DATASET RELEASE AND QUALITY CONTROL REVIEW OF LIVERMORE NEVADA NETWORK (LNN) RECORDINGS OF A SUBSET OF NEVADA NUCLEAR SECURITY SITE NUCLEAR EXPLOSIONS FROM 1979 TO 1992.

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Introduction

Geophysical research on historical nuclear tests is an important aspect of future monitoring capabilities in seismic research. This research is challenging due to the limited number of digital seismic recordings during the peak of nuclear testing (1945-1992). These limited records are unique and non-reproducible data with potential high research impact. Releasing available nuclear explosion seismic records to the explosion monitoring community is thus of high value and is the motivation for this dataset release.

The target of this effort was on compilation and quality control of regional seismic records of nuclear explosions recorded on Lawrence Livermore National Laboratory stations ELK, KNB, LAC, and MNV, known collectively as the Livermore Nevada Network (LNN) (Figure 1). LNN was established in the early 1960s for the primary purpose of monitoring underground nuclear testing the former Nevada Test Site (NTS), now known as the Nevada Nuclear Security Site (NNSS) following the signing of the Limited Test Ban Treaty (LTBT). LNN consisted initially of short-period vertical component Benioff's recorded on film located at Mina, NV (MNV) and Kanab, Utah (KNB). LNN added two additional stations at Landers, CA (LAC) and Elko, NV (ELK) in 1967 and upgraded equipment to broadband seismometers recorded on frequency modulation (FM) tapes from 1967-1979, followed by digital recordings after 1979 (Jarpe, 1989). The digital recordings were on a variety of now obsolete media, including 9-track, Exabyte, and DAT tapes. Jarpe (1989) describes the seismic station instrumentation details over the period of deployment. LNN recorded valuable non-repeatable unique data of several hundreds of nuclear explosions at NNSS, as well as earthquakes and chemical and mining explosions (Walter, 2020). The details of these nuclear tests are provided in the Department of Energy Report NV-209 Rev 16 (DOE, 2015).

Several digitization recovery efforts of LNN recordings have occurred since these were recorded several decades ago. These digital recordings were read and archived at LLNL in a geophysical database and repository. Of these recordings, 73 nuclear explosions were published alongside records from the Leo Brady Network (LBN), western U.S. IMS stations, and Southern Great Basin Network (SGBN) (Walter et al., 2004). In addition to the waveforms and composite event catalog, Walter et al. (2004) published analyst picks that were used to identify potential timing errors in the data. The Western U.S. dataset described in Walter et al. (2004) was sent via CD-ROM upon request to many researchers since release and in 2018 was made available as an assembled dataset at IRIS at http://ds.iris.edu/mda/18-001/.

There were also over a hundred additional nuclear events at NNSS that were not published in Walter et. al. (2004). Of these events, LLNL has recordings from at least one of the LNN stations for 108 additional nuclear explosions that occurred after 1979 (digital tape era). The data released alongside this report are of the LNN recordings of these 108 nuclear explosions.

Data Selection

We selected the subset of nuclear explosions at NNSS based on availability of digitized LNN recordings of the events. To be included in this release, the event required a regional recording from at least one LNN station. Additionally, we only targeted events after 1979 as we were more confident in the instrument responses for that period. The instrument responses for this period had been previously reviewed and released in the Western U.S dataset release (Walter et. al., 2004). Based on these criteria, 108 events were identified for possible release.

Figure 2 shows the selection of events included in this data release. All events are nuclear explosions that were conducted from January 24,1979 to April 30, 1992, at NNSS between 36.994° and 37.348° latitude and -116.500° and -115.998° longitude. 97 of the explosions were U.S.-led shots, while 11 were U.K-led shots. The spatial distribution of the explosions is spread over three regions, Pahute Mesa in the Northwest, Yucca Flat to the Southeast, with Rainier Mesa in between. “The events in Yucca Flat cover a range of sizes and depths while those in Rainier Mesa tend to be smaller and shallower and in Pahute Mesa they are larger and deeper.

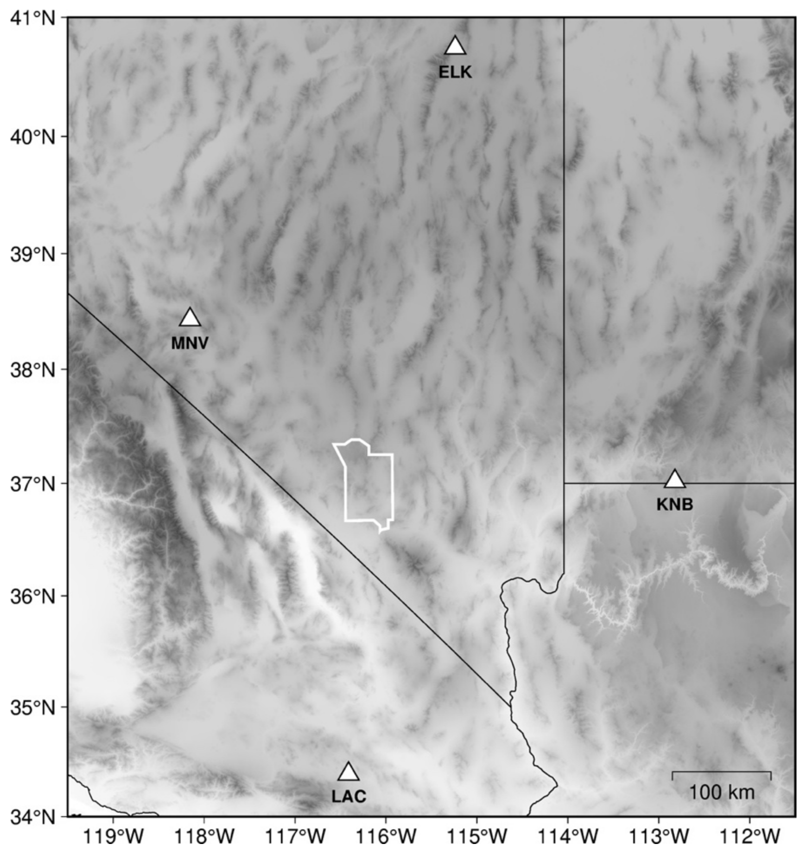

Figure 1. Livermore Nevada Network of stations shown as white triangles. The Nevada Nuclear Security Site (NNSS) outlined in white. The topography model used is SRTM (NASA, 2013).

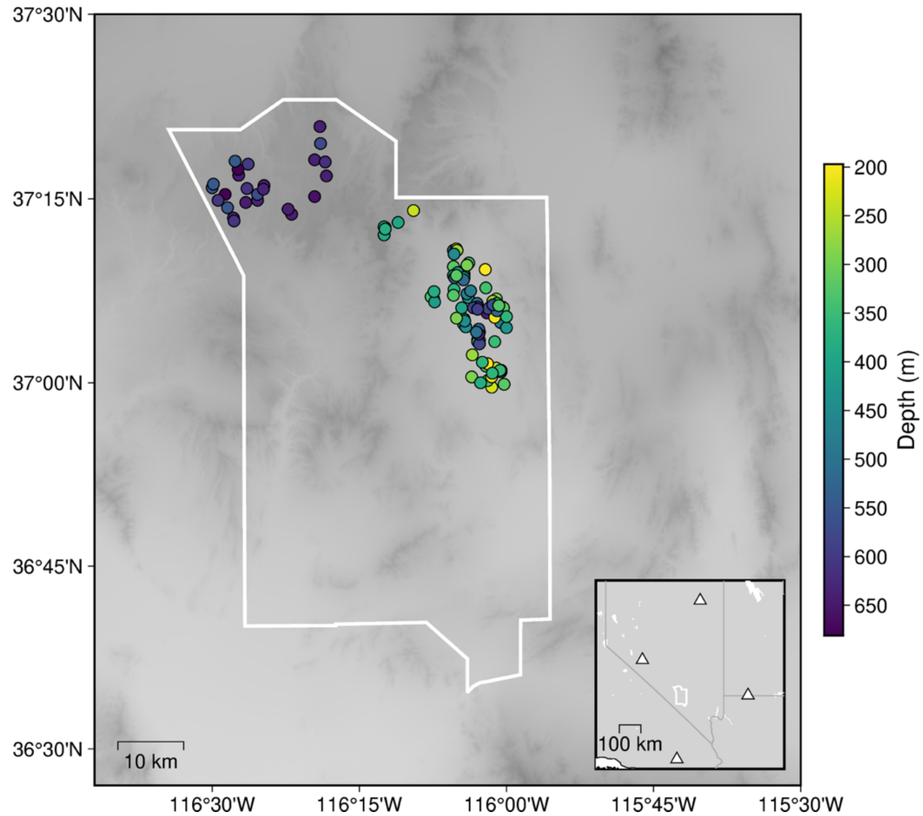

Figure 2. Map of nuclear explosions reviewed and released colored by depth in meters. NNSS is outlined in white. The subset map shows the LNN network from Figure 1.

Table 1. Station locations for the LNN legacy network.

Station	Latitude	Longitude	Elevation (m)
ELK	40.7448	-115.2388	2.21
KNB	37.0166	-112.8224	1.715
LAC	34.3898	-116.4115	0.792
MNV	38.4328	-118.1531	1.507

Table 2. Explosion information, including event name, time, and location for events in this release. Events with QC issue are identified in yellow. Events that are discluded from release due to significant timing issue are shown in red.

Event ID	Name	Time	Lat	Long	Dep (km)	QC Issue	Included	Notes
1	Baccarat	1979/01/24 (024) 18:00:00.100	37.105	-116.013	0.326		x	
2	Quinella	1979/02/08 (039) 20:00:00.090	37.102	-116.056	0.579		x	
3	Kloster	1979/02/15 (046) 18:05:00.160	37.152	-116.073	0.536		x	
4	Memory	1979/03/14 (073) 18:30:00.100	37.028	-116.041	0.365		x	
5	Pepato	1979/06/11 (162) 14:00:00.170	37.29	-116.456	0.681	x	x	
6	Chess	1979/06/20 (171) 15:00:13.540	37.108	-116.016	0.335		x	

7	Fajy	1979/06/28 (179) 14:44:00.170	37.143	-116.088	0.536		x	
8	Burzet	1979/08/03 (215) 15:07:30.160	37.084	-116.071	0.45		x	
9	Offshore	1979/08/08 (220) 15:00:00.110	37.015	-116.009	0.396		x	
10	Nessel	1979/08/29 (241) 15:08:00.170	37.121	-116.067	0.464		x	
11	Sheepshead	1979/09/26 (269) 15:00:00.090	37.229	-116.365	0.64	x	x	
12	Backgammon	1979/11/29 (333) 15:00:00.100	36.994	-116.025	0.229	x	x	
13	Tarko	1980/02/28 (059) 15:00:00.090	37.127	-116.089	0.369	x	x	
14	Norbo	1980/03/08 (068) 15:35:00.090	37.18	-116.084	0.271		x	
15	Liptauer	1980/04/03 (094) 14:00:00.090	37.15	-116.083	0.417		x	
16	Pyramid	1980/04/16 (107) 20:00:00.090	37.101	-116.031	0.579		x	
17	Colwick	1980/04/26 (117) 17:00:00.080	37.248	-116.423	0.633		x	
18	Canfield	1980/05/02 (123) 18:46:30.090	37.056	-116.02	0.351	x	x	
19	Flora	1980/05/22 (143) 13:00:00.090	37.003	-116.032	0.335	x	x	
20	Kash	1980/06/12 (164) 17:15:00.090	37.282	-116.455	0.645	x	x	
21	Huron King	1980/06/24 (176) 15:10:00.070	37.023	-116.035	0.32	x	x	
22	Tafi	1980/07/25 (207) 19:05:00.080	37.256	-116.478	0.68		x	
23	Verdello	1980/07/31 (213) 18:19:00.090	37.013	-116.024	0.366		x	
24	Bonarda	1980/09/25 (269) 14:45:00.090	37.056	-116.049	0.381	x	x	
25	Rioia	1980/09/25 (269) 15:26:30.080	37.116	-116.065	0.424	x	x	
26	Dutchess	1980/10/24 (298) 19:15:00.120	37.075	-116	0.427		x	
27	Miners Iron	1980/10/31 (305) 18:00:00.090	37.211	-116.206	0.39		x	
28	Dauphin	1980/11/14 (319) 16:50:00.080	37.111	-116.02	0.32		x	
29	Serpa	1980/12/17 (352) 15:10:00.090	37.325	-116.316	0.573		x	
30	Seco	1981/02/25 (056) 15:00:00.080	37.182	-116.085	0.2	x	x	
31	Aligote	1981/05/29 (149) 16:00:00.090	37.102	-116.005	0.32	x	x	
32	Harzer	1981/06/06 (157) 18:00:00.080	37.303	-116.326	0.637		x	
33	Niza	1981/07/10 (191) 14:00:00.100	37.129	-116.035	0.341		x	
34	Pineau	1981/07/16 (197) 15:00:00.100	37.089	-116.02	0.207		x	
35	Havarti	1981/08/05 (217) 13:41:00.090	37.154	-116.036	0.2	x	x	
36	Islay	1981/08/27 (239) 14:31:00.090	37.16	-116.067	0.294		x	
37	Trebbiano	1981/09/04 (247) 15:00:00.100	37.058	-116.049	0.305		x	
38	Cernada	1981/09/24 (267) 15:00:00.090	37.008	-116.025	0.213		x	
39	Paliza	1981/10/01 (274) 19:00:00.100	37.082	-116.01	0.472		x	
40	Tilci	1981/11/11 (315) 20:00:09.090	37.076	-116.069	0.445		x	
41	Rousanne	1981/11/12 (316) 15:00:00.100	37.108	-116.05	0.517	x	x	
42	Akavi	1981/12/03 (337) 15:00:00.100	37.148	-116.072	0.494		x	
43	Caboc	1981/12/16 (350) 21:05:00.090	37.114	-116.124	0.335		x	
44	Molbo	1982/02/12 (043) 14:55:00.080	37.224	-116.464	0.638	x	x	
45	Hosta	1982/02/12 (043) 15:25:00.090	37.348	-116.317	0.64		x	

46	Tenaja	1982/04/17 (107) 18:00:00.090	37.017	-116.011	0.357	x	x	
47	Gibne	1982/04/25 (115) 18:05:00.010	37.256	-116.423	0.57	x	x	
48	Kryddost	1982/05/06 (126) 20:00:00.080	37.117	-116.128	0.335		x	
49	Bouschet	1982/05/07 (127) 18:17:00.110	37.069	-116.046	0.564		x	
50	Kesti	1982/06/16 (167) 14:00:00.080	37.114	-116.017	0.289		x	
51	Nebbiolo	1982/06/24 (175) 14:15:00.090	37.236	-116.371	0.64		x	
52	Monterey	1982/07/29 (210) 20:05:00.080	37.102	-116.076	0.4	x	x	
53	Cerro	1982/09/02 (245) 14:00:00.090	37.02	-116.017	0.229	x	x	
54	Huron Landing	1982/09/23 (266) 16:00:00.090	37.212	-116.208	0.408		x	
55	Frisco	1982/09/23 (266) 17:00:00.090	37.175	-116.089	0.451		x	
56	Manteca	1982/12/10 (344) 15:20:00.090	37.08	-116.073	0.413	x	x	
57	Cheedam	1983/02/17 (048) 17:00:00.090	37.163	-116.064	0.343	x	x	
58	Cabra	1983/03/26 (085) 20:20:00.090	37.301	-116.461	0.542	x	x	
59	Turquoise	1983/04/14 (104) 19:05:00.120	37.073	-116.047	0.533		x	
60	Armada	1983/04/22 (112) 13:53:00.080	37.111	-116.023	0.265	x	x	
61	Crowd ie	1983/05/05 (125) 15:20:00.080	37.146	-116.09	0.39		x	
62	Mini Jade	1983/05/26 (146) 14:30:00.090	37.209	-116.206	0.379	x		Timing Issue - No signal in waveforms for time window
63	Fahada	1983/05/26 (146) 15:00:00.090	37.103	-116.007	0.384		x	
64	Danablu	1983/06/09 (160) 17:10:00.090	37.158	-116.09	0.32	x	x	
65	Laban	1983/08/03 (215) 13:33:00.100	37.119	-116.09	0.326		x	
66	Sabado	1983/08/11 (223) 14:00:00.120	36.998	-116.004	0.32		x	
67	Romano	1983/12/16 (350) 18:30:00.090	37.14	-116.073	0.515		x	
68	Tortugas	1984/03/01 (061) 17:45:00.090	37.066	-116.047	0.639		x	
69	Agrini	1984/03/31 (091) 14:30:00.080	37.146	-116.085	0.32		x	
70	Mundo	1984/05/01 (122) 19:05:00.090	37.106	-116.023	0.566		x	
71	Caprock	1984/05/31 (152) 13:04:00.100	37.103	-116.049	0.6		x	
72	Duoro	1984/06/20 (172) 15:15:00.090	37	-116.044	0.381		x	
73	Kappeli	1984/07/25 (207) 15:30:00.080	37.268	-116.412	0.64		x	
74	Correo	1984/08/02 (215) 15:00:00.090	37.017	-116.009	0.334	x	x	
75	Dolcetto	1984/08/30 (243) 14:45:00.100	37.09	-116	0.365		x	
76	Breton	1984/09/13 (257) 14:00:00.000	37.087	-116.072	0.483	x	x	
77	Egmont	1984/12/09 (344) 19:40:00.090	37.27	-116.498	0.546		x	
78	Tierra	1984/12/15 (350) 14:45:00.000	37.281	-116.306	0.64		x	
79	Vaughn	1985/03/15 (074) 16:31:00.100	37.058	-116.046	0.426	x	x	
80	Cottage	1985/03/23 (082) 18:30:00.080	37.18	-116.09	0.515		x	
81	Hermosa	1985/04/02 (092) 20:00:00.090	37.095	-116.033	0.64		x	

82	Misty Rain	1985/04/06 (096) 23:15:00.090	37.201	-116.208	0.389		x	
83	Towanda	1985/05/02 (122) 15:20:00.080	37.253	-116.326	0.66		x	
84	Salut	1985/06/12 (163) 15:15:00.080	37.248	-116.49	0.608		x	
85	Ville	1985/06/12 (163) 17:30:00.090	37.088	-116.085	0.293		x	
86	Maribo	1985/06/26 (177) 18:03:00.080	37.124	-116.123	0.381		x	
87	Serena	1985/07/25 (206) 14:00:00.090	37.297	-116.439	0.597	x	x	
88	Ponil	1985/09/27 (270) 14:15:00.080	37.09	-116.003	0.365	x	x	
89	Mill Yard	1985/10/09 (282) 21:40:00.130	37.209	-116.206	0.371	x		Timing Issue - No signal in waveforms for time window
90	Roquefort	1985/10/16 (289) 21:35:00.090	37.11	-116.122	0.415		x	
91	Kinibito	1985/12/05 (339) 15:00:00.070	37.053	-116.046	0.579		x	
92	Goldstone	1985/12/28 (362) 19:01:00.090	37.238	-116.474	0.549	x	x	
93	Mighty Oak	1986/04/10 (100) 14:08:30.100	37.218	-116.184	0.394	x	x	
94	Jefferson	1986/04/22 (112) 14:30:00.090	37.264	-116.441	0.609		x	
95	Panamint	1986/05/21 (141) 13:59:00.080	37.125	-116.061	0.48		x	
96	Tajo	1986/06/05 (156) 15:04:00.060	37.098	-116.016	0.518		x	
97	Darwin	1986/06/25 (176) 20:27:45.090	37.265	-116.5	0.549	x	x	
98	Cornucopia	1986/07/24 (205) 15:05:00.090	37.143	-116.072	0.381	x	x	
99	Aleman	1986/09/11 (254) 14:57:00.110	37.069	-116.051	0.503		x	
100	Labquark	1986/09/30 (273) 22:30:00.100	37.3	-116.308	0.616		x	
101	Belmont	1986/10/16 (289) 19:25:00.090	37.22	-116.463	0.605		x	
102	Gascon	1986/11/14 (318) 16:00:00.070	37.1	-116.049	0.593		x	
103	Bodie	1986/12/13 (347) 17:50:05.090	37.263	-116.413	0.635		x	
104	Whiteface-A	1989/12/20 (354) 22:00:00.060	37.026	-116.032	0.197	x		Timing Issue - No signal in waveforms for time window
105	Sundown-A	1990/09/20 (263) 16:15:00.000	37.038	-116.058	0.27	x		Timing Issue - No signal in waveforms for time window
106	Ledoux	1990/09/27 (270) 18:02:46.000	37.008	-116.059	0.291	x		Timing Issue - No signal in waveforms for time window
107	Montello	1991/04/16 (106) 15:30:00.070	37.245	-116.443	0.642		x	
108	Diamond Fortune	1992/04/30 (121) 16:30:00.000	37.234	-116.158	0.236	x	x	

Table 2. Explosion information, including event name, time, and location for events in this release. Events with QC issue are identified in yellow. Events that are discluded from release due to significant timing issue are shown in red.

Manual Quality Control (QC)
For each event, all available LNN waveforms were manually reviewed for quality issues. We utilized Python packages Matplotlib, Obspy (Beyreuther, 2010), and Pisces (MacCarthy, 2020) to read and plot the waveform recordings of the nuclear explosion events stored in a geophysical database at LLNL. The observed (i.e., raw waveforms) were inspected for quality issues and defects including dead channels, spiking, gaps, noise, and large timing errors.

Significant timing errors could be identified when the signal arrival was not within the window of the event. However, most timing errors were not assessed in this manual review as it required calculating the time residual of expected arrival times and actual arrival times. An analyst has not reviewed and picked arrivals on these waveforms; thus, the time residuals could not be determined. The usefulness of this technique in identifying clock problems in LNN stations is described in Walter et. al. (2004) and could be a focus of future work on this dataset (see Future Work section).

After inspection of the raw waveforms, instrument responses were deconvolved from the observed waveform. The waveforms were again inspected for errors in instrument response, including abhorrent amplitude measurements (i.e., not physically feasible) and errors in response file resulting in failed deconvolution. Some preliminary scoping and analysis were done comparing synthetics to deconvolved filtered waveforms as a method to identify and quantify amplitude discrepancies and instrument response errors (see Preliminary Automated QC section). This could be an additional area of automated quality control assessment on this dataset (see Future Work).

Initially, other regional stations of interest were reviewed. However, after consistently identifying issues in either station quality and/or instrument responses, we focused our efforts solely on LNN stations. Table 3 lists the QC issues identified for a given event-station-channel. We've included examples of several QC issues in Figures 3-8. If a figure is present for a given QC item, it is listed in Table 3.

Table 3. Quality control issues identified for a given event, station, and channel. If the QC issue is shown in a figure in Appendix B, they are listed under the Figure column.

Event ID	Station	Channel	Dead	Non-Seismic Noise	Low SNR	Spikes	Gaps	Clip	Figure	Notes
3	MNV	r		x						Not seismic data, no signal observed
3	MNV	t		x						Not seismic data, no signal observed
3	MNV	v		x						Not seismic data, no signal observed
11	KNB	r		x		x				spike/noise in the coda wave, possible sensor/cable issue
12	ELK	r			x					signal visible with filter
12	ELK	t			x					signal visible with filter

12	ELK	v			x					signal visible with filter
12	KNB	r			x					signal visible with filter
12	KNB	t			x					signal visible with filter
12	KNB	v			x					signal visible with filter
12	LAC	r			x					signal visible with filter
12	LAC	t			x					signal visible with filter
12	LAC	v			x					signal visible with filter
12	MNV	r			x					signal visible with filter
12	MNV	t			x					signal visible with filter
12	MNV	v			x					signal visible with filter
13	ELK	r		x						non-seismic noise, bad data
13	ELK	t		x						non-seismic noise, bad data
13	ELK	v		x						non-seismic noise, bad data
18	ELK	r					x		Fig 8	8 s gap ~16s after arrival during S-wave
18	ELK	t					x		Fig 8	8 s gap ~16s after arrival during S-wave
18	ELK	v					x		Fig 8	8 s gap ~16s after arrival during S-wave
19	ELK	r			x					signal visible with filter
19	ELK	t			x					signal visible with filter
19	ELK	v			x					signal visible with filter
19	KNB	r			x					signal visible with filter
19	KNB	t			x					signal visible with filter
19	KNB	v			x					signal visible with filter
19	LAC	r			x					signal visible with filter
19	LAC	t			x					signal visible with filter
19	LAC	v			x					signal visible with filter
19	MNV	r			x					signal visible with filter
19	MNV	t			x					signal visible with filter
19	MNV	v			x					signal visible with filter
20	ELK	v						x		truncated values in surface wave, but lower amplitude than other non-clipped values
21	ELK	r		x					Fig 4	Triangular wave pattern
21	ELK	t		x					Fig 4	Triangular wave pattern
21	ELK	v		x					Fig 4	Triangular wave pattern
24	ELK	r					x		Fig #	~2m 7s gap, ~3m 3s after origin time
24	ELK	t					x			~2m 7s gap, ~3m 3s after origin time
24	ELK	v					x			~2m 7s gap, ~3m 3s after origin time
24	KNB	r					x			~1m 30s gap, ~3m 3s after origin time
24	KNB	t					x			~1m 30s gap, ~3m 3s after origin time
24	KNB	v					x			~1m 30s gap, ~3m 3s after origin time
24	LAC	r					x			~1m gap, ~3m 3s after origin time

24	LAC	t					x			~1m gap, ~3m 3s after origin time
24	LAC	v					x			~1m 20s gap, ~3m 3s after origin time
24	MNV	r					x			~1m 20s gap, ~3m 3s after origin time
24	MNV	t					x			~1m 20s gap, ~3m 3s after origin time
24	MNV	v					x			~1m 20s gap, ~3m 3s after origin time
25	ELK	r					x			Multiple short gaps during event signal, followed by ~2m gap at ~15:28:00
25	ELK	t					x			Multiple short gaps during event signal, followed by ~2m gap at ~15:28:00
25	ELK	v					x			Multiple short gaps during event signal, followed by ~2m gap at ~15:28:00
25	KNB	r					x			Multiple short gaps during event signal, followed by ~2m gap at ~15:28:00
25	KNB	t					x			Multiple short gaps during event signal, followed by ~2m gap at ~15:28:00
25	KNB	v					x			Multiple short gaps during event signal, followed by ~2m gap at ~15:28:00
25	LAC	r					x			Multiple short gaps during event signal, followed by ~2m gap at ~15:28:00
25	LAC	t					x			Multiple short gaps during event signal, followed by ~2m gap at ~15:28:00
25	LAC	v					x			Multiple short gaps during event signal, followed by ~2m gap at ~15:28:00
25	MNV	r					x			Multiple short gaps during event signal, followed by ~2m gap at ~15:28:00
25	MNV	t					x			Multiple short gaps during event signal, followed by ~2m gap at ~15:28:00
25	MNV	v					x			Multiple short gaps during event signal, followed by ~2m gap at ~15:28:00
30	ELK	r			x					signal visible with filter
30	ELK	t			x					signal visible with filter
30	ELK	v			x					signal visible with filter
30	KNB	r			x					signal visible with filter
30	KNB	t			x					signal visible with filter
30	KNB	v			x					signal visible with filter

30	LAC	r			x					signal visible with filter
30	LAC	t			x					signal visible with filter
30	LAC	v			x					signal visible with filter
31	KNB	t		x						Not seismic data, likely broken sensor
35	ELK	r			x				Fig 7	signal visible with filter
35	ELK	t			x				Fig 7	signal visible with filter
35	ELK	v			x				Fig 7	signal visible with filter
35	KNB	r			x				Fig 7	signal visible with filter
35	KNB	t			x				Fig 7	signal visible with filter
35	KNB	v			x				Fig 7	signal visible with filter
35	LAC	r			x				Fig 7	signal visible with filter
35	LAC	t			x				Fig 7	signal visible with filter
35	LAC	v			x				Fig 7	signal visible with filter
35	MNV	r			x				Fig 7	signal visible with filter
35	MNV	t			x				Fig 7	signal visible with filter
35	MNV	v			x				Fig 7	signal visible with filter
41	KNB	r		x						Step up with noise at ~24s after first arrival
44	KNB	r					x			4s and 12s gaps after S-wave arrival
44	KNB	t					x			4s and 12s gaps after S-wave arrival
44	KNB	v					x			4s and 12s gaps after S-wave arrival
46	ELK	r		x						Step up with noise ~5 m 32 s after first arrival
47	MNV	r					x			~x gap in ~x after arrival
47	MNV	t					x			~x gap in ~x after arrival
47	MNV	v					x			~x gap in ~x after arrival
52	MNV	r				x				Gaps in coda wave
52	MNV	t				x				Gaps in coda wave
52	MNV	v				x				Gaps in coda wave
53	KNB	r		x					Fig 5	Bad data, possible broken sensor/cable
53	KNB	t		x					Fig 5	Bad data, possible broken sensor/cable
56	KNB	r					x			~1s gap in at 15:23:52
56	KNB	t					x			~1s gap in at 15:23:52
56	KNB	v					x			~1s gap in at 15:23:52
57	MNV	r					x			~21s gap in coda wave
57	MNV	t					x			~21s gap in coda wave
57	MNV	v					x			~21s gap in coda wave
58	MNV	r				x				Minor
58	MNV	t				x				Minor
58	MNV	v				x				Minor
60	KNB	r			x					Low SNR, noisy data
64	KNB	r	x							flat-line after S-wave arrival
64	KNB	t	x							flat-line after S-wave arrival
64	KNB	v	x							flat-line after S-wave arrival
74	KNB	e		x	x		x			Spike and high noise ~5m after arrival

76	ELK	e					x			~4s gap at 14:01:47
76	ELK	n					x			~4s gap at 14:01:47
76	ELK	v					x			~4s gap at 14:01:47
79	KNB	n		x			x			Noise and gaps, calibration?
87	KNB	e		x				x		bad data and clipping
88	KNB	v		x						square wave through entire signal
92	KNB	e		x			x			Square wave in S-wave coda and 1s gap at 19:02:19.4
93	LAC	e	x						Fig 3	Digitizer noise
93	LAC	n	x						Fig 3	Digitizer noise
93	LAC	v		x					Fig 3	
97	KNB	e		x						non-seismic noise, bad data, possible broken sensor/cable
97	KNB	n		x						non-seismic noise, bad data, possible broken sensor/cable
98	KNB	n		x		x			Fig 6	large spikes and noise, possible broken sensor/cable
98	LAC	e		x		x			Fig 6	large spikes and noise, possible broken sensor/cable

Table 3. Quality control issues identified for a given event, station, and channel. If the QC issue is shown in a figure in Appendix B, they are listed under the Figure column.

Dead Channels, Non-Seismic Noise, Low SNR, Spikes

Table 3 shows columns for dead channels, non-seismic noise, spiking, and low SNR. Dead channels are identified by flat-line or nearly flat-lined (i.e., low counts with minimal variation) and typical digitizer noise.

Figure 3 displays waveform recordings on KNB, MNV, and LAC for event 93. There were no available digitized recordings of this event on ELK. LAC channel e and n are digitizer noise and channel z is also non-seismic noise.

Non-seismic noise is generic for any noise that was not seismic. Examples seen in this dataset are square waves, triangular waves (Figure 4), excessively garbled data (Figures 5 and 6) typical of a bad sensor or cable, etc. Figure 4 displays waveform recordings of all LNN stations for event 21. While KNB, LAC, and MNV recorded the event well, ELK waveform is a triangular wave pattern. Figures 5 and 6 display two examples of non-seismic noise and spiking for events 53 and 98, respectively. This type of noise is characteristic of either a sensor or cable problem, such as corrosion.

Low SNR was flagged for waveforms that had visually (no calculated SNR) lower signal-to-noise and required filtering to identify the energy arrivals (Figure 7).

Gaps

Eleven events were identified with at least a single waveform gap (Table 3). In some cases, the gaps are across multiple stations, a single station, or a single channel. Some are single gaps and multiple gaps that vary in duration. The notes section provides details on timing and duration of gap(s) for each waveform. Figure 8 displays waveform recordings for event 18 and the ~8 second gap after the S-wave arrival on all ELK channels.

Timing

We identified 5 of the 108 events with significant timing issues. There was no observable signal on any LNN station for 4 of these events. The 5th event had a signal on KNB only, but timing of the arrivals was later than expected. In each event, other regional stations had signal recordings and we'd expect the LNN network to as well. This suggests these waveforms were misattributed to these events or had timing offsets large enough such that the arrival did not appear within the segmented waveform. These 5 events, noted in Table 2, were not included in this release as they were not usable.

Dataset Release Content

The dataset in this release includes the LNN seismogram recordings of the 103 NNSS nuclear explosions described in this manuscript (5 events with significant timing error not included). Waveforms are provided in the .w format (i4) with accompanying metadata in NNSA KbCore standard (Carr, 2002; Carr, 2007). Station metadata is provided in site, sitechan, sensor, and instrument tables. Instrument responses are provided in SAC pole-zero files with linkage to the metadata by the sensor and instrument table. Event information is provided in event, origin, and netmag tables. The waveform metadata is provided in wfdisc which links the waveform files to the station and waveform metadata. The entire dataset is packaged into a tar file and can be found with this report at https://ds.iris.edu/mda/23-014/.

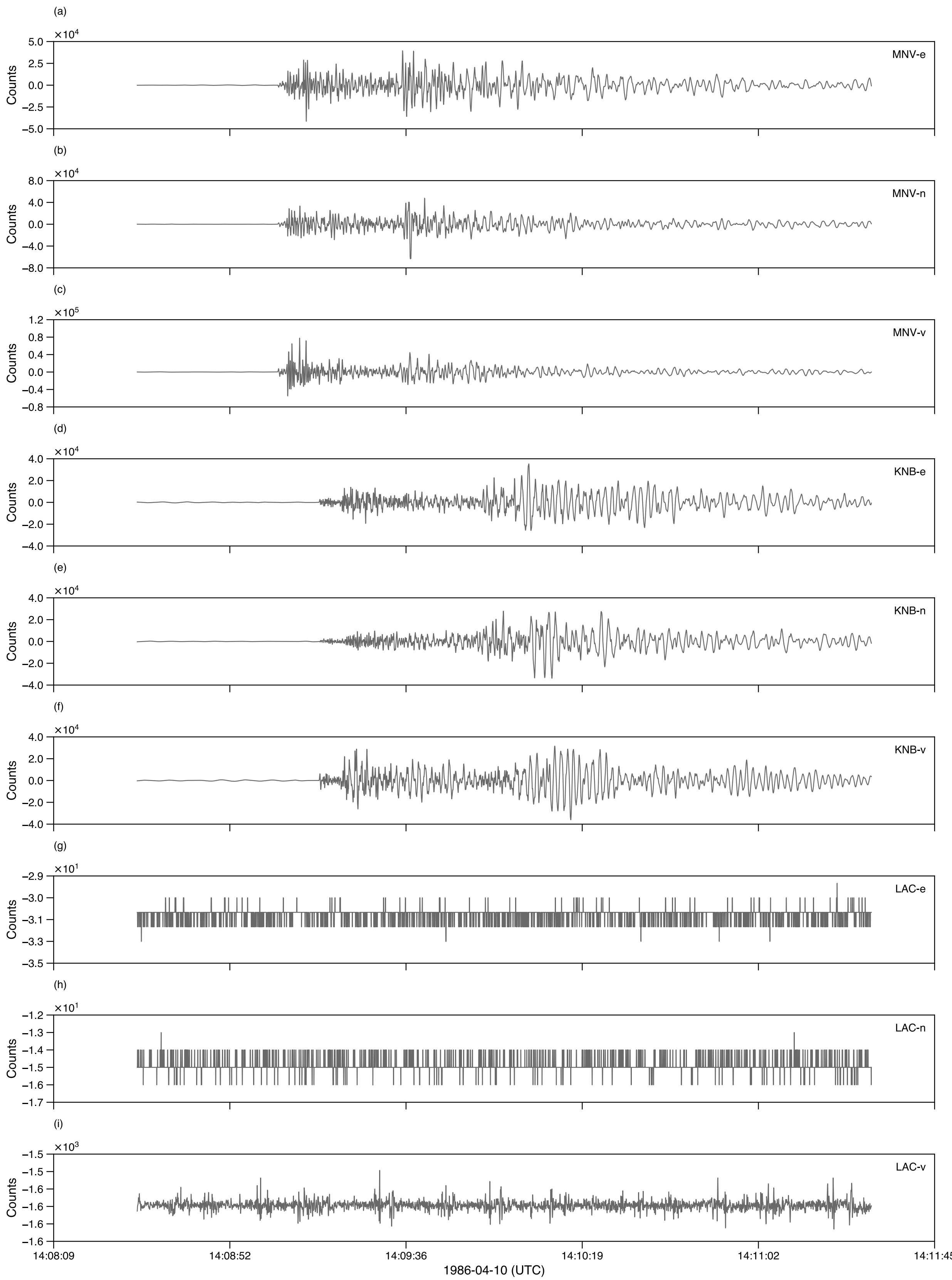

Figure 3: LNN waveform recordings of event 93 with an identified QC issue. LAC recordings are non-seismic noise recordings and e- and n- channels are digitizer noise.

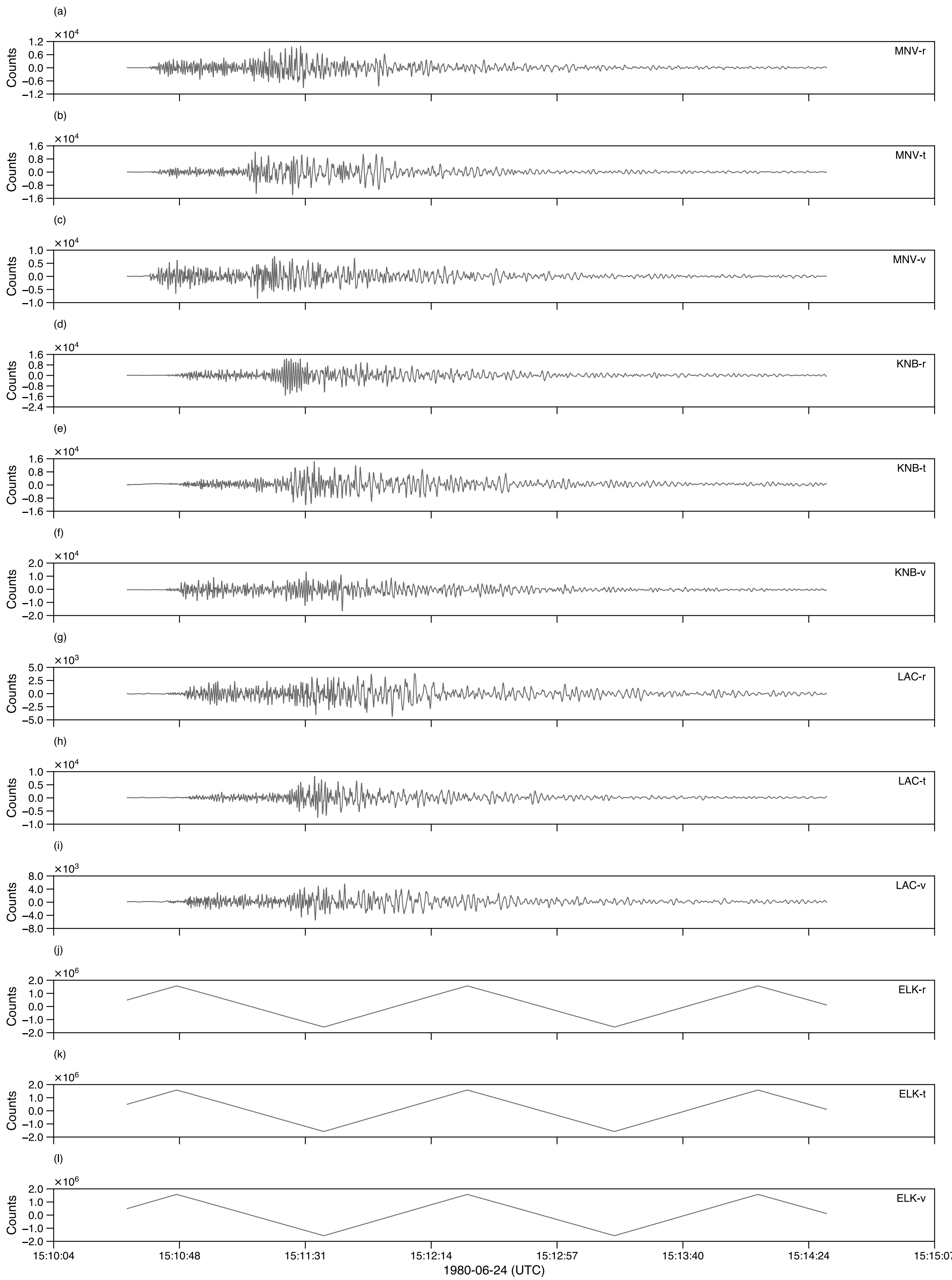

Figure 4: LNN waveform recordings of event 21 with an identified QC issue. ELK recordings are non-seismic triangular-wave recordings.

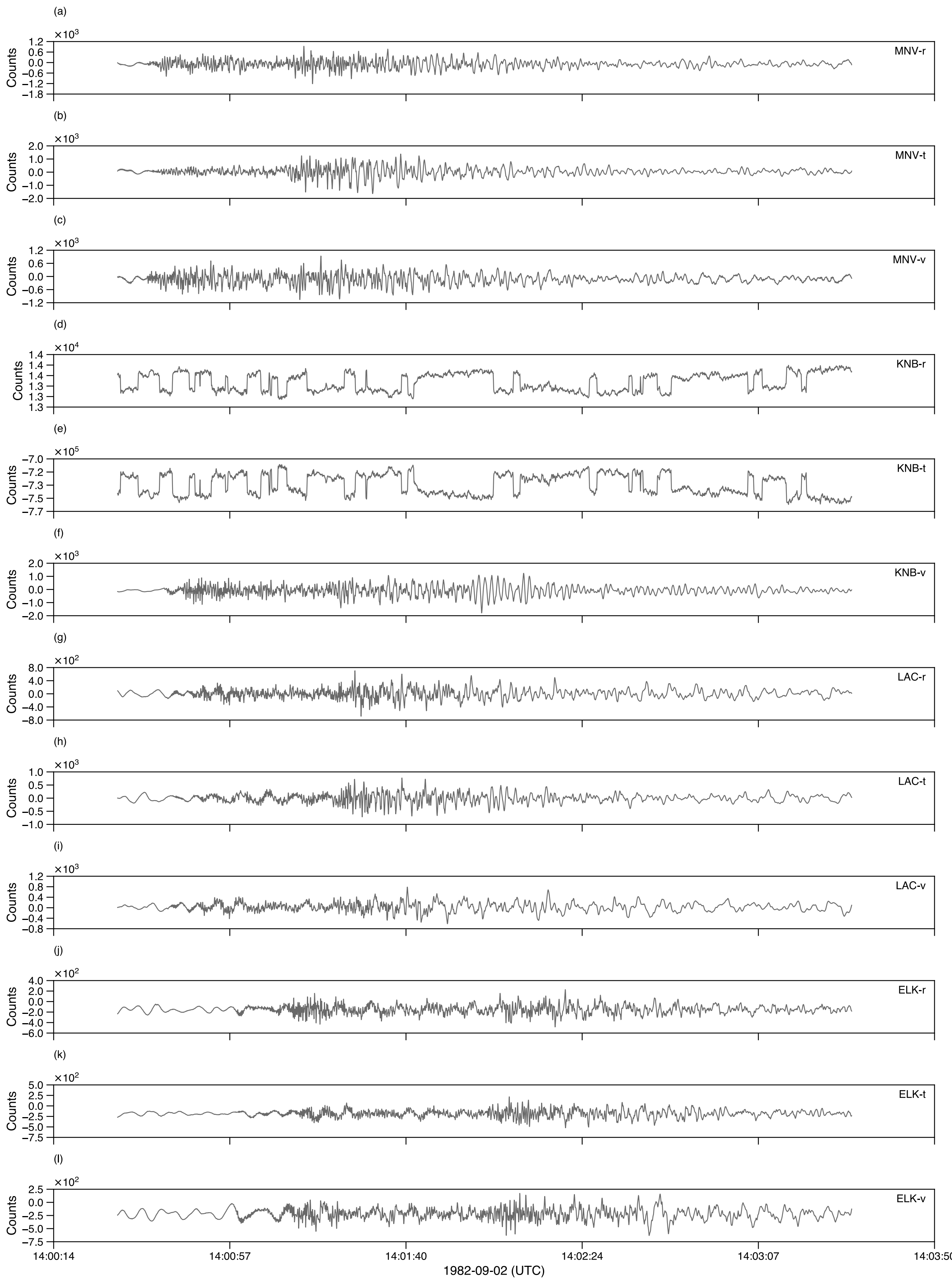

Figure 5: LNN waveform recordings of event 53 with an identified QC issue. KNB r- and t- component waveforms have noise characteristic of sensor and/or cable issues, such as corrosion.

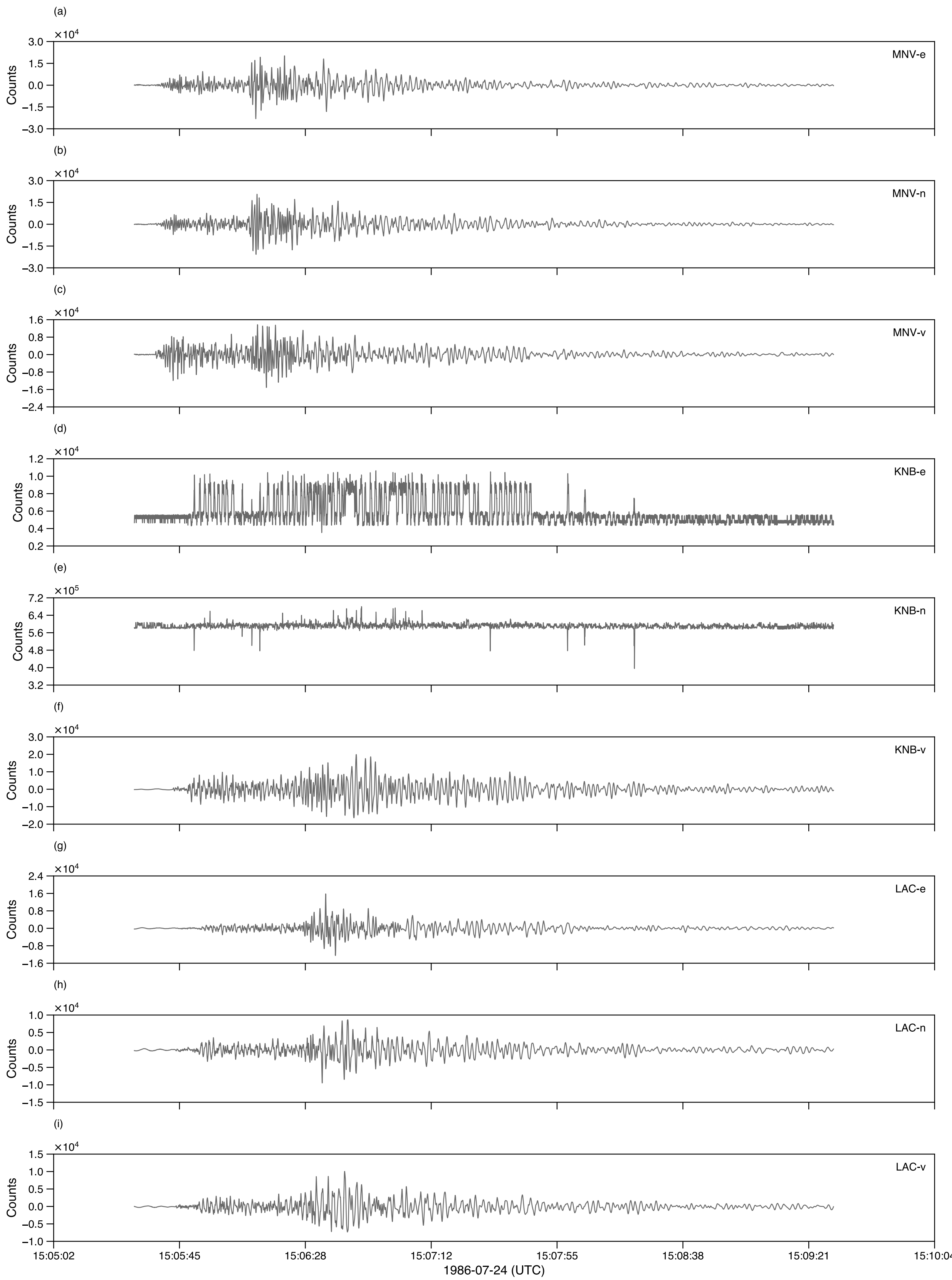

Figure 6: LNN waveform recordings of event 98 with an identified QC issue. KNB e- and n- component waveforms have noise characteristic of sensor and/or cable issues, such as corrosion.

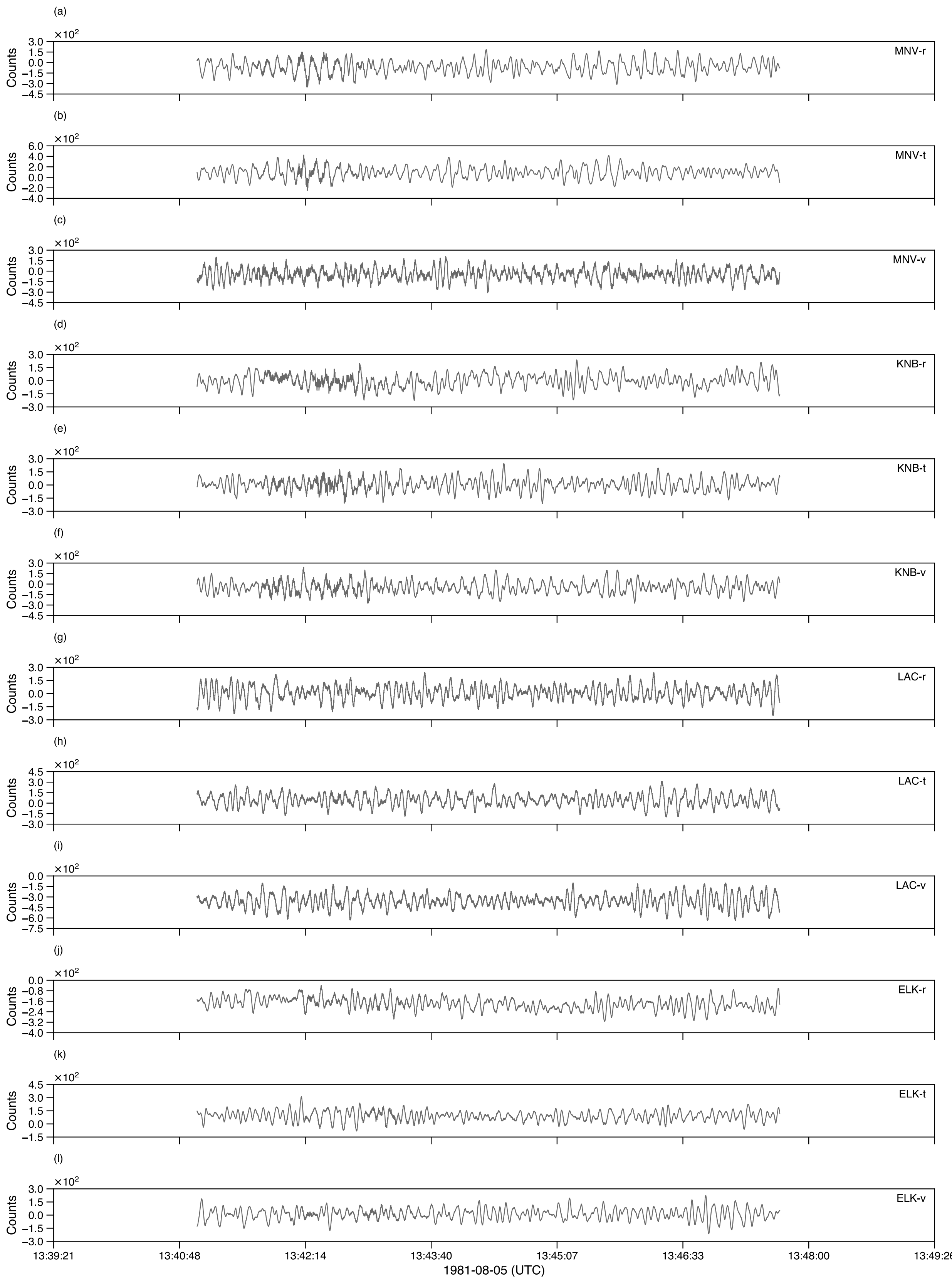

Figure 7: LNN waveform recordings of event 35 with an identified QC issue. All station's waveforms have low SNR and filtering will enhance the SNR.

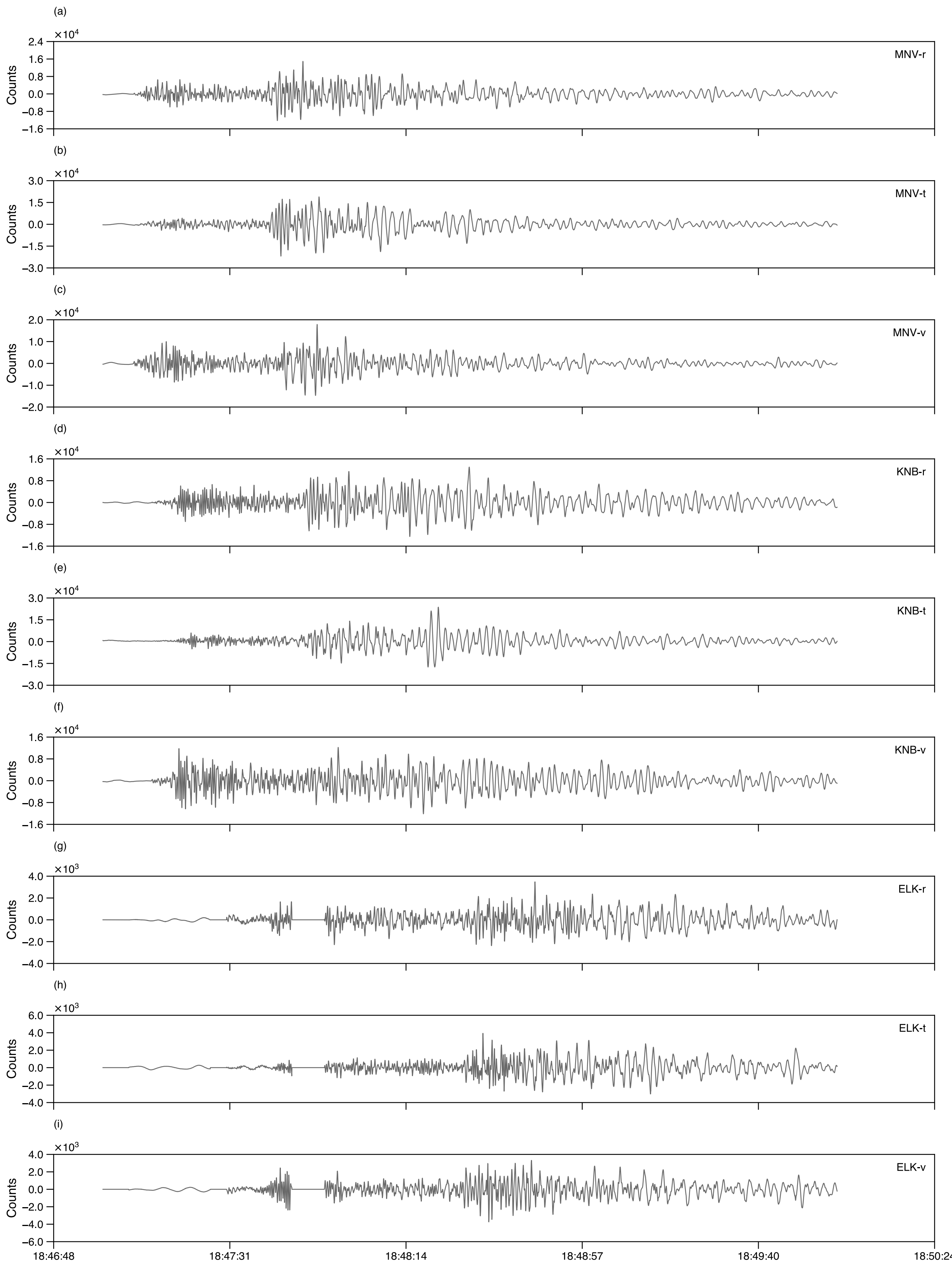

Figure 8: LNN waveform recordings of event 18 with an identified QC issue. All ELK waveforms have a gaps for ~8 seconds 15 seconds after the P-wave arrival.

Future Work

The primary scope of this project was to manually review the LNN waveform data and release the dataset alongside the documented QC issues. Any seismic datasets can have a variety of quality issues due to error in sensor, cables, digitizers, network connectivity, etc. Legacy seismic data is further challenging due to introduction of possible digitization error, lack of knowledge on legacy recording systems, and unknown or incomplete metadata. Manual QC is both time-intensive and cannot detect non-visible waveform issues, such as small timing errors, amplitude offsets, all instrument response errors, etc. Thus, automated QC methods can be particularly useful when applied to legacy seismic data.

Pycheron

Applying and interpreting automated QC methods to all waveforms was outside of the scope of this dataset release. A tool that would be useful to apply to this dataset and others for rapid QC is Pycheron, a Sandia National Laboratory python-based QC algorithm (Aur et al., 2021). Pycheron can be applied to the wfdisc tables provided in this dataset release to confirm the manual QC and possibly identify additional issues.

Synthetic Comparison

Another method useful for detecting QC issues is comparing synthetic seismograms against the recorded seismograms. This is an effective method when the synthetics are generated using trusted moment tensor solutions calculated from other "trusted" stations with high azimuthal coverage. Synthetics were generated for events with moment tensor solutions and compared to the real waveforms. The synthetic waveforms showed good agreement with the real waveforms, indicating there were no polarity reversals. In the future, ore analysis can be done to identify possible amplitude discrepancies and timing issues using this method.

Timing Checks

An additional area of quality control checks needed is on timing errors that are not detectable by manual review. This effort would require an analyst to phase pick on the seismograms and compare the phase arrivals to calculated arrivals based on modeling. This simple method can detect some timing issues, however, if the timing error is less than the arrival picking error and/or modeling error, timing issues could still be missed. Utilizing this method, Walter et al. (2004) identified several events recorded on LNN that had network and individual station clock problems of a couple of seconds to tenths of a second. It is likely that some recordings within this dataset release have clock problems and further work should be done to identify these potential timing issues.

Conclusion

Waveform data from the nuclear testing era is limited and due to the nuclear testing moratorium in 1992, seismogram recordings of nuclear testing are rare and non-repeatable. These data are necessary for ongoing and innovative explosion monitoring research efforts. We provide this dataset for release in hopes that it can be a valuable resource to the explosion monitoring community. There are several additional analyses that could be run on this dataset to further verify the quality as described above and we hope in the future to run such analyses on this dataset.

References

Aur, K. A., J. Bobeck, A. Alberti, and P. Kay (2021). A Python-Based Seismic Waveform Data Quality Control Software Package. *Seismol. Res. Lett., 92(5), 3165-3178.* doi: https://doi.org/10.1785/0220200418

Beyreuther, M., R. Barsch, L. Krischer, T. Megies, Y. Behr, and J. Wassermann (2010). ObsPy: A Python Toolbox for Seismology, *Seismol. Res. Lett.*, *81(3),* 530-533, doi:10.1785/gssrl.81.3.530

Carr, D. B. (2002). National Nuclear Security Administration Knowledge Base Core Table Schema Document (No. SAND2002-3055). Sandia National Laboratories, Albuquerque, NM.

Carr, D. B., J. E. Lewis, S. Ballard, E. M. Martinez, B. J. Merchant, R. Stead, M. Crown, J. Roman-Nieves, and J. Dwyer (2007). Advances in the Integration of Large Data Sets for Seismic Monitoring of Nuclear Explosions (No. SAND2007-4484C). Sandia National Laboratories, Albuquerque, NM.

Jarpe, S. P (1989). Guide for Using Data from the LNN Seismic Monitoring Network (No. UCID-21872). Lawrence Livermore National Laboratory, Livermore, CA.

MacCarthy, J. M. (2021). Pisces: A practical seismological database library in Python. https://pypi.org/project/pisces/.

U.S. Department of Energy, National Nuclear Security Administration Nevada Field Office (2015). United States Nuclear Tests, July 1945 through September 1992. United States. doi.org/10.2172/1351809

Walter, W. R., K. D. Smith, J. L. O'boyle, T. F. Hauk, F. Ryall, S.D. Ruppert, S. C. Myers, R. Abbot, and D. A. Dodge (2004). An Assembled Western United States Dataset for Regional Seismic Analysis (No. UCRL-TR-206630). Lawrence Livermore National Laboratory, Livermore, CA. doi:10.2172/15014811.