Final Technical Report – Award #G17AC00314

Earthquake Early Warning in Eastern California

Principal Investigators: **Graham Kent and Ken Smith**

Authors: **Jayne Bormann, Graham Kent, Ken Smith, Gabe Plank, Mark Williams, and Dave Slater**

Nevada Seismological Laboratory
University of Nevada, Reno MS174
1664 N. Virginia St.
Reno, NV 89557
Phone: (775) 784-4975
Fax: (775) 784-4165

E-mail: jbormann@unr.edu, gkent@unr.edu, ken@unr.edu, gabe@seismo.unr.edu, markwilliams@seismo.unr.edu, dslater@unr.edu

Term covered by the award: 8/15/2017-8/14/2019

This material is based upon work supported by the U.S. Geological Survey under Grant No. G17AC00314. 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.

Abstract

The Nevada Seismological Laboratory (NSL) at the University of Nevada, Reno is working with partners from the California Integrated Seismic Network to install and operate low-latency-capable sensors in the High Sierra and eastern California in support of earthquake early monitoring (EEW) in California. Our two primary areas of focus under award G17AC00314 include: 1) Eastern California sensor and microwave communication upgrades, and 2) reducing and monitoring latency from NSL to the ShakeAlert system. To this end, we have complete upgrades or new installs of 13 EEW strong motion stations between July 2017-Nov 2019, and we operate an additional 4 EEW stations that were inherited as stations on the EEW “dots map” without upgrade. We are awaiting instrumentation and/or pursuing permits for an additional 15 upgrades, however site visits have been conducted with many upgrade materials purchased, so we are poised to respond as soon as instrumentation arrives and permits are granted. We have made major advances in building and upgrading our microwave telemetry mesh to incorporate path redundancy and diversity, and strengthening our power systems to ensure continuous and low-latency delivery of EEW data to ShakeAlert datacenters. Many of the telemetry and power upgrades have been funded through NSL’s fire camera monitoring program, ALERTWildfire, to the benefit of EEW operations. We have continued the development of our network latency and state of health monitoring tools, investigated datalogger configurations for ideal EEW performance, and improved our real-time EEW SEEDlink server for faster data exchange with EEW partners. We look forward to continued collaboration and integration with EEW partner networks as the ShakeAlert project continues.

Introduction

The Nevada Seismological Laboratory (NSL) at the University of Nevada, Reno supports earthquake early warning (EEW) efforts by operating low-latency seismic stations in the High Sierra and eastern California that will contribute data to ShakeAlert. Between awards G16AC000358, G17AC00314, and G19AC00265, NSL has been funded to install or upgrade 28 EEW seismic monitoring stations and additionally operates 4 stations that were inherited as EEW “dots” without upgrade. NSL’s operates EEW stations in remote and high-elevation locations where continuous year-round operation is complicated by a lack of cellular telemetry infrastructure and grid power, limited seasonal solar exposure due snow pack, and damaging winds over 100 mph during storm events along the Sierra crest. In response to these challenges, a major focus of our EEW efforts centers on designing robust and redundant station infrastructure, power, and telemetry systems for our EEW seismic stations. These efforts benefit from station power, microwave telemetry advances and communication network upgrades made through NSL’s ALERTWildfire wildland fire monitoring program. Progress made toward achieving these goals is described below under **Task 1: Eastern California Sensor and Microwave Communication Upgrades**. Data from NSL operated stations are transferred to our California Integrated Seismic Network (CISN) partners to be imported into ShakeAlert via our real-time EEW-specific seed-link server. Our strategies and systematic improvements made toward providing low-latency delivery of quality data are reported below under **Task 2: Reducing and Monitoring Latency from NSL to ShakeAlert System**.

Coordination of EEW activities with ShakeAlert Partners

In July 2019, NSL hired an EEW and Fire Camera Monitoring program coordinator, Jayne Bormann, to coordinate the symbiotic growth of our seismic and fire camera monitoring networks in Nevada and Eastern California. Prior to July, Ken Smith, NSL Associate Director and Seismic Network Manager, and Graham Kent, NSL Director, oversaw the coordination and planning of EEW operations. In response to NSL’s growing role in EEW operations in Eastern California, Jayne recently joined the EEW regional coordinators working group, where she works with ShakeAlert partners on overall project coordination, development and implementation of standards, and supporting installation of EEW-capable stations.

In the past two years, NSL has worked with project partners to coordinate station siting using the EEW “dots” map, permitting, telemetry system design, and data delivery to CISN partners. NSL provided significant input into the EEW telemetry plan, as NSL has many years of experience with private VPN mesh high-bandwidth microwave networks. USGS personnel, Lind Gee, Valerie Thomas and Dave Croker visited NSL for one day to familiarize themselves with the NSL communications approach and to better coordinate on E. California EEW site installations. Land-use and environmental permitting for new or significantly altered stations continues to be a major delay in station installation. NSL is very appreciative of USGS support in permitting of EEW stations on U.S. Forest Service lands. We are optimistic that having a representative in the EEW regional coordinators working group will help streamline the process of EEW site selection, permitting, and general transfer of information between NSL and EEW project partners. In addition to participating in the regional coordinators working group, NSL members contribute to many other ongoing or short-term focused working groups: Ken Smith (EEW Regional Seismic Network Managers working group - ongoing), Graham Kent (Telemetry Performance working group – 2019), Gabe Plank (Datalogger Configuration working group – 2019), Dave Slater (Data Transport Networking working group – 2017), John Torrisi (Site-Specific EEW Node Site Standardization working group – 2017).

Task 1: Eastern California Sensor and Microwave Communication Upgrades

In total, the Nevada Seismological Laboratory has been funded to install 28 EEW stations in the High Sierra and eastern California primarily concentrated in the Truckee-Tahoe, Mammoth Lakes-Bishop, and Death Valley regions. Installation and continuous operation of EEW stations in remote and high-elevations locations is considerably more complicated than lower elevation stations due to unique considerations such as narrow field season due to snow coverage, limited solar exposure due to storms and snow pack, and winds over 100 mph during storm events along the Sierra crest. In addition, communication "back haul" is equally difficult given the lack of reliable cell coverage (and the pitfalls therein) and access to hardwired LAN/Fiber connections. To this end, NSL has built, and is continuing to expand, a state-of-the-art high-speed and high-bandwidth microwave communications network to bring back seismic data from EEW upgraded stations reliably with transit latencies typically between 200-500 ms, while also carrying other emergency data streams such as fire camera video live feeds, GPS data, and weather data. Our efforts to build, upgrade, and maintain our sensor and telemetry networks in support of EEW monitoring between the August 2017-August 2019 award period are summarized in the following sections.

Station Upgrades and Installs:

NSL maintains a flexible and pragmatic approach toward working the USGS to select station and install low-latency sensors in support of EEW operations. Our willingness to adapt planned installations in light of weather and permitting challenges, and in response to evolving ShakeAlert needs, has resulted in a complex history of EEW upgrades. NSL currently operates 17 stations in support of EEW operations. Of these stations, 10 were NSL analog stations that have been upgraded to digital strong motion stations, 3 are new strong motion station installs, and 4 were inherited for EEW operations without sensor or datalogger upgrades. NSL has been funded to upgrade sensors and communications for an additional 15 analog stations; however, these upgrades have been delayed due to permitting or equipment set-backs. NSL's seismic infrastructure improvements in support of EEW operations have been funded in three phases, described below:

- **Phase 1 (August 2016-August 2017, Award #G16AC000358)**
  Installation of 5 digital strong motion stations in the Truckee-Tahoe region. NSL worked with Dave Croker, at the USGS Northern California network, to select 10 existing NSL analog stations for upgrade to digital sensors and communications (BMR, BEK, SBT, IND, TNK, WILL, LVO, GZY, EBP, SJC). NSL planned to upgrade the first 5 sites to receive permits and be snow free during the spring and summer of 2017. Phase 1 upgraded stations include: BAB (an NSL communications hub adopted for EEW during early 2017), QNBC (temporary installation, officially adopted for ShakeAlert during Phase 2), SAG5 (swapped for IND due to land use restrictions), SJC, and SUGR (swapped for TNK due to existing power and communications infrastructure).
- **Phase 2 (August 2017-August 2019, Award #G17AC00314)**
  Continued installation of the initial 10 Truckee-Tahoe digital strong motion upgrades. Consultation with the USGS between Phase 1 and Phase 2 resulted in adding BAB and VPK strong motion upgrades to the planned station list, bring the total of strong motion upgrades to 12. USGS consultation during the project period resulted in the decision to convert the BEK and BMR upgrades to low-latency broadband stations, add station WAK as a low-latency broadband upgrade, and to add the LOY strong motion upgrade and QNBC temporary install as officially funded stations.
- **Phase 3 (Feb 2019-August 2020, Award #G17AC00314 Supplement & G19AC00265)**
  Installation of 3 new strong motion stations in the northern Sierra Foothills and upgrades of 10 analog stations in the Mammoth and Death Valley region. In late 2018, NSL was asked to submit a proposal for supplemental EEW funds to install 3 new strong motion stations that are co-located with NSL ALERTWildfire Cameras in the northern Sierra Foohills (BIGH, BUNK, LEEK), and to upgrade 10 analog sensors and associated telemetry in the Mammoth-Death Valley region (BEN, BHP, LUL, MCA, MGN, MPT, ORC, POC, RCC, WMD). Funding for these efforts was split between a supplement to Award #G17AC00314, with an August 2019 end date, and year 1 of our current EEW agreement, Award #G19AC00265. Splitting Phase 3 efforts between two different award periods resulted in a strategy where supplemental funds were used to complete the Sierra

Foothills installations and to purchase materials for the Mammoth-Death Valley upgrades scheduled for Spring and Summer 2020.

Most NSL operated EEW sensors are installed on a concrete pad inside a shallow seismic vault with solar power and microwave telemetry to NSL's private high-speed microwave backbone. We currently have three varieties of strong motion stations based on the sensor and datalogger combinations: 1) stations with an Episensor ES-T strong motion sensor, an L-4 short period seismometer, and a Kinematrics Obsidian 4X datalogger (Figure 1); 2) stations with an Episensor ES-T strong motion sensor and a Kinemetrics Obsidian 4X datalogger that may have an L-4 added in the future; and 3) stations with an ETNA2 installed either in a vault or on an indoor concrete surface where infrastructure is available. We plan to add L-4 vertical short period channels to all sites with obsidian dataloggers as station infrastructure allows. Currently operating EEW broadband stations (CTC, DSP, EMB, and MPK) were inherited as EEW stations without instrumentation upgrades. These stations include a Nanometrics Trillium 120 or Trillium Compact 120s broadband seismometer with an Episensor ES-T strong motion and a Kinemetrics Q330S datalogger. Upgraded stations will either include the currently installed Trillium 120 or Compact 120s broadband seismometer with the addition of an Episensor ES-T strong motion sensor and a Kinemetrics Q330S+ datalogger (BEK, WAK), or a Trillium 120 posthole broadband seismometer with an Episensor ES-T strong motion sensor and a Kinemetrics Q330S+ datalogger (BMR, BEN, MCA).

Figure 1. (left) Sugar Bowl (SUGR) EEW vault with Episensor strong motion sensor and L-4 vertical short-period seismometer. **(right)** Example of a typical NSL EEW seismic installation (LOYB) with solar power and microwave telemetry infrastructure.

The following tables summarize the status of NSL's EEW operated stations divided by region and installation phase.

Table 1. EEW Stations Inherited without upgrades

Station (NN.)	Upgrade Install Date	Station Type	Datalogger	Primary Telemetry	Comments
CTC	N/A	Broadband	Q330S	Microwave	
DSP	N/A	Broadband	Q330S	Microwave	
EMB	N/A	Broadband	Q330S	Microwave	Will be moved to site with better power and telemetry LOS in Spring 2020.
MPK	N/A	Broadband	Q330S	Microwave	

Truckee-Tahoe Sensor Upgrades

Table 2. Truckee-Tahoe Phase 1 upgrades

Station (NN.)	Upgrade Install Date	Station Type	Datalogger	Primary Telemetry	Comments
BAB	11/29/2017	Strong Motion*	Obsidian	Microwave	
QNBC	11/14/2017	Strong Motion	Obsidian	Cellular	Indoor install, will be moved to vault with microwave telemetry pending BLM permit approval.
SAG5	7/26/2017	Strong Motion*	Obsidian	Microwave	
SJC	8/16/2017	Strong Motion*	Obsidian	Microwave	
SUGR	7/27/2017	Strong Motion*	Obsidian	LAN	

*Strong motion stations that also include an L-4 vertical short period seismometer

Table 3. Truckee-Tahoe Phase 2 upgrades

Station (NN.)	**Upgrade Install Date**	**Station Type**	**Datalogger**	**Primary Telemetry**	**Comments**
BEK	TBD	Broadband	Q330S+	Microwave	Awaiting permits - Plumas NF.
BMR	TBD	Broadband PH	Q330S+	Microwave	Awaiting permits - Plumas NF.
EBPB	11/01/2018	Strong Motion	Obsidian	Microwave	
GZY	TBD	Strong Motion	Obsidian	Microwave	Awaiting permits - Plumas NF.
LOYB	10/07/2019	Strong Motion	Obsidian	Microwave	
LVO	TBD	Strong Motion	Obsidian	Microwave	Awaiting permits - Plumas NF.
SBT	11/05/2018	Strong Motion	Obsidian	Microwave	Tower damaged during 2018-2019 winter storms. New Rohn-55 tower is installed, station will be back online pending fabrication of a non-standard-length sensor cable.
VPK	Installation in Nov '19	Strong Motion	Obsidian	Microwave	New vault constructed, ready for sensor and radio installation.
WAK	TBD	Broadband	Q330S+	Microwave	Upgrade ready, pending fabrication of a non-standard-length sensor cable.
WILB	11/01/2018	Strong Motion	Obsidian	Cellular	Will be moved to microwave pending upgrade of Hawkins Peak com site.

Sierra Foothills Strong Motion Station Installations

Table 4. Sierra Foothills Phase 3 fire camera co-location new station installations

Station (NN.)	**Install Date**	**Station Type**	**Datalogger**	**Primary Telemetry**	**Comments**
BIGH	10/07/2019	Strong Motion	ETNA2	Microwave	Indoor install.
BUNK	10/07/2019	Strong Motion	ETNA2	Microwave	Indoor install.
LEEK	11/13/2019	Strong Motion	ETNA2	Microwave	Temporary indoor install, will be moved to vault pending permit.

Mammoth-Death Valley Sensor Upgrades

Table 5. Mammoth-Death Valley Phase 3 upgrades

Station (NN.)	Projected Upgrade Date	Station Type	Datalogger	Primary Telemetry	Comments
BEN	Summer 2020	Broadband PH	Q330S+	Microwave	Awaiting permits - Inyo NF.
BHP	Spring 2020	Strong Motion	ETNA2	Microwave	Awaiting permits - Inyo NF.
LUL	Summer 2020	Strong Motion	ETNA2	Microwave	Awaiting permits - Inyo NF.
MCA	Spring 2020	Broadband PH	Q330S+	Microwave	Awaiting permits - Death Valley National Park.
MGN	Summer 2020	Strong Motion	ETNA2	Microwave	Awaiting permits - Inyo NF.
MPT	Spring 2020	Strong Motion	Obsidian	Microwave	Awaiting permits - Inyo NF.
ORC	Spring 2020	Strong Motion	ETNA2	Microwave	Awaiting permits - Inyo NF.
POC	Spring 2020	Strong Motion	Obsidian	Microwave	Awaiting permits - Inyo NF.
RCC	Summer 2020	Strong Motion	ETNA2	Microwave	Awaiting permits - Inyo NF.
WMD	Spring 2020	Strong Motion	ETNA2	Microwave	Awaiting permits - Inyo NF.

* Site visits for the Mammoth-Death Valley region have been completed, and remaining Phase 3 G17AC00314 Supplemental funds were used to purchase upgrade supplies prior to the award end date.

EEW Telemetry – building reliable and redundant mesh topology:

Remote seismic stations can suffer from significant reliability problems. Issues such as reliance on solar power, inclement weather, failing equipment, lightning/static discharge, wireless network interference, antenna icing, signal fade due to precipitation, long path distances, wind affecting antenna alignment, disturbances from domestic livestock and wild animals, and vandalism, all contribute to power, telemetry, and communication site failure which can disrupt communications from a seismic station.

To make matters worse many stations are telemetered using multiple data link hops, which multiplies the chance of failure along the data path from the station to the data center (e.g., 5 data links with 99% uptime => 95% uptime on the data path). Of course, cellular service suffers the same ills, using multiple commercial microwave links combined with poorly understood in-ground fiber topology (i.e., multiple owners and poorly understood interdependencies). Telemetry failures can also disrupt data acquisition from stations in an entire region due to multiple stations sharing the same failed data path. This is similar to the communication impacts when fiber is cut that supplies service to a cellular provider causing an entire region to go completely dark for hours. Managed telemetry path diversity helps mitigate many of these potential problems.

NSL uses Layer 3 mesh topology to bypass failed communication links and down sites. Link state routing technology configured on low power multi-layer Internet Protocol routers implements the automatic transparent failure from primary to secondary and tertiary backup links if they should exist via OSPF routing. As NSL's multi-hazard private network expands to more mountain top locations with the rapid growth of the ALERTWildfire network, we are building secondary and tertiary radio links, which benefits all data transported along the network. We increase our path diversity and network reliability by adding fiber drops onto the Internet via VPN tunnels or dedicated fiber circuits. Every additional managed redundant data path radically reduces the chances of wholesale telemetry failure (e.g., 99% uptime + 99% uptime =~ 99.99% uptime).

The topology of the NSL private network is an a priori known commodity, whereas many public networks such as cellular, and surprisingly fiber backhaul, are very complex and with poorly understood failure modes. To minimize and eliminate these unknowns, privately managed microwave backhaul is the preferred data transport mechanism, whenever possible. Recently, NSL has also incorporated the ability to insert a Cradlepoint cellular backhaul at critical communication sites as a secondary or tertiary option within an in-house electronic box design to provide as much continuity possible. All NSL communication links are designed, installed, and maintained by qualified lab engineers and/or development technicians.

NSL's EEW operations require critical communication infrastructure to backhaul seismic data from remote stations. NSL telemetry improvements that benefit EEW operations during the project period include:

- Fire Camera funded communication nodes at Babbitt, Ca; Bald Mountain, NV; Fort Sage, NV; and Hawkins Peak, CA were completed and provide communication infrastructure required to telemeter Truckee-Tahoe EEW stations. (ALERTWildfire)
    - Fort Sage, NV communication site backhauls data from the Sierra Buttes EEW station (SBT) as well as data from the Smith Peak communication station that will serve the LVO, GZY, and BMR EEW upgraded stations.
    - Bald Mountain, NV communication site backhauls data from the Ebbett's Pass (EBPB) and Sonora Junction (SJC) EEW stations.
    - Hawkins Peak, CA communication site backhauls data from the Willow Creek (WILB) EEW station.
- Completed low-latency digital upgrades of the northern redundant telemetry loop that backhauls Truckee-Tahoe area stations. The auto-fail-over telemetry loop consists of seven wireless backhaul links: LMR-Virginia-Curnow-Babbitt-Sagehen5-Peavine-NOAA-LMR.
- 2.4 GHz Mikrotik Point-To-Multi-Point Access Point has installed at Babbitt (BAB) to bring in Verdi Peak (VPK) and Loyalton (LOYB) EEW data. (EEW funded)
- Wireless links on the northern loop have been upgraded to new high speed Airfiber radios in order to provide low latency data connections for EEW operations. (partially EEW funded)
- 24-V power system at upgrade SageHen Tower 5 (SAG5). (partially EEW funded)
- 11 GHz licensed wireless links bought for multiple Reno-area backhaul links to support low-latency telemetry from Reno to our mountain top sites (Slide, Peavine, Virginia) that telemeter EEW data in and around the Tahoe basin and free space for local Reno area communications on the overused 4.9 and 5.8 GHz spectrums. (NSL/ALERTWildfire funded)
- Funding secured for the Tahoe Basin 11 GHz microwave link upgrades, scheduled for the 2019-2020 winter. Upgrades funded by U.S. Forest Service Tahoe Basin Management Service and the Tahoe Prosperity System that will benefit low-latency EEW data backhaul.
- 4G high-speed/low-power Cradlepoint cellular routers bought to replace outdated 3G cellular telemetry dongles for EEW stations that currently require cellular communications (e.g. WILB and BEK) and as tertiary backups in NSL mesh network topology. (EEW funded)

EEW Remote power monitoring and control:

The power system design is often the weakest link in a remote seismic station. Most broadband and many EEW strong motions sites are located in remote regions without reliable grid power. Solar power is often less expensive than running grid power; however, the main drawback is that solar power can be unreliable, especially in prolonged ice and snow or overcast conditions that can affect multiple stations in a wide geographic area. The most significant impact is at communications sites with cameras and multiple radios that backhaul seismic data from neighboring stations.

Recent growth of NSL's fire monitoring camera system has required us to develop in-house designed automatic remotely-controlled power monitoring systems at sites with multiple sensors and radios, so that we can shut down the high-power consumption equipment while leaving the lower power consumption equipment running, when low-solar conditions dictate. Such scenarios may require shutting down a 4.9 GHz backbone Cambium radio, while maintaining a lower power Ubtik 5.8 GHz radio link to conserve power and transmit seismic data (the fire risk is low in winter months). In addition, we have added solar modules and battery storage equipment to supply power for fire cameras during the summer that greatly lengthen the uptime of seismic stations and overall basic telemetry service during low solar power winter conditions when fire cameras are not required 24/7. Fire cameras offer an additional benefit that they be powered during the dead of winter to check for potential damage from high winds or ice storms at stations that are difficult to access overland: a "win- win" configuration.

The historic winter of 2018-2019 tested our system with few sunny days and wide spread power losses; nevertheless, the basic functionality of the system, particularly the seismic network, stayed up despite buried towers, damaged solar panels, etc. We have used the lessons learned the 2016-2017 and 2018-2019 record setting snow fall winters and during recent Public Safety Power Shutoff (PSPS) events to further harden our power systems by installing a propane generators at high elevation communication sites such as the Sugar Bowl Ski Resort Mt. Lincoln fire camera and communication site by adding battery banks at grid powered sites to ensure power if back-up generators fail or if there are momentary power losses (Figure 2). We use the Nagios network monitoring utility monitor for power at each communication site maximizing uptime, schedule preventative maintenance, and understanding potential failure modes without requiring costly, limited winter access, site visits. This can greatly help the recovery of a failed site by reducing the downtime and the number of trips required for power system maintenance. Multiple local sensors, of various kinds, are used to implement effective power monitoring strategies.


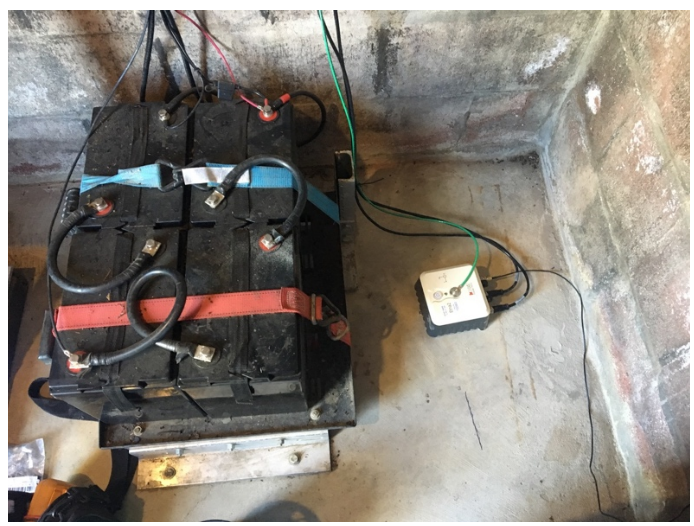

Figure 2. (left) Mt. Lincoln (Sugar Bowl Ski Resort) **c**ommunication hub/fire camera with back-propane generator that supports microwave communications in the Truckee EEW region. This site was funded through ALERTWildfire efforts to monitor extreme weather events in the Sierra Nevada. **(right)** Big Hill EEW ETNA2 indoor installation at ALERTWildfire camera site. This AC grid-powered site incorporates a 24V battery backup system to power the equipment through PSPS events and unplanned lapses in power.

Challenges Encountered:

As expected, permitting continues to be the major hurdle impeding the timely installation of new or significantly altered EEW stations. NSL successfully permitted and completed upgrades of seismic station and microwave communication sites within the Tahoe National Forest, the Lake Tahoe Basin Management Unit, and California State Parks. We also secured memorandums of understanding with UC-Davis Sagehen Field Station, Sugar Bowl Ski Resort, and Alpine County, CA and arranged land use with private landowners. We are also in the process of renewing permits in Humboldt-Toiyabe National Forest. We are working with the USGS to secure permits for EEW stations on U.S. Forest Service lands, while concurrently conducting our own efforts to renew existing NSL permits in Inyo National Forest, Plumas National Forest, and Death Valley National Park. We installed three new EEW strong motion sensors that are co-located with NSL fire monitoring cameras. The ALERTWildfire project is advantageous for EEW installations as we already have land-use agreements in place at fire camera locations, and the coordinated expansion of co-located sensors provides highly-desirable wildfire monitoring capabilities for future land-use partners.

The second major obstacle to EEW installations during the August 2017-August 2019 project period was short High Sierra field seasons due to a very wet Spring 2018 and historically large snow pack during the 2018-2019 winter that didn't allow site access for most high elevation sites until July-August, 2019. The winter storms took a tool on NSL communications and seismic infrastructure (Figure 3), which required significant restoration before new station installs could deliver data.

Figure 3. Sierra Butte (SBT) Rohn-25 tower failure to 2018-2019 winter storms.

Task 2: Reducing and Monitoring Latency from NSL to ShakeAlert System

Latency Monitoring Tools:

During the past two years, NSL has focused on improving network monitoring at the applications level. We have developed custom software to determine data latency, application health, and system performance from different types of dataloggers. We translate these parameters into standards as early as possible in the analytical process so that we can use open source software and analytical tools developed in industry. As dataloggers send more packets more frequently in response to decreased packet length for

EEW monitoring, the value of individual packet latency numbers decreases, and they are no longer a good indicator of station performance. At this scale, we have recently moved to statistical solutions, (e.g., histogram bins, time rollups, percentile aggregations, etc.) to develop a timely, effective picture of station performance.

At the technical level, we timestamp packets at OSI Layer 7 as soon as we can when they arrive at our data centers. We use these timestamps to measure packet & data latencies (and possibly other data extracted from packet content) from the individual datalogger protocol (e.g., RefTek RTP) when possible, or our internal ORB protocol. These metrics are generally output from monitoring programs in statsd format. Sidecar metric programs aggregate this data and send it to our time-series database in 10s bins, which are immediately available for query, and are saved for 7 days. Using standard databases allows us to move to dashboard programs like Grafana (past year) to build custom views of metrics without writing front-end software. The data are also available for custom analytics solutions when needed, at various levels of processing. For some high-value projects, we maintain an in-memory database of state for each datalogger, and monitor configuration, performance and metadata constantly in real-time. Our move towards open-source standards and away from seismic specific solutions has enabled us to more easily adapt to the Internet of Things and integrate with more diverse data sources.

Visualization

We have developed a “manto” dashboard for internal station uptime and data latency monitoring. This system measures:

- *Time to last packet (“downtime”)*: this is a duration measurement from “now” since our datacenter last saw a packet from a given station or datalogger. This is useful for determining whether a station is operating, and is an excellent “canary” statistic for identifying problems. Measured in real-time per packet.
- *Last data packet latency (“latency”)*: This is a duration measurement, usually taken from the time of last data sample until the packet arrived at the data center. The specific measurement depends on the datalogger model and may slightly differ depending on acquisition specifics. This is roughly a measurement of packet travel time and processing time. Measured in real-time per packet.
- *Packet latency history*: We currently run statistics on the “last packet latency” metric, using bins of 10 seconds. We calculate low, mean, 90th percentile, and high values for each bin in real-time and store these in a time-series database for 7 days. This is extremely useful for identifying lower-level network interference, packet loss, and bandwidth issues, and is vital to visualizing the actual performance of a link/station at the application level (See Fig. 5). This is basically a mandatory prerequisite for establishing/monitoring any Quality-of-Service features at the network level, such as bandwidth reservation or traffic prioritization. For dataloggers with high transmission rates (e.g., Obsidians at 30-40pps), the latency of any one datalogger packet becomes less useful, while aggregate statistics give a much better picture of system performance.
- *Packet count (“rate”)*: This is a count of packets seen per unit time. This can be usefully considered a proxy for bandwidth at a lower network layer, but can also be useful for determining the performance of a system at the application level, and becomes more important as packets become shorter in time duration and increase in number.

Over the project period, we improved this system to implement the Vue Javascript framework for the frontend web interface, which makes it easier to make changes and add new features in the future. We also improved the user interface, by reducing the number of alert colors, coloring by data latency and station downtime, and linking to time-series statistics for the last few hours of station history (Figures 4 and 5). Toggling of "down" stations makes it easier to identify problems in the field vs. problems in the data center.

Figure 4. NSL seismic network station data availability "Manto" dashboard that monitors station downtime and data latency. The dashboard includes all NN and SN stations in NSL's acquisition system. Stations names are color coded with stoplight-inspired downtime alert status color scheme, and the background color indicates latency. For example, all stations with a green background routine return data with latencies less than 1 second.

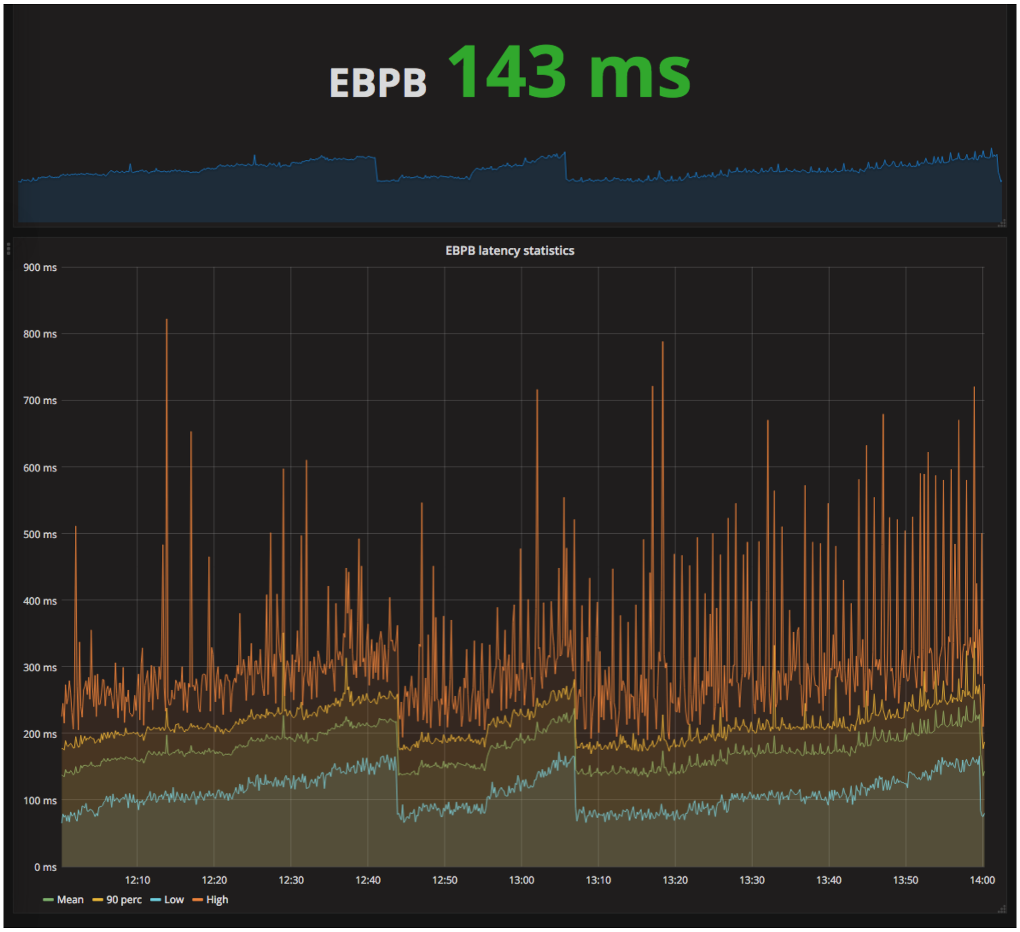

Figure 5. Screenshot of last two-hour latency statistics at station EBPB (10sec bins) [low, mean, 90 percentile, high]. Large green number is the current mean data packet latency.

Measurement & Observability

Concurrent with visualization and troubleshooting of latency is measurement and recording of latency data itself. We have improved interoperability by adopting monitoring standards used by the wider engineering community. This includes wrapping new events in the CloudEvents schema (https://cloudevents.io/), to ensure all programs have a basic context for troubleshooting and archiving. We are also considering the nascent tracing paradigm of OpenTelemetry (https://opentelemetry.io/), which will be a common collaboration of existing tracing and monitoring protocols. Using new technologies like Trace Context should make it easier to interoperate and share tracing data in the future of distributed systems.

There still remains the question of passing metric and trace info among data centers, which will be critical to building performant and well-monitored distributed systems, like EEW. We believe that the next-generation of tools (such as miniSEED3) and sharing protocols need to allow for this data to be propagated across boundaries for true real-time data sharing to work. This has -- so far -- not been a priority of the community, but this need will not go away, and we work towards our goals with this inevitability in mind.

Implementing these new latency and monitoring features into our production systems is an ongoing process, and we will continue this work past this project, which includes adopting storage and analysis for these new large volumes of time-series metrics, and developing best practices, taking examples from industry and modern technology companies, who frequently make their operations and tools available to the public. We see drafting off established and proven technology as a wise path forward, and we continue to advocate for the progress of solid engineering practices moving ahead.

Datalogger Configurations and System Performance:

NSL's efforts during the project period toward better understanding datalogger configurations and system performance centered around 3 primary tasks described below: creating a batch configuration process for Kinemetrics Rock datalogger, mitigating backfill flooding for sub-second enabled dataloggers, and testing Rapid Event Notification applications on RT130 dataloggers.

Batch Configuration System for Rock Instruments (Basalt, Obsidian, Etna2)

KMI Rock instruments provide three types of on-board buffers for telemetering data: Ringserver, SEEDLink, and Earthworm. NSL employs the KMI-native Ringserver because it allows us to pull data to directly from the datalogger to our internal ORB buffers, using Antelope's *orb2orb* program. Additionally, this allows us to use the Antelope *orbstat* program to monitor the status, and content, of the on-board Ringserver.

To configure these systems for Ringserver telemetry, the default acquisition layout must be deleted, and the Ringserver module installed. Unfortunately, the Rock web interface has a software bug that prohibits this operation. If the UI were to work as advertised, the configuration process would still be slow and prone to user error. KMI provides an alternate configuration method wherein a group of configuration files can be uploaded and then installed automatically on reboot. We researched the process and developed a system for using the latter configuration method for all Rock data logger types. With properly constructed config files, we set not only the instrument's telemetry layout but also the hardware, recording, and network-station-channel parameters with a single operation. This method of configuration reduces setup errors and allows us to quickly program a batch of instruments on the bench for testing, or remotely after an instrument has been deployed. It also ensures consistent parameters across our KMI deployments.

Rapid-Backfill Floodgate for Sub-Second-Enabled Instruments

KMI/Rock and RefTek instruments have the ability to backfill data after a network interruption. When these instruments are configured to send sub-second packets, local acquisition buffers can be flooded during backfilling, straining downstream archival and data export processes network-wide. This is especially true for instruments on high-bandwidth connections, and for RefTek instruments which use UDP, instead of slower TCP protocol. A further complication is that backfilled packets are not necessarily sent in order. With an extremely high packet rate, this greatly increases the load on archival processes that store data in miniSEED format, because the miniSEED archive must be uncompressed and then recompressed to splice out-of-sequence data.

To mitigate the effects of backfill flooding, we developed an acquisition configuration to prevent system-wide effect of backfill flooding with the following features:

(1) Primary acquisition processes uncompress EEW packets to a dedicated "fast" ORB and store them locally as 4-byte uncompressed data, as a backup archive.
(2) Archival, event processing, and data export buffers pull this uncompressed data from the "fast" ORB but ignore packets older than 10-seconds.

This implementation ensures that EEW packets are propagated through the analysis/archival/export systems when network links are operating normally, but protects those systems from flooding after network outages. It also ensures that data can be recovered after an outage. This is a work in progress, and we anticipate working with EEW partners to determine the ideal buffer length parameter for EEW purposes.

RT130 Rapid Event Notification (REN) Testing

Beginning with firmware version 3.7, RefTek RT130 instruments are able to create 0.25 second packets. RefTek supplies two versions of the firmware, "R" and "F" (e.g., 3.7.8F). The "F" series firmware is tailored for streaming-only REN applications and will fill up RAM if network links go down, i.e. no TOSS parameter is implemented. The "R" series functions more like standard RT130 firmware however we were unable to set the TOSS parameter without error.

We deployed v3.7.X firmware-updated RT130 instruments and tested the REN systems end-to-end. Initial testing was successful but was subject to the backfill-flooding problem described above. This was exacerbated by the inability of the "R" series firmware to honor the TOSS parameter. RefTek REN packets are no longer sent as standard SEED packets, and instead use a new Multiplexed RefTek Format (MRF) packet type. For testing, RTPD acquisition buffers had to be initialized with MRF enabled in order to accept these packets. We also had to modify our RTPD-to-ORB software to deal with this new packet type.

In our experience the REN firmware was unstable and not well supported by the software utilities, which appeared to have conflicts with the REN firmware, or by Trimble, who gave us varying opinions on how the firmware was supposed to work. We currently do not operate any testing or production RefTek systems with the REN configuration.

Data Exchange through Real-time EEW SEEDlink Server:

NSL has been working to improve low-latency data exchange with EEW partners. We anticipate that have a representative on the EEW regional coordinators working group will help smooth this process and ensure the delivery of NSL EEW data to ShakeAlert partners.

In 2018 NSL configured a dedicated, cloud-based SEEDLink server for distribution of waveform data from all stations running Obsdian, Etna2, and Q330 data loggers. Only the Rock instrument data is currently running with sub-second packet telemetery, however we made the decision to include Q330-generated waveforms for stations that could potentially be upgraded to sub-second configurations. To optimize data transfer to the server, we initially implemented the standard IRIS version of *orb2ringserver*, using the 'f=1' parameter to send and flush data packets older than 1 second. To further optimize transfer, we implemented a version of *orb2ringserver* modified by Doug Neuhauser that sends packets to the SEEDLink server as they arrive in the source buffer. This system has been running and exporting EEW data since August of 2018. We are working with partner CISN networks to develop a strategy for data importation into ShakeAlert, and we will continue to monitor latencies both at NSL and using ShakeAlert Station Acceptance metrics to ensure continued improvement of the data transfer system.