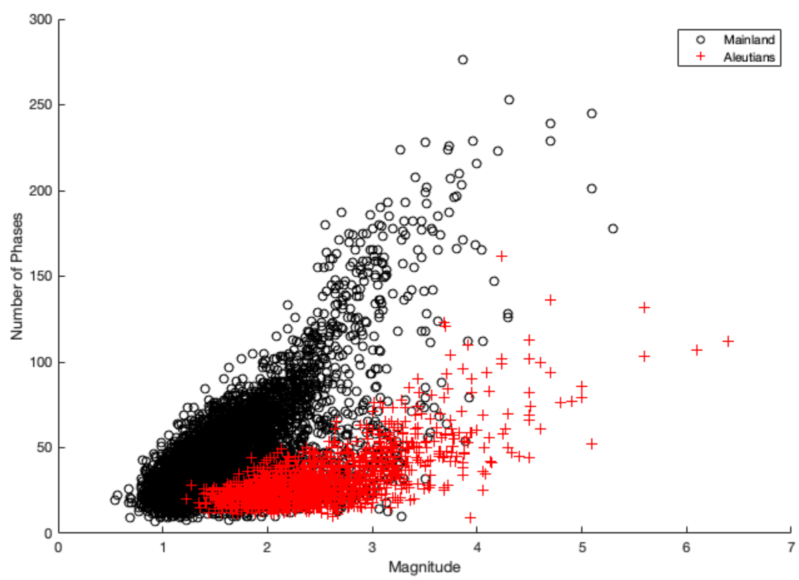


Figure 2.7. *Number of phase picks depending on magnitude and region for October 1-December 31, 2023.*

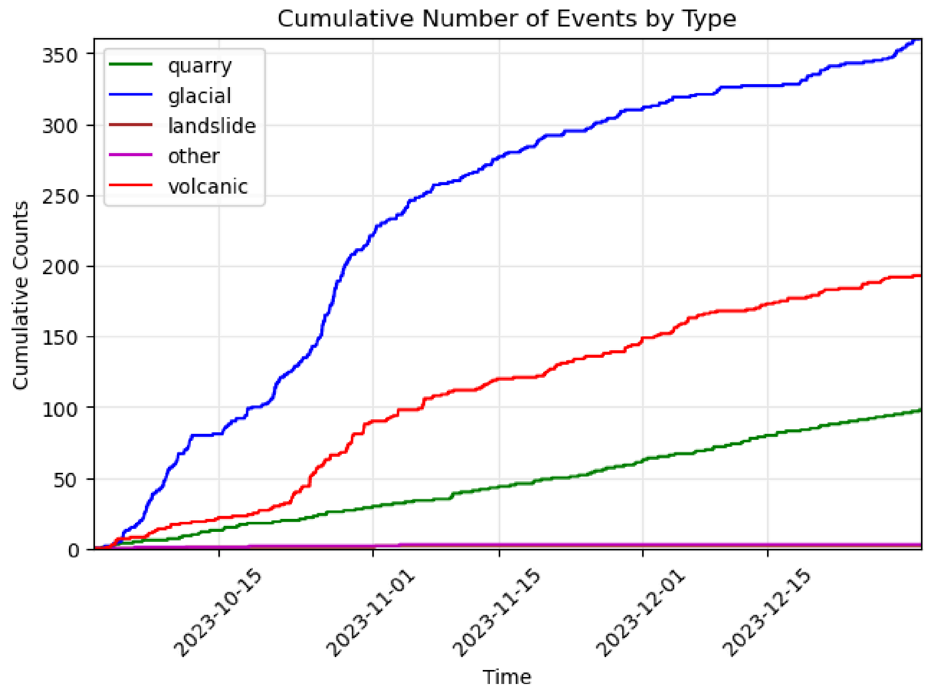


Figure 2.8. *Cumulative number of non-tectonic seismic events for October 1-December 31, 2023 (volcanic, glacial, landslide, other, and quarry blast types).*

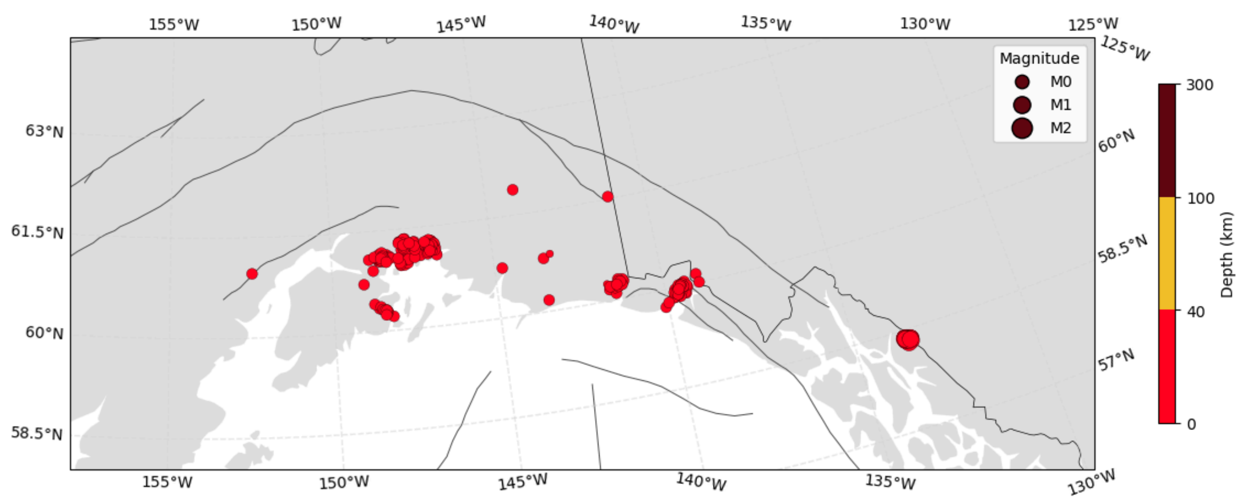


Figure 2.9. *Map of glacial events for October 1-December 31, 2023.*

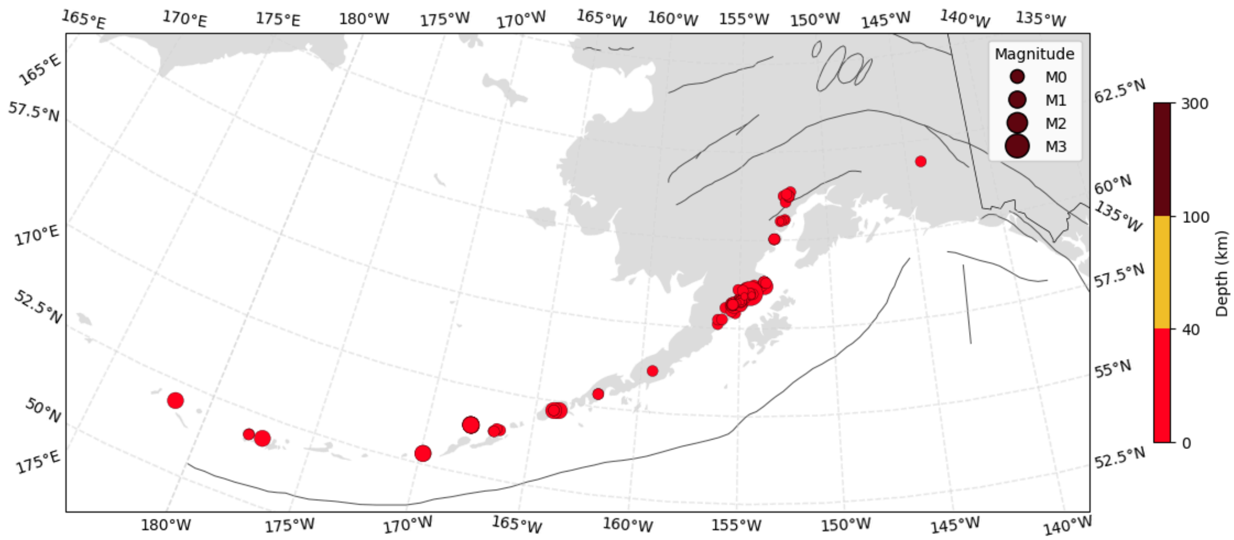


Figure 2.10. *Map of volcanic events for October 1-December 31, 2023.*

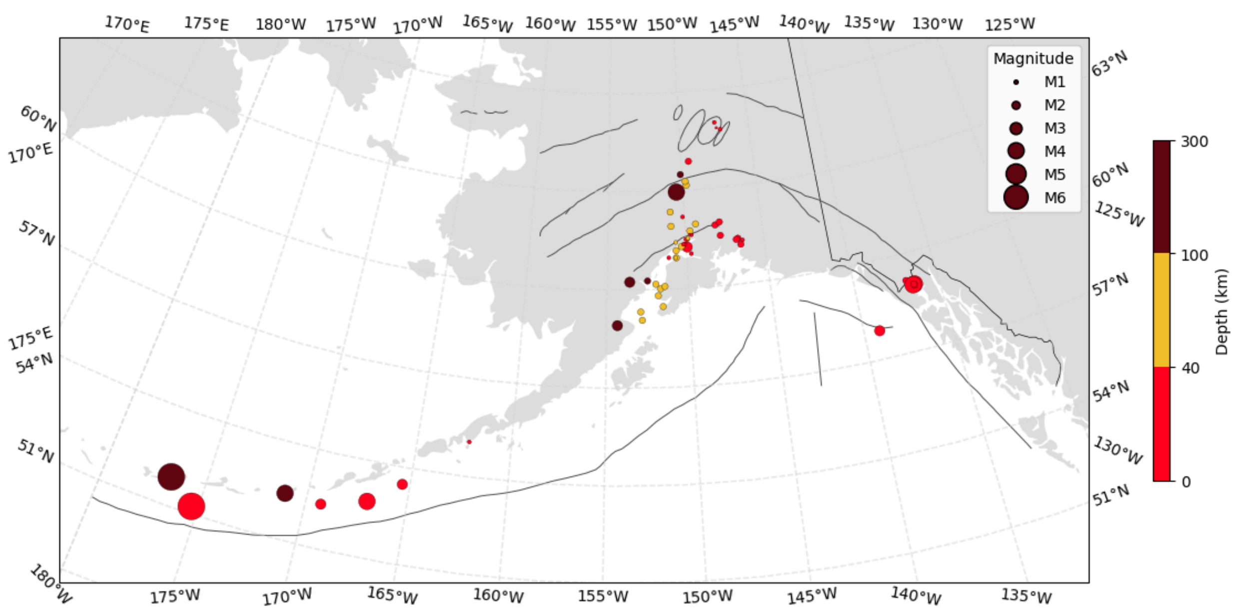


Figure 2.11. *Map of felt events (magnitudes M=1.8-6.4) for October 1-December 31, 2023.*

The following is a description of the most notable earthquakes and sequences for this period, starting with the new sequences.

M6.4 and M6.1 Andreanof Islands Earthquakes. On October 16, at 11:35 UTC, a magnitude 6.4 earthquake occurred under Adak Island at 205 km depth (Figure 2.12). No immediate aftershocks were recorded. This event was reported as felt on Adak. This was the largest earthquake during this quarter. Earthquakes as deep as 300 km may occur in the central Aleutian Islands. Such deep events are located inside the subducted Pacific Plate.

On December 21, at 5:35 UTC, a magnitude 6.1 occurred 116 km southeast of Adak at 4 km depth (Figure 2.12). It was the second largest earthquake during this quarter. AEC reported about 40 aftershocks through the end of the year (Figure 2.13), with magnitudes ranging between 2.0 and 4.9 (Figure 2.14). A total of five aftershocks measured at magnitude 4 or greater. The source mechanism of the mainshock indicates that it ruptured the plate boundary along the Aleutian megathrust.

M5.1 and M5.3 Glacier Bay Earthquakes. Two nearly back-to-back earthquakes of M5.1 and M5.3 occurred near Glacier Bay in Southeast Alaska on October 28 (Figure 2.15). These two events occurred within approximately 45 minutes of each other, with the M5.1 being the first of the two. Approximately 141 aftershocks followed during the remainder of the quarter, with approximately 110 occurring in the first 48 hours (Figure 2.16). The two mainshocks and the larger aftershocks were felt in Southeast Alaska communities as well as in northern British Columbia, Canada. The events in this sequence were shallow, typically 1-7 km depth (Figure 2.17).

This region is characterized by two major strike-slip faults: the Denali Fault to the northeast and the Fairweather Fault to the southwest. The area between the two faults is under compressional forces, which are released by moderate-sized earthquakes such as the two M5+ earthquakes on October 28. The most recent significant activity near these two events includes M6.2 and M6.3 events in 2017, approximately 60 miles north of the October 28 events. The 2017 M6+ events also occurred within one hour of each other.

Bogoslov Volcanic Swarm. An unusual but short-lived swarm was associated with the Bogoslof Volcano that occurred between October 23-31 (Figure 2.18). AEC recorded a total of 79 events, with the largest being M2.8 (Figures 2.19-2.20). Bogoslov is slightly north of the Aleutian volcanic arc, and last erupted in 2017. The Alaska Volcano Observatory temporarily raised the alert level of this volcano during this late October swarm.

Point Hope Earthquake Swarm. A swarm off of Point Hope in the Chukchi Sea (Figure 2.21) began last quarter on August 26, with an M2.5 event. This swarm had 27 events this quarter (Figure 2.22), for a total of 58 events since the onset. The largest event this quarter was an M3.6 on November 10 (Figure 2.23). None of the events in this swarm were reported as felt. The depths of these events are shallow, ranging from about 0-37 km below sea level. Western Alaska is characterized by diffuse zones of seismicity, with a more concentrated band extending from the northwestern Brooks Range through the Seward Peninsula and across the Bering Strait into eastern Russia. This zone is believed to mark the northern boundary of the Bering Plate. Seismicity in this region tends to exhibit swarm-like behavior.

2020 M7.8 Simeonof Earthquake. The 2020 M7.8 Simeonof Earthquake sequence continued at a decreased rate compared to the previous quarter (Ruppert et al., December 2023). We reported 289 aftershocks for this quarter. The magnitude of completeness slightly decreased again this quarter due to minor improvements in the network performance. There was only one aftershock over magnitude 4 for the entire quarter (M4.5 on November 11). The Simeonof aftershock sequence is now in its third year (Ruppert and Gardine, February 2021, February 2022; Ruppert, February 2023).

2018 M7.1 Anchorage Earthquake. The 2018 M7.1 Anchorage Earthquake aftershock sequence continued at a decreased rate as compared to the previous quarter (Ruppert et al., December 2023). The largest aftershock this quarter was an M4.2 on October 6. The aftershock sequence is now in its sixth year (Ruppert and Gardine, February 2021, February 2022; Ruppert, February 2023).

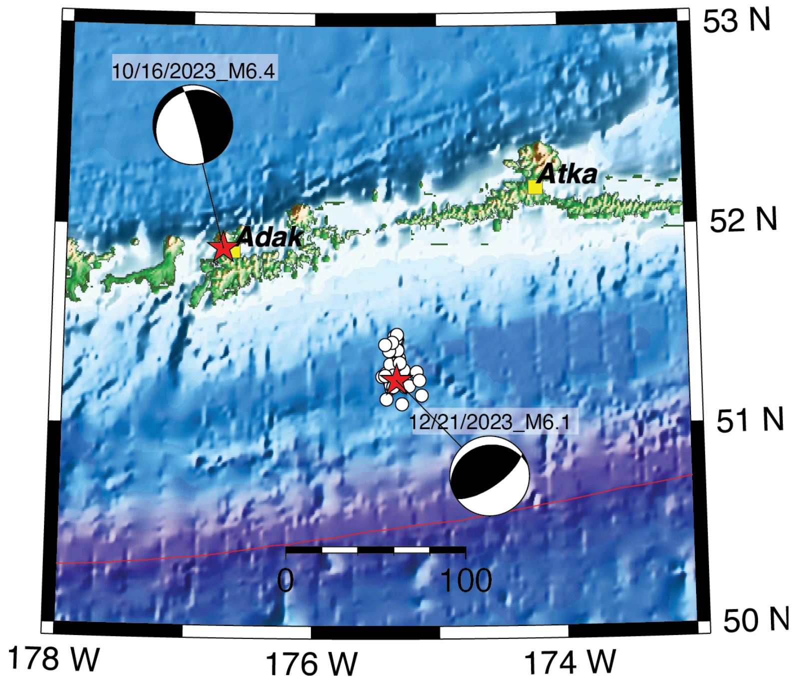


Figure 2.12. *Location map for the two largest earthquakes recorded during this quarter in Alaska. Red stars are epicenters of the October 16 M6.4 and December 21 M6.1 earthquakes. White circles are M6.1 aftershocks reported through December 31. Focal mechanisms are from the ANSS ComCat catalog.*

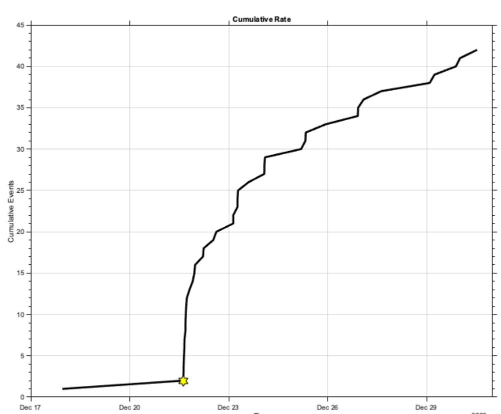


Figure 2.13. *Cumulative number of events in the M6.1 Atka aftershock sequence. The star indicates the M6.1 mainshock.*

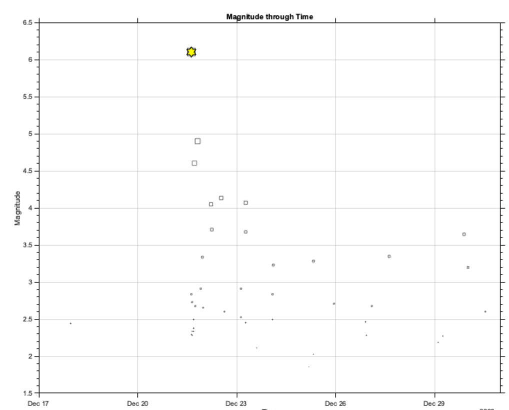


Figure 2.14. *A time-magnitude plot of events in the M6.1 Atka aftershock sequence. The star indicates the M6.1 mainshock.*

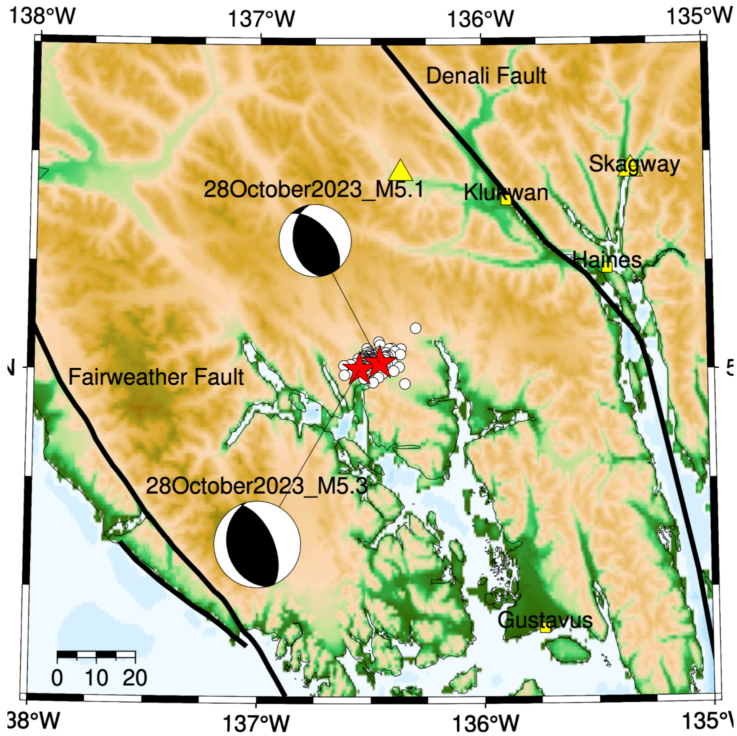


Figure 2.15. *Earthquake location map for the two October 28, 2023, M5.1 and M5.3 Glacier Bay earthquakes (red stars). White circles are aftershocks of these two events. Yellow triangles are nearby seismic stations. Yellow squares are nearby communities. The focal mechanisms are from the ANSS ComCat catalog.*

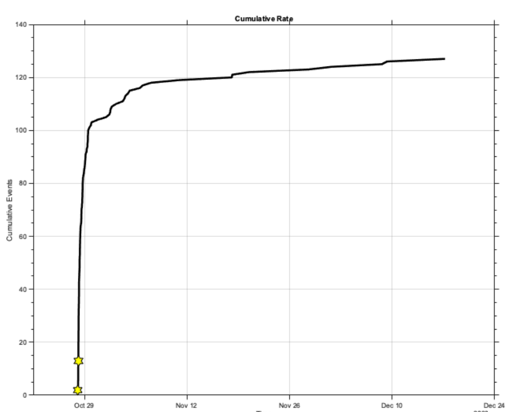


Figure 2.16. *Cumulative number of events in the Glacier Bay sequence for this quarter. The stars indicate the two largest earthquakes.*

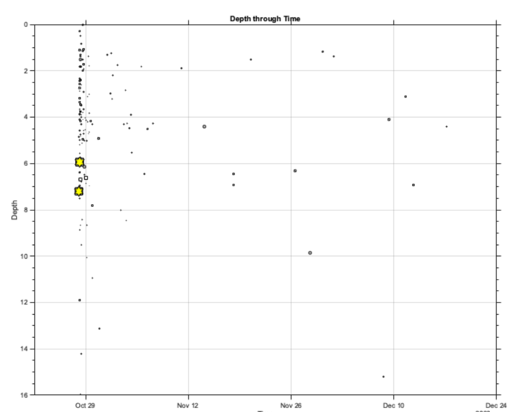


Figure 2.17. *A time-depth plot of events in the Glacier Bay sequence for this quarter. The stars indicate the two largest earthquakes.*

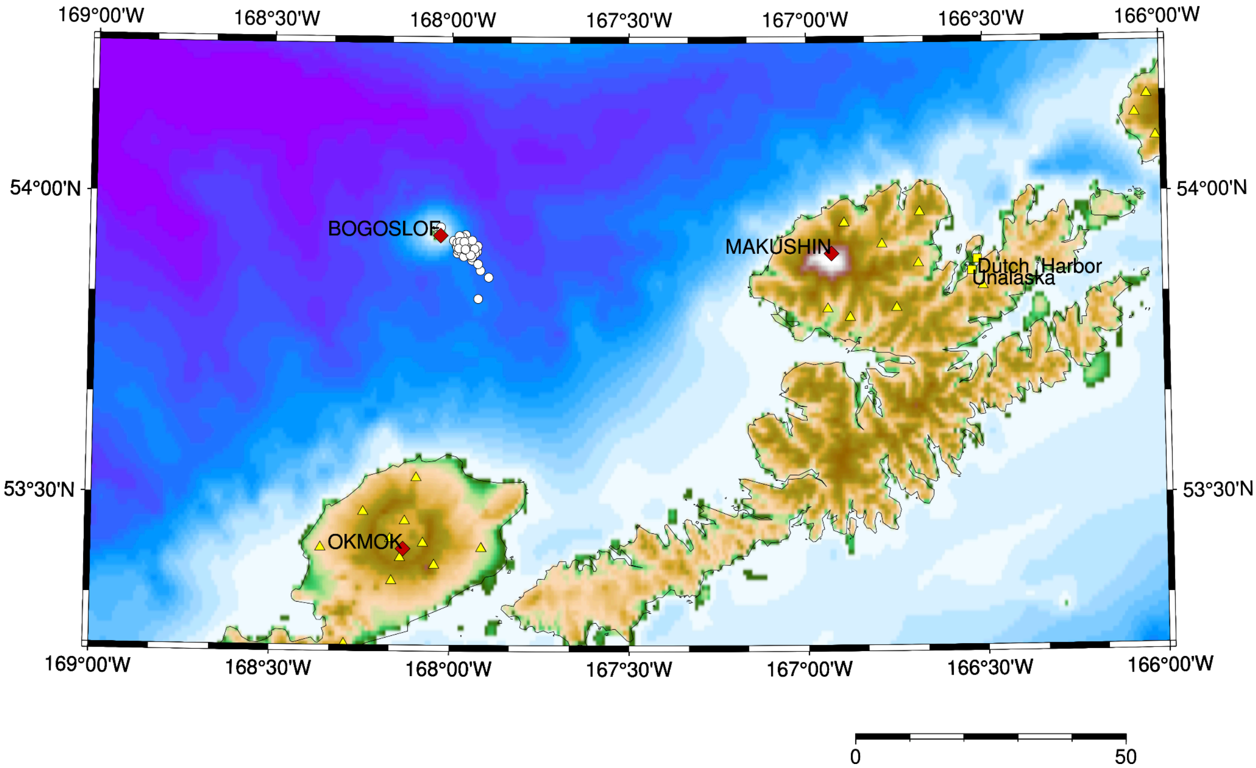


***Figure 2.18**. Earthquake location map for the swarm near Bogoslov Volcano, north of the main Aleutian arc. White circles are events recorded between October 23-December 1, 2023. Yellow triangles are seismic stations, yellow squares are villages. Red diamonds are volcanoes.*

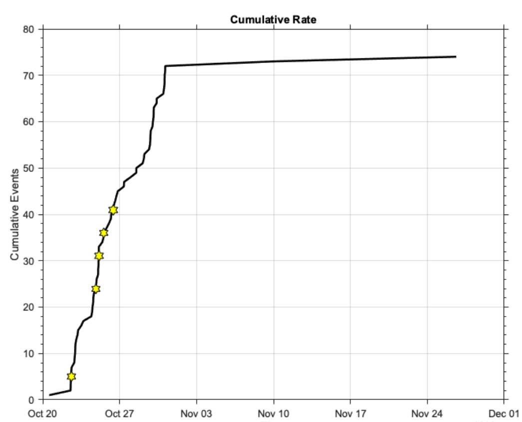


***Figure 2.19**. Cumulative number of events in the Bogoslov swarm for this quarter. The stars indicate the five largest earthquakes.*

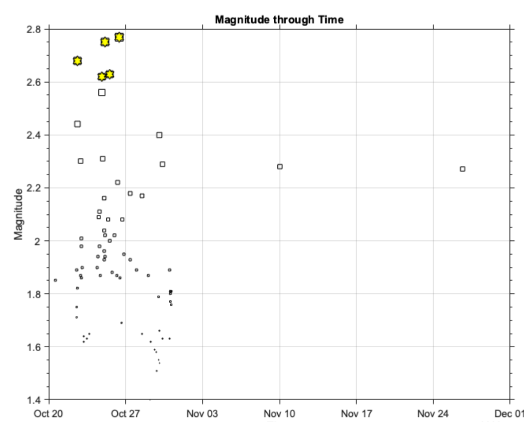


***Figure 2.20**. A time-magnitude plot of events in the Bogoslov swarm for this quarter. The stars indicate the five largest earthquakes.*

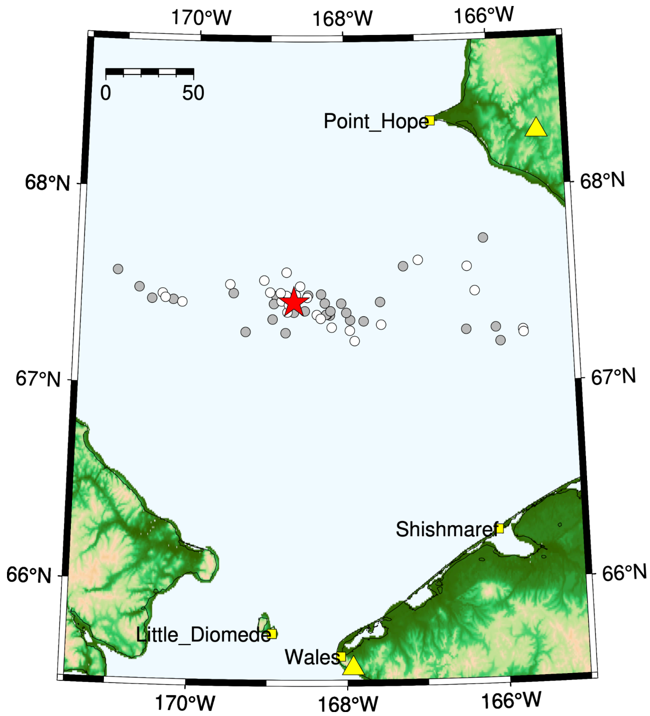
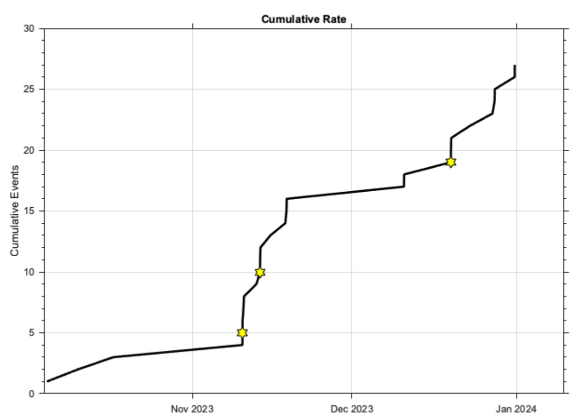


Figure 2.21. *Earthquake location map for the swarm off of Point Hope, in the Chukchi Sea. White circles are events recorded between October 1-December 31, 2023. Gray circles are events recorded during the previous quarter and are discussed in the 2023 Q3 Quarterly Report. The red star is the largest event during this quarter, an M3.6. Yellow triangles are seismic stations, yellow squares are villages.*



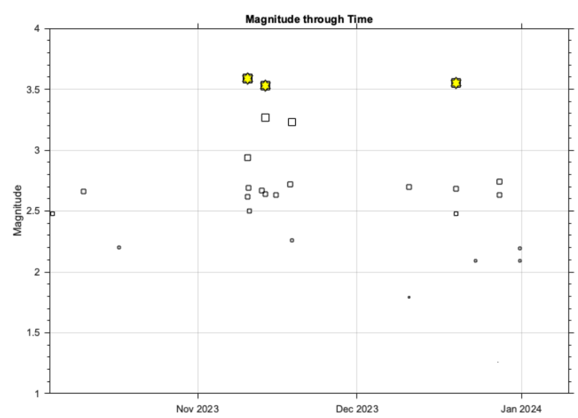


Figure 2.22. *Cumulative number of events in the Point Hope swarm for this quarter. The stars indicate the three largest earthquakes.*

Figure 2.23. *A time-magnitude plot of events in the Point Hope swarm for this quarter. The stars indicate the three largest earthquakes.*

3. Field network

As of December 31, 2023, AEC maintains and acquires data from 254 seismic sites of the Alaska Geophysical Network (Figure 3.1) (https://earthquake.alaska.edu/network). The sites can be divided into the following groups based on their locations and sensor types:

- 209 free-field broadband stations, 87 of which have co-located strong motion sensors (an addition of 6 strong motion sensors after 2023 field season), 107 of which have infrasound data streams, 67 of which have meteorological sensor packages, and 7 of which have GNSS sensors;
- 25 strong motion sites in the greater Anchorage and Mat-Su Valley region;
- 9 strong motion sites in Fairbanks;
- 9 strong motion sites located in coastal communities from Chignik to Yakutat and Bethel;
- 1 structural array located in the Joseph E. Usibelli Engineering Learning and Innovation Building on the University of Alaska Fairbanks campus;
- 2 Netquake sites in Fairbanks that record only triggered data (these are not included in the data return rates);
- 2 sites were decommissioned this summer due to performance issues: BWN and NICH.
- We also have 22 sites with soil temperature probes, but these data are not acquired in real-time.

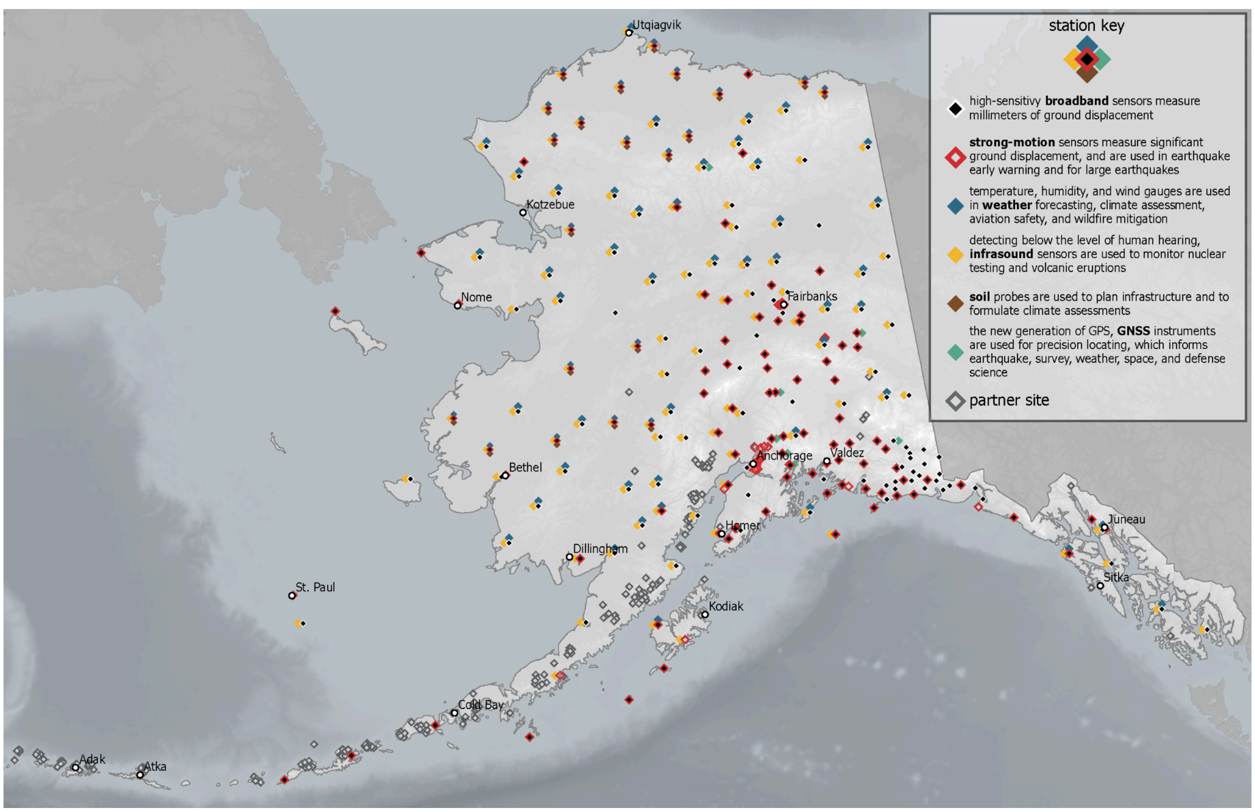


Figure 3.1. *Alaska Geophysical Network as of December 2023.*

Between October 1 and December 31, 2023, the network had an average data completeness rate of 81.9%, with the daily rates ranging from 76.2% to 85.0% (Figures 3.2 and 3.3). The overall performance was comparable to last year, but below the 2019-2021 years.

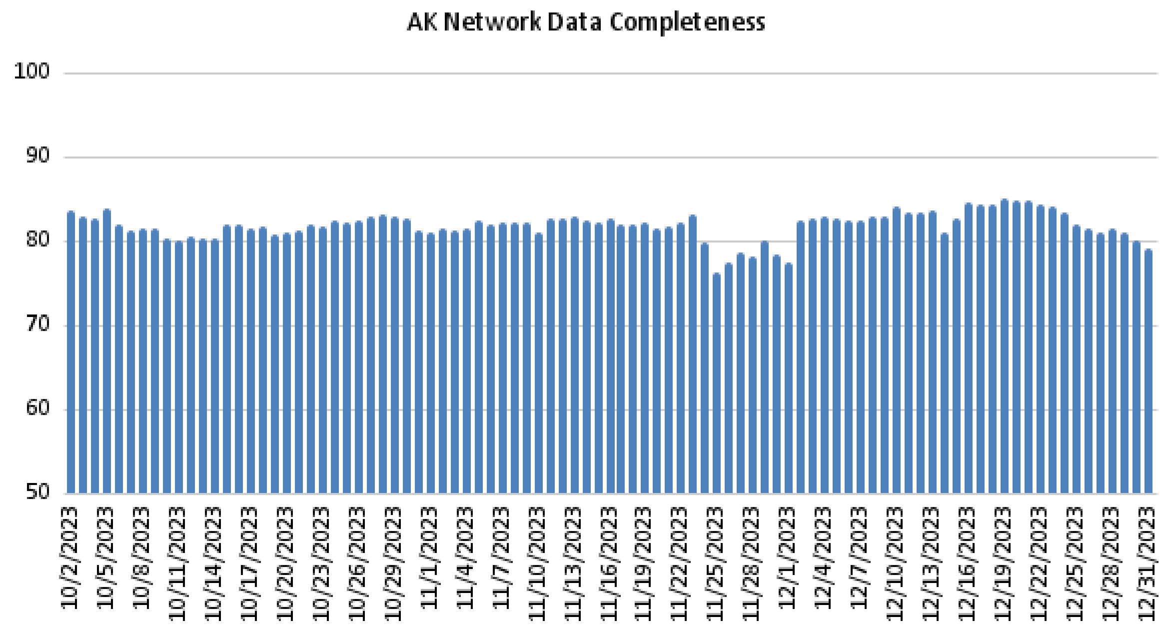


Figure 3.2*. Daily data completeness in percent for the AK network, October 1-December 31, 2023.*

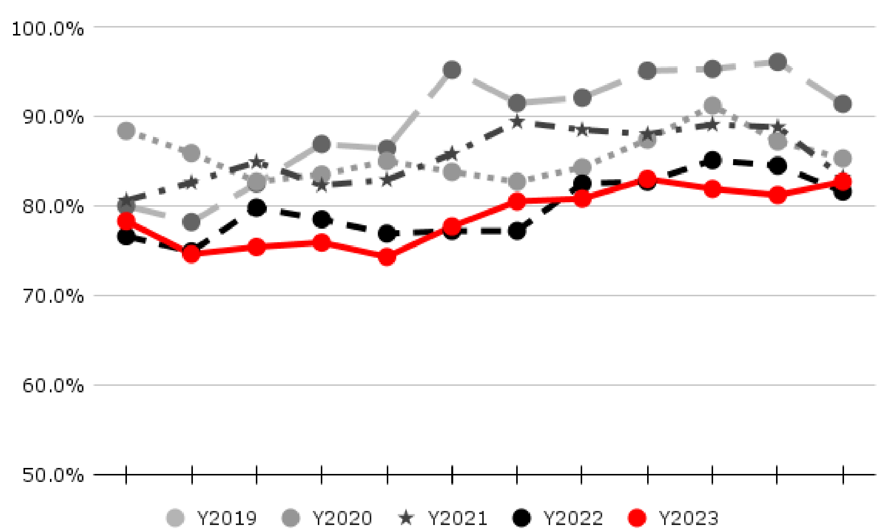


Figure 3.3*. Average monthly data completeness in percent for the AK network, 2019-2023.*

4. Data quality assurance

4.1 Seismic data

Data Quality Control (QC) efforts at the center consist of data integrity (up-time, completeness, latencies) and quality (signal quality/noise performance). We define “QC” broadly as quantitative data that help assess the performance of our stations. This includes data on the overall health of the station (data completeness, clock quality, latency, etc.), as well as data specific to individual channels (broadband, strong-motion, weather, infrasound, etc.). QC metrics are values derived from the data and state-of-health channels (SOH), as well as from the IRIS MUSTANG website (http://services.iris.edu/mustang/measurements/1/). Standardized QC reports are produced weekly and include percent availability, gaps, and amplitude-related metrics (dead and pegged channel, spikes, high and low amplitudes compared to the global New High and New Low Noise Models, flat amplitudes for strong motion sensors, and dc offset).

During this quarter we continued to use our two new amplitude-based strong motion metrics: SM_dead and SM_spikes. SM_dead flags if the max_range is less than 100, the absolute value of the sample_mean is less than 1000, and the sample_rms is less than 25. SM_spikes flags if the max_range is greater than 10,000 and the sample_rms is greater than 2500. Additionally, we analyzed the numbers of mass recenters at each station with broadband sensors for the last 3 years. We did temporal and spatial analyses to determine the stability of each broadband sensor and made recommendations to our field team on what can be done to improve the data quality of unstable sensors. These recommendations include replacing the sensor type or upgrading a site from a borehole to a vault. Furthermore, during this analysis we found that there has been an issue with the recentering commands being much less frequent in the last year compared to prior years, resulting in data quality issues, and are working to correct the problem.

Each piece of our QC information has multiple end-users. Maintaining a comprehensive set of QC products allows us to feed these end-uses while minimizing the need to perform one-off QC requests. Internal end-users include the field team to help steer repairs and upgrades, the analyst team to identify stations that should not be used for routine earthquake analysis, as well as project reports specific to certain stations (TsuNet, Greely, Pipeline, Donlin, etc.). We also communicate performance issues to the research community and partner organizations (Alaska Climate Research Center and the Wilson Alaska Technical Center).

Stations with the lowest data availability or sensor/datalogger failures October 1-December 31, 2023 (also see Figure 4.1):

- Stations that continue to have 0% availability as compared to 2023 Q3: A21K, BWN (decommissioned site but remained in our database), CHI, D24K, DCPH, E18K, K218, L26K, M26K, NICH (decommissioned site but remained in our database), R18K, SSN
- Stations that now have 0% as compared to 2023 Q3: B22K, CHN, CYK, E21K, G27K, K27K, L18K, YAKA
- Stations that continue to have 1-50% availability as compared to 2023 Q3: A19K, BCP, CHX, H23K, K222, KAI, PPD, TABL, YAH,
- Stations that now have 1-50% availability as compared to 2023 Q3: C18K, FA01, GOAT, I26K, J25K, M19K, O20K, Q19K, RAG,

- Stations that came back during 2023 Q4 but still had 1-50% availability for the entire period: L17K, M16K, SII, TRF, UNV,
- Stations that have come back to above 50% availability since 2023 Q3 due to field maintenance or on their own: ATKA, BAGL, FYU, G19K, JIS, KTH, MESA, N15K, O14K, PTPK, RKAV, SAMH, TNA, UAFE.03
- BB data-quality issues caused by faulty sensors and/or dataloggers: A19K, A22K, BESE, C21K, C26K, CYK, H21K, KTH (BHE channel), NICH, NIKH, PS01 (BHN channel), PS04 (BHE channel), PS06, PS10, RND, SII, SSN, TOLK 01 (both horizontal channels)
- SM data-quality issues caused by faulty sensors and/or dataloggers: NIKH, PS06, PPLA, WAT7
- Stations that had data-quality issues that were fixed during 2023 Q4: CRQ, RDOG
- Stations with timing issues: CHN, K209, K210, M11K, S19K

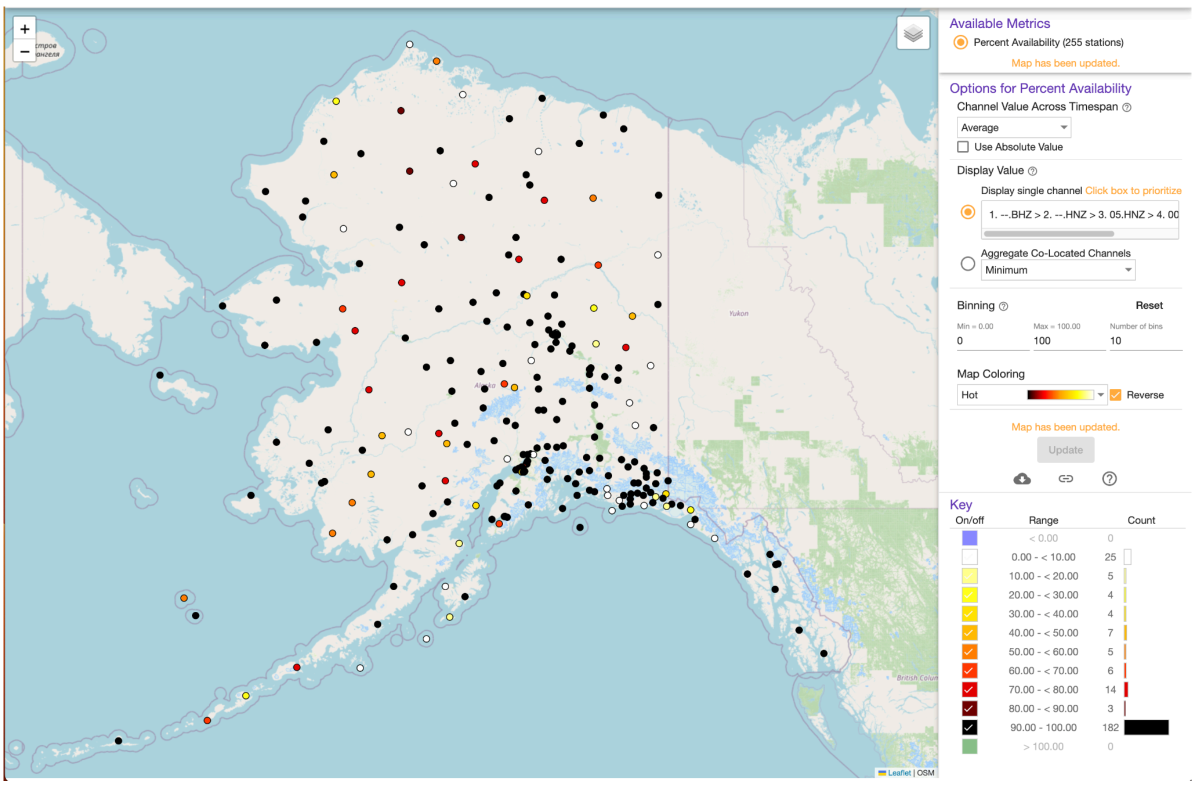


***Figure 4.1**. Map of average percent availability for all AK network broadband and strong motion stations for October 1 - December 31, 2023. Black circles represent stations at 90-100% availability, white circles represent stations at 0-10% availability. Other colors represent a gradient of availability.*

4.2 Environmental data

The Earthquake Center adopted 89 stations with non-seismic instrumentation from the EarthScope Transportable Array project. All 89 stations have Hyperion infrasound and Setra microbarometer instruments. Of these stations, 67 are equipped with Viasala WXT weather packages (7 channels recording wind speed and direction, humidity, barometric pressure, temperature, and rain/hail gauges). In total, we recorded 825 individual environmental channels.

We run monthly QC checks of these environmental channels, quantifying the percent availability for each instrument, as well as scanning for periods of non-physical values and flat data return. A channel will flag as “flat” if over 20% of the samples are non-unique. For non-physical values, we conducted a literature review of the global maximum/minimum values for each of the environmental channels we acquired. For example, if a temperature sensor reports a measurement below -60 C or above 70 C, we flag that as non-physical. Please note that these monthly environmental QC reports do not fall on calendar months, but instead run from the 7th to the 6th of the next month, due to reporting requirements of the Synoptic National Mesonet Program. This report is for October 7 through January 6, 2024.

The fourth quarter of 2023 was marked by degrading performance, with 56% of the network reporting over 90% data return by December 2023 and 16% of the network returning less than 25% of data. November was an outlier, with only 44% of the network reporting over 90% data return, but this recovered significantly by December. November was when stations were switched to power-saving telemetry modes, so perhaps the timing of that switch is related to the degraded performance. Several stations had upgraded or repaired WXT modules, so we are hopeful that the first quarter of 2024 will not see as drastic a drop in station performance as it had in 2023.

In October 2023, 62% of the stations reported data availability of 90% or higher, while 19% of the stations had less than 25% data availability. In November, the stations with data availability of 90% or higher dropped significantly to 45%, and those with less than 25% data availability fell to 16%. Since the worst-performing stations actually got a bit better, and the biggest change was several stations dropping from above 90% data return to just under 90% data return, the timing of the winter telemetry mode switch may have been the cause of this drop. By December, 56% of stations had a data availability of 90% or higher, and the stations with less than 25% data availability increased to 20%.

5. Real-time earthquake detection system

The Earthquake Center is the authoritative source of earthquake information in Alaska. Our real-time automated earthquake detection system is tuned to rapidly determine locations and magnitudes of seismic events in the state and disseminate this information to state and federal agencies, scientists, and the general public via website and other data feeds. The real-time earthquake detection system at AEC is based on the Antelope software package from BRTT, Inc.

First, waveforms are being continuously scanned by the *orbdetect* module to identify seismic arrivals. When a group of concurrent arrivals is identified, the *orbassoc* module searches over several pre-calculated, three-dimensional grids to find the best fit for the set of arrivals. Each successful association is relocated by the *orbgenloc* module. Once the event is located, its magnitude is calculated through the *orbevproc* module. Automatic and reviewed locations and magnitudes, along with the set of associated arrivals and other information, are written into the real-time earthquake database (CSS3.0) by the *orb2dbt* module.

Beginning in January 2021, we have been producing monthly reports on the performance of the real-time detection system. We document numbers of detected events (Figure 5.1), percent of bogus events that get deleted by the duty seismologist, percent of events with automatic magnitudes computed, location errors, detection latencies (Figures 5.2 and 5.3), and overall magnitude of completeness (Figure 5.4). We compare some metrics to ANSS (Advanced National Seismic System) performance standards, for example 2 minutes latency post time for hypocenters in High-Risk areas. See Table 5.1 for detailed information on some of the current metrics.

Table 5.1. *Real-time earthquake detection system performance.*

Metric	October	November	December
Number of automatic event detections	3,200	2,398	2,461
First origin latency below ANSS 2 min. standard	76%	75%	69%
Number of automatic events with magnitudes	2,587	1,932	1,934
Percent origins with magnitudes	81%	80%	79%
First magnitude latency below ANSS 3 min standard	60%	57%	52%
Magnitude latency from origin post time below ANSS 2 min standard	98%	99%	98%
Events deleted by duty seismologist	18%	18%	15%
Magnitude of completeness	1.7	1.6	1.6
Number of earthquake alarms	10	8	8
Number of ShakeMaps	46	38	49
ShakeMap latency below ANSS 15 min standard	80%	79%	83%

During the October-December 2023 time period, we reported 8,059 automated events in Alaska and neighboring regions (Figure 5.1). This represents a 29.0% decrease in detections compared to the previous quarter, which is consistent with previous years as a result of the switch to winter telemetry mode. October 22, 2023 had the highest number of detections. December 24 experienced longer detection delays, due to a handful of events having latencies of >6 hours. Detection delays were back to normal on December 25 (Figure 5.2). A single event on December 24 had a magnitude post time latency from origin post time of several hours, causing the mean for that day to be very high (Figure 5.3). The cause of this delay is unknown at this time. There were 26 earthquake alarms during this reporting period. Our goal is to have duty-seismologist-reviewed solutions for alarm events within 20 minutes. Five alarm events were reviewed with a larger delay (Figure 5.5). There were 133 earthquakes with shakemaps produced, with 80.8% of them being produced within the ANSS 15-minute standard (Table 5.1).

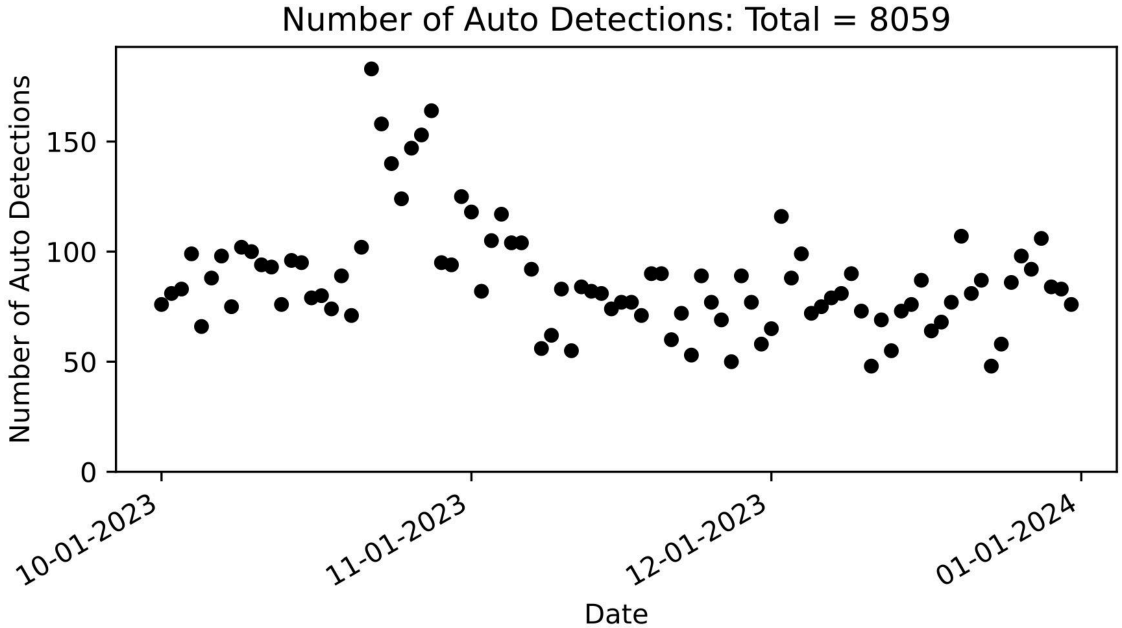


Figure 5.1. *Number of automatic event detections for each day.*

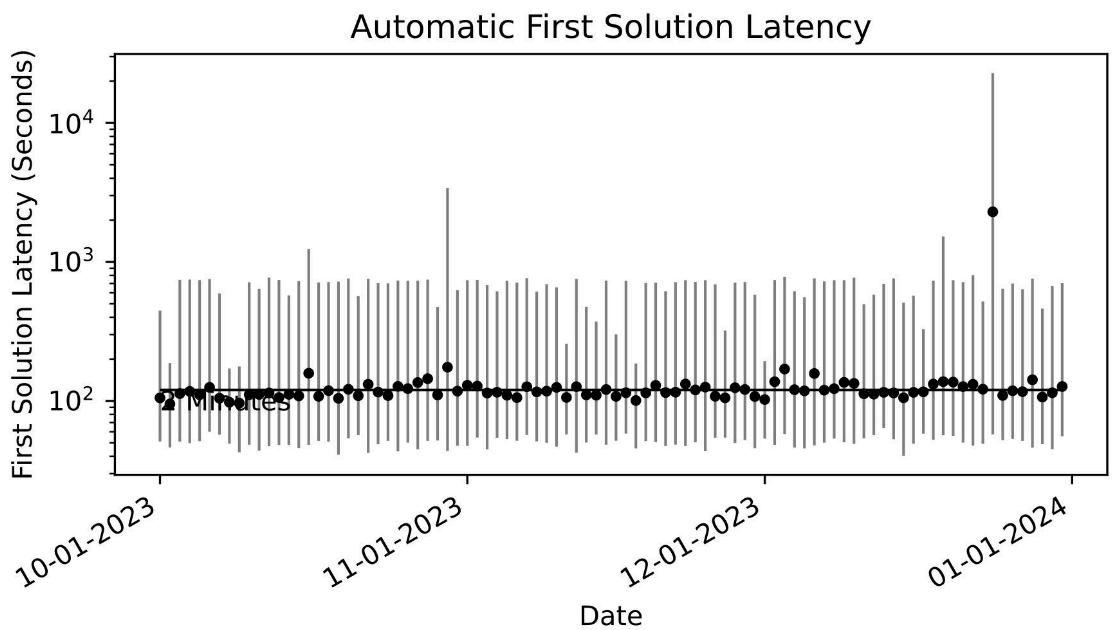


Figure 5.2. *Average daily latency (dots) and range (lines) of the first automatic solution for each event.*

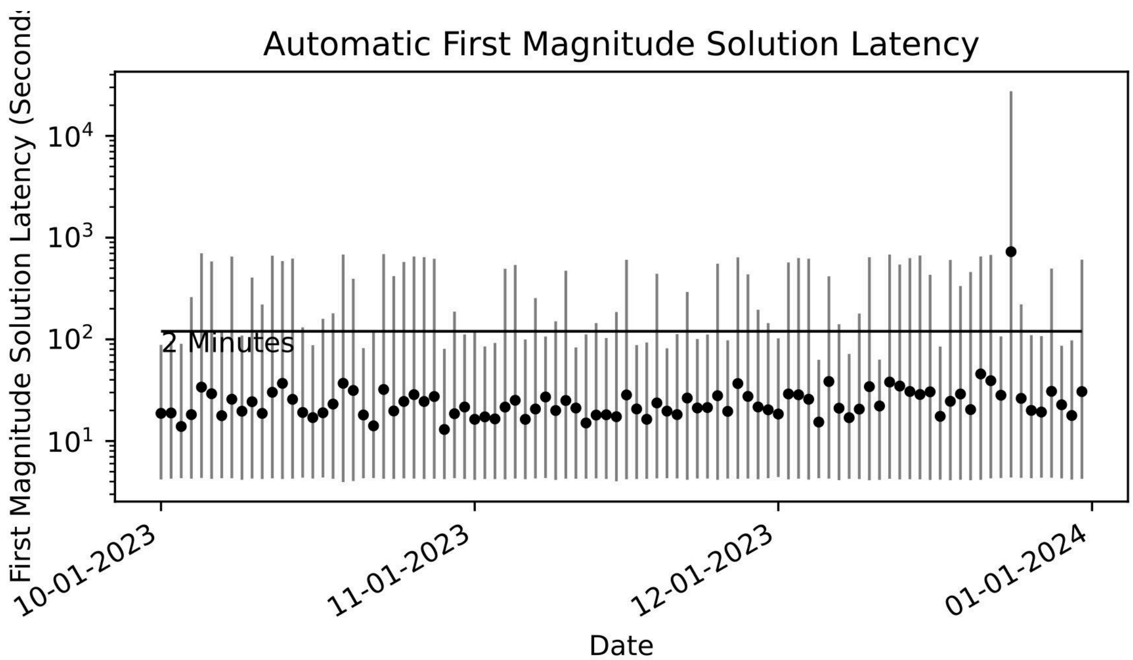


Figure 5.3. *Average daily latency (dots) and range (lines) of the first automatic magnitude for each event after the event detection.*

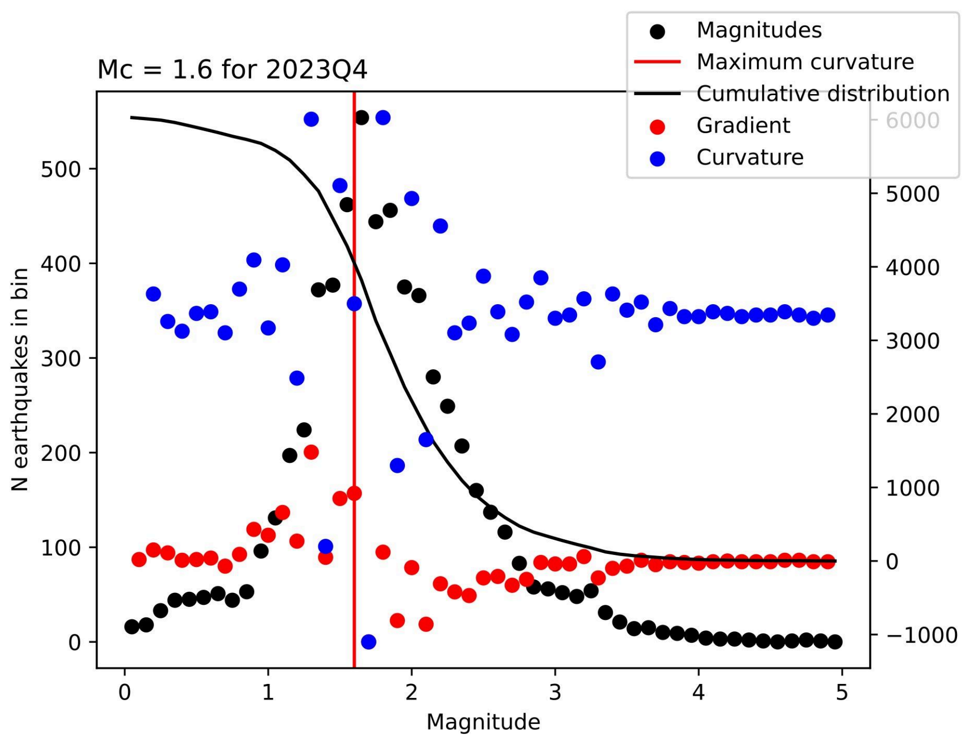


Figure 5.4*. Magnitude of completeness of the automatic catalog for the reporting time period.*

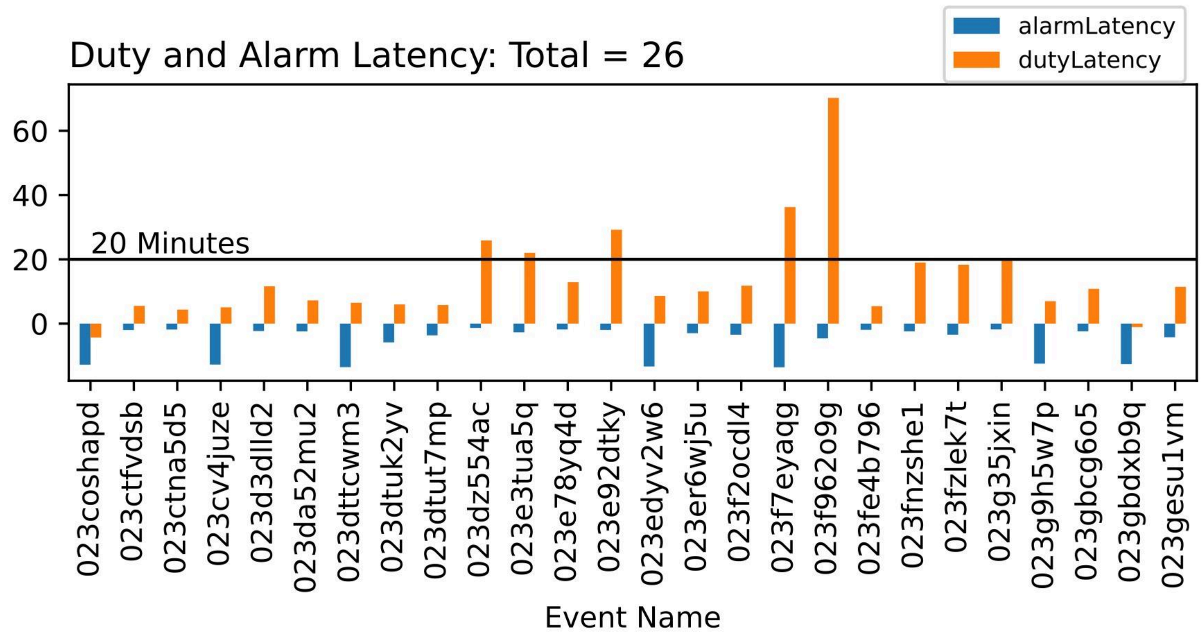


Figure 5.5. *Earthquake alarm and duty review latency from alarm time (bottom of the blue bar is origin time, top of the orange bar is duty review post time, 0 is time of the alarm). Earthquakes are labeled with their event names.*

6. Computer systems

6.1 Computer resources

The Earthquake Center operates a computing cluster hosting an enterprise-grade virtual environment for nearly all operational needs. During this quarter, we have worked with Research Computing Systems (RCS) to update our two in-rack network switches to the latest firmware version on December 19th. There were no major hardware changes during this quarter.

Current status is as follows:

Number of hosts	Total CPUs	Total CPU (GHz)	Total RAM (GB)	Total vSAN storage (TB)
4	96	258.62	1022.49	41.92

Resource utilization is as follows:

Virtual Systems				Operating System		
Production	Staging	Development	Users	CentOS	Windows	Ubuntu
29	28	12	6	65	3	8

6.2 Waveform storage

The Earthquake Center maintains a permanent archive of all available seismic data in the state in miniSEED format. Continuous waveforms have been stored since 1997, and segmented data is available from 1988-2012. Currently, AEC has 67.1 TB in continuous waveform data and 1.1 TB of segmented data. During the quarter, we acquired and archived 1.10 TB of new data (Figure 6.2.1).

6.3 Metadata

AEC maintains metadata in css3.0 format for internal use, and provides dataless SEED volumes to IRIS for public distribution. During this quarter, the following station entries were modified:

- No new stations added;
- Stations modified: SKN, BCP, SAMH, YAKA, UAFE_03
- No stations removed;

We have continued to add new station metadata into the Station Information System (SIS) during this quarter. At the end of this quarter, we have successfully loaded 155 sites into production SIS. These sites cover the entire Southern Tier adoption, as well as a few additional sites that shared a similar configuration with Southern Tier sites, and most strong-motion only sites within the network. We will continue to add sites to SIS in the coming quarter.

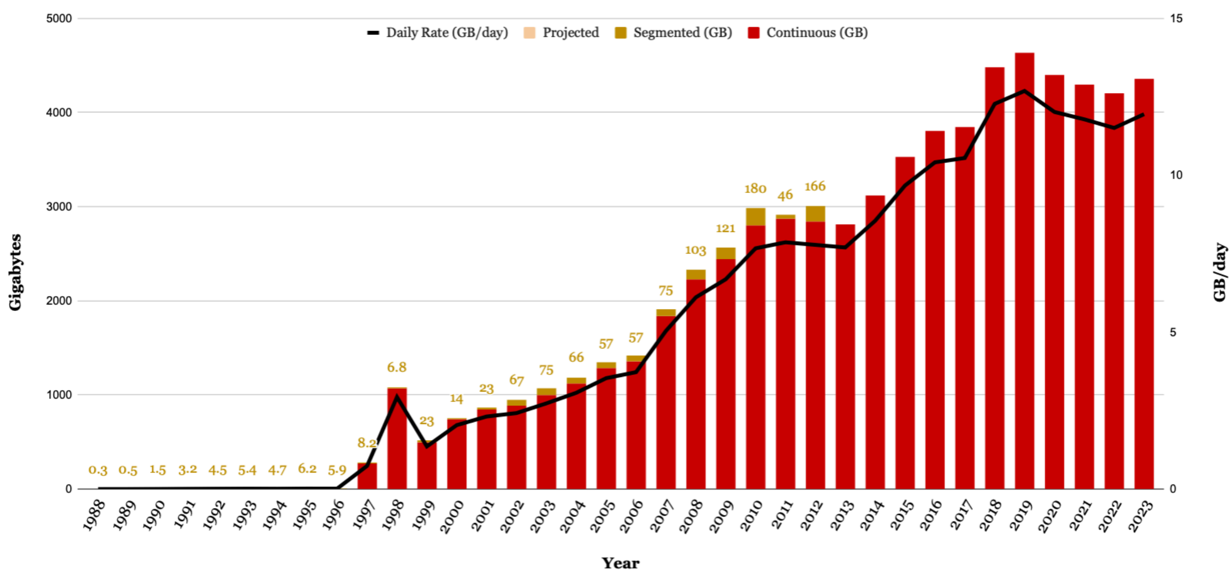


Figure 6.2.1. *Digital waveform archival storage for continuous (red) and segmented (brown) data.*

6.4 Software development

During this time, our active code branches under the following scopes of work were:

Antelope	Website	Real-time environments	Other
3	2	5	10

During Q4 of 2023, we updated the Mac OS version to Ventura and the Antelope version to 5.13 for laptops. We have also worked toward familiarity with Ubuntu as a Centos replacement. The team completed 95 IT Support tickets this quarter.

Most of our development this quarter was project-focused. The team spent significant time working on projects that update mission-critical and display functionality, such as a replacement for our webdlmon state-of-health monitoring website and building up an in-office display suite replacement. We also made significant progress in our Global navigation satellite system (GNSS) project and are now storing real-time 1Hz files of geodetic data on a virtual machine. This data has also been mounted on workstations. Several of these projects are expected to finish in 2024 Q1.

We have also finished implementing our two Synology diskstations as redundant waveform storage devices, ensuring that upon the failure of one device we can switch the mount point to the other with minimal interruption.

7. Fieldwork

During the fourth quarter of 2023, Earthquake Center staff visited 5 field sites over 6 field days to resolve telemetry-based data outages (100% of work total effort). Vehicles and commercial airplanes were used for 3 days each of the total 6 field days this quarter. Four staff members conducted visits, for a total of 10 person-days of site maintenance work during the fourth quarter of 2023. Of the total work effort performed, field crews departed stations with an 100% rate of successful resolution of station issues, with 1 site having issues that recurred and required another trip (local networking IP switching from the host).

The fieldwork completed during this quarter was in Fairbanks and Dutch Harbor/Aleutians. The Fairbanks work addressed two sites in the local strong motion network and dealt with networking IP issues. The Aleutian work consisted of two days' effort at site UNV, also troubleshooting local host internet access, but was ultimately resolved with a rapid hot-potato-style shipment of a new cell modem from Fairbanks to our collaborator in Anchorage and out to Dutch Harbor. The cell modem installation was successful and the site has remained online. While on island, we also assisted our collaborators at Earthscope with their AK09 station. We brought that online as well with components they had provided and handed off en route to the sites during an Anchorage layover.

8. Social media and outreach

The Alaska Earthquake Center maintains a vibrant and dynamic social media presence on Facebook and Twitter/X. We currently have 60,700 followers across the two platforms. Our social media posting strategy takes a multifaceted approach to public engagement. Social media is one of the primary ways that earthquake information is shared and that remains our primary focus. We also seek to highlight the human element of the center. We do not produce autogenerated posts. We aim to have 50% of our posts be related to recent earthquakes. The remaining 50% is divided between topics that highlight the various aspects of the center itself. We also acknowledge that we can fill a vital role in helping to amplify the messaging of our partner agencies.

The person who handled social media content and tracked metrics over the past year left the organization in October 2023. Additionally, metrics tracking changed significantly for Google Analytics and Facebook. Twitter/X metrics are currently undergoing change. As a result, quarterly report metrics are anticipated to change from report to report.

8.1 Website

We track website traffic using Google Analytics. On July 1, 2023, Google Analytics migrated to a new version, GA4, and stopped streaming data to its former version. Unfortunately, we lost data collection after July 31, and did not catch this loss until the third week of October 2023; thus, for this quarter we report the web traffic data we have for October 23 through December 31. In the new version, GA4 captures distinct user interactions under a single term, "event," which includes all clicks and interactions with embedded files.

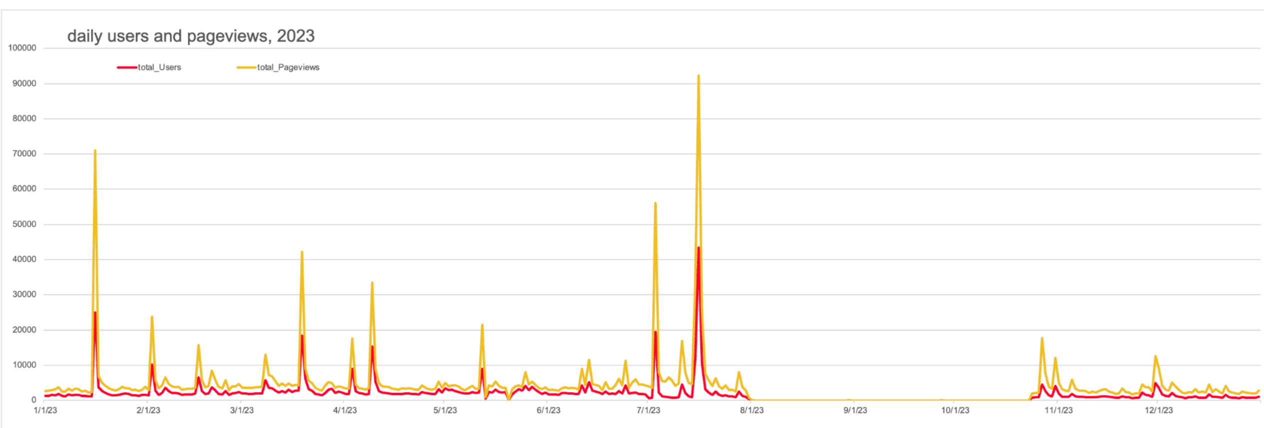


Figure 8.1.1. *Total number of website users (red) and pageviews (yellow) per day in 2023. The largest spike, on July 16, is due to the M7.2 Sand Point Earthquake.*

During this quarter, we had 238,000 website views and 618,000 events from October 23–December 31. The "slowest" day still had about 1,600 views (Figure 8.1.1). The peak visits were on October 27, with almost 18,000 views for the M5.3 Klukwan event. The recent earthquake list accounted for 50% of users during the reporting period. Many visitors (26%) also went directly to the home page during this quarter. Fig. 8.1.2 shows the distribution of page views for this quarter. More people visit our site on mobile devices (Figure 8.1.3). Tablets and mobile devices such as phones accounted for 68% of website sessions.

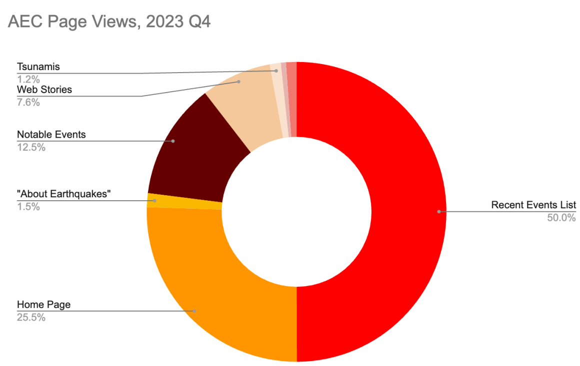


Figure 8.1.2. *Distribution of web pages accessed from Oct. 1 – Dec. 31, 2023. The main pages visited were the recent event list (50%), and the home page (26%). The two unlabeled slices are ShakeMaps at the top and reports to the left.*

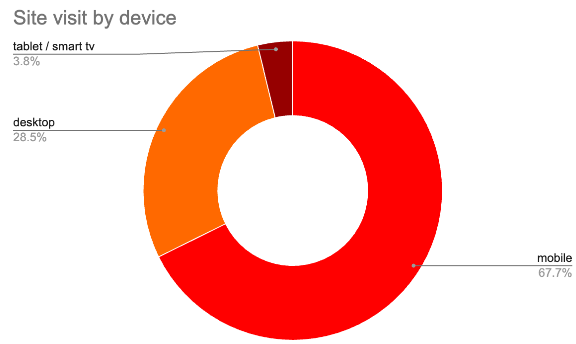


Figure 8.1.3*. Percentage of website sessions for the major device types: mobile (i.e., phones), tablets/smart tvs, and desktop.*

This quarter we published three website stories. One of our internal goals is to include a diversity of voices, with authors from different teams within the Earthquake Center. Authors work with Communications Team members to varying degrees to produce high-quality stories. The stories this quarter covered a range of topics, including an introduction into Earthquake Early Warning in Alaska, an earthquake in Southeast Alaska, and research from a former student intern using seismic and weather data from our stations. In December, we started working heavily on the Perspective 2024 articles, some of which may be adapted to website stories in the future. The website stories are promoted through our social media channels.

Table 8.1. *Website stories published this quarter. Website stories are written by Earthquake Center staff or students. Names in* ***bold italic*** *are students and postdocs affiliated with the Earthquake Center.*

Date	Author	Title
10/20	Beth Grassi	How to Make Earthquake Early Warning Work in Alaska
10/29	Natalia Ruppert	Faults Put the Squeeze on Glacier Bay Region
11/24	***Cade Quigley***	A Seismic Record in the Wind

8.2 Twitter/X

In the fourth quarter of 2023, we gained 93 followers, bringing our total following to nearly 26,700. We made 56 posts this quarter. Figure 8.2.1 shows the distribution of post types this quarter.

Figure 8.2.2 shows the number of posts made per day and the number of impressions per day for the entire year. Impressions represent the number of times our tweet is shown on a screen. Our average in Quarter 4 was 1,500 per day. The number of impressions does not scale directly with the number of posts based on the Twitter/X algorithm, as evidenced by the days with impressions and no posts. This is used to determine how often our followers view our posts. There were no significant spikes in impressions (Figure 8.2.2) during this quarter.

Our engagement rate with time (Figure 8.2.3) remained consistent during this quarter, averaging around 4%, with a high around 8% at the end of October, following two M>5 earthquakes in the Glacier Bay region.

Reviewed event posts continue to account for the majority of impressions and engagements (Fig. 8.2.4).

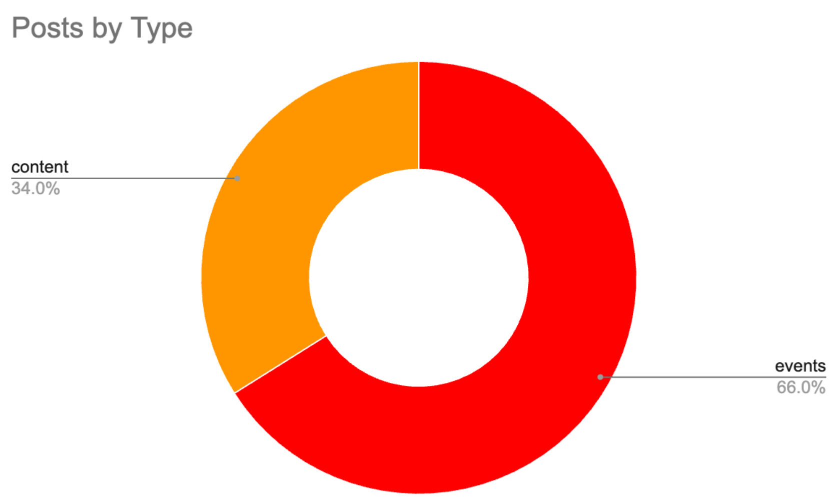


Figure 8.2.1. *Post type distribution for tweets for the fourth quarter of 2023.*

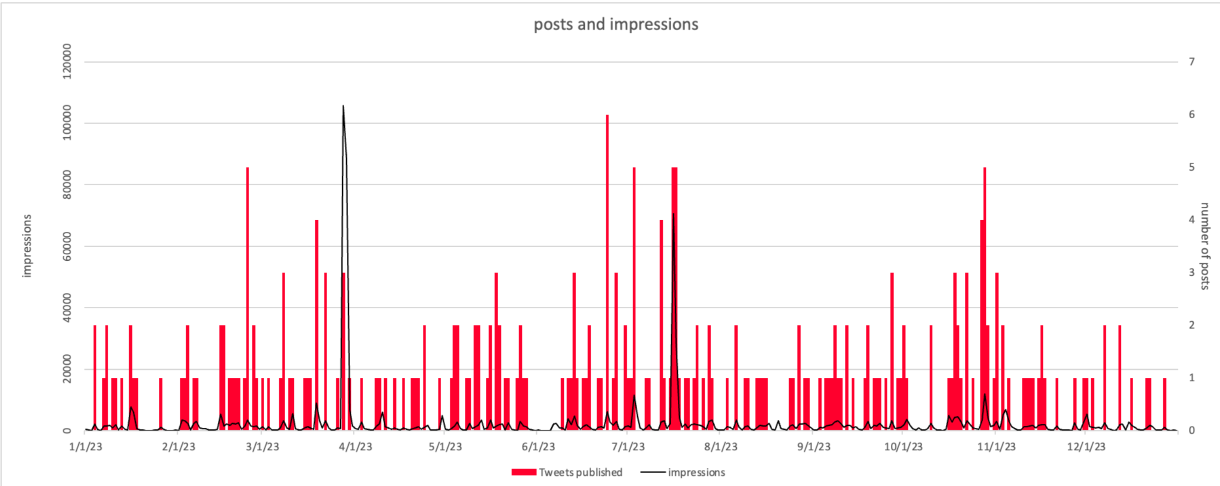


Figure 8.2.2. *Number of posts per day (right axis, red bars) compared to the number of impressions received per day (left axis, black line) in 2023.*

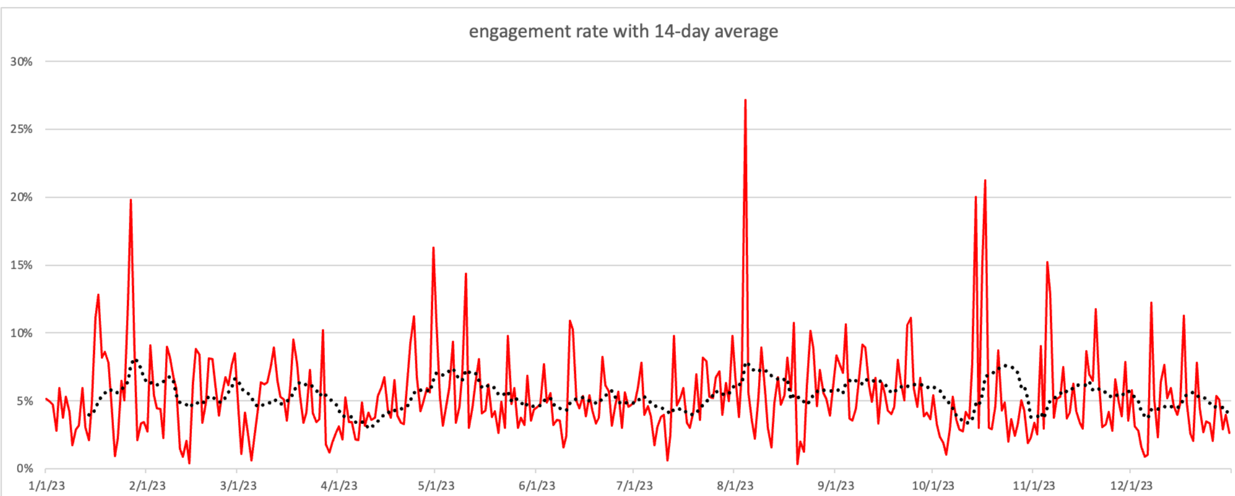


Figure 8.2.3. *Twitter engagement rates with time (red line) and 14-day moving average (black dotted line) in 2023.*

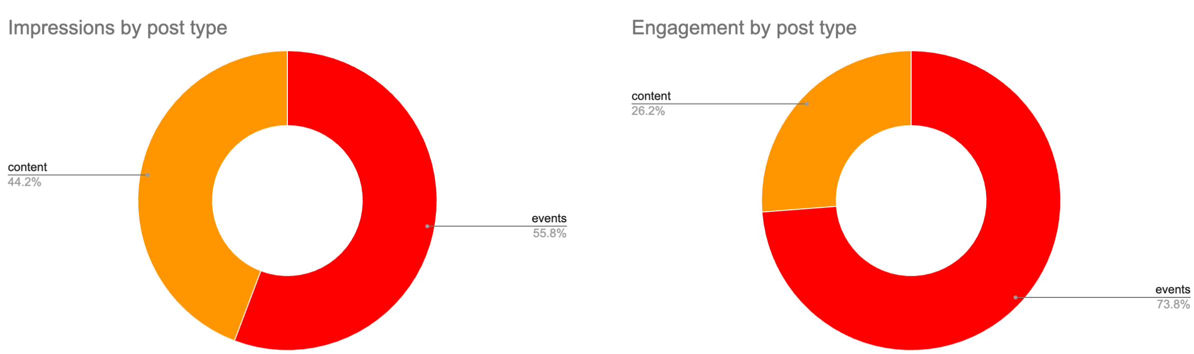


Figure 8.2.4. *Percentages of impressions and engagements based on tweet type.*

8.3 Facebook

Our Facebook Page was created in December 2020. Its main purpose is to give us the ability to track metrics, which can no longer be done for a Facebook Group. We created 86 posts for the Page in this quarter. Our Facebook Discussion Group, created in 2013, is mainly used to share content posted to our page, and allows group members to post (we review these posts first). Membership to the group remains high, at roughly 20,800. There were 103 posts and 130 new members to the Discussion Group in Q4.

Total Facebook Page "likes" grew by 468, to 13,704 in this quarter, and we had 15,708 total followers at the end of 2023. Oct. 4 and Oct. 8 received the greatest boosts in followers, directly after felt events in the Cook Inlet and Valdez regions, respectively. A post on Nov. 9 marking the anniversary of the 1938 Shumagin M8.3 received the greatest reach.

The distribution of post type is shown in Figure 8.3.1. Reviewed events accounted for 67% of the 81 posts made in the third quarter and represented 45% of reach. Thirty-three percent of posts were content-related, and represented 55% of reach. We stopped doing "Trivia Tuesday" and "Field-Work Friday" posts. Since our primary social-media staff member, Shila Cotton, left in Q3, we do not have the bandwidth for weekly Trivia Tuesday posting and follow-up with mailings.

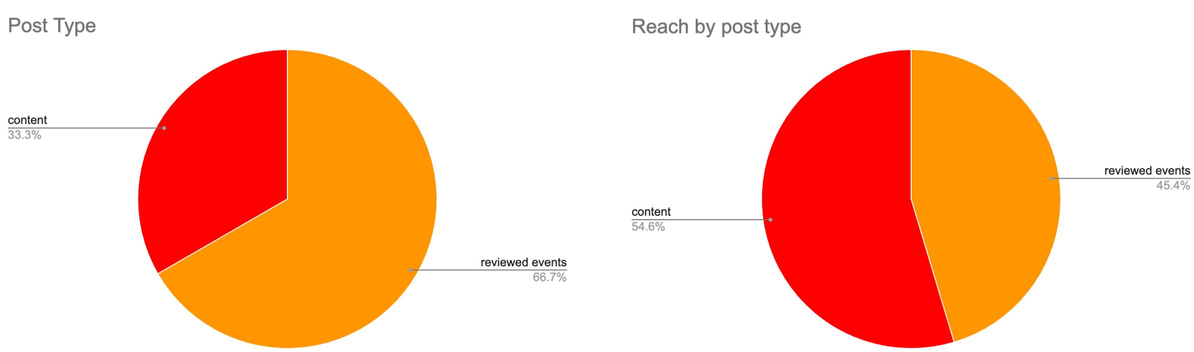


***Figure 8.3.1**. Distribution of Facebook Page posts by type (left) and audience reach by type (right).*

8.4 K-12 and community outreach

The Earthquake Center participated in, as well as organized, various K–12 and community outreach events during the fourth quarter of 2023. On October 7, Gabriel Low partnered with Jennifer Pickering from Anchorage School District/EarthScope ANGLE to offer a teacher training at Kodiak High School, focused on working with Raspberry Shake seismometers in the classroom. Beth Grassi gave a presentation to about 60 7th and 8th grade science classes at Barnette Magnet School, focusing on an overview of earthquakes in Alaska and including some hands-on use of the interactive maps and tools on our website. Elisabeth

Nadin and Beth gave tours of the Earthquake Center lab to a middle-school girl scout troop, undergraduate GeoLearning Community group, and students from the Pathways alternative high school program in Tok, Alaska, among others. Elena Suleimani visited multiple communities in the Kenai and Cook Inlet region where she had meetings with representatives of local governments and emergency services, visited schools and gave public lectures (Figure 8.4.1). See detailed list in Section 9.2.

***Figure 8.4.1**. Elena Suleimani and Barrett Salisbury (DGGS) meet with city officials in Hope, Alaska to discuss the upper Cook Inlet tsunami hazard assessment, which was published in August. This was part of a series of public presentations and meetings in upper Cook Inlet communities during September and October following up on the release of the assessment.*

On October 20, Gabriel and Carolyn Parcheta led a group of 14 Earth Observation Club students on a field trip to AEC station K216 during the Club Kickoff event hosted at University of Alaska Anchorage. Station K216 is at an AT&T cell tower near Flat Top Mountain just outside of Anchorage. High-school students traveled in from seven rural communities across the state to receive a technical introduction to sensors and remote monitoring equipment. Throughout the quarter, Gabriel continued to work with students participating in the Earth Observation Club. The students meet weekly via video conference and are working on remote sensing projects to address issues in their communities.

Figure 8.4.2. *Gabe Low (far left) and Carolyn Parcheta (back row, second from right) took students to visit station K216 to learn about instrumentation and remote sensing in the field.*

9. Publications and presentations

Names in **bold** are Earthquake Center staff. Names in ***bold italic*** are students and postdocs affiliated with the Earthquake Center, and names in *italic* are students and postdocs not directly affiliated with the center.

9.1 Publications

Quigley*, *C. A., **M. E. West (**2023). The Seismic Record of Wind in Alaska. *Bulletin of the Seismological Society of America,* doi: https://doi.org/10.1785/0120230097.

Ruppert, N. A., A. Farrell, B. Grassi, S. G. Holtkamp, G. Low, H. McFarlin, E. Nadin, C. Parcheta, M. E. West, and S. Wiser (December 2023). *Alaska Earthquake Center Quarterly Technical Report July-September 2023*. UA ScholarWorks, 53 pp., http://hdl.handle.net/11122/14769.

Schaefer, L. N., J. A. Coe, K. Wikstrom Jones, B. D. Collins, D. M. Staley, **M. West, E. Karasozen**, C. Miles, G. J. Wolken, R. P. Daanen, K. W. Baxstrom (2023). Kinematic evolution of a large paraglacial landslide in the Barry Arm fjord of Alaska. *Journal of Geophysical Research: Earth Surface*, 128, e2023JF007119. https://doi.org/10.1029/2023JF007119.

9.2 Public presentations

Please note, several September presentations were mistakenly not included in the previous quarterly report, so they are included in this summary.

Date	Presenter(s)	Event/Workshop	Title	Virtual/ In person
9/4	**Elena Suleimani, Dmitry Nicolsky,** Anthony Picasso	Whittier Fire Department	Tsunami preparedness in Whittier	In person
9/4	**Elena Suleimani,** Barrett Salisbury, Anthony Picasso	Alaska Wildlife Conservation Center at the head of Turnagain Arm	Tsunami preparedness in the WildlIfe Conservation Center	In person
9/5	**Elena Suleimani,** Barrett Salisbury	Cook Inlet Aquaculture Association Building, Kenai	New tsunami inundation maps for Cook Inlet communities of Kenai, Nikiski, and Ninilchik	In person
9/7	**Elena Suleimani,** Barrett Salisbury	Seldovia Tribal Association	Tsunami evacuation line and brochure for Seldovia	In person
9/7	**Elena Suleimani**	Seldovia Susan B. English school	Tsunamis in Alaska and around the world	In person
10/7	**Gabriel Low,** Jennifer Pickering (Anchorage School District, ANGLE)	Kodiak High School	Kodiak Raspberry Shake/ ANGLE Teacher Training	In person
10/13	**Beth Grassi,** LJ Evans (GI)	Girl Scout group (jr. high age)	Alaska Earthquake Center lab tour	In person
10/16	**Elena Suleimani,** Barrett Salisbury	Hope public library	Tsunami evacuation line and brochure for Hope	In person
10/16	**Elisabeth Nadin, Beth Grassi**	GeoLearning Community tour (12 UAF Geos students)	Alaska Earthquake Center lab tour	In person
10/17	**Elena Suleimani,** Barrett Salisbury	Girdwood public library	New tsunami inundation map for Girdwood	In person
10/18	**Elena Suleimani,** Barrett Salisbury	Mat-Su Assembly Chambers in Palmer	New tsunami inundation map for Matanuska-Susitna Borough	In person
10/19	**Elena Suleimani,** Barrett Salisbury	Anchorage Office of Emergency Management	New tsunami inundation map for Anchorage area: presentation for first responders	In person

Date	Presenter(s)	Event/Workshop	Title	Virtual/ In person
10/19	**Elena Suleimani,** Barrett Salisbury	Anchorage Assembly Chambers in Anchorage Public Library	New tsunami inundation map for Anchorage area: presentation for the public	In person
10/20	**Elena Suleimani,** Barrett Salisbury	Anchorage Assembly Chambers in Anchorage Public Library	New tsunami inundation map for Anchorage area: presentation for the public	In person
10/24	**Elena Suleimani**	Alaska Geotechnical Advisory Commission monthly meeting	New tsunami inundation mapping study for Upper Cook Inlet	Virtual
11/15	**Beth Grassi**	Barnette Magnet School 7th and 8th grade science classes (teacher: Christy Shaw, 2 classes)	What's Shaking in Alaska: Earthquakes and Tsunamis (overview and history, website activity)	In person
11/15	**Elena Suleimani**	Whittier City Assembly	Upcoming new Whittier tsunami hazard study	Virtual
12/7	**Beth Grassi**	Pathways program (an alternative high school program) in Tok, with some non-traditional students.	Alaska Earthquake Center lab tour	In person
12/11	**Ezgi Karasözen,** ***Gabrielle Davy,*** **Michael E. West,** Brian Collins, Mason Einbund, John Lyons, Charles Miles, Dennis Staley, *Liam Toney*	2023 American Geophysical Union Annual Meeting	Can a diverse array of monitoring techniques reveal insights into precursor activity in the Barry Arm Landslide, Alaska?	In person (poster session)
12/11	**Ezgi Karasözen,** Pinar Buyukakpinar, Deniz Ertuncay, Emre Havazli, Elif Oral	2023 American Geophysical Union Annual Meeting	A call from early-career Turkish scientists: seismic resilience is only feasible with “earthquake culture”	In person (poster session)
12/11	**Elisabeth Nadin**	Lab Tour for Wainwright the Environmental Community Partnership	Alaska Earthquake Center lab tour	In person
12/12	Patrick Matulka, Douglas Wiens, Zongshan Li, Geoffrey Abers, **Natalia Ruppert**	2023 American Geophysical Union Annual Meeting	Rupture of many parallel strike-slip faults during the 2018 Mw 7.9 Offshore Kodiak Earthquake	In person (poster session)

9.3 GI Geoscience lunch seminar talks

The talks are informal opportunities for faculty, staff, students, and guest speakers to present their research.

Date	Presenter	Title	Virtual/ In person
11/28	Bella Seppi, UAF graduate student	Seismic Soundscape of Parks Highway, Central Alaska	Hybrid

10. References

Ruppert, N. A. (February 2023), *2022 Alaska Seismicity Summary,* UA ScholarWorks, 21 pp., http://hdl.handle.net/11122/13139.

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., and L. Gardine (February 2022). *2021 Alaska seismicity summary*. ScholarWorks@UA, 23 pp, http://hdl.handle.net/11122/12683.

Ruppert, N. A., A. Farrell, B. Grassi, S. G. Holtkamp, G. Low, H. McFarlin, E. Nadin, C. Parcheta, M. E. West, and S. Wiser (December 2023). *Alaska Earthquake Center Quarterly Technical Report July-September 2023*. UA ScholarWorks, 53 pp., http://hdl.handle.net/11122/14769.

Appendix A: Data availability for broadband stations from the AK network.

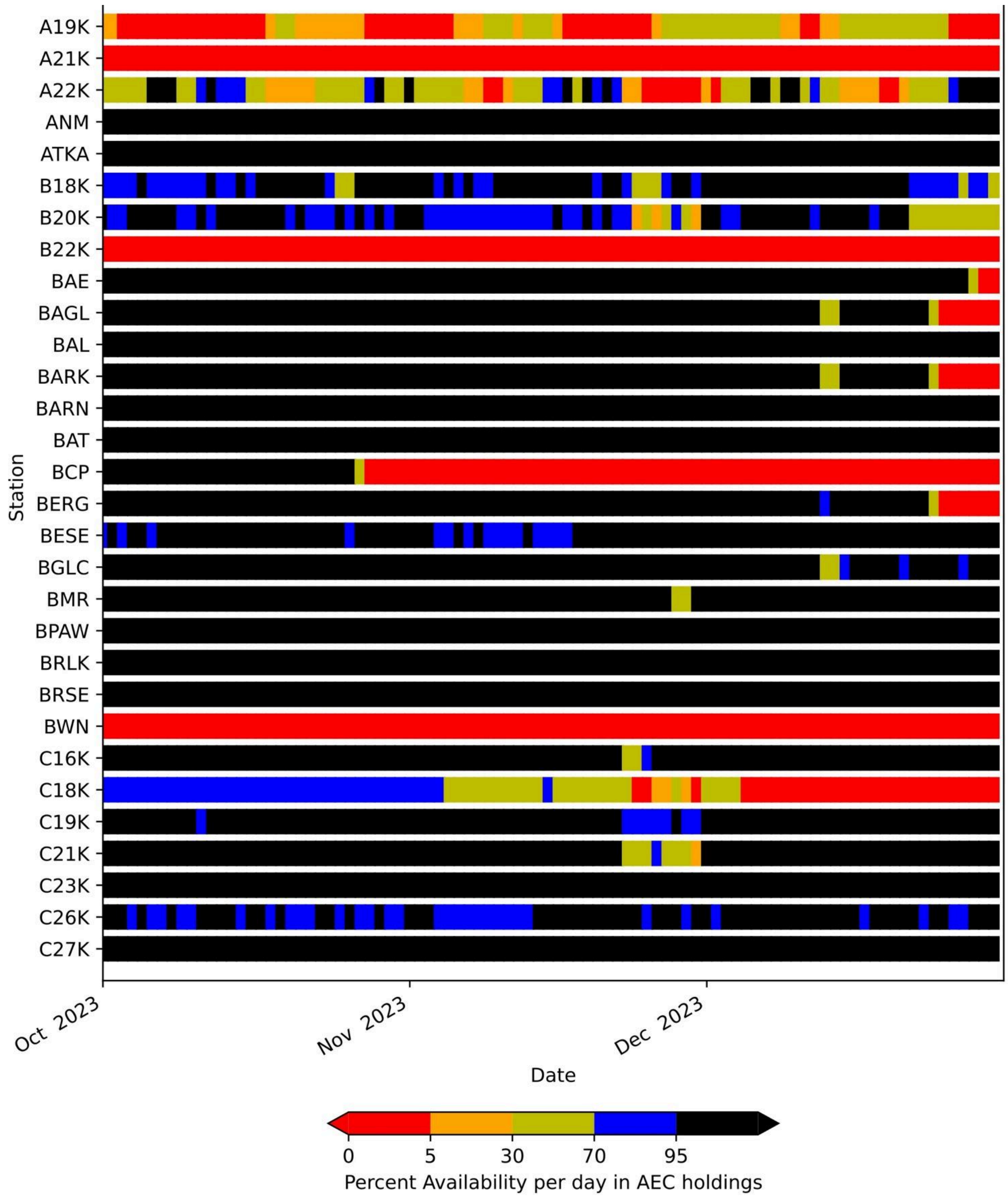


***Figure A1**. Data availability for stations A19K-C27K (listed alphabetically).*

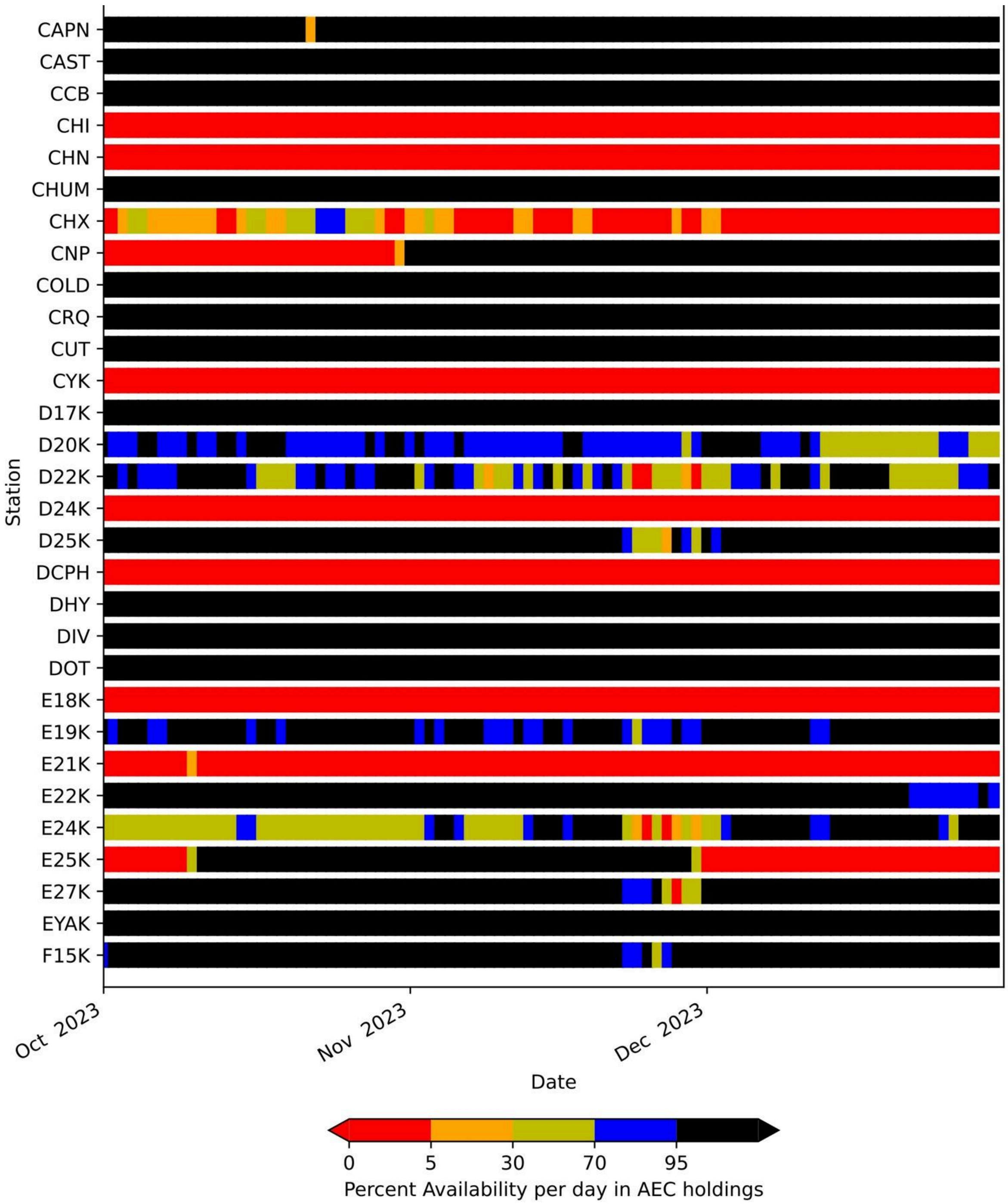


Figure A2*. Data availability for stations CAPN-F15K (listed alphabetically).*

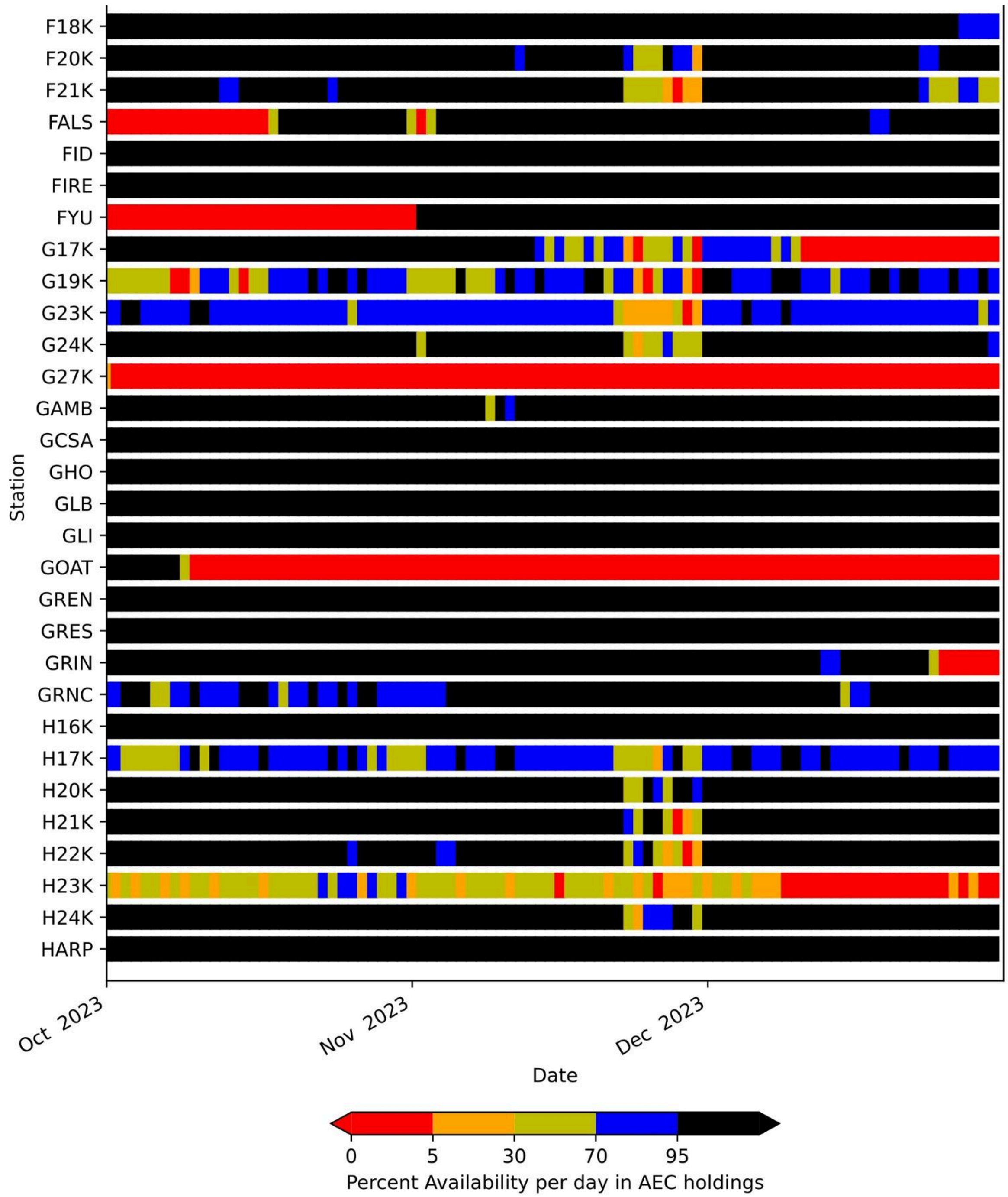


***Figure A3**. Data availability for stations F18K-HARP (listed alphabetically).*

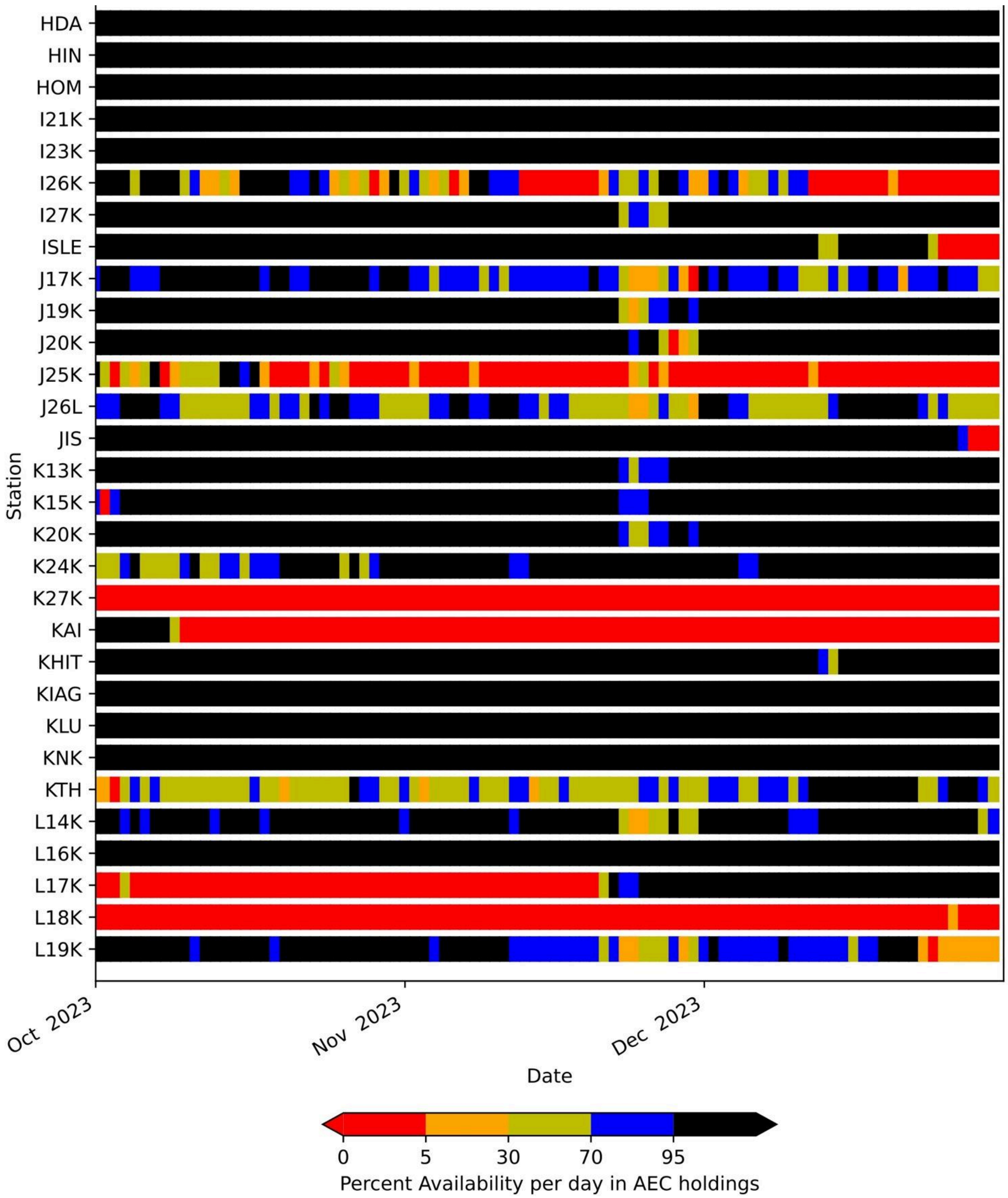


***Figure A4**. Data availability for stations HDA-L19K (listed alphabetically).*

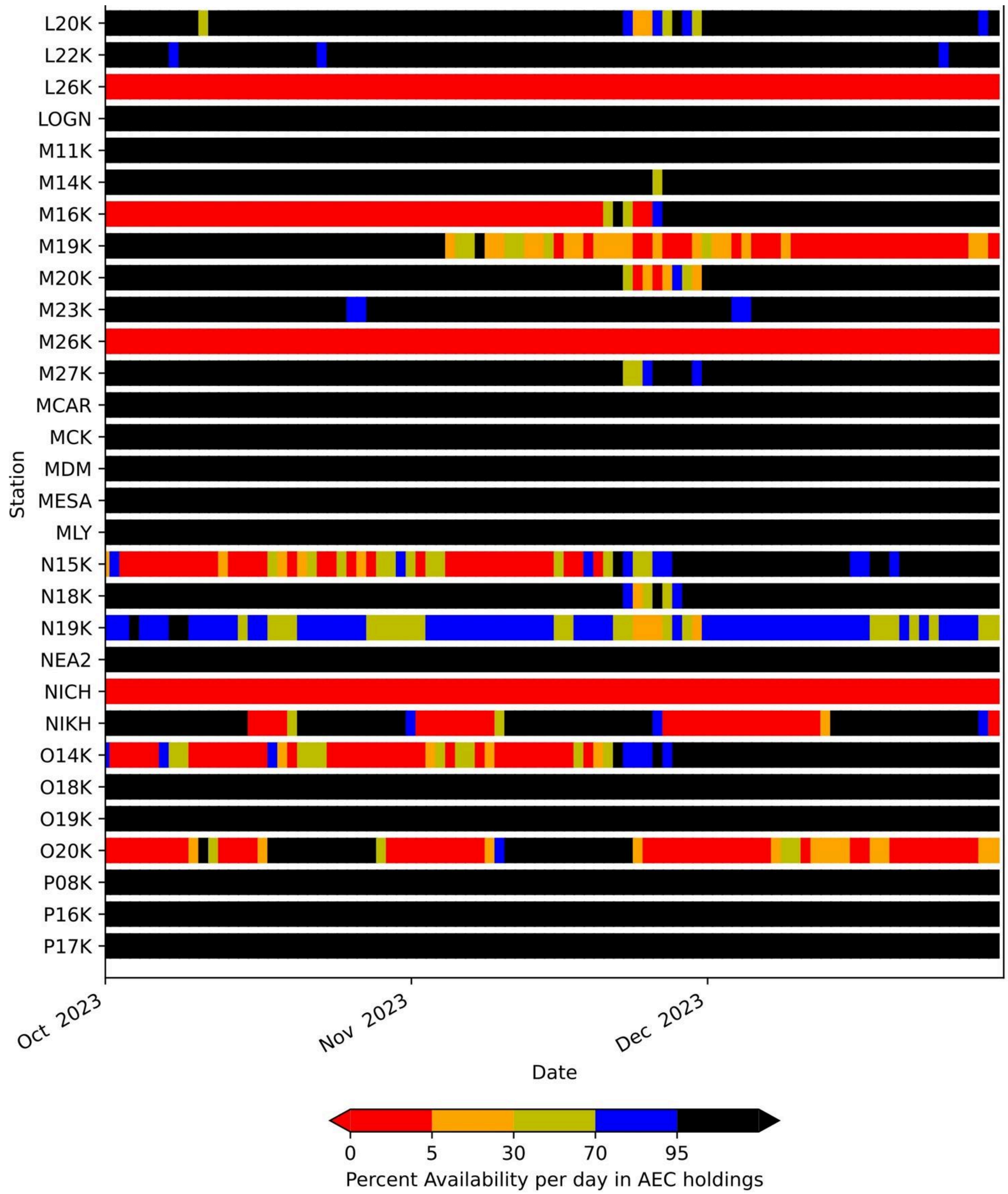


***Figure A5**. Data availability for stations L20K-P17K (listed alphabetically).*

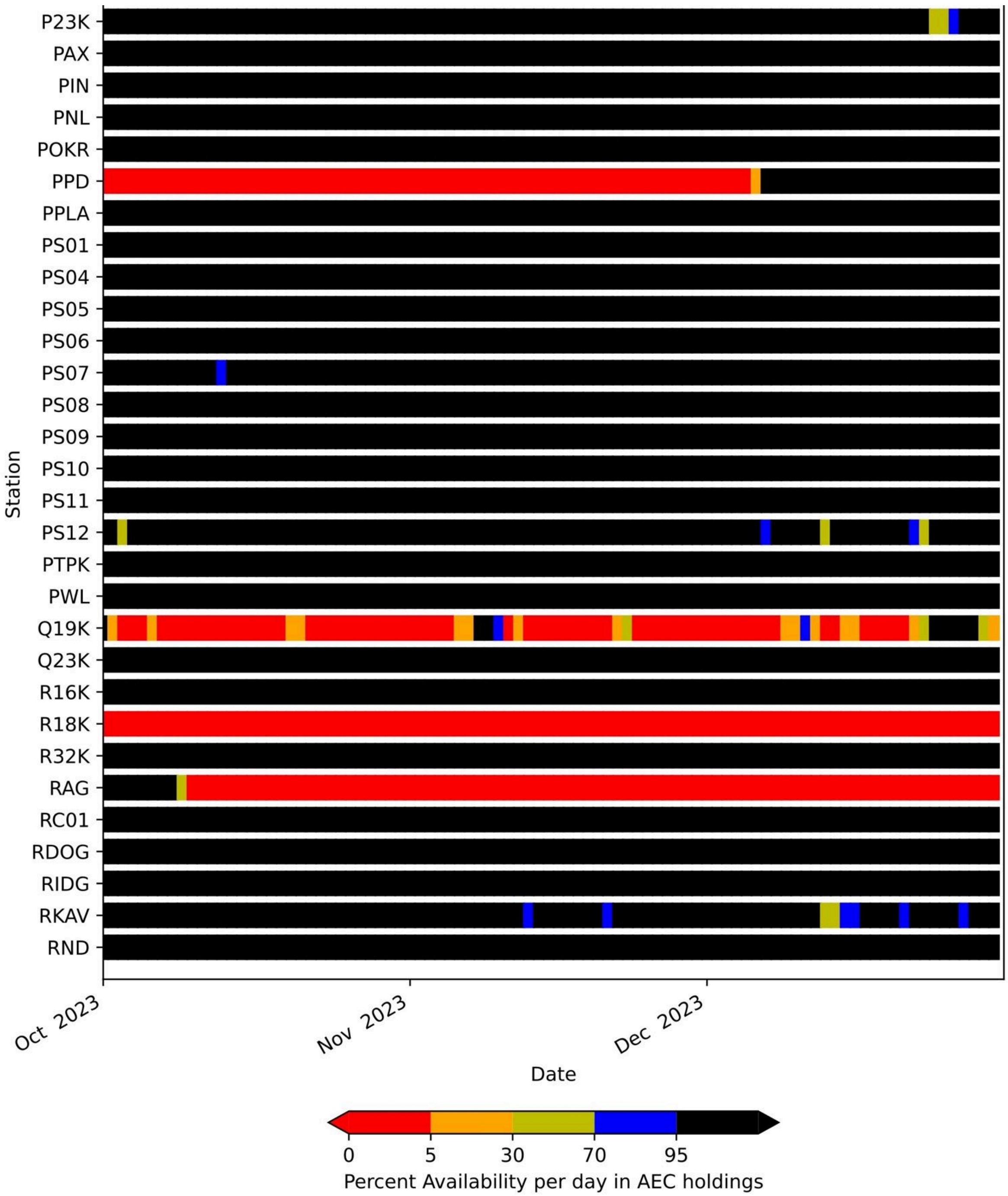


Figure A6. *Data availability for stations P23K-RND (listed alphabetically).*

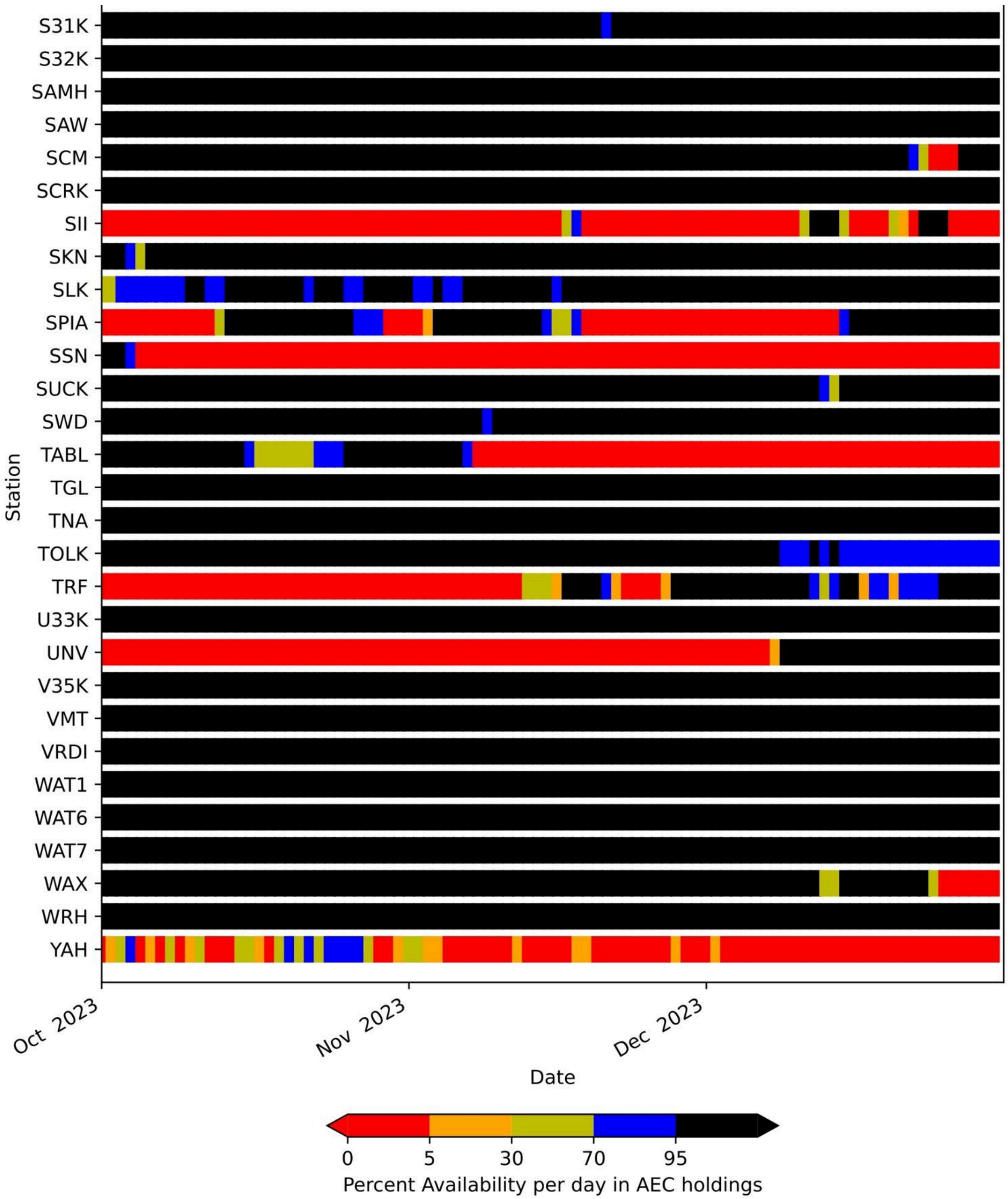


***Figure A7**. Data availability for stations S31K-YAH (listed alphabetically).*

Appendix B: Gaps for broadband stations from the AK network.

***Figure B1**. Number of gaps per day[1] for stations A19K-CAPN (listed alphabetically).*

[1] Stations with 0% data availability are denoted in the same color as stations with 0 gaps.

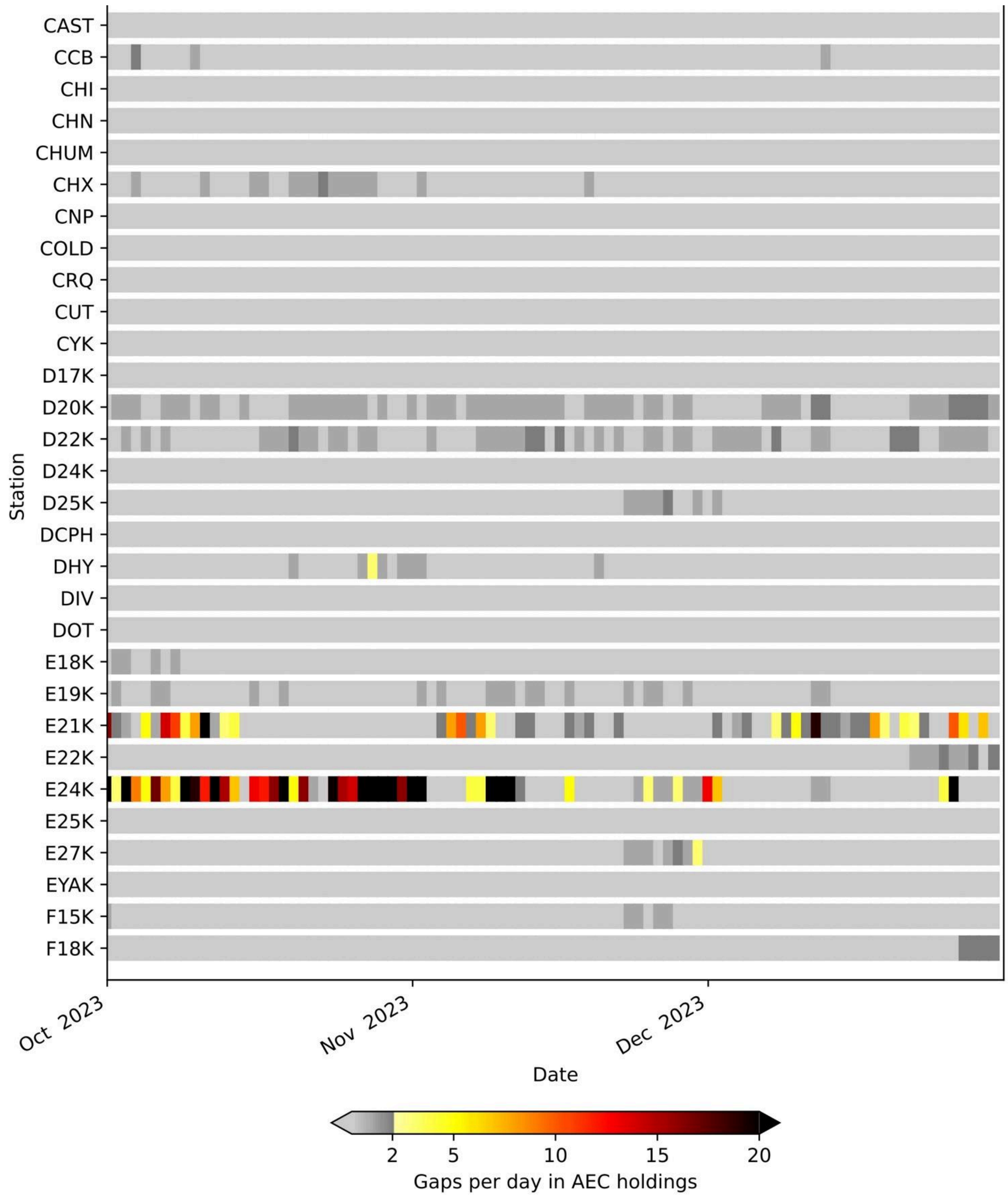


***Figure B2**. Number of gaps per day for stations CAST-F18K (listed alphabetically).*

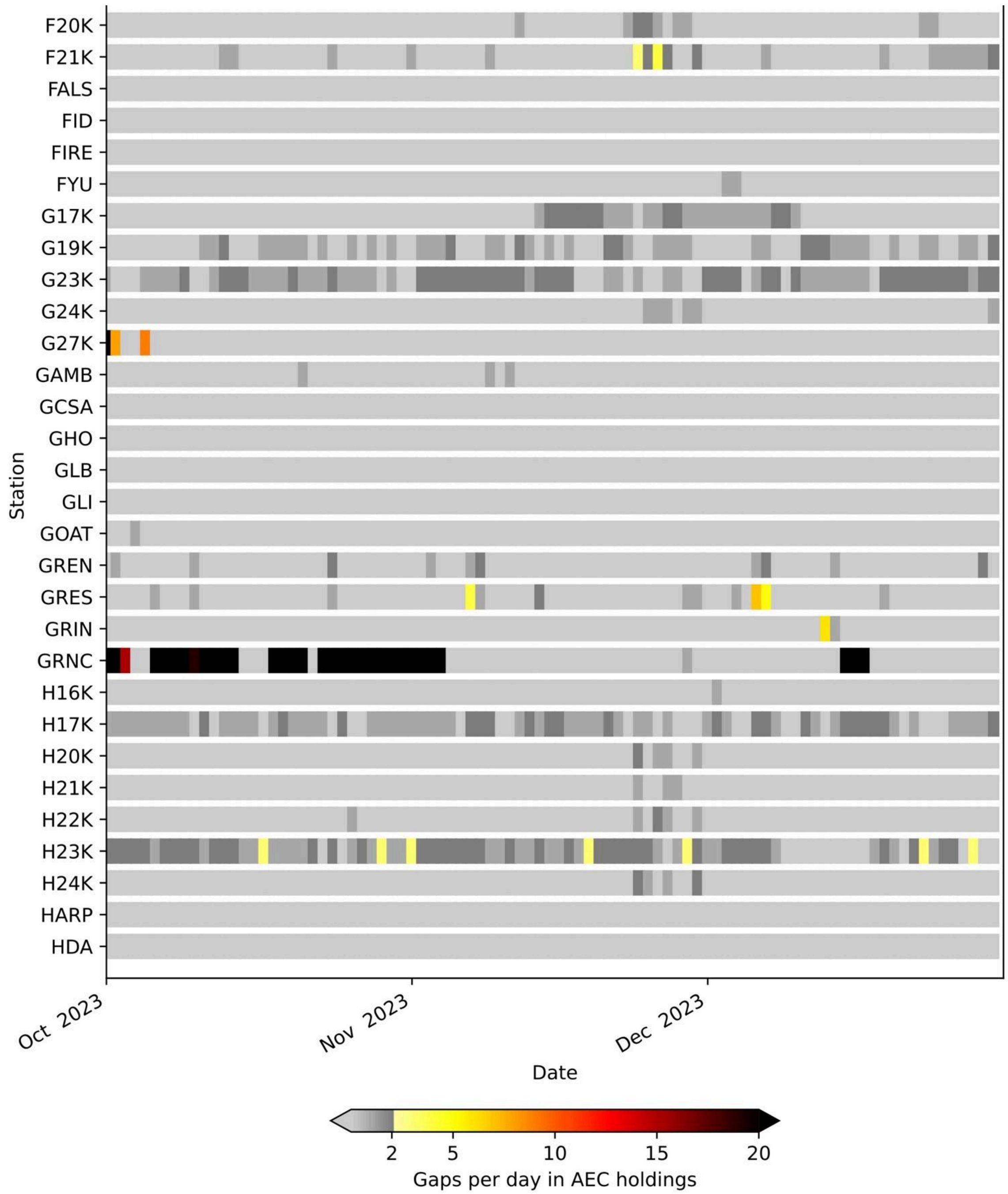


***Figure B3**. Number of gaps per day for stations F20K-HDA (listed alphabetically).*

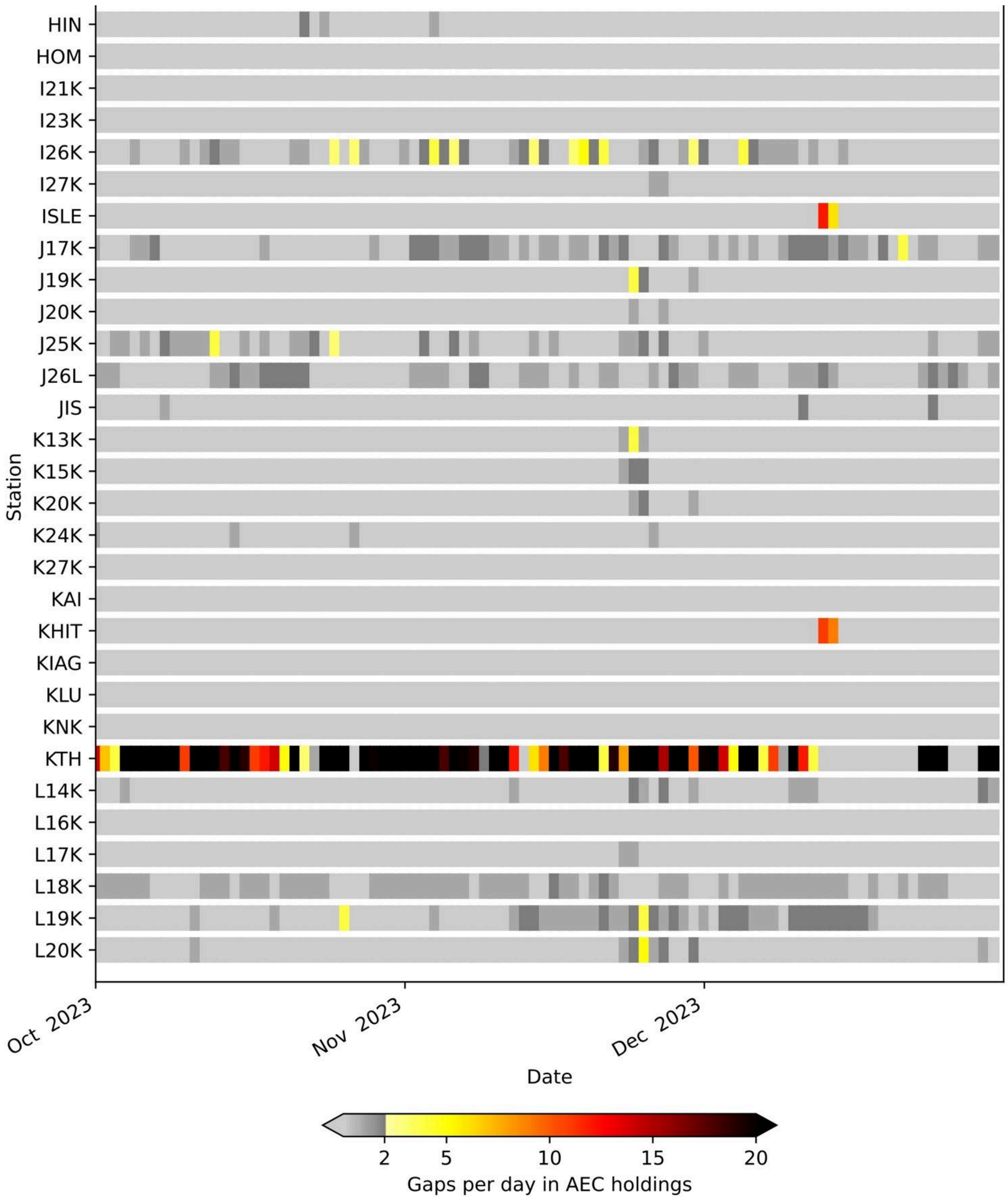


***Figure B4**. Number of gaps per day for stations HIN-L20K (listed alphabetically).*

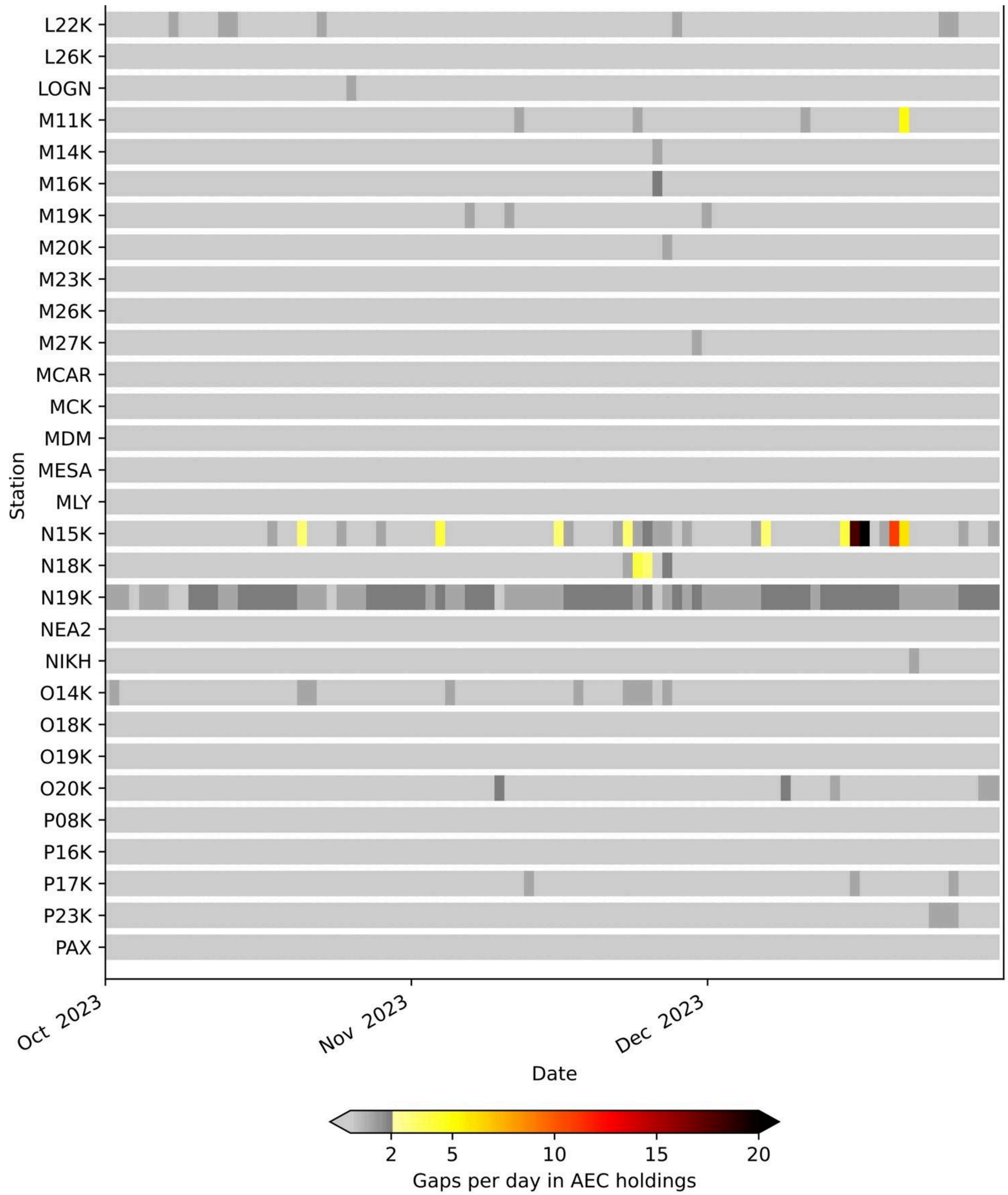


***Figure B5**. Number of gaps per day for stations L22K-PAX (listed alphabetically).*

***Figure B6**. Number of gaps per day for stations PIN-S32K (listed alphabetically).*

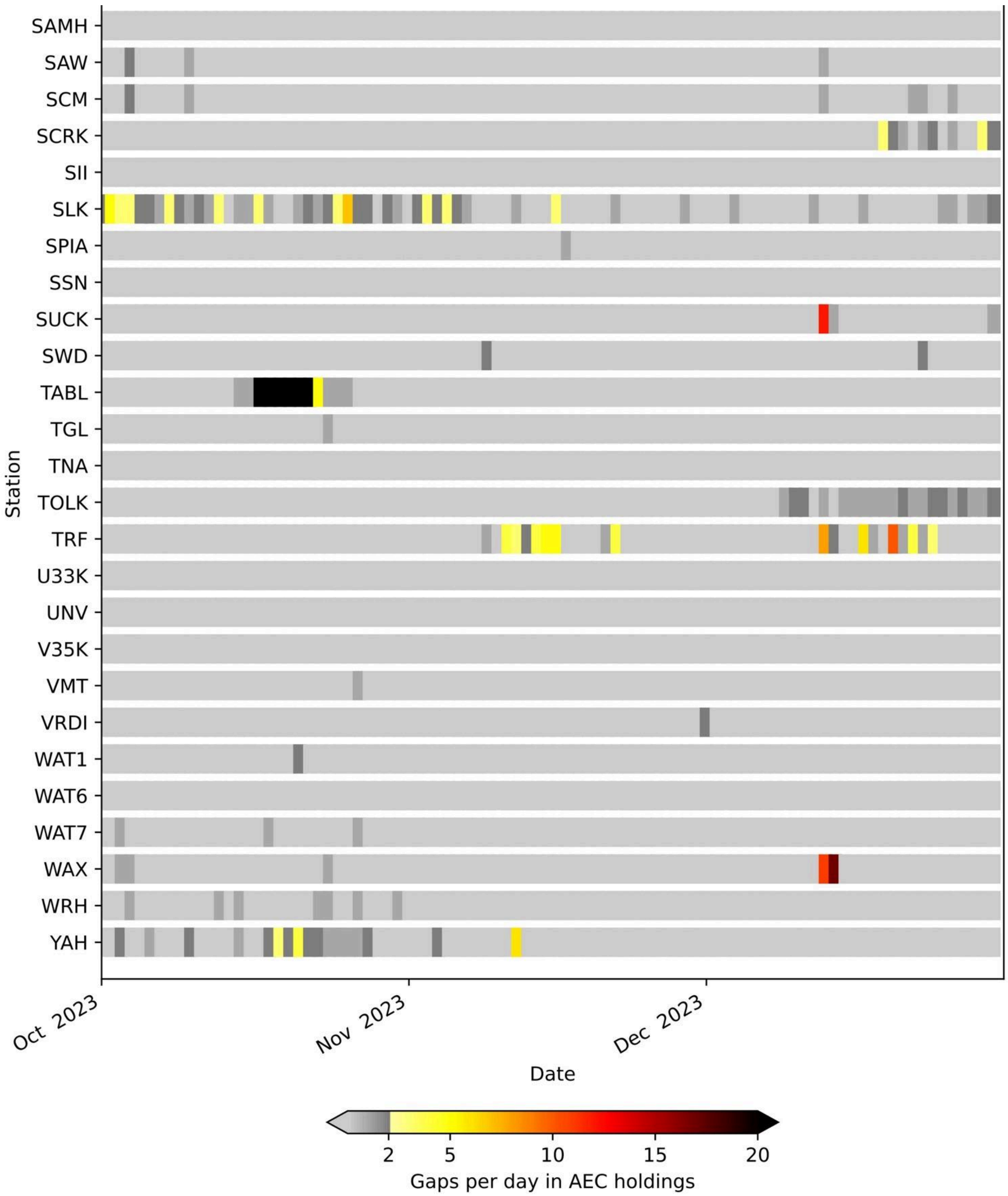


***Figure B7**. Number of gaps per day for stations SAMH-YAH (listed alphabetically).*