Final Technical Report

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1. Abstract

In recent years, ANSS support to the Alaska Earthquake Center has evolved into two tranches: our five-year cooperative agreement that supports data analysis and separate awards (including this one) that support field operations, data acquisition and dissemination, and partial product support.

As of December 31, 2023, AEC maintains and acquires data from 252 seismic sites of the Alaska Geophysical Network (https://earthquake.alaska.edu/network, Figure 1). Some of these sites are maintained under other dedicated awards, but all are used in our unified acquisition and processing system to generate ANSS data products. The sites can be divided into the following groups based on their locations and sensor types:

- 206 free field broadband stations, 89 of which have co-located strong motion sensors, and 7 of which have GNSS sensors;
- 25 strong motion sensor sites in the greater Anchorage and Mat-Su Valley region (Figure 2);
- 9 strong motion sensor sites in Fairbanks;
- 9 strong motion sensor 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).

- 5 sites were decommissioned during the reporting period due to poor performance or permitting stipulations.

The proposal that led to this award outlined six tasks. Activities for these tasks are provided in the sections that follow.

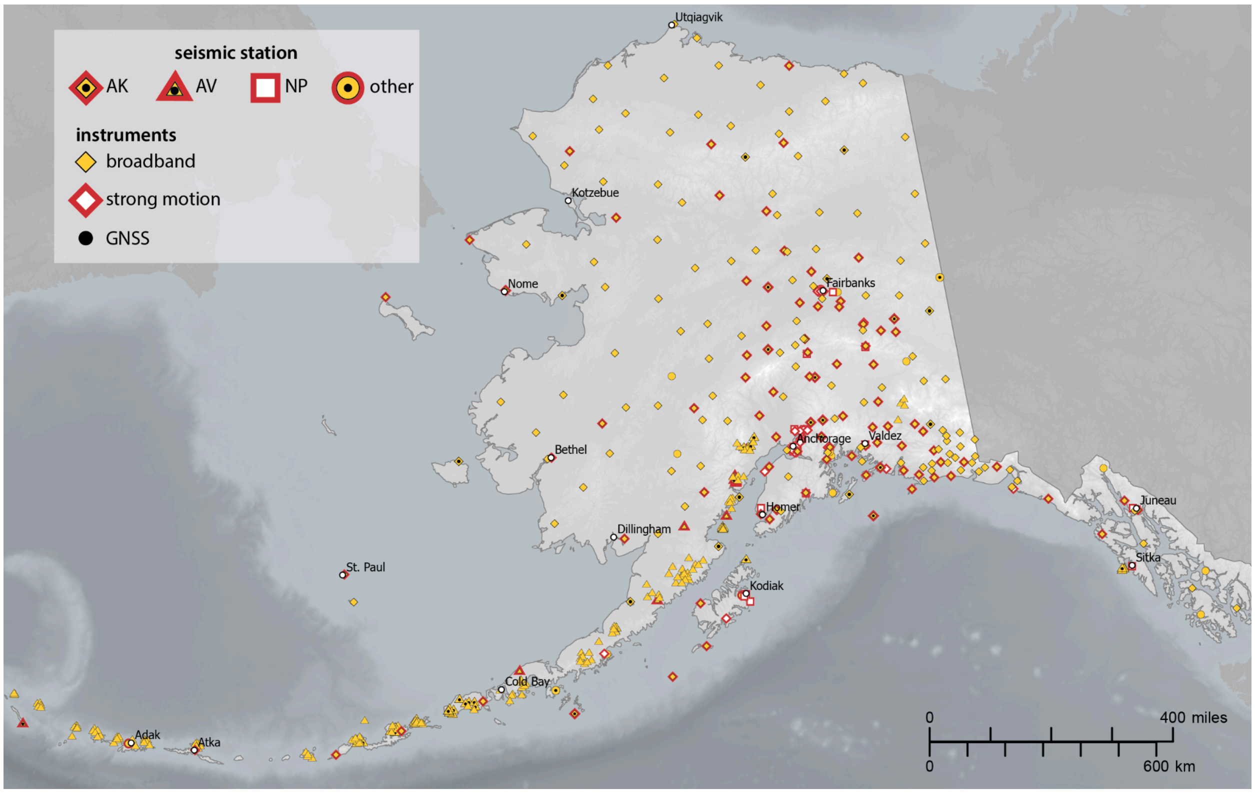

Figure 1. *Alaska Earthquake Center geophysical field network map*

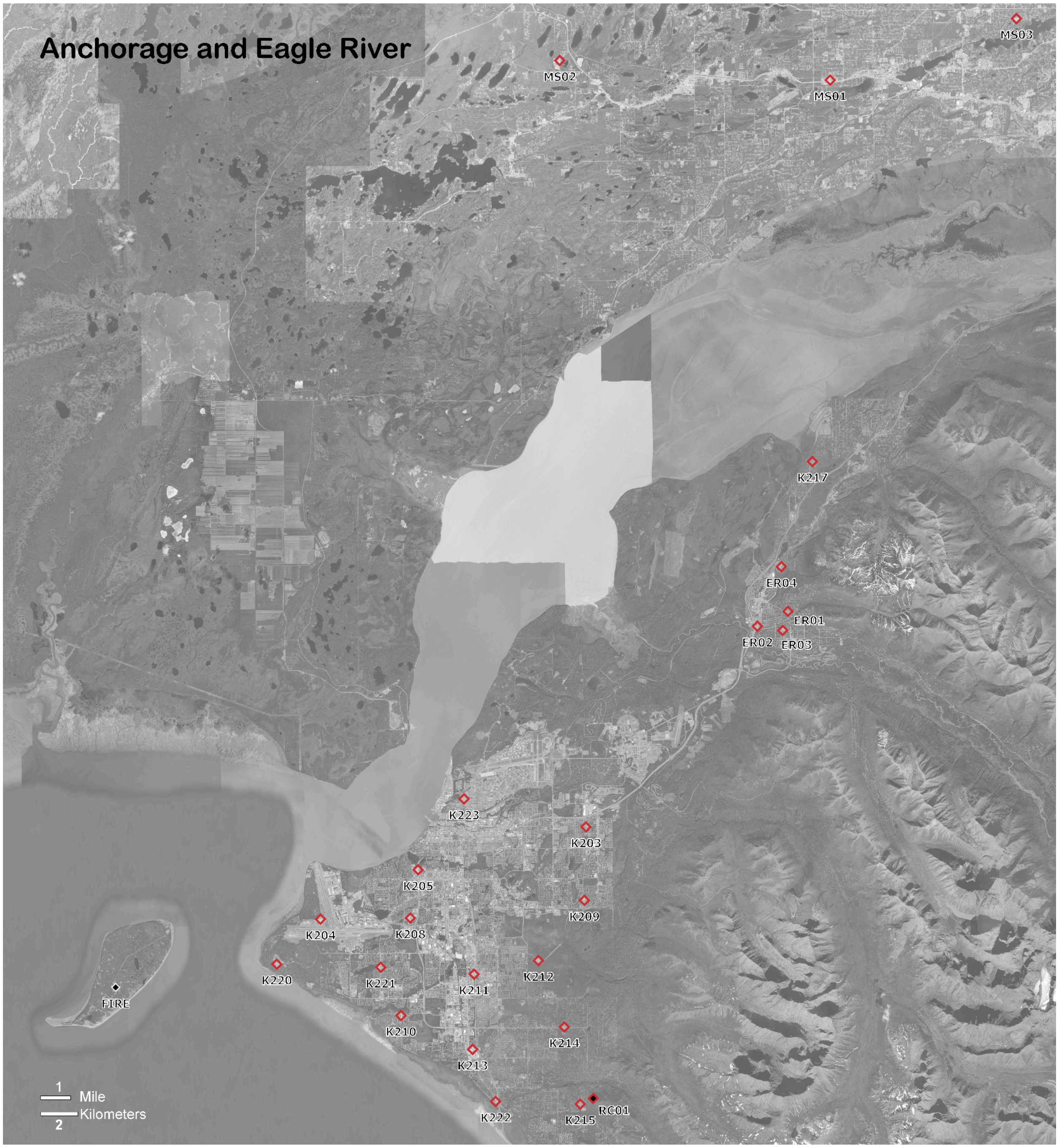

Figure 2. *Anchorage Strong Motion Network map*

2. Task: Field support and Task: Field transportation

Field season planning for 2022 and 2023 began with an assessment of maintenance needs at each site based on the previous year's field notes, diagnostic information collected on power and telemetry systems during the non-field season, waveforms QC reports, and trouble tickets. This planning work was carried out by our field technicians and engineers in the late winter/early spring prior to each season (May – October).

We prioritized sites and areas which contributed to data loss for both seasons. Fieldwork was conducted mostly via dedicated helicopter charters, with some sites accessible via road access, commercial air, and fixed-wing charters. We utilized multiple hubs for staging our fieldwork, specifically, we worked out of Anchorage, Fairbanks, Utqiagvik, Prudhoe Bay, Kotzebue, Bethel, Girdwood, Valdez, Cordova, Yakutat, and Juneau. Most air carrier contracts had to be in place weeks and sometimes months ahead of actual field campaigns due to competition from the mining and tourism industries. While the majority of this work was performed under ANSS support, a few dozen sites are tied closely to non-ANSS awards. The Field Logistics Coordinator role did not carry through for the 2022 and 2023 seasons, and that duty was shared between the Executive Assistant and the Field Operations Manager.

The 2022 season leveraged 8 AEC staff field members for 356 person-days in the field. Of the 8 field-specific staff, five were new hires and trained throughout the summer. A total of 29 campaigns were conducted for 132 site visits to perform maintenance. The field season work focused on resolving station outages from power (17 sites) and telemetry issues (12 sites) as well as removal and clean-up of two decommissioned sites. The field teams also completed new sensor installations, including GNSS at BAT and E22K, five new strong-motion sensors at existing sites, and two new strong-motion sensor sites in Bethel (in cooperation with the University of Alaska Anchorage Engineering Department). Four Anchorage strong motion sites were upgraded with Etna-2 sensors.

The 2023 season leveraged 8 AEC staff field members for 313 person-days in the field. A new Field Operations Manager was hired at the start of the field season. A total of 26 campaigns were conducted for 130 site visits to perform maintenance. The 2023 field season work resolved multiple station outages from power (7 sites) and telemetry issues (57 sites). We also scouted out logistics for the demobilization of two problem sites, one due to high noise issues and another due to repeated bear vandalism. The field teams also completed new sensor installations, including adding GNSS and strong-motion sensors at existing sites and replacing aging Basalts with Etna2 sensors at urban strong-motion network sites. A half dozen sensor swaps were performed for posthole instruments to improve data quality. One station (A22K) had to be completely rebuilt after a polar bear destroyed the site once it gained access to the hut interior and posthole by removing the door and lid respectively. Several other sites experienced various degrees of damage from bear vandalism.

3. Task: Field instrumentation

Our instrumentation updates included new installations and replacements of faulty dataloggers, broadband, or strong motion sensors:

- We added new boreholes and posthole broadband sensors to two existing sites in Southern Alaska using the TA portable drill.
- We replaced Q330 dataloggers at 11 sites, including replacements of 3-channel units with 6-channel units at several sites to accommodate additions of strong motion sensors.
- In line with expanding our strong motion coverage within the network, we installed new strong motion instruments at seven existing sites and replaced malfunctioning strong motion instruments at several other sites.
- We installed two new strong-motion sensor sites in Bethel in cooperation with the University of Alaska Anchorage Engineering Department. The purpose of this project is to study wave propagation in permafrost.
- Four Anchorage, one Fairbanks, and one Yakutat strong motion sites were upgraded with Etna-2 sensors.
- We installed four new GNSS receivers, co-located with existing seismic sites already equipped with broadband and strong motion sensors.

- We replaced malfunctioning shallow vault broadbands at four sites and posthole broadbands at five sites.
- We installed new Q8 dataloggers (next-generation Quanterra dataloggers from Kinemetrics) at four sites. We keep evaluating this new technology for potential roll-out to replace the aging fleet of Kinemetrics Q330 loggers.
- We continue evaluating the performance of Nanometrics Centaur dataloggers installed at two sites on Fort Greely missile fields.

We worked on power systems repairs and hardening at dozens of sites:

- Replaced aging/broken solar panels and added supplemental solar charging capacity at multiple sites.
- We replaced lead-acid battery banks at nine sites, installing a total of about 160 new batteries.
- We replaced the non-rechargeable battery bank at one site. This site is buried in snow about 9 months of the year and solar panels get routinely destroyed by heavy snow loads.
- We also augmented existing power systems by adding air cell batteries at nine sites.

4. Task: Data communications

Telemetry strategies for each site are based on the availability of existing commercial options, geographic setting, and power system. Multiple methods may be involved for data leaving the site, reaching the intermediate hub and eventually arriving at our facilities in Fairbanks (Table 1, Figure 3). The majority (70) of the sites use 900MHz, spread-spectrum radios to send the data out on the first leg, however only four of these sites transmit the data directly to the Geophysical Institute. The rest of the radio sites are routed to data communication hubs, sometimes via multiple radio repeater links.

The next two largest groups of sites use either satellite communications via BGAN terminals (52) or cell modems (46) as the first data transmission leg. We prefer cell modems over BGAN due to lower power consumption and subscription costs. However, cell networks in Alaska still have limited coverage. Thirty-two stations use the host organization's internet, which provides free internet access, but also requires unique networking strategies and extra coordination with external organizations. Sixteen stations are on dedicated Hughes Gen2 VSAT communications, 11 stations are on DSL lines with various carriers, and 3 stations are on GCI's rural broadband (RBB) service. While each of these three latter categories are only a small percentage, in most cases they are often the most dependable option for stable internet connections.

The remaining two groups both utilize dedicated T1 lines that provide direct communication lines from the stations to AEC servers at UAF. The first group is 11 sites located at Alaska Pipeline stations, which are transmitted over the dedicated T1 line from the Alyeska Pipeline Service Company network to the Geophysical Institute. The second group is 18 stations that connect directly to the Geophysical Institute through the State of Alaska Telecommunications System (SATS) network with a dedicated T1 line between AEC servers to the SATS network.

Our field network communication hubs mostly use VSAT and cell communications and most are located in remote places with no other available options. Except for Alyeska, direct radio links, SATS, or on-campus sites (44 sites combined), data from the remaining 215 sites travel the last leg to our acquisition facilities via public internet (Figure 3).

During the 2022 and 2023 summer field seasons AEC replaced the last three remaining USGS Networx lines in use by the network. These replacements included: (1) replacing the circuit for AK.BESE, near Juneau, with a cell modem on AT&T, (2) replacing the circuit for

AK.SPIA, on St. Paul Island, with a cell modem on GCI, and (3) replacing the circuit in Yakutat (seven sites in the region) with a cell modem on AT&T.

During August 2023, we replaced the BGAN systems at AK.C23K, AK.C26K, and AK.C27K with RV50X cell modems. In addition to lowering the financial cost, the reduced power requirements of the cell modems, compared to the BGANs, allow these stations to now send real-time data throughout the year rather than send intermittent data bursts during the winter months.

During the 2023 field season, we installed a Starlink High-Performance Dish at AK.TNA, replacing a non-operational Hughes Gen2 satellite receiver system. To date, we have seen strong performance from the Starlink system, with AK.TNA having an uptime of nearly 100% since the install. We also coordinated with EarthScope to install Starlink High-Performance Dishes for our cooperative networks for AK.S19K, the Kodiak region (AK.CHI and AK.SII), and AK.YAKA. While other telemetry issues have kept AK.SII and AK.CHI from remaining online consistently, we have seen strong performance from the Starlink systems in all three networks.

During the 2023 field season, we also began limited installations of the new Freewave Zumlink 900 MHz radios in our AK.S19K and Barry Arm (AK.BAE, AK.BAT) networks. These are a direct replacement for Freewave FGR+ and FGR2 radios and have performed well in the field networks to date. The larger bandwidth available in the Zumlink radios, compared to the FGR+ and FGR2 models, has allowed us to have more consistent image retrieval for monitoring potential landslide activity in Barry Arm, which is critical for monitoring potential tsunami hazards in northwest Prince William Sound.

Table 1. *AK network telemetry type from the site, from the hub for radio-linked sites, and arriving at the AEC facility.*

Telemetry Type	At Site	At site (%)	Radio Site Comms Hub	Arriving at AEC	Arriving at AEC (%)
Internet				215	87%
GCI RBB	3	1%	1		
AK SATS	7	3%	11	18	7%
Alyeska	11	4%		11	4%
DSL	11	4%	6		
VSAT	16	6%	15		
Host	32	13%	11		
Cell	46	18%	24		
BGAN	52	21%			
Radio	70	28%		4	2%
Starlink	3	1%	2		
Total	251		70	248	

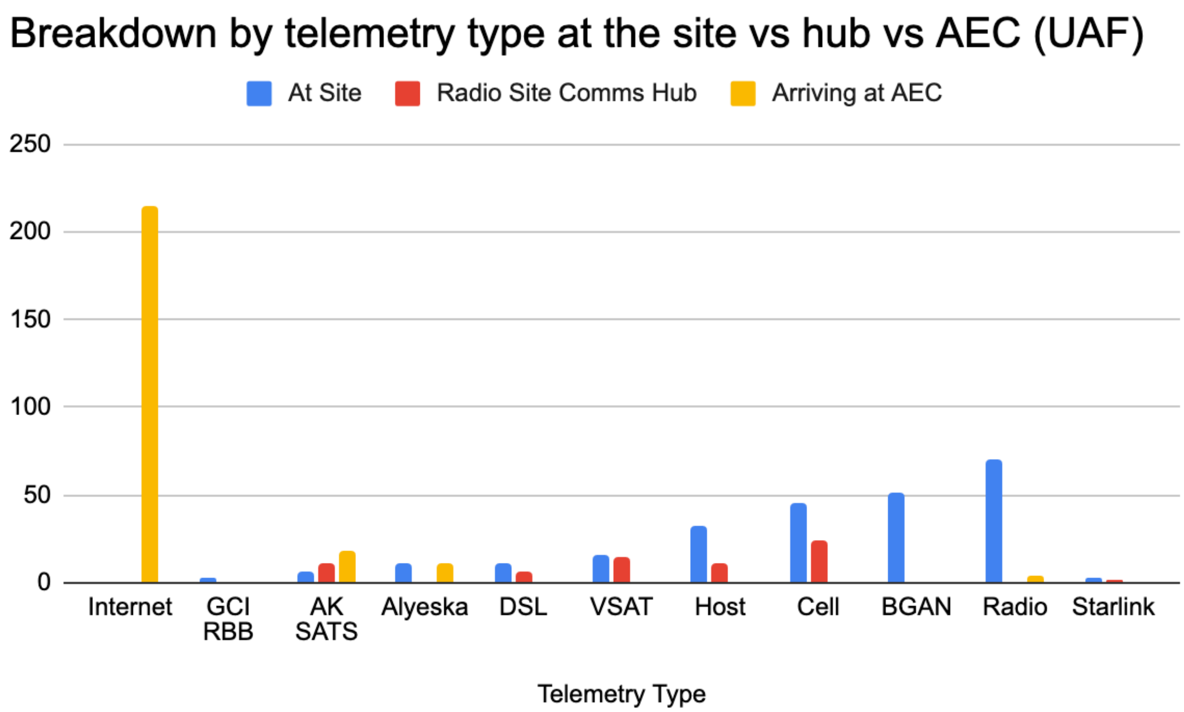

Figure 3. *AK field network by telemetry type*

5. Task: Data acquisition and computing support

a. *Computing hardware*

This award provided continued support for hardware maintenance from Dell, virtualization software licensing from VMware, and staff resources to support and maintain our primary operational cluster. This cluster supported nearly all critical monitoring systems, including our data acquisition and archiving, real-time event detection, alarming, ShakeMap, data exports, and web hosting, plus hosting numerous development and testing systems.

Our current computer cluster contains four Dell R740xd PowerEdge servers purchased in 2020. Each node provides 24 CPUs with 64.8 GHz total clock speed and 256 GB of RAM, for a total cluster of 96 cores operating at 259 GHz and 1024 GB of RAM.

To address storage, we opted for a newer technology from VMWare called vSAN. This technology allows for storage to be abstracted, much like how compute resources are abstracted in the normal VMWare system (for example, how a single node can host dozens of virtual machines). Under this architecture, each of our nodes have approximately 13 TB of extremely high performance flash NAND storage, which are pooled into a (usable) cluster capacity of 37 TB operating at a much higher performance level than older spinning drive arrays.

To supplement the vSAN storage, we utilize two Synology RS4017xs+ rack-mounted network-attached storage (NAS) devices, each with approximately 190 TB of usable storage capacity. These have been deployed in a redundant setup, whereby the data on one is directly mirrored to the other. These devices provide long-term storage of our waveform archive, as well as backups of production virtual machines. To store in-office workstation backups for ease of restoring computer systems for AEC users, we also purchased a rack-mounted Synology RS1221+ NAS device and have implemented daily Time Machine backups to this device.

On August 31st, 2023, we collaborated with UAF's Research Computing Systems (RCS) to install two new Cysco Catalyst C9300X-48TX switches to our server rack. These each have 48 1G/2.5G/5G/10G ports as well as 8-25G ports and replaced two aging switches. The switches have been wired to be redundant so that if one fails, the other will provide network connectivity.

b. *Cybersecurity*

We are always pursuing means to keep our network secure. This includes updating the configurations of our field routers to match best practices, removing outdated devices that are no longer supported, and continuing to use private Access Point Names (APNs) to keep our devices unreachable from beyond the Earthquake Center's networks. We have also continued updating router configurations to disallow any outside services (such as ICMP or SSH) from networks outside of our lab. Finally, we continually check to ensure that all devices' firmware is current and all applicable OS and software patches are applied on field devices as well as in the lab. During the period of this report, we have not had any devices compromised or detected signs of concerted efforts to gain unauthorized access to our equipment.

c. *Data archiving*

AEC stores continuous waveforms for all available seismic stations operating in Alaska (including those from partners such as AVO, NTWC, and USArray) from 1997-present, and segmented data from 1988-2012. This data is available on-demand internally to AEC staff as well as seismology researchers and students at the Geophysical Institute and externally via the IRIS DMC.

Our data storage needs have grown dramatically in the last few years (Figure 4), and AEC has been proactive in ensuring that we have sufficient capacity to host a permanent archive of all digital seismic records in the state. Long-term seismic catalog and waveform storage is provided by two redundant network-attached storage (NAS) devices, each providing ~100 terabytes of storage capacity. These NAS devices were purchased in 2020. These two NAS devices are now set up as interchangeable waveform storage so that if one fails we will be able to almost seamlessly switch over to the other device to continue serving data.

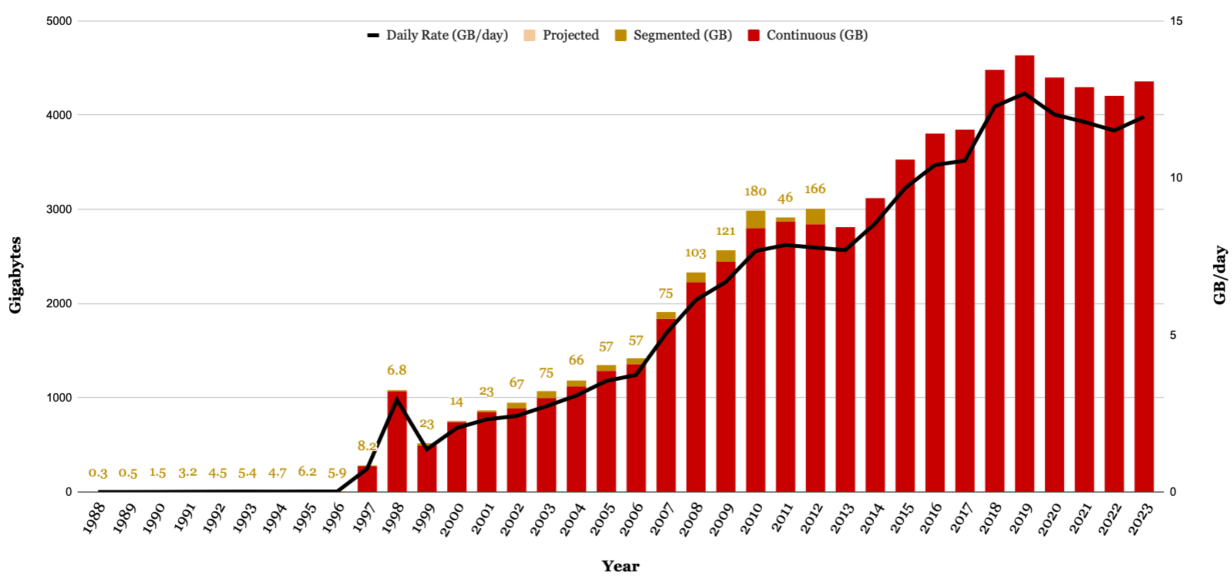

Figure 4. *AEC yearly waveform storage*

d. *Acquisition and distribution of waveform data*

Data directly acquired by AEC from approximately 250 stations is made available in real-time via Antelope ORB and SeedLink to critical stakeholders such as the National Tsunami Warning Center, USGS, the Alaska Volcano Observatory, and the Canadian Geological Survey. A copy of our data is also sent to the IRIS Data Management Center for access by the general scientific community and the public. All AK network data is publically available, regardless of funding source.

e. *Acquisition and distribution of geodetic data*

We are completing work on a project to acquire real-time GNSS data from seven active sites around the state, as well as a basic quality control (QC) suite. QC metrics we are working to calculate are station up-time, percentage of recorded observations to predicted observations, and satellite signal strength. At this point, we are operationally acquiring and archiving the data. Previously, the acquisition of GNSS data was done in partnership with the UAF Geodesy Lab under the direction of Dr. R. Grapenthin. Now, AEC is Earthscope's primary point of contact for these seven geodetic sites.

6. Task: Data quality control

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 helps 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 available through an in-house archive of state of health channels (SOH), as well as from the Earthscope's MUSTANG website.

We have established daily protocols for state-of-health checks carried out by members of the field team. Each person is assigned a subset of sites that they check for outages, gaps, and other issues. Frequent, routine checks allow for timely detection of a problem and ensure appropriate troubleshooting and follow-up procedures. During this reporting period, we implemented a comprehensive SOH training procedure and compiled a manual.

QC efforts at AEC also have continued to use the EarthScope tool QuARG and web service tool MUSTANGULAR. Standardized QC reports are produced bi-weekly and quarterly. Quarterly reports are published at the University of Alaska Scholarworks in the AEC Reports collection and remain a permanent and citable publication (e.g., 2023-Q3: https://scholarworks.alaska.edu/handle/11122/14769).

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) and the analyst team (to identify stations that should not be used for routine earthquake analysis).

a. *Waveform completeness*

Over the period between November 1, 2021, and October 31, 2023, the network had an overall data completeness of 81.4%, with the average monthly rates ranging between 75% and 90.0% (Figure 5). These statistics, compared to prior years, are greatly influenced by the rapid addition of 96 new stations between 2019 and 2020. Many of the adopted USArray sites have unusual power and communication challenges (this is why IRIS relied in part on retrieving on-site data records to improve long-term data completeness). As an organization, AEC is still growing into these sites. Our maintenance regimes have changed significantly, and the power and communication technologies we use have changed significantly. We are using current strong financial support from both USGS (this award) as well as NSF to develop the capabilities and infrastructure to operate these sites at higher levels of performance for the years to come. The ANSS standard of 90% data return remains our goal. Going forward, we have a longer-term maintenance plan to increase our data return up to 90%.

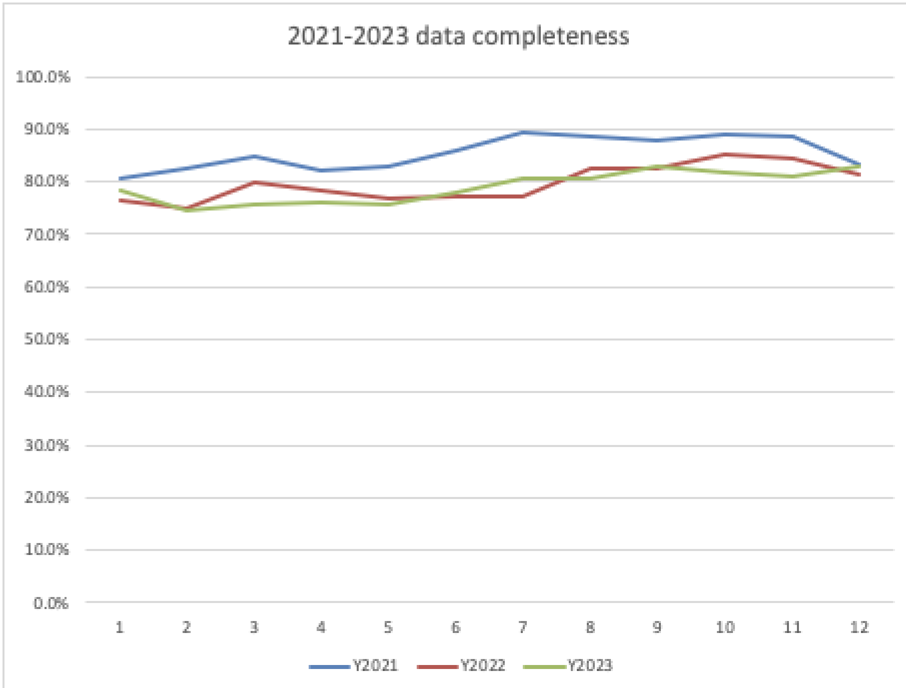

***Figure 5**. Monthly seismic data completeness for AK network in 2021-2023*

b. *Metadata*

We continue to maintain and distribute station metadata updates via dataless SEED and StationXML with partners and make our full metadata available via the IRIS DMC. This includes all seismic (broadband and strong motion), infrasound, and meteorological data streams.

Under this award, we also began integrating the ANSS Station Information System (SIS) into our metadata workflow. Currently, 155 AK sites have been loaded into SIS (Figure 6). These sites include all 43 stations covered under the Southern Tier adoption effort of the USArray Transportable Array, as well as additional sites that shared a similar configuration with Southern Tier sites and most strong-motion-only sites within the network. These sites contain a full record of the station post-adoption by AEC for seismic data (broadband and strong motion sensors). We will continue to work with SIS developers on adding infrasound and meteorological data streams to complete station records.

We have also further developed our suite of checks to help verify that metadata loaded into SIS matches our internal records. This process has helped us create accurate response files for Centaur dataloggers which had not previously existed in our metadata build system. While not fully comprehensive, we intend to continue building out the checks to better streamline the SIS-AEC workflow going forward.

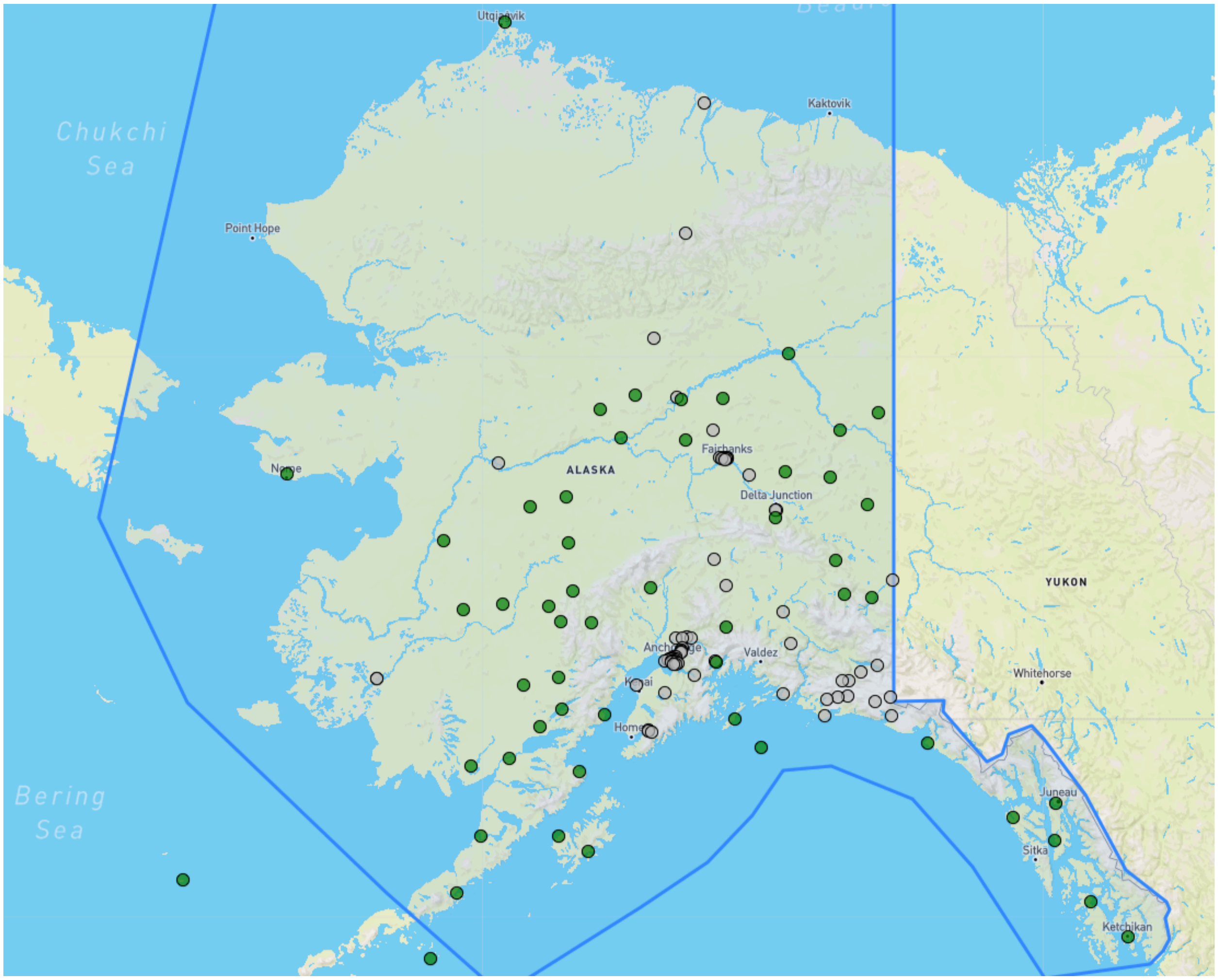

Figure 6. *AK sites currently loaded into production SIS. Green stations were loaded in 2022 and gray in 2023.*

c. *Quality control of broadband data*

Amplitude-based metrics for broadband sensors include measuring the number of spikes, DC offset, the percent of data above or below the New High or New Low Noise Models (NHLM and NLNM, respectively), number of unique samples, whether the data in the 4-8 second period band falls below a set threshold compared to the NLNM, a measure of the sample RMS, a measure of the absolute value of the sample mean, a measure of the cross-correlation between channels on the same sensor, and various combinations of the above amplitude metrics. Issues that these metrics flag may be indicative of sensor and datalogger problems or environmental characteristics: spikes and DC offset may indicate an issue with the digitizer or cabling; low sample RMS and high sample mean may indicate a pegged channel; a dead channel can be identified by a 5 dB deviation from the NLNM in the 4-8 second period band; DC offset alone can indicate a tilted sensor (usually easily fixed by a mass recenter); cross-talk (the cross-correlation close to the absolute value of 1 between two channels on the same sensor) may indicate that either the mass positions are tilted such that the data appears to be the same on the two channels, or that there is a problem with the cabling and there is leakage from one channel to another. Other metrics include percent availability and number of gaps to measure continuity.

The ratio of these two metrics is used to identify stations that have degraded availability due to a large number of gaps, rather than singular long-term outages.

d. *Quality control of strong motion data*

The QC team has continued to use the same continuity metrics for strong motion data as is used for broadband data. During 2023, we developed two new amplitude-based metrics for our strong motion data that indicate amplitude spikes or a potentially dead channel. Current amplitude metrics used include a measure of the max range, a measure of the absolute value of the sample mean, and the sample RMS, as well as combinations of the above. A low max range combined with a low sample mean and low sample RMS can indicate a dead strong motion channel and a high max range combined with a high sample RMS can indicate spikes in the strong motion data. Identification of station issues continues to include a visual inspection of power spectral density curves and waveforms. We will continue to focus our future efforts on building up more specific metrics.

e. *Quality control of geodetic data*

AEC has established a basic QC workflow for GNSS sites now under AEC operation. We have transitioned the acquisition from the older UAF Geodesy Lab system to a new system within the AEC infrastructure. The QC is now running on these data streams in test mode. This built significant AEC expertise in GNSS real-time acquisition and data formats and resulted in substantial revision and optimization of the previous graduate student-driven, quasi-biweekly checks of GNSS data. In this process, we also transitioned from the end-of-life teqc software for basic QC to modern maintained tools (RINGO or gfzrnx) after thorough evaluation. At present, the QC reporting continues to emphasize acquisition latency and data completeness. We continue to build toward reporting that includes measures of data quality by leveraging a combination of in-house and EarthScope-hosted tools.

7. Project data

Seismic data generated under this award is archived at and available from the IRIS Data Management Center (http://ds.iris.edu/ds/nodes/dmc/data/). ShakeMap products and data are archived and available via ANSS Comcat (https://earthquake.usgs.gov/earthquakes/search/) and the AEC website (http://earthquake.alaska.edu/earthquakes/shakemaps/list). Seismic data is made available to USGS via a dedicated seed-link export data server.

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