



ADS-VTN-23G02

Digitization of Lop Nor Explosion Seismograms from Kyrgyzstan Stations, and Establishment of the GT Calibration Explosion Working Group

Final Report

Contract No. 19AQMM20P1473

Report Period: September 30, 2020 – September 29, 2023

Date Report Submitted: December 29, 2023

Sponsored by

U.S. Department of State

Bureau of Arms Control, Verification, and Compliance

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REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.				
1. REPORT DATE (DD-MM-YYYY) 30-12-2023		2. REPORT TYPE Final		3. DATES COVERED (From - To) 30-09-2020 – 30-09-2023
4. TITLE AND SUBTITLE Digitalization of Lop Nor Explosion Seismograms from Kyrgyzstan Stations, and Establishment of the GT Calibration Explosion Working Group			5a. CONTRACT NUMBER 19AQMM20P1473	
			5b. GRANT NUMBER	
			5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Kevin Mackey, Daniel Burk, Anna Berezina, Kanatbek Abdhrakhmatov, and Kaitlynn Stibitz			5d. PROJECT NUMBER	
			5e. TASK NUMBER	
			5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Dept. of Earth and Environmental Sciences Institute of Seismology Michigan State University Academy of Science of the Kyrgyz Republic 288 Farm Lane #207 A. Tokombaev St. 7/8 East Lansing, MI 48824 720060 Bishkek, Kyrgyz Republic			8. PERFORMING ORGANIZATION REPORT NUMBER NERSP-38	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Department of State Bureau of Arms Control, Deterrence, and Stability Washington, DC 20520			10. SPONSOR/MONITOR'S ACRONYM(S)	
			11. SPONSOR/MONITOR'S REPORT NUMBER(S) ADS-VTN-23G02	
12. DISTRIBUTION / AVAILABILITY STATEMENT Distribution to Public Authorized				
13. SUPPLEMENTARY NOTES				
14. ABSTRACT Data from the Lop Nor Test Site (LNTS) in the Peoples Republic of China is of interest to seismologists and the nuclear explosion monitoring community. Unfortunately, as most nuclear explosions from Lop Nor were detonated when there were very few digital seismic stations, there is a lack of digital waveforms at regional distances from this test site, though there are a significant number of legacy analog waveforms held in regional archives. This study recovered and digitally scanned analog paper seismograms of LNTS nuclear explosion seismograms held in the archive of the Institute of Seismology, National Academy of Sciences of the Kyrgyz Republic. The explosion seismograms were converted into digital waveforms that can be analyzed using modern digital techniques. The digitization technique takes into account individual system channel response, and the resulting waveforms rival modern digital seismograms. Regional seismograms were recovered from 35 different stations, that provide digital waveforms for 27 LNTS explosions that range in time from 1966 through 1996. 258 seismograms, mostly 3-component, were completed in this project, resulting in a total of 773 digitized components. The seismogram scans, digitization, and many ancillary files accompany this report. These digitalized waveform arrivals represent travel paths of LNTS nuclear tests, at regional distances between 9 and 16 arc degrees.				
15. SUBJECT TERMS Seismology, Seismogram, Geophysics, Northern Asia, Nuclear Explosion, Lop Nor				
16. SECURITY CLASSIFICATION OF: UNCLASSIFIED			17. LIMITATION OF ABSTRACT SAR _i	18. NUMBER OF PAGES 119 + xi
a. REPORT SAR	b. ABSTRACT SAR	c. THIS PAGE SAR		19a. NAME OF RESPONSIBLE PERSON Rongsong Jih (COR)
				19b. TELEPHONE NUMBER (include area code) 202-647-8126

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1. INTRODUCTION

Much of northern Asia has historically lacked sufficient geophysical study for adequate monitoring of nuclear explosions. Although the situation is slowly improving because of dedicated regional studies, much of the area is aseismic and lacks well described and verified ground-truth events. There is also a lack of calibrated nuclear explosion waveforms from local and regional distances available even though they exist in historic archives throughout the region. These archives, although once a part of an integrated Soviet seismic network, are now scattered across separate seismic networks in the states of the Former Soviet Union (FSU). Nuclear explosions from many source regions were well recorded by the regional seismic networks, where thousands of seismograms are still retained. One of the source regions for these explosions is the Lop Nor Test Site (LNTS) in the Peoples Republic of China (PRC). The LNTS is located in the Xinjiang province, in the north-western region of the PRC, about 700 km south-eastward from Kyrgyz Republic-PRC border. Between 1964 and 1996 there were 48 nuclear tests, including 3 surface, 19 atmosphere and 26 underground explosions (Johnston, 2005). The underground nuclear explosions were conducted in boreholes and horizontal tunnels. The maximum yield of atmosphere explosions reached a yield (Y) of 4 Mt – for the explosion on November 17, 1976; for underground nuclear tests the maximum yield was $Y=660$ kt for the explosion conducted on May 21, 1992 (Johnston, 2005). This project recovers and digitizes seismograms from the Institute of Seismology, Academy of Science of the Kyrgyz Republic (ISKR) from nuclear tests conducted at the LNTS. Digitizations are integrated with station responses to produce digital waveforms for quantitative research.

The first part of this report focuses on seismogram digitization process and variables in the digitization process. We have researched the effect of seismogram scan resolution versus frequency recovery as well as line thickness, impact of amplitude, and others. For the Soviet short period seismograms that we are digitizing, scanning of the seismograms should be at a minimum resolution of 600 dpi to reliably recover 5 Hz signals.

Second, we apply routines to remove the instrument response from the digitized seismograms to display displacement waveforms in units of ground motion. This effort is supported by the recovery of the original station calibrations and metadata from both the Soviet network as well as the Kyrgyz seismic network, following the dissolution of the USSR.

Third, regional seismograms were recovered from the archives in the Kyrgyz Republic from 35 different stations, that provide digital seismograms for 27 LNTS explosion tests that range in time from 1966 through 1996. These seismograms were scanned, digitized, quality controlled, curve-fit, and converted to miniseed format. 258 seismograms, mostly 3-component, were completed in this project, resulting in a total of 773 digitized components. The seismogram scans, digitizations and ancillary files accompany this report.

Fourth, we complete a small study using tests from 1993 through 1996 in which the analog station AAK was co-located with a broadband digital station with known response, to show that the digitalized waveforms are trustworthy: The common passband of the two instruments correlate within 3 dB when they are compared in the frequency spectrum.

Overall, this project demonstrates that historic analog seismograms can be converted to digital waveforms of sufficient quality as to allow modern digital quantitative research to be conducted. However, the process is tedious and requires significant attention to detail.

Successful digitalization also must include recovery of calibration and metadata information. Our project includes this metadata in the form of dataless SEED files that are derived, for most stations, from the original yearly calibrations of each individual sensor and recording system from each station. These files accompany the seismogram library and are included in this report.

The data set recovered in this report is important because it brings digital waveforms of PRC nuclear tests at regional distances to the research community. Very little regional distance digital data was previously available, and many new ray paths are represented in the data set. The data set will allow improved research on Lop Nor, including regional discrimination, velocity and attenuation models, phase propagation, yield estimation, and other variables.

This project included two other regional tasks. MSU researchers conducted outreach to the seismologists and Ministry of Emergency Situations in the Republic of Uzbekistan. During this outreach, MSU researchers visited and evaluated the site of the planned DoS sponsored broadband seismometer Global Seismic Network (GSN) installation at Karasai. MSU reported on site conditions and provided infrastructure recommendations.

MSU, in conjunction with the International Science and Technology Center (ISTC), hosted a workshop in Almaty to discuss the feasibility of conducting seismic calibration explosions in Central Asia, the Caucasus, or other locations in eastern Europe. Representatives from 9 countries were in attendance. A full-scale calibration explosion test would be difficult to conduct in the current political climate. However, significant historic data of known regional chemical and nuclear tests are available across the regional archives. It became understood that a multinational collaborative effort could recover, combine across networks, digitize, and analyze this data to meet some of the goals of new dedicated calibration experiments.

2. METHODOLOGY

2.1. Study Location

The LNTS is in the Xinjiang province in the north-western region of the PRC, about 700 km east from Kyrgyz Republic-PRC border (Figure 1). Geologically, the LNTS is located within the Kuruktag Mountains of the eastern Tien Shan Range where earthquakes of $M > 7.0$ occur. The region is characterized by complex tectonic settings and is cut by several regional tectonic faults of east-west trend following the orogenic structures of the East Tien Shan. All these faults are active, including the Dzhungariya fault coming from the Semipalatinsk Test Site (STS) side in Kazakhstan (Velikanova and Uzbekov, 2013).

Seismological raypaths originating in the LNTS and received in the Kyrgyz Republic transit the northern Tarim Basin and terminate at Kyrgyz Republic seismic stations in the western portions of the Tien Shan Range. This study should help improve the quality of the nuclear explosion research from the LNTS and Tien Shan regions.



Figure 1. Location of the LNTS, shown by the red markers, relative to the Kyrgyz Republic at left.

2.2. Seismological Network

2.2.1 History of the Kyrgyz Republic Seismological Network

Instrumental seismic observations in Kyrgyzstan began in 1927, when the first seismic station Frunze (FRU) was established and a seismograph with direct optical registration, developed by P. Nikiforov, was installed (Figure 2). Starting in the 1950's, the Complex Seismological Expedition of the Institute of the Physics of the Earth, Academy of Science, USSR (CSE IPE AS USSR) began seismic observations in the Northern Tien Shan region to assess the seismic hazard of the southern and south-eastern regions of Kazakhstan and northern part of Kyrgyzstan. Naryn, Przhevalsk and Rybachye seismic stations in Kyrgyzstan started their

operations in 1950. Frunze, Naryn and Przhevalsk stations were included into the national ESSN network (USSR).



Figure 2. Seismograph with direct optical registration, designed by P. Nikiforov. Frunze station (FRU) of the Institute of Seismology of National Academy of Sciences of the Kyrgyz Republic (1927-1950, NS, EW components).

In the late 1960s the National Institutes were established in the Central Asia Republics and Kazakhstan; the Complex Seismological Expedition (CSE) of the Institute of the Physics of the Earth (IPE), Academy of Science (AS) of the Union of Soviet Socialist Republics (USSR) transferred many of their stations to the newly established Institutes. For Kyrgyzstan, this occurred in 1969. Since 1969, Kyrgyzstan has operated its own regional network, the development of which was completed by the mid-1980s. The network consisted of 34 permanent stations evenly distributed over the territory of Kyrgyzstan (Figure 3). All stations were equipped with the standard Kirnos SKM-3 seismometer with nominal magnifications of $V=20000$ (Figure 4) and SKD with nominal magnifications of $V=1000$. In addition to the permanent stations, temporary local networks were installed in certain places for specific tasks, such as seismic hazard assessment of places for future construction of civil and industrial structures, for research of aftershock zones of strong earthquakes, etc. The seismograms digitized in this project are from the permanent analog stations of this era.

In October 1990, the digital GSN seismic station Ala-Archa (AAK) was installed in the Kyrgyz Republic. It is the first digital seismic station in the territory of Kyrgyzstan, which was included in the Comprehensive Nuclear-Test-Ban Treaty Organization's (CTBTO) International Monitoring System (IMS) as three-component auxiliary seismic station AS060 (Figure 5). Station AAK is in a 100m long granite tunnel, away from seismic noise sources, allowing effective monitoring of both regional and teleseismic events (earthquakes, explosions, etc.).

The legacy analog photopaper station co-located at AAK continued operation for several years following installation of the GSN station. This is fortunate as it allows direct comparison of our digitized waveform derived from the Soviet seismometer and analog recording system to a modern digital recording of the same signal.

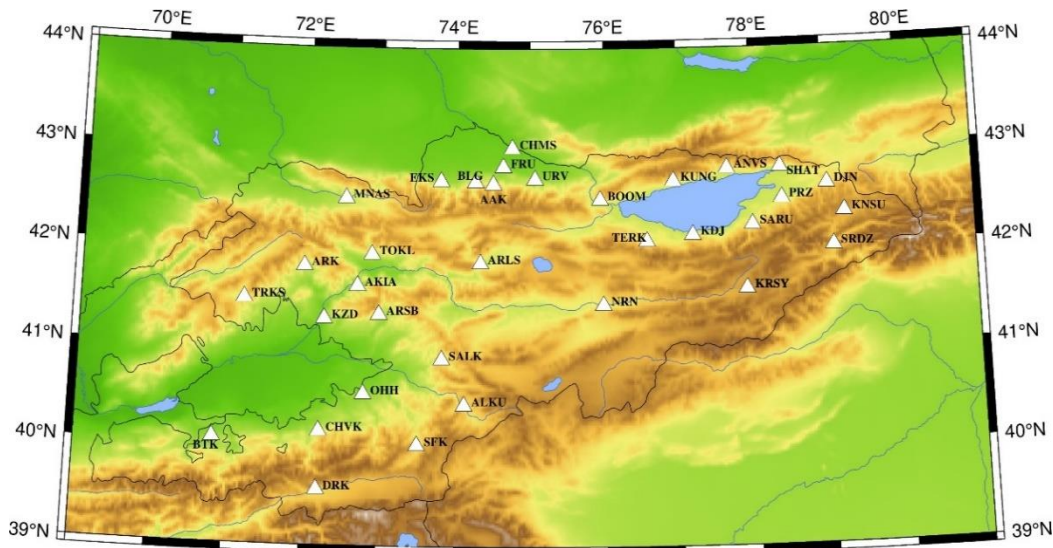


Figure 3. Map of location of analog seismic stations of the ISKR.



Figure 4. Kirnos SKM-3 seismograph with a magnification $V=20000$, installed at the Frunze (FRU) seismic station in Bishkek, and an example of a recorded seismogram.

In September 1991, 10 digital stations with real-time data transmission system (telemetry) were installed in the Chuy depression and surrounding mountains (the so-called Bishkek Prediction Site) sending all information to Data centers in Bishkek (Kyrgyz Republic) and San Diego (California, USA). The global seismological community knows this first network of digital broadband seismic stations in Kyrgyz Republic and Central Asia as KNET (Kyrgyz Seismic Telemetry Network). The KNET network is today maintained by specialists from the Research Station of the Russian Academy of Science (RS RAS).



Figure 5. Photos of the GSN station AAK showing tunnel location, tunnel, telemetry antenna, and sensor pier.

By the 2000's, most of the analog seismic stations in Kyrgyzstan were no longer in operation due to physical deterioration, lack of photographic paper, etc. Thus, the transition from analog to digital registration in the Kyrgyz seismic monitoring network became an urgent task. In 2007, within the frame of cooperation with the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO), the Norwegian Seismological Service (NORSAR), supported by the Norwegian Ministry of Foreign Affairs, provided 10 digital broadband stations to the ISKR. Most of these were installed in the south of the Kyrgyz Republic, in areas characterized by high seismic activity. In 2009, the new seismic network was registered in the Federation of Digital Seismograph Networks (FDSN) as KRNET (Kyrgyz Republic Digital Network). Currently, the KRNET network consists of 18 digital broadband seismic stations (Figure 6), transmitting seismic data to IRIS/DMC (www.iris.edu) in real time mode. All stations of the KRNET network are highly sensitive to both local and regional events due to their location in terms of the geology and seismic noise characteristics. Moreover, the new stations together with KNET stations located in the north and north-west part of the Republic provide good coverage of the territory and have significantly improved the accuracy of localization of seismic events in the region, ensuring effective use of this network in the national and international seismic monitoring.

One of the advantages of seismic stations in the Kyrgyz Republic is their location at regional distances in relation to practically all Asian nuclear test sites (Semipalatinsk Test Site (STS, Kazakhstan), LNTS (China), Pokharan (India), Chagay (Pakistan), and Peaceful Nuclear Explosion (PNE) sites across the former USSR).

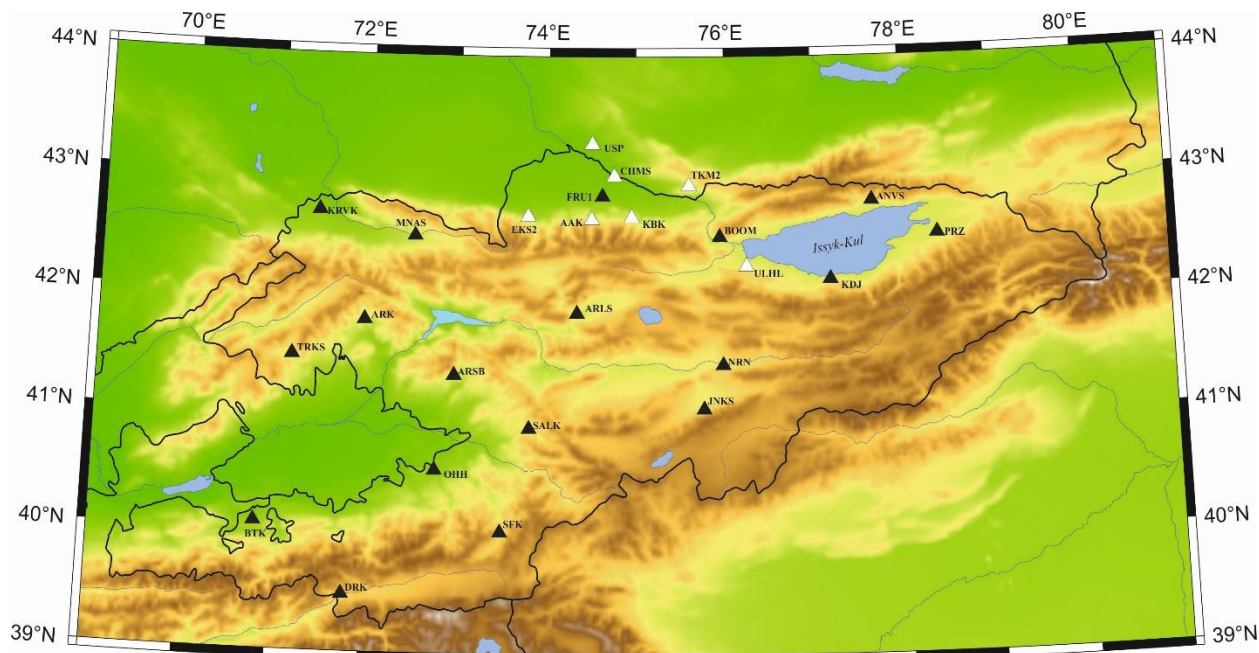


Figure 6. Location of contemporary digital seismic stations in the Kyrgyz Republic. White triangles indicate KNET network stations (RS RAS), black - KNET network (IS NAS KR).

2.2.2 Instrumentation

Most of the permanent analog stations of the Kyrgyz Republic stations used in this project produced analog seismograms recorded by a three-component, short-period seismograph known as SKM-3, with natural period 1 – 2 s and nominal damping constant of about 0.5 (slightly under-damped), and a galvanometer (type GB-4) which recorded on photographic paper (Aranovich et al., 1974). The SKM-3 seismograph had various standard configurations for its seismometer and galvanometer settings (Table 1; Figure 7).

Most permanent seismic stations were also equipped with a three-component, long-period (broadband) seismograph known as an SKD (Aranovich et al., 1974). Two types of configurations were used, namely SKD-1 with $T_0 = 25$ s, and SKD-2 with $T_0 = 20$ s. A few records were derived from an SK seismograph with intermediate period band ($T_0 = 12.5$ s). Displacement amplitude responses of these long-period seismographs are plotted in Figure 8 and their instrument constants are given in Table 1. The SKD seismographs have relatively wide pass bands (see Table 1), namely 0.05 – 10 Hz, which indicates that it is similar to a modern intermediate range broadband seismometer (see Figure 8), although the recording media and amplification may not fully represent the dynamic range of the instrument, particularly at the higher frequencies. Figure 9 shows photos of the main types of seismic instruments operated at the Central Asia stations (Aranovich et al., 1974).

Table 1. Generalized parameters of Soviet analog seismic stations. Not all listed station configurations were utilized in this study.

Seismograph type/response	sensor	$T_0(s)$	D_0	Pass band ⁽²⁾ (Hz)	$f_N^{(3)}$ (Hz)	Amplification range	Recording media	Channel name	Characteristics and notes
SKM3-1	SM2 ⁽¹⁾	1.49	0.46	1.0-2.5	0.625	25 - 80K	3-component, recording on photographic paper using galvanometer	SP-Z,N,E	Narrow response
SKM3-2		1.47	0.62	1.0-10.0	0.571			SP-Z,N,E	Widely used
SKM3-3		1.99	0.40	0.7-3.1	0.667			SP-Z,N,E	Narrow band
SKM3-4		2.02	0.55	0.7-10.0	0.606			SP-Z,N,E	Most wideband
SKM3-5		1.25	0.495	1.0-2.5	0.625			SP-Z,N,E	
RVZ-T-1	SM2	1.50	0.62	0.8-8.0 Hz	3.98	100-300 K	4-channel, ink pen on 180 cm x 29 cm paper, trace separation 2-100 mm	SP-Z,N,E	Wide response
RVZ-T-2		1.25	0.645	0.9-2.5 Hz	2.62			SP-Z,N,E	
KSE-1-1	SM2	1.50	0.46	0.7-2.0 Hz	1.02	300 - 1,000 K	Single vertical-component, ink pen on 180 cm x 9 cm paper, recording speed 15-240 mm/minutes; max amplitude= ± 2 cm	SPZ00	
KSE-1-2		1.25	0.495	0.8-2.1 Hz	1.21			SPZ10	Supplements RVZ-T
KSE-1-3		1.00	0.50	1.0-1.7 Hz	1.33			SHZ	High-gain, narrow band.
SKD-1	SKD	25.0	0.46	0.04-12.5	0.07	1 - 1.5 K	3-component, recording on photographic paper using galvanometer	LP-Z,N,E	
SKD-2		20.0	0.46	0.05-10.0	0.07			LP-Z,N,E	
SK		12.5	0.45	0.08-8.0	0.2			LP-Z,N,E	

* ⁽¹⁾SM2 = short-period seismometer with nominal natural period, $T_0=1-2$ seconds, and damping=0.5; ⁽²⁾ frequency range in which amplitude is down by 3 db from the peak value; ⁽³⁾ normalization frequency where peak amplitude response is set to unity.

SKM Responses

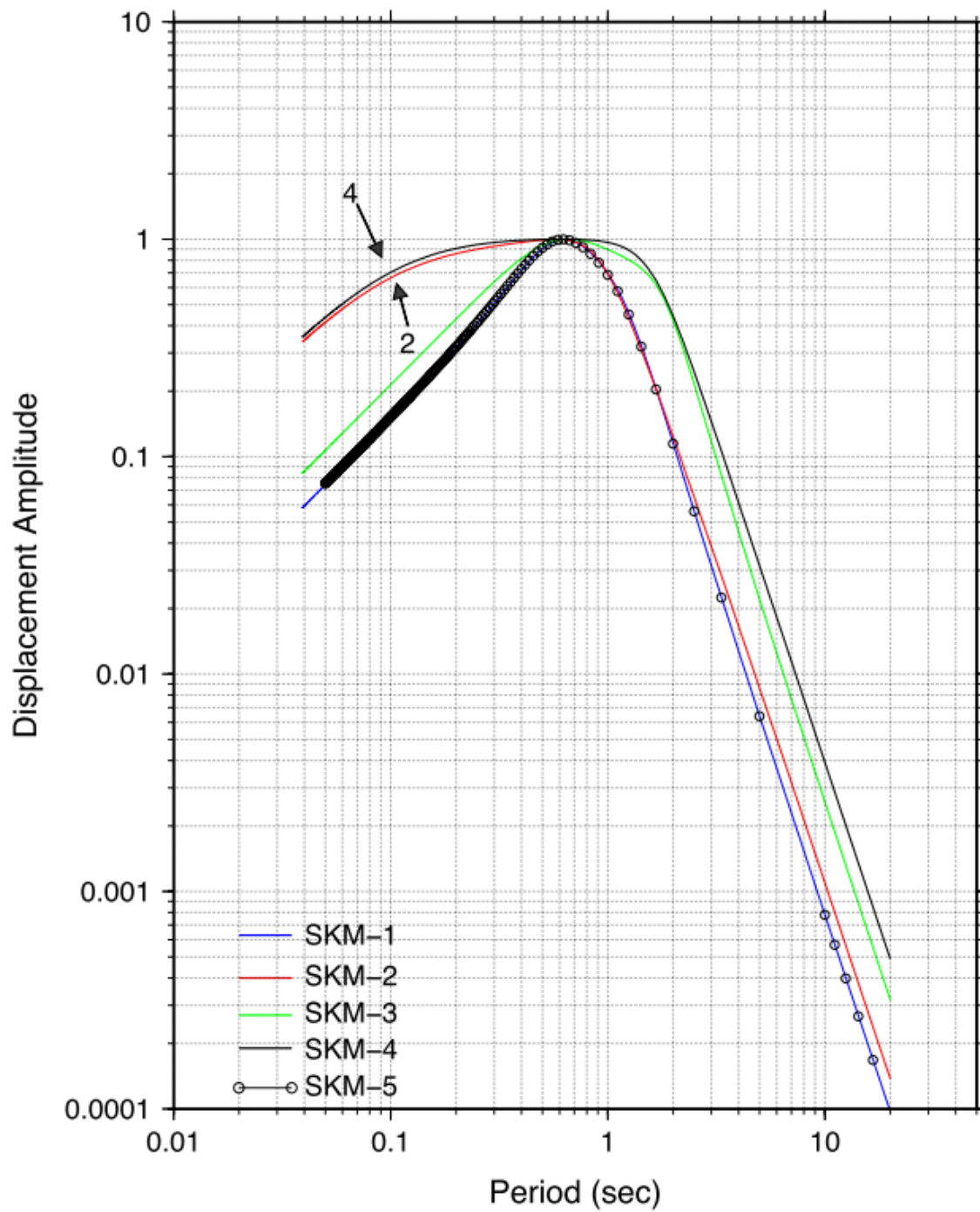


Figure 7. Among the five configurations, SKM-2 ($T_0 = 1.5s$) and SKM-4 ($T_0 = 2.0s$) are the ones most often used by permanent stations.

SKD Responses

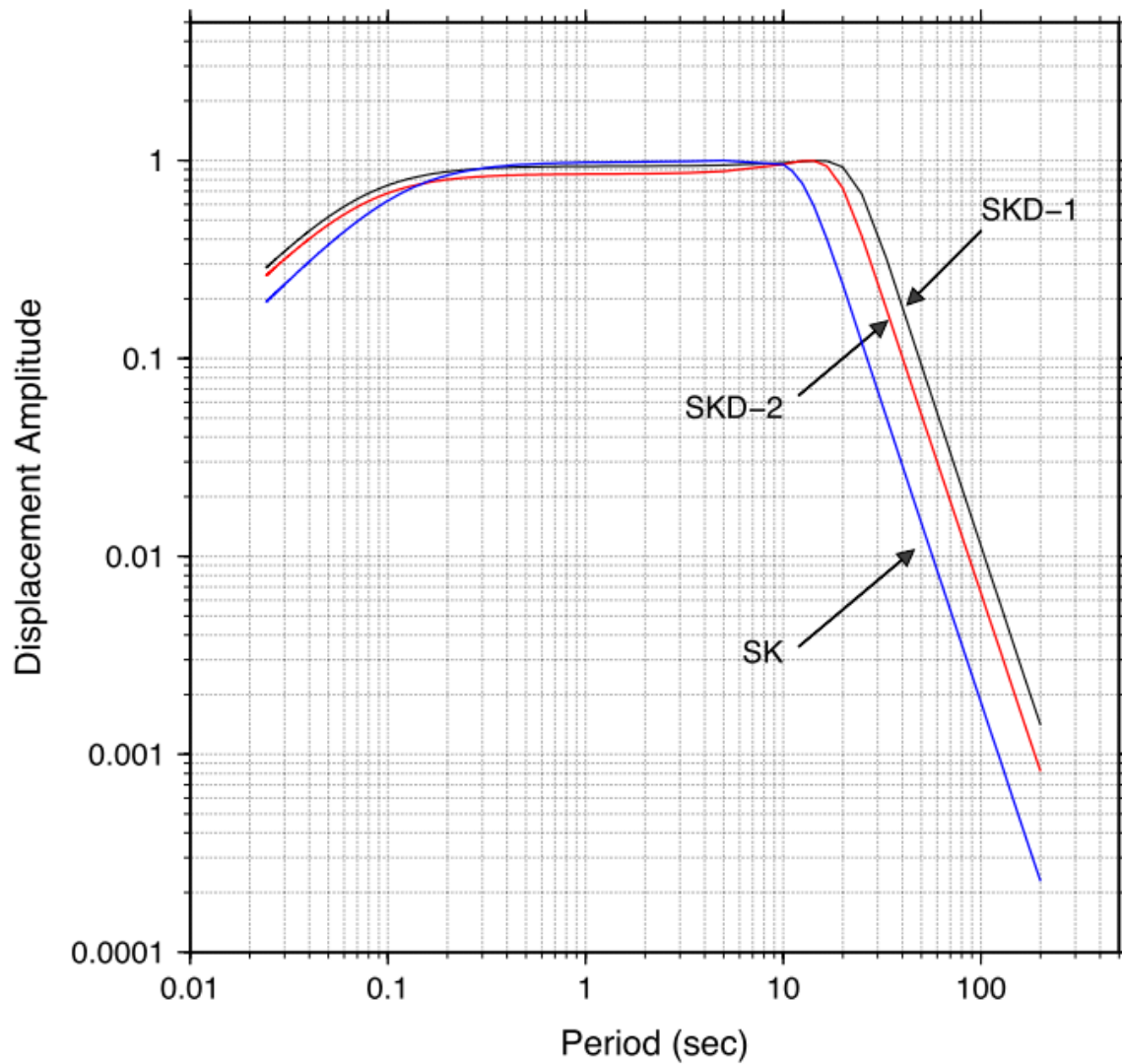
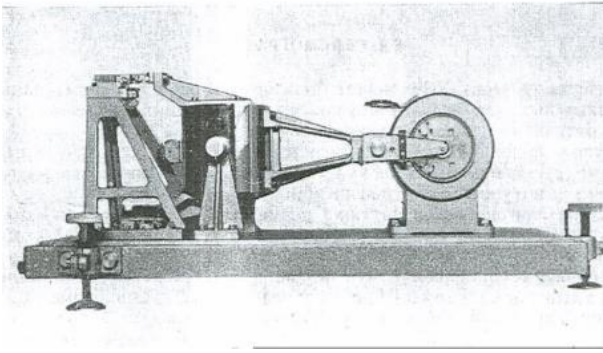
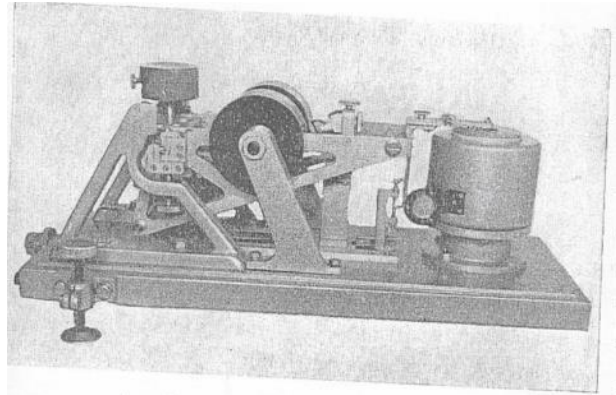


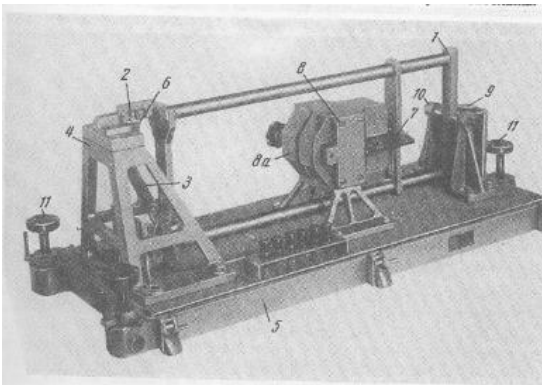
Figure 8. Displacement amplitude response curves of SKD-1 ($T_0 = 25\text{s}$), SKD-2 ($T_0 = 20\text{s}$), and SK ($T_0 = 12.5\text{s}$) seismographs. These responses indicate that SKD seismographs have a wide passband and are intermediate-range broadband seismographs.



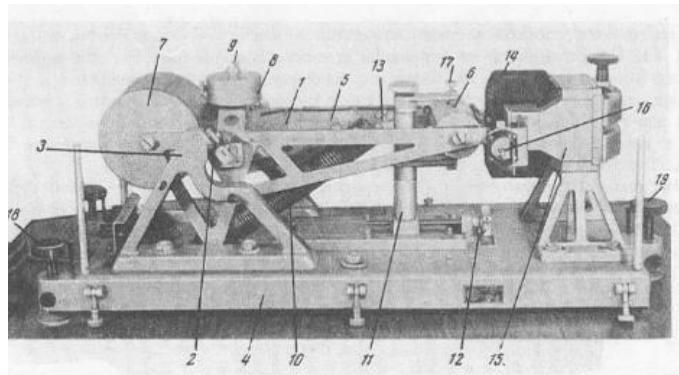
a)



b)



c)



d)

Figure 9. Main types of seismometers used at analog seismic stations in Kazakhstan and Central Asia. a) SGKM-3, b) SVKM-3, c) SGKD, d) SVKD (Aranovich et al., 1974).

2.2.3. Seismogram Archive

The ISKR maintains the archive of analog seismograms for the country from Soviet times through present (Figure 10). The ISKR previously inventoried their holdings of analog nuclear explosion recordings, finding a total of 24,283 seismograms of nuclear explosions (Figure 11). This includes 1093 seismograms from explosions at the LNTS, which are the focus of this study. Additionally, the archive contains 2,114 seismograms of large chemical explosions.



Figure 10. Seismogram Archive of the ISKR.

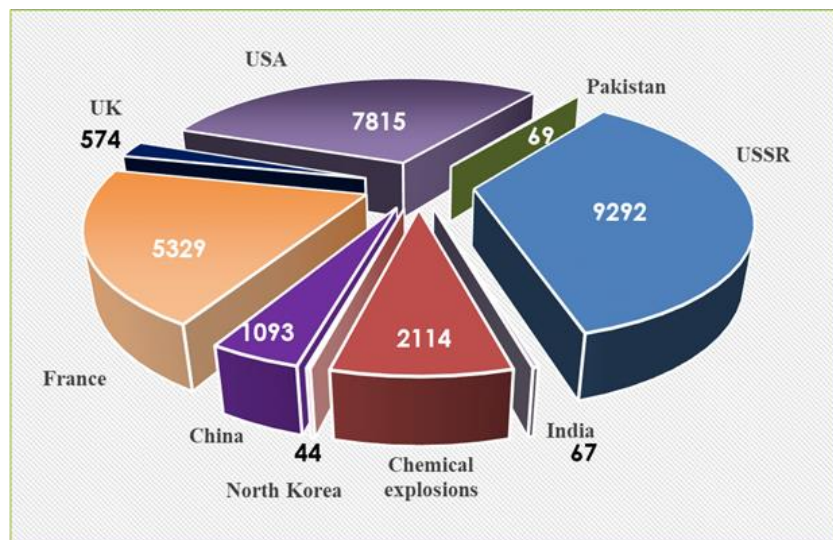


Figure 11. Pie chart showing the numbers of nuclear explosion seismograms in the ISKR archive.

2.3. Lop Nor Test Site

2.3.1. Test Site Configuration

We used Gupta (1995) for the general layout of the LNTS, where it is divided into four zones, termed A, B, C and D (Figure 12). In total, the LNTS is about 50,000 km² in area. From 1964 to 1996 there were up to 48 nuclear tests at the LNTS. Among the explosions, there were 22 atmospheric tests (3 at the surface and 19 at various elevations at the D site), and 26 underground tests (2 explosions in 2 tunnels at the B-north site; 6 explosions in 5 tunnels at the A site; 2 low-yield explosions preliminary attributed to 2 tunnels at the B-south site; 16

explosions in 15 boreholes at the C site). Sources may differ on the exact numbers and configurations of testing at each location. A few tests indicated in some lists may have been failures as parameters are missing and no data are apparent. Note that the events and locations listed here should not be considered as ground truth or definitive. Additional discussion can be found in Sokolova and Mackey (2021).

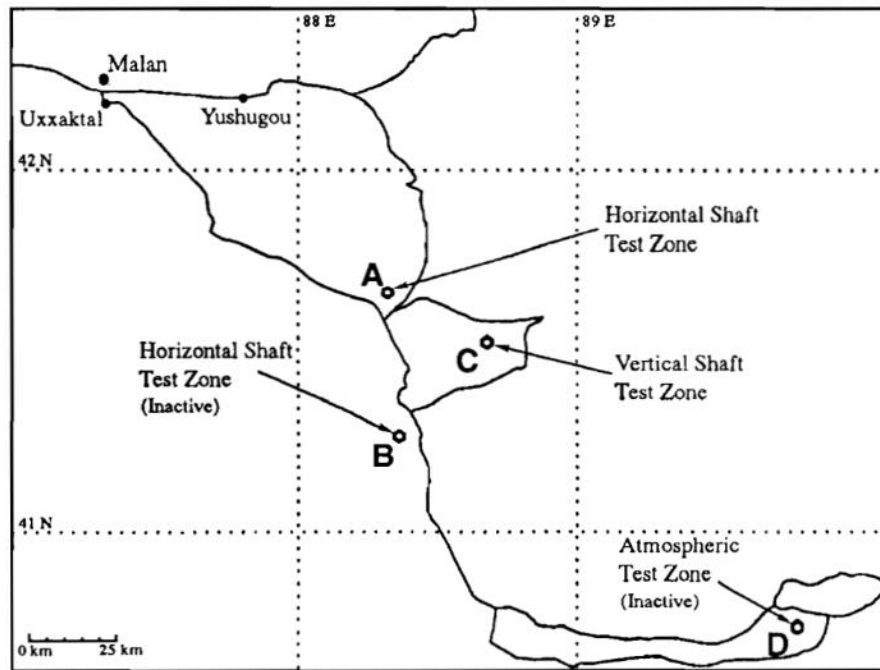


Figure 12. The scheme of the Chinese Lop Nor Test Site (Gupta, 1995). A – test zone with horizontal tunnels; B – test zone with horizontal tunnels; C – test zone with vertical shafts; D – atmosphere tests zone

2.3.2. LNTS Explosions

Table 2 lists the LNTS nuclear explosion tests. The test zone is indicated for each event as well as basic parameters. Also listed are the number of stations and seismogram components digitized for each event.

Table 2. Parameters of Lop Nor nuclear tests. The number of seismograms, stations and components digitized in this project are shown at right. 2 supplemental PNEs in Kazakhstan, Mangyshlak-2 and Azgir A-4, are listed for which seismograms were digitized in this project. Green shading indicates events for which seismograms were digitized.

TEST NAME	DATE	TIME (UTC)	LAT. (Deg.)	LONG. (Deg.)	Site	Type	Mag. (Mb)	Parameter Reference	Seismo- grams	Stations	Digitized components
CHIC 1/ Project 596	16 Oct 64	07:00	42.35	88.3	LN	AS-T		Johnston, 2005	0	0	0
CHIC 2	14 May 65	02:00	41.5	88.5	LN	A-AD		Johnston, 2005	0	0	0
CHIC 3	09 May 66	08:00	41.5	88.5	LN	A-AD		Johnston, 2005	1	1	3
CHIC 4	27 Oct 66	01:10	41.5	88.5	LN	A-R		Johnston, 2005	0	0	0
CHIC 5	28 Dec 66	04:00	41.5	88.5	LN	AS-T		Johnston, 2005	1	1	3
CHIC 6	17 Jun 67	00:19:08.2	40.744	89.775	LN-D	A-AD	4.7	Johnston, 2005	1	1	3
CHIC 7	24 Dec 67	04:00	41.5	88.5	LN	A-AD		Johnston, 2005	0	0	0
CHIC 8	27 Dec 68	07:30	41.5	88.5	LN	A-AD		Johnston, 2005	3	3	9
CHIC 9	22 Sep 69	16:14:59.21	41.376	88.318	LN-B	UG-T	5.2	Johnston, 2005	0	0	0
CHIC 10	29 Sep 69	08:40:12.36	40.722	89.515	LN-D	A-AD	4.37	Johnston, 2005	0	0	0
CHIC 11	14 Oct 70	07:29:56.91	40.52	89.779	LN-D	A-AD	4.6	Johnston, 2005	2	2	6
Manglyshak-2	12 Dec 70		43.9096	54.7937	KAZ	UG-S		Mackey and Bergman, 2014	3	3	9
CHIC 12	18 Nov 71	06:00	41.5	88.5	LN	AS-T		Johnston, 2005	0	0	0
CHIC 13	07 Jan 72	07:00	41.5	88.5	LN	A-AD		Johnston, 2005	0	0	0
CHIC 14	17 Mar 72	06:00	41.5	88.5	LN	A-AD		Johnston, 2005	0	0	0
CHIC 15	27 Jun 73	03:59:46.29	40.798	89.809	LN-D	A-AD	4.8	Johnston, 2005	2	2	6
CHIC 16	17 Jun 74	05:59:53.72	40.518	89.619	LN-D	A	4.5	Johnston, 2005	3	3	9
CHIC 17	27 Oct 75	00:59:58.23	41.375	88.326	LN-B	UG-T	5.0	Johnston, 2005	0	0	0
CHIC 18	23 Jan 76	06:00	41.5	88.5	LN	A		Johnston, 2005	0	0	0
Azgir-A-4	29 Jul 76		47.871	48.138		UG-S		Mackey et al., 2022	3	3	7
CHIC 19	26 Sep 76	06:00	41.5	88.5	LN	A		Johnston, 2005	0	0	0
CHIC 20	17 Oct 76	05:00:00.82	41.7086	88.3897	LN-A	UG-T	4.9	Johnston, 2005	0	0	0
CHIC 21	17 Nov 76	6:00:12.7	40.696	88.627	LN-D	A-AD	4.7	Johnston, 2005	3	3	9
CHIC 22	17 Sep 77	07:00	41.5	88.5	LN	A		Johnston, 2005	0	0	0
CHIC 23	15 Mar 78	05:00	41.5	88.5	LN	A		Johnston, 2005	0	0	0
CHIC 24	14 Oct 78	01:00:00.17	41.5413	88.7545	LN-C	UG-S	4.9	Johnston, 2005	1	1	3

Table 2. Cont.

TEST NAME	DATE	TIME (UTC)	LAT. (Deg.)	LONG. (Deg.)	Site	Type	Mag. (Mb)	Parameter Reference	Seismo- grams	Stations	Digitized components
CHIC 25	14 Dec 78		41.5	88.5	LN	UG		Johnston, 2005	0	0	0
CHIC 26	13 Sep 79		41.5	88.5	LN	UG		Johnston, 2005	0	0	0
CHIC 27	16 Oct 80	04:30:29.67	40.719	89.651	LN-D	A	4.44	Johnston, 2005	1	1	3
CHIC 28	05 Oct 82		41.5	88.5	LN	UG	4.5	Johnston, 2005	7	7	21
CHIC 29	04 May 83	05:00:00.31	41.7187	88.3669	LN-A	UG-T	4.5	Johnston, 2005	6	6	18
CHIC 30	06 Oct 83	10:00:00.14	41.5409	88.7283	LN-C	UG-S	5.47	Johnston, 2005	7	7	21
CHIC 31	03 Oct 84	06:00:00.08	41.5799	88.7246	LN-C	UG-S	5.2	Johnston, 2005	12	12	36
CHIC 32	19 Dec 84	05:59:59.82	41.7081	88.3862	LN-A	UG-T	4.7	Johnston, 2005	6	6	17
CHIC 33	05 Jun 87	05:00:00.48	41.5558	88.7431	LN-C	UG-S	6.3	Johnston, 2005	13	13	39
CHIC 34	29 Sep 88	07:00:00.49	41.7219	88.3574	LN-A	UG-T	4.7	Johnston, 2005	7	7	21
CHIC 35	26 May 90	08:00:00.04	41.5756	88.7130	LN-C	UG-S	5.5	Johnston, 2005	18	18	54
CHIC 36	16 Aug 90	05:00:00.5	41.5274	88.7358	LN-C	UG-S	6.2	Johnston, 2005	22	22	90
CHIC 37	21 May 92	04:59:59.84	41.5337	88.7670	LN-C	UG-S	6.5	Johnston, 2005	15	14	60
CHIC 38	25 Sep 92	08:00:00.56	41.7165	88.3776	LN-A	UG-T	5.0	Johnston, 2005	11	11	33
CHIC 39	05 Oct 93	01:59:59.69	41.5957	88.7060	LN-C	UG-S	5.9	Johnston, 2005	12	11	39
CHIC 40	10 Jun 94	06:26:00.19	41.5277	88.7118	LN-C	UG-S?	5.8	Johnston, 2005	16	16	48
CHIC 41	07 Oct 94	03:26:00.18	41.5735	88.7191	LN-C	UG-S	6.0	Johnston, 2005	16	16	48
CHIC 42	15 May 95	04:06:00.2	41.5513	88.7496	LN-C	UG-S	6.1	Johnston, 2005	22	22	75
CHIC 43	17 Aug 95	01:00:00.14	41.5412	88.7522	LN-C	UG-S?	6.0	Johnston, 2005	20	20	63
CHIC 44-1,-2	08 Jun 96	02:56:00.16	41.5804	88.6893	LN-C	UG-S?	5.9	Johnston, 2005	10	10	48
CHIC 45	29 Jul 96	02:56:00.16	41.5804	88.6893	LN-C	UG-S?	4.9	Johnston, 2005	14	14	42

Site— LN – Lop Nor

Type - A - atmospheric

LN-A – Lop Nor, area A

LN-B – Lop Nor, area B

LN-C – Lop Nor, area C

LN-D – Lop Nor, area D

A-AD - airdrop

A-R – rocket of missile

AS – atmospheric, surface

AS-T - tower

UG – underground

UG-S - shaft

UG-T - tunnel

2.4. Previous Work

2.4.1. Data Availability

Nuclear explosions conducted at the LNTS have not been studied completely and very few digital waveforms from the nuclear tests are available. Most testing occurred before the widespread use of digital seismic stations, which generally occurred in the late 1980's and early 1990's for the primary global networks, but later for the regional networks in the area. The closest recording seismological stations to the LNTS outside of the PRC are located in Mongolia and the former Soviet Republics of Kazakhstan and Kyrgyzstan. Most data from stations in these regions recorded the LNTS explosions on analog drum recorders. The seismograms were generally not available to the global community, and it is difficult or impossible to apply modern processing techniques to the original paper seismograms. Even basic processing from most of the regional seismograms was not available. The International Seismological Centre (ISC) bulletins, for instance, contain information on only 28 of the nuclear tests conducted at the LNTS (ISC, accessed 2020). Until 1990, the bulletins were compiled mainly with data of distant seismic stations located more than 1500 km away from the LNTS and the ISC did not receive seismic bulletins of the stations installed on the territory of Central Asia. Fortunately, most of the original seismograms of the LNTS explosions from Central Asia stations remain in the regional archives. The existence of these seismograms allows for them to be reprocessed for arrival times, etc. and to be scanned and converted into digital waveforms. Seismograms of stations operated by the Talgar Complex Seismological Expedition explosions were reprocessed in Kazakhstan (Sokolova and Mackey, 2021), adding additional regional arrivals to the LNTS data set. Seismic phase arrivals from several atmospheric tests were picked within this study.

2.4.2. Previous LNTS Seismogram Digitizations from the Kyrgyz Republic

Our efforts are preceded by a large digitization project that was conducted at the Kazakhstan National Data Centre (KNDC) in Kazakhstan (Richards et al., 2015). This project digitized over 6,000 nuclear explosion seismograms, including 537 from LNTS explosions. The LNTS seismograms digitized by Richards et al. (2015) include many originating from stations in Kazakhstan and elsewhere, as well as stations in the Kyrgyz Republic. Considering only stations in the Kyrgyz Republic, 275 seismograms of LNTS explosions were digitized in this earlier Richards et al. (2015) effort. Of this number, 85 digitized seismograms are common with our effort here. The digitizations completed in common between both projects allow comparison of the techniques used and the resulting waveform quality.

2.5. Data Set

2.5.1. Archive and Seismogram Selection

The Kyrgyz Republic seismogram archive contains 1093 seismograms of LNTS tests. However, not all seismograms are good candidates for the digitization process. We selected seismograms for digitization that had clear signals throughout the record of interest. Although this reduces the total number of digitization, it results in higher quality digital waveforms. There are many reasons why a seismogram was not initially selected for digitization (Figure 13). The analog nature and photopaper media of the original seismograms results in some records

that have clipped waveforms, are over or under exposed, are torn or missing pieces. High amplitudes from larger events create intermingled waveform traces on the analog record that cannot be separated. Additionally, high amplitudes result in a rapidly translating light beam passing too quickly to expose the photopaper, rendering the signal too faint to see. A seismogram recorded with a light beam that is out of focus results in very thick waveform traces that merge together and are unreadable. Additionally, high wind or high microseism noise may have resulted in specific seismograms that were essentially unreadable. In a few cases, the paper on the recording drum was changed during the arrival of the event. Although the beginning and end of the trace of interest could be digitized, there will be a 1–2-minute data gap in the waveform, rendering it less useful.

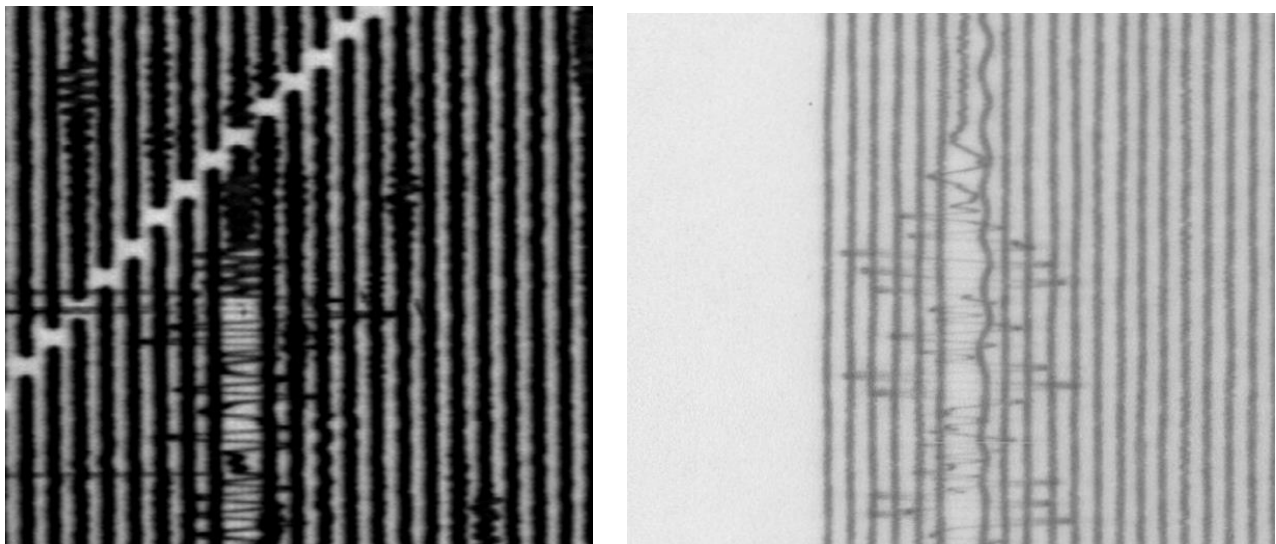


Figure 13. *Left.* Scan of a portion of a lower quality seismogram where thick dark lines obscure much of the signal, causing recovery to be less accurate. *Right.* Scan of a portion of a higher quality scan, from which recovery is more accurate.

It is our goal to digitize all three sensor components (North-South, East-West, and Vertical), though if there was a significant problem on one component, the seismogram was often bypassed. On a positive side, some seismograms contain more than three components, with the additional component being a different sensor or magnification. In this project, we digitized over 840 channels, representing over 250 seismograms, from 35 different Lop Nor tests. Figure 14 depicts a map view showing the ray paths of the event-station paired seismograms that were digitized.

It is the general case that the seismograms chosen for digitization provide better coverage of the later underground tests that took place at the LNTS. Tests in the 1980's and 1990's occurred when the seismic network had more stations and with higher quality operation. There are fewer seismograms chosen for the atmospheric tests and older events in the 1960's and 1970's when fewer stations were in operation. Although many atmospheric tests were seismically recorded by the Kyrgyz network, the records are of poorer quality with low signal to noise ratios (SNR). It is important to note that many seismograms not chosen for

digitization in this effort still retain valuable data and can be digitized in the future. Because of the time-consuming nature of the digitization process, additional digitizations in this data set should be focused on specific events or goals of interest. The digitization procedures and variables in the process are described in Section 2.6.

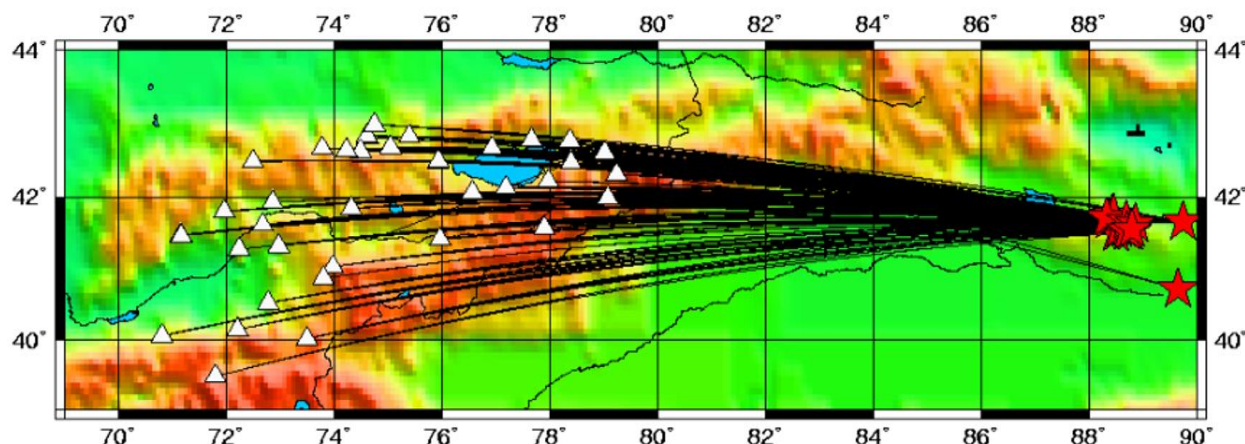


Figure 14. Lop Nor nuclear tests (red stars) and their respective travel paths (black lines) to seismic stations (white triangles) within the Kyrgyz Republic.

2.6. Seismogram Digitization Procedures

2.6.1. Introduction

The global archives of analog seismological data are of critical importance as they contain the only recordings for many of Earth's historic large earthquakes; they contain many seismograms from the era of nuclear testing (mid 1940s to 1990s), which was largely completed by the time most stations were converted to digital. Up until the late 20th century most of the world's seismological data was recorded on analog media, such as paper, photographic film, or magnetic tape. A pen or a stylus would inscribe the ground motion on various forms of media which in turn produced different levels of signal definition due to the nature of the recording method. For example, an ink pen seismogram has sharp lines compared to photosensitive paper where a light beam has a potential for being out of focus and draws 'fuzzy' signal. Almost all seismological stations were converted to digital recording of seismometers in the 1990s and early 2000s. The analog nature of the older data prevents modern digital processing techniques from being used for their analysis. The analog data archives are also aging, and as such the analog data is at a risk for loss due to degradation, disposal, and/or destruction.

An option to modernize these analog records and to save them from further deterioration and loss is to scan them into high resolution digital image files. Scanned seismograms can preserve the raw data and allow the re-creation of the original analog waveform into a digital signal that allows the data to be digitally processed. Digitization can be conducted manually by selecting points at the peak, trough, or a change of slope in the signal,

or by a computer automatically identifying and tracing the signal and producing a digital waveform.

Numerous projects around the world have started to preserve, scan, and digitize analog seismograms. However, the successful digital recovery and usage of these signals is dependent on the accurate and complete recovery of information from the analog seismogram. Unfortunately, there are no universal standards or recommendations on how to achieve the level of accuracy required nor has 'the level of accuracy required' even been defined. For example, if a waveform is of high frequency, and the known signal contains data up to 10 Hertz (Hz), there has been no published guidance on the reliable recovery of this data. The goal for digitizing seismograms is to achieve the most precise waveform as possible retaining the frequencies, amplitudes, and signal integrity, all while limiting artifacts arising from the process of digitization. That cannot be done unless the variables within the digitization process are fully understood.

Stibitz (2023) and Mackey et al. (2022) conducted the first comprehensive evaluation of the variables involved in the process of digitizing analog seismograms. Variables considered were scan resolution, seismogram trace thickness, amplitude variability, orientation of the scanned seismogram, original recording velocity, curve fitting algorithms, and differences in technician ability. With an understanding of the digitization variables and seismograms digitized, waveforms from the short period seismograms digitized here should be reliably recovered to at least 5 Hz.

2.6.2. Methodology

2.6.2.1. Digitization Overview

The first technical step in the digitization process is to scan the seismogram on a wide format scanner that can accommodate the entire record. In this project, all seismogram scans were done in color at 600 dpi and saved in BMP format. BMP format is 'loss-less', meaning that there is no smoothing or loss of resolution due to compression, such as what would occur when saving as a JPG file. Although this results in large files, preservation of image details and shading is of critical importance.

We are digitizing the seismograms using a Russian developed software package called Wavetrack. The Wavetrack software was developed at the Institute of Petroleum Geology and Geophysics in Novosibirsk, Russia. It was originally developed to digitize well logs but was adapted there for seismograms. The basic procedures and MSUs original digitization efforts with this software are covered in Mackey et al. (2009). The process is manual, but we can accurately recover high quality digitizations of short period records. Figure 15 shows a screenshot of the digitization in process. In the process, the scan is overlain with a time/amplitude grid. The time grid allows minute-by-minute adjustment of the time scale, which is important because rotation speed on Soviet drum recorders was poorly regulated and minutes across a seismogram may vary +/- 2 mm, corresponding to a potential timing error of the same number of seconds. In this project, much of our effort has been to refine the digitization process and process the output of the Wavetrack software to generate a better seismogram.

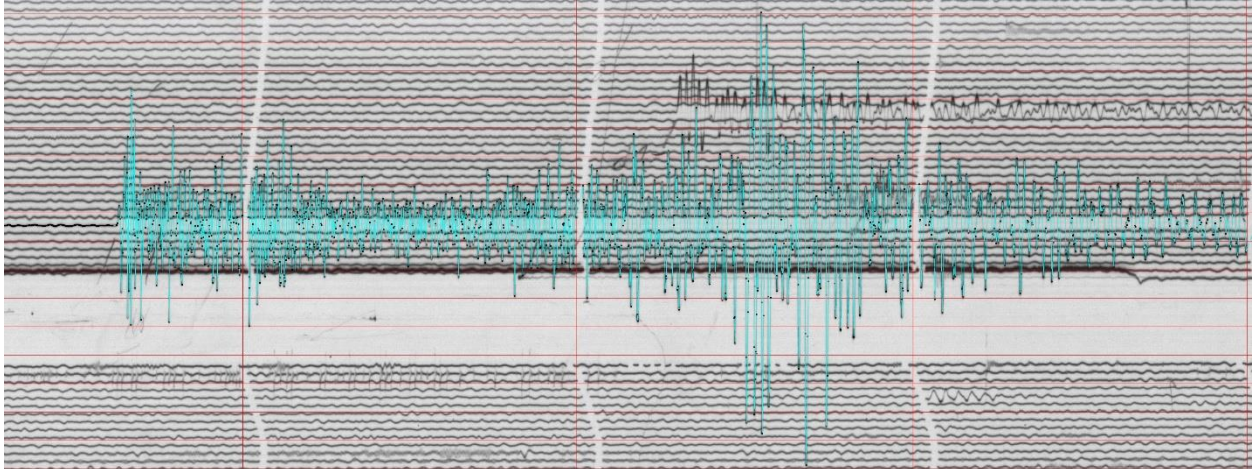


Figure 15. Sample nuclear explosion seismogram during the Wavetrack digitization process. The red grid is the reference for time and amplitude recovery. The blue line represents the digitized record.

Digitization is done by selecting all points on the waveform of interest. The selected points are output as an X, Y columnar text file representing Time and Amplitude respectively. These can be plotted as a raw digitized seismogram (Figure 16).

Earlier in our digitization efforts, some deficiencies in the Wavetrack program became apparent to us. Unfortunately, the Wavetrack software code is not available to us, and the developing institute is not supporting the code or willing to make changes. We have largely found or developed workarounds to these deficiencies. Additional post-processing routines have also been developed to improve the product. The workarounds and post-processing routines are included in the discussion below.

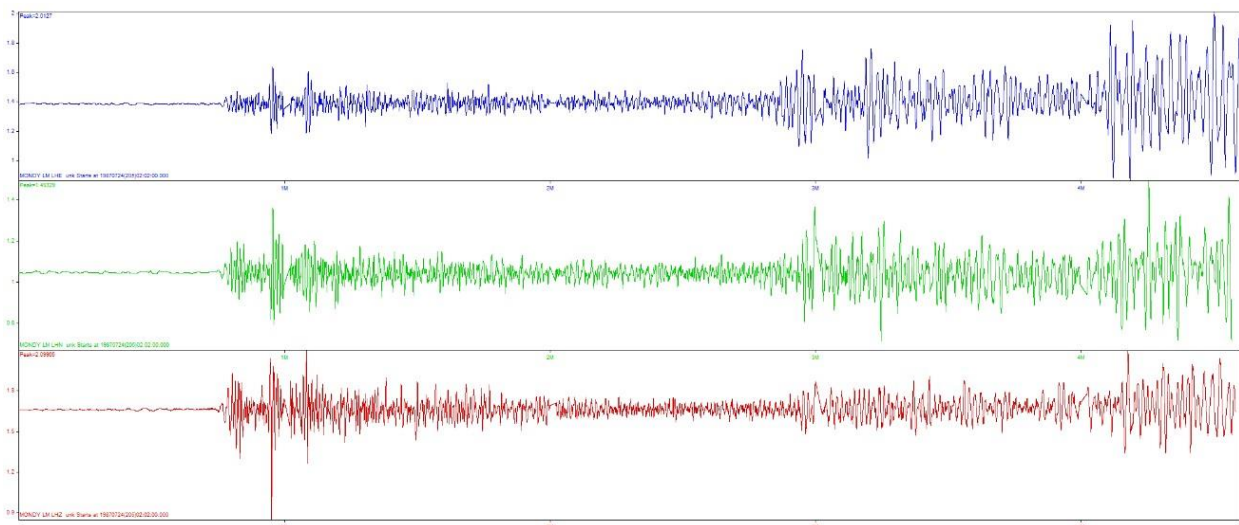


Figure 16. Raw digitized seismogram of the Neva-2-2 PNE at station Mondy.

2.6.2.2. Generation of Templates for Wavetrack Digitization

In the digitization process, the scan is overlain by grid that establishes the time and amplitude reference to correlate the analog seismogram to the digitized waveform. In earlier digitization, a new grid tailored to the specific region on the seismogram to be digitized was required for each component. The set-up parameters varied depending on the original scan resolution of the seismogram. This process was tedious, as it required selection and linking of specific pixels on the image. To speed up the process, we generated universal time/amplitude grid templates for each scan resolution (200, 220, 300, 400, 600, and 1200 dpi), each photopaper recording speed (30, 60 and 120 mm/min), and different seismogram widths (30 and 40 cm) that are encountered. The templates extend over the full seismogram and can be used for all components on the record. Manually adjusting the minute marks throughout the entire grid is still required by the user, though this is not an overly onerous task. A comparison of an old grid and the new template are illustrated in Figure 17.

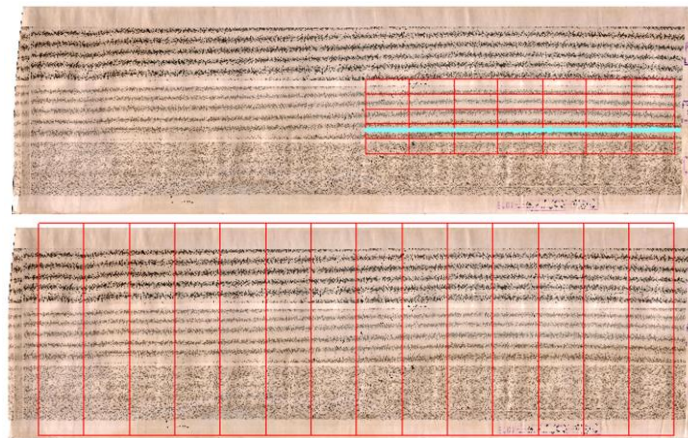


Figure 17. Grid for the digitization process that establishes the time and amplitude references. Top: Original custom grid surrounding the section of waveform to be digitized. New grids are required for each digitization. Bottom: New generic template extending the grid over the entire paper and all minutes used for all components and stations with the same resolution.

2.6.2.3. Removal of Wavetrack's Linear Interpolation

The original Wavetrack software uses operator-derived click points to generate a CSV file that is then oversampled at a user specified samples/second interval (usually 100 sps for this study; Figures 18 and 19). The sample points are determined via linear interpolation between the points chosen during the digitization process. The 100 sample/second interval means that the interpolated samples do not always intercept the original operator click-points. This results in sharp transitions, especially in the derivative (slope) bracketing the original (but now missing) click point. The result is a distortion of the digitized waveform and introduction of increased noise, especially at higher frequencies. The nature of the linear interpolation between the clickpoints expressed as a high sample-rate precludes the use of a curve-fitting

algorithm that would generate a more realistic seismogram. A Python code was created to back calculate and export the original recovered clickpoints without any interpolation.

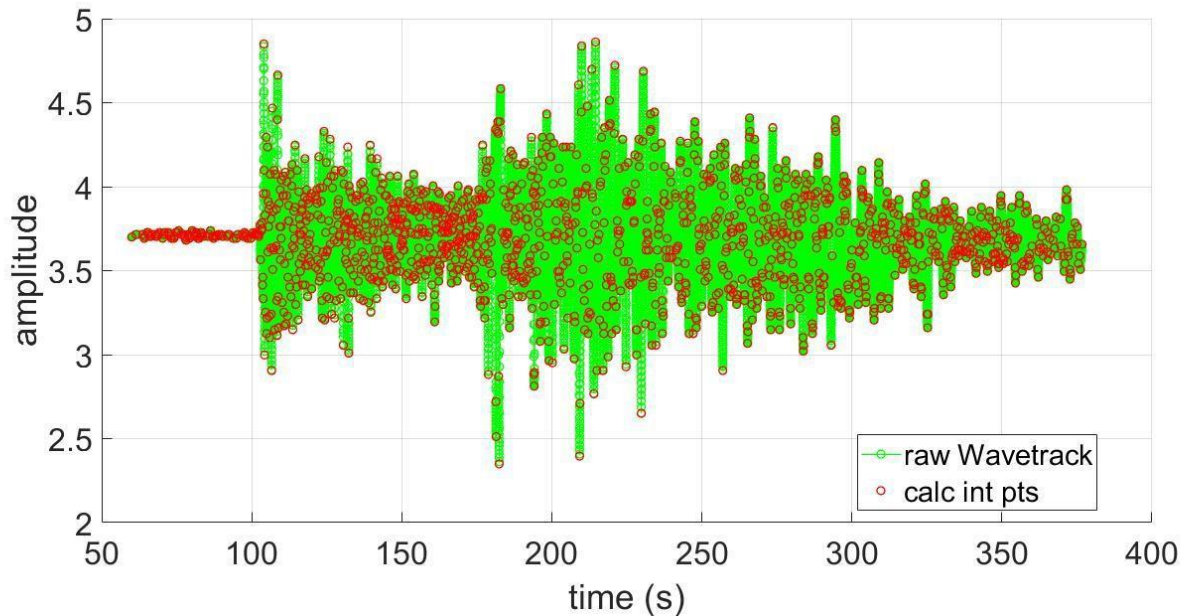


Figure 18. Calculated intersection points (red) from the Wavetrack text file (green) by comparing slopes of each point. Seismogram is from the Meteorite 4 PNE recorded at station Mondy (MOY).

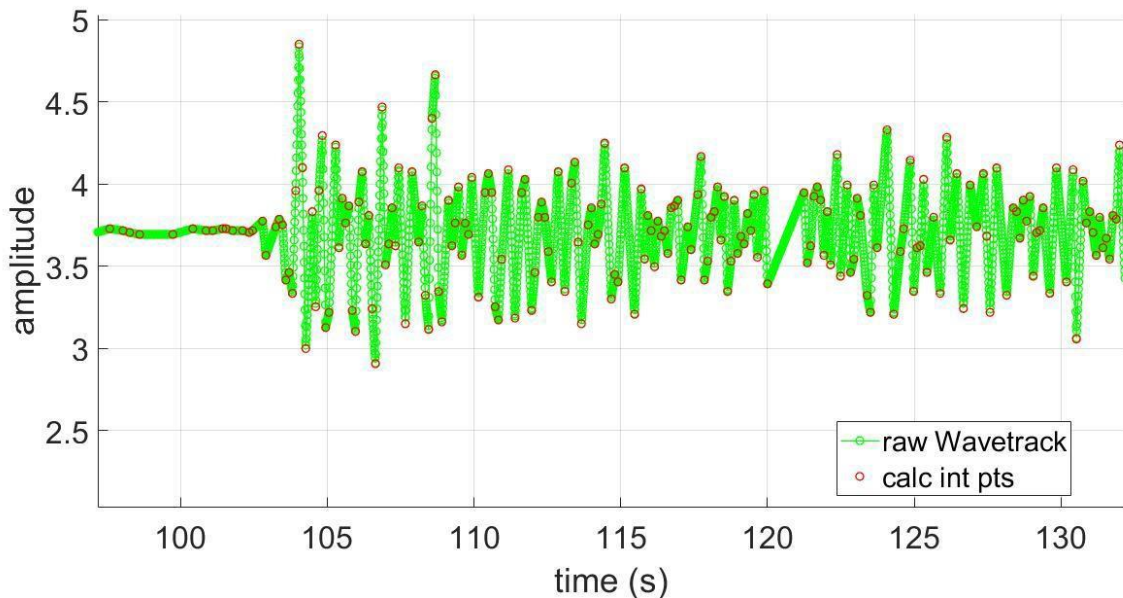


Figure 19. Close-up of the P wave arrival from Figure 5 above. Calculated intersection points (red) from the Wavetrack text file (green) by comparing slopes of each point. Seismogram is from the Meteorite 4 PNE recorded at station Mondy (MOY).

The code processes the Wavetrack output file and identifies all linear segments that are defined by three or more points. The slope and position of this line segment is then calculated and the intersection (time and amplitude) of each adjacent pair of sequential line segments is determined. These intersections represent the locations of the original chosen clickpoints, which are exported to a separate file. Unlike the Wavetrack text file where each point is an equal time interval, the calculated point time intervals are uneven. From the recovered clickpoints, we can fit curves and resample the data to recover a more realistic seismic waveform.

2.6.2.4. Interpolation Method

Post-digitization processing is needed to better recreate the original waveform shape from the time/amplitude clickpoints chosen on the seismogram. Several curves-fitting routines were evaluated in Stibitz (2023) and Mackey et al. (2022), where a Piecewise Cubic Hermite Interpolation Polynomial (PCHIP; Fritsch and Carlson, 1980) was found to be the best for this interpolation application as it follows closely to the original waveform. The PCHIP algorithm passes through all clickpoints and preserves all amplitudes. As all clickpoints represent real locations on the original waveform, it is critical that the curve fit to them preserves the waveform at that location. Additionally, as peaks are always chosen as clickpoints, they must also be preserved. Many spline functions do not preserve exact points and overshoot peaks in the waveforms (Figure 20). There are other curve fitting interpolation methods, however, we limited the study to those methods readily available within Python ObsPy (Bayreuther et al., 2010).

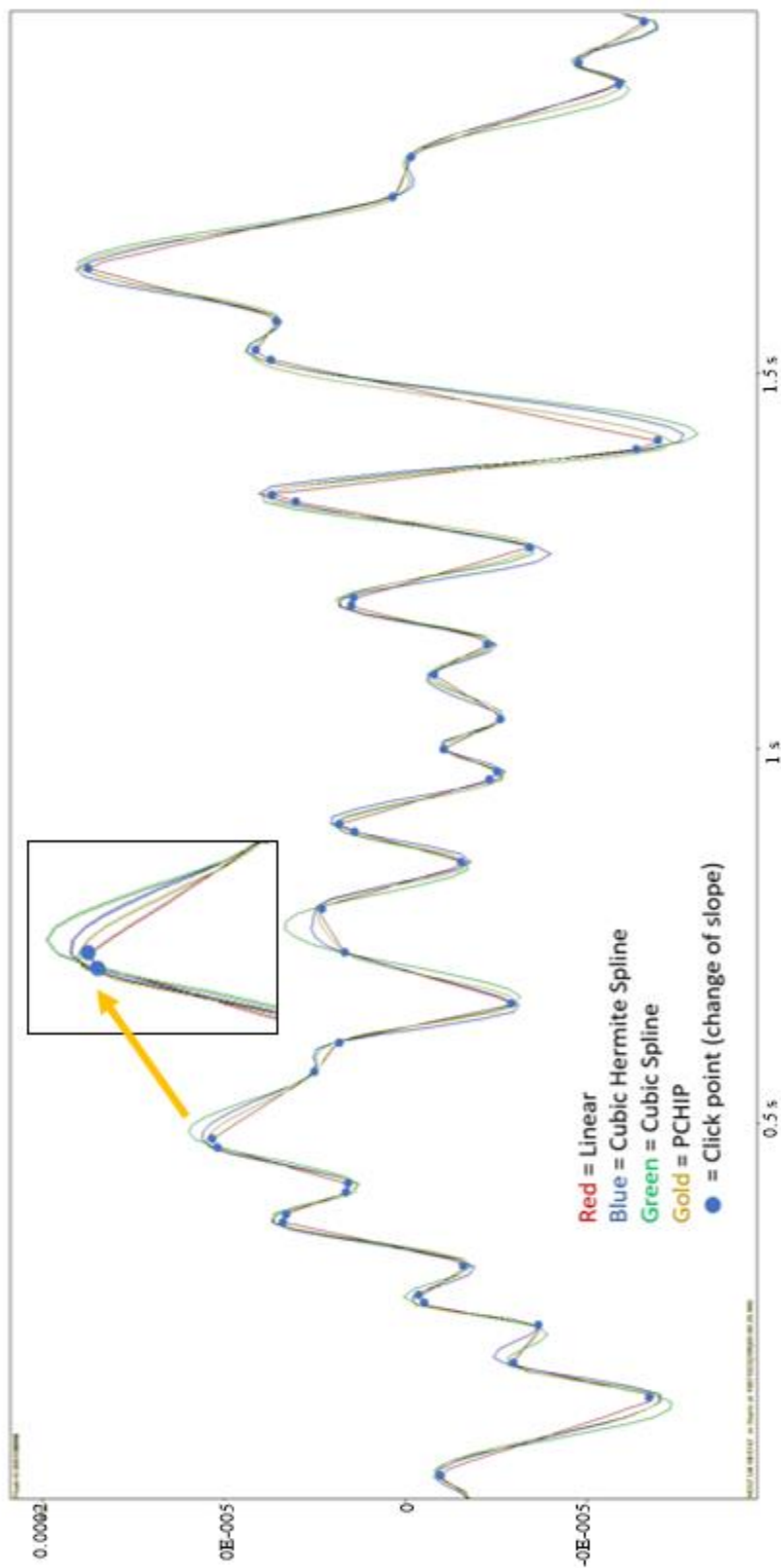


Figure 20. waveform with the application of different interpolation methods. The blue circles are the click points chosen in the digitization process. Red is the linear output from the manual digitization program Wavetrack. The blue and green lines are spline interpolations, and the gold line is the PCHIP interpolation. The inset illustrates a zoomed in peak of the waveform.

2.7. Metadata and Recovery of Station Response

2.7.1. Introduction

An essential part of the process of creating a digital record of an analog seismogram is to estimate or determine the station response to be able to remove it from the digital record. The digitized seismogram is transformed from a scanned image into a digital seismogram via several software packages, such as Wavetrack and PNE2SAC. Wavetrack provides an output that converts the pixelized image into a waveform that is measured in terms of centimeters. The waveform represents a deflection of light onto photopaper. The velocity of the light beam as it tracks across the paper corresponds to velocity of the seismometer's frame relative to its mass. The track that is traced onto the paper is therefore a measurement of displacement. Thus, when examining the original seismogram, we are looking at a record of displacement. The transformation of paper seismogram to station ground motion is therefore a measure of a unitless amplification factor, V_m , which is specified at a single frequency. Originally, the analyst would make a measurement from paper in terms of millimeters of deflection and would divide this by the gain factor to arrive at a measurement of ground motion in terms of microns. For example, a 10 mm deflection on a seismogram, using an instrument with a gain of 1000, would yield a measure of $10.000 \text{ mm} / 1000 = 0.01 \text{ mm}$, or 10 microns. This gain holds true at the single frequency at which the peak amplification is specified. However, because the instrument is non-linear, the gain is different at different frequencies. Therefore, a channel response consisting of poles and zeros is required to re-create the channel gain at any arbitrary frequency within the operating bandwidth of the seismic channel.

2.7.2. Calibration procedures of the USSR

From their inception in the early 1960's until the early 1990's, the Soviet seismic networks established standardized calibration methods across all official stations. Each station was calibrated and perhaps parameters adjusted on a yearly basis. These annual calibrations were recorded and published in station parameter booklets for the Soviet "backbone" stations and some of the regional networks.

The calibration process resulted in the measurement of six critical parameters, namely seismometer free period (T_s) and damping ratio (T_d), galvanometer free period (G_s) and damping ratio (G_d), magnification ratio (V_o), and σ^2 , which is a coupling constant between the seismometer and galvanometer. The parameters were used to mathematically describe both response sensitivity and phase and describe each seismic channel in the form of a graph representing the response. The formulas and calculations to derive the fundamental calibration parameters and the resulting station responses and graphs are found in the published annual Soviet station calibration reference booklets (e.g., Glevskyy et al., 1984, and many others).

These six parameters have been mathematically demonstrated to be translatable into conventional poles and zeros (Hagiwara, 1958; Peterson and Hutt, 2014). This section of the report describes our implementation of converting those 6 parameters into poles and zeros and applying the results to remove the instrument response from our digitized seismograms. There is additional discussion on the importance of applying the station responses to the digitized seismograms when using modern digital processing.

2.7.3. Calculating Station Response

MSU developed a code called “PZCalc” (Burk, 2022) to utilize the 6 fundamental calibration parameters to generate dataless SEED files. The dataless SEED files are then available for use with the digitized seismograms to allow removal of instrument response and allow the seismogram to be represented in ground displacement. represent ground motion.

PZCalc utilizes a ‘direct computation’ solution from the six instrument parameters to determine the pole/zero solution to instrument response using Equation 1 (Hagiwara,

$$H(s) = \frac{-S_c s}{s^4 + (2\lambda_s \omega_s + 2\lambda_g \omega_g)s^3 + (\omega_s^2 + \omega_g^2 + 4\lambda_s \omega_s \lambda_g \omega_g (1 - \sigma^2))s^2 + (2\lambda_s \omega_s \omega_g^2 + 2\lambda_g \omega_g \omega_s^2)s + \omega_s^2 \omega_g^2} \quad (1)$$

Equation 1. Formula to solve for poles and zeros.

1958; Peterson & Hutt, 2014) that describes the eigenvalues s and their relationships to the seismic channel parameters (see Figure 21), where $\omega_s = 2\pi/T_s$ (sensor period term), λ_s is T_d (sensor damping term), $\omega_g = 2\pi/G_s$ (galvanometer period term), $\lambda_g = G_d$ (galvanometer damping term), $S_c = V_o$ (sensitivity constant), and σ^2 is the coupling coefficient term. Using these calibration parameters, we now generate a four zero, three pole solution using these parameters, where the poles are derived from the equation. The factors s^4, s^3, s^2, s represent the poles of the response curve. The AO normalization factor is derived to generate a normalized curve with a peak amplitude of 1.0. The poles and zeros, amplitudes and normalization factors are individually calculated for each channel. Figure 21 shows an example of the matching calibration curves from PZCalc’s directly calculated poles and zeros. Special acknowledgement is given to Dr. John Nabelek for his assistance and guidance in developing this method.

2.7.4. Generation of Dataless SEED Files

The PZCalc software generates, based on an existing template, a dataless SEED file (Figure 22). This dataless SEED utilizes the derived poles / zeros from PZCalc, along with station metadata such as station coordinates to generate a standalone, three channel, or six-channel dataless SEED representing station response for any Miniseed files that represent scanned and digitized analog records from that station. The dataless SEED converts millimeters of deflection on the paper record to meters of corrected ground motion (usually a typical magnitude of 1E-07 meters; About 100 nanometers).

Station	Inst.	Comp.	Ts	Td	Gs	Gd	σ^2	Vo	Vm	Period	Date
9. "Монды"	CRM-3	C-D Bapt B-3	1,74	0,53	0,37	1,84	0,0752	30000	30955	0,2-1,2	05.02.82r.
			-	-	-	-	0,102	-	31096	-	
							0,0732	-	30944	-	

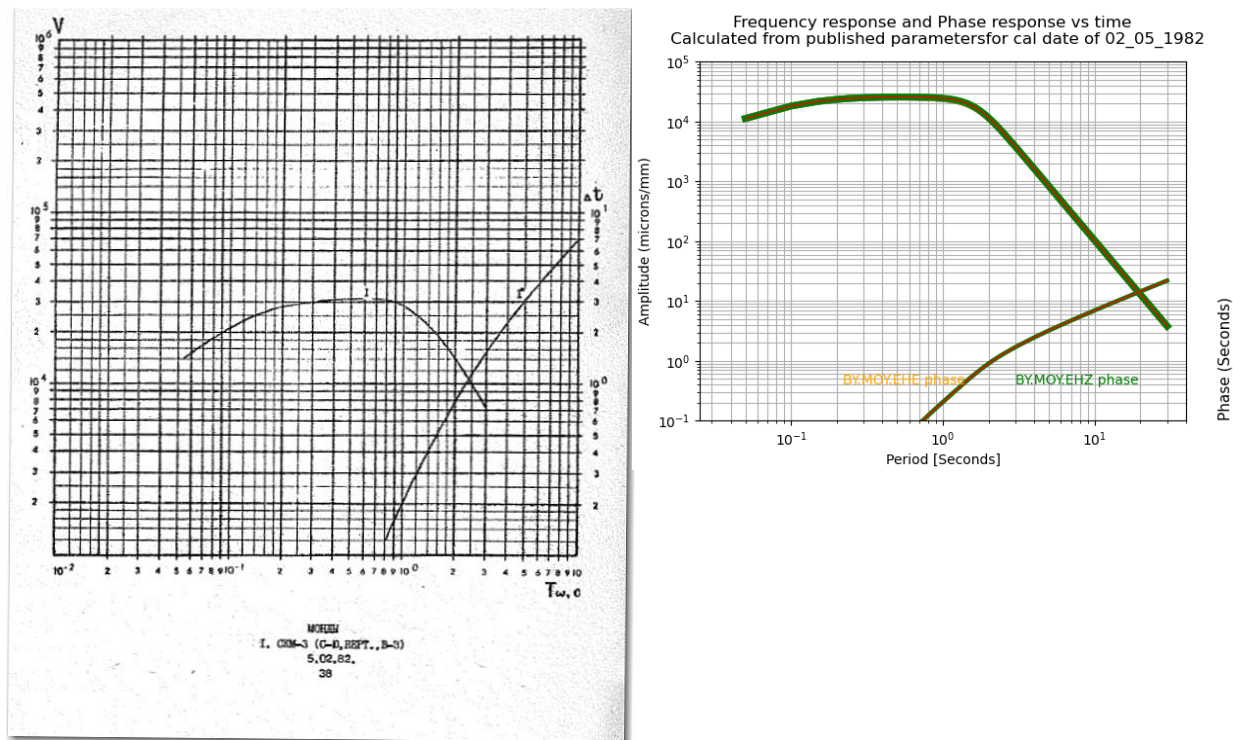


Figure 21. Directly calculated station response curves example for Soviet seismic station Mondy, for the period of 1982, as reproduced by MSU's PZCalc utility. The upper block shows published parameters used in the calculation of the response. At left are the original published response curves for amplitude and phase. In the image at right the thick green lines represent the reproduced response curve from the original Soviet literature. The thin red lines that overlie represent the response as described by the poles and zeros derived from PZCalc. The upper set of curves represent the amplitude response while the lower right curves represent phase delay in seconds (y axis), with both measured against period. Visual differences between the left and right panels are due to scaling.

The development of the pole/zero description of instrument response and generation of dataless SEED files results in a digital waveform that correctly reports amplitude in terms of meters of displacement that is based upon published calibration parameters for the channel for that timeframe (Figure 23). The dataless SEED files generated by PZCalc also include station coordinates, channel instrument type, poles and zeros for the channel, AO normalization factor, and a series of gain stages that properly convert the miniseed file from its native output of centimeters displacement from the paper seismogram into SI units of meters of displacement representing earth ground motion.

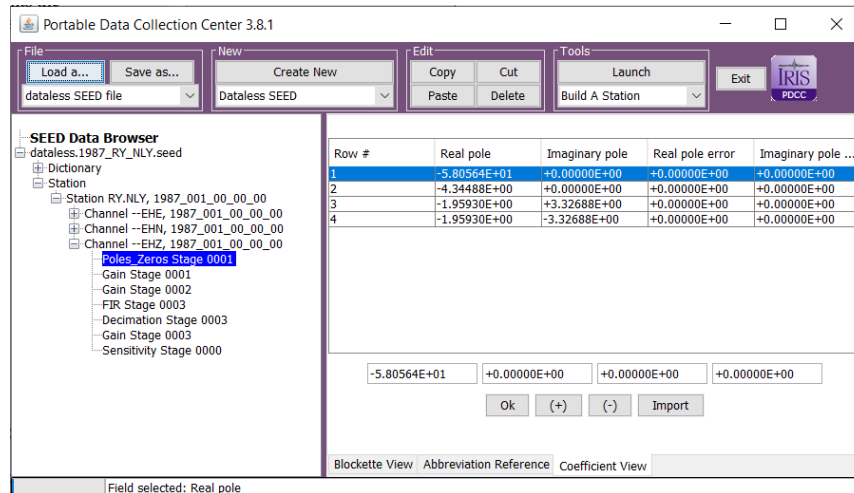


Figure 22. A dataless SEED file is created for a station (as observed in PDCC; Casey, 2016). In SEED, the station file maps the conversion from ground motion into waveform. In the case of the analog seismogram, a translation is made from centimeters of displacement on the paper seismogram into meters of ground displacement. The poles and zeros describe how the seismometer and galvanometer affect the displayed signal. By placing the calculated pole/zero parameters into the SEED file, seismic analysis software can remove instrument response to properly display ground motion.

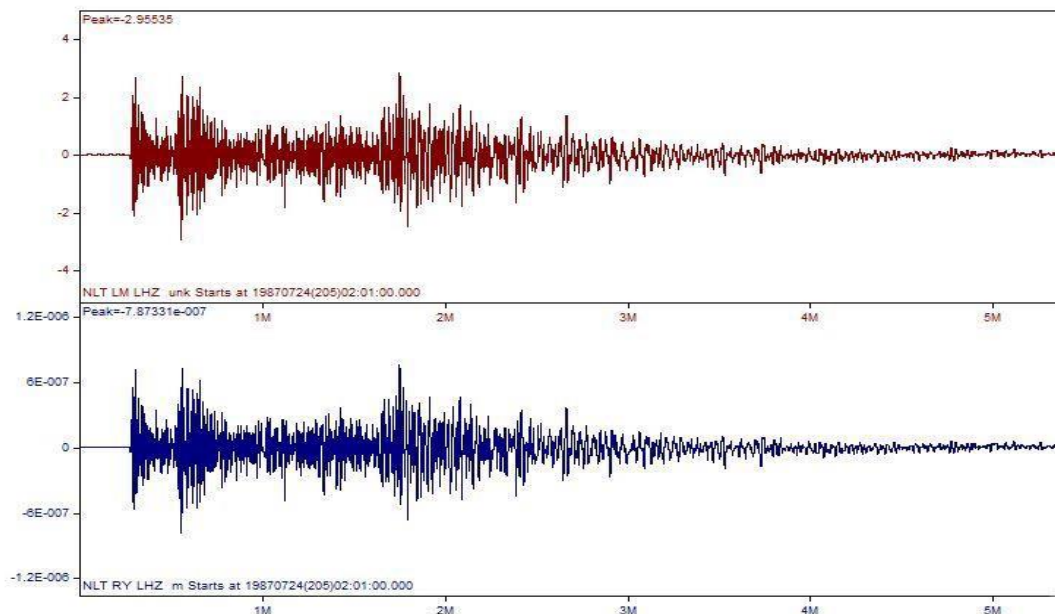


Figure 23. Corrected seismogram (bottom) shown with amplitude in units of meters of ground motion as compared to the original waveform (top) shown with amplitude in units of centimeters on the paper seismogram. The dataless SEED has applied the gain to the resulting seismogram and translates ground displacement into SI units of meters. 7.873E-07 meters = 787 nm, from the original peak of 2.955 centimeters. This equates to a gain of about 37,600, close to the gain from the published literature (36400).

2.7.5. Removal of Instrument Response

One of the important reasons for generating dataless SEED files for each digitized seismogram component is to allow the removal of the instrument response from the digital seismogram. This is a critical step in preparing waveforms for quantitative research. On a short period station with a relatively narrow band of frequency response, amplitudes of ground motion recovered will be accurate around the free period of the sensor, assuming that the sensor is critically damped. For higher and lower frequencies, the amplitudes will be under reported. Removing the instrument response from the seismogram corrects this. Using the calculated poles and zeros and the generated dataless SEED files, we observe the expected response when applied to our digitized waveforms. Specifically, boosting of both low and high frequencies, which is consistent with the published response of the original analog record (Figure 24). Low frequency features, such as Love and Rayleigh waves not easily seen within the original short-period digitized seismogram are enhanced (Figure 25). In the passband of the instrument, from $\sim 1 - 3$ Hz, the waveform spectral energy content remains essentially unchanged.

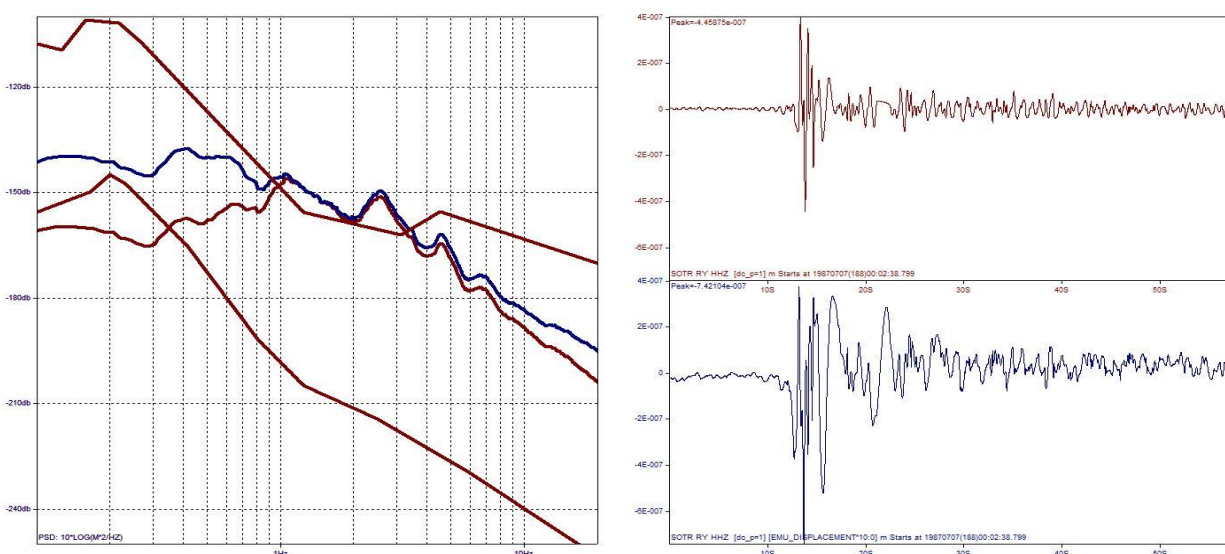


Figure 24. Instrument Response removal from a digitized analog waveform (right) and corresponding PSD (left). Uncorrected waveform is in red. Instrument response removal waveform is colored in blue.

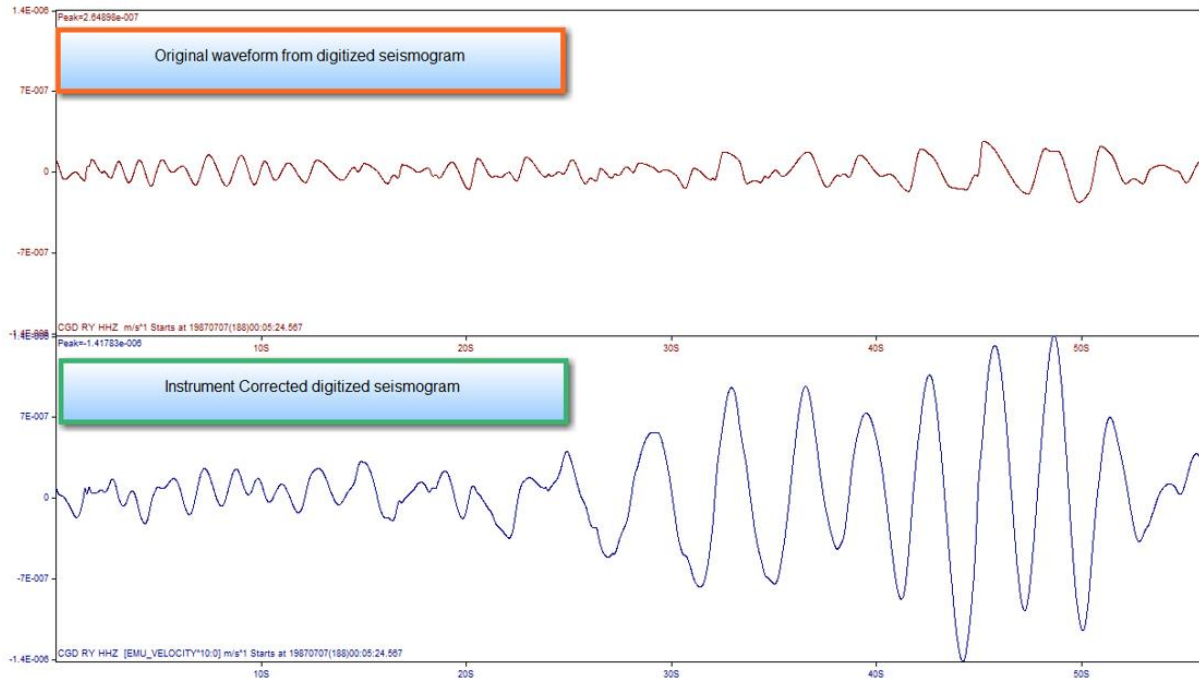


Figure 25. Demonstration how instrument response removal can enhance the recovery of low frequency energy (bottom) that is not easily seen in the original seismogram (top).

2.7.6. Variability of Station Response

Previous digitization efforts addressed station response by creating a series of generalized seismograph constants for a dozen or so instrument configurations used within the Soviet network (Richards et al., 2015). These configurations address some common seismometers such as the SKM and SKD used by the Soviet stations by providing a standardized set of instrument parameters. They do not address channel response for other common sensors that were used earlier in the regional networks, such as VEGIK, nor with newer model seismometers, such as the SM-3 that became commonplace during the 1970's and 1980's. The standardized instrument parameters were then utilized to create a series of frequency vs. amplitude & phase instrument CSS3.0 tables. These tables accompany the digitized seismograms from Richards et al. (2015) and describe the generalized channel response as a series of poles and zeros. The amplification gain (V_m), for each specific channel is noted within the tables, so that a rough characterization of channel response is attainable.

Since the Soviet stations used electromechanical seismometer models featuring adjustable periods and damping ratios, instrument response can vary from channel to channel and from year to year. Some stations were more consistent than others, but in many cases, there are very different responses from channel to channel, especially between the vertical and horizontal channels. In several cases, there is a mixing and matching of seismometer parameters, even within a single triaxial channel set. Hence, a “canned” estimation of station response based purely on seismometer model is insufficient (Figure 26). Both amplitude and phase vary across the three components of this station such that a standardized pole/zero solution would not be a good fit. This illustrates the importance of recovering the individual

response of each sensor in each station for each time interval in the recovery of accurate ground motion from a digitized seismogram. Although generally not the case for this study, often the seismograms exist, but some or all station responses are lost or otherwise unavailable. In this case, the only option is to use a generalized response, as was necessary in Richards et al. (2015).

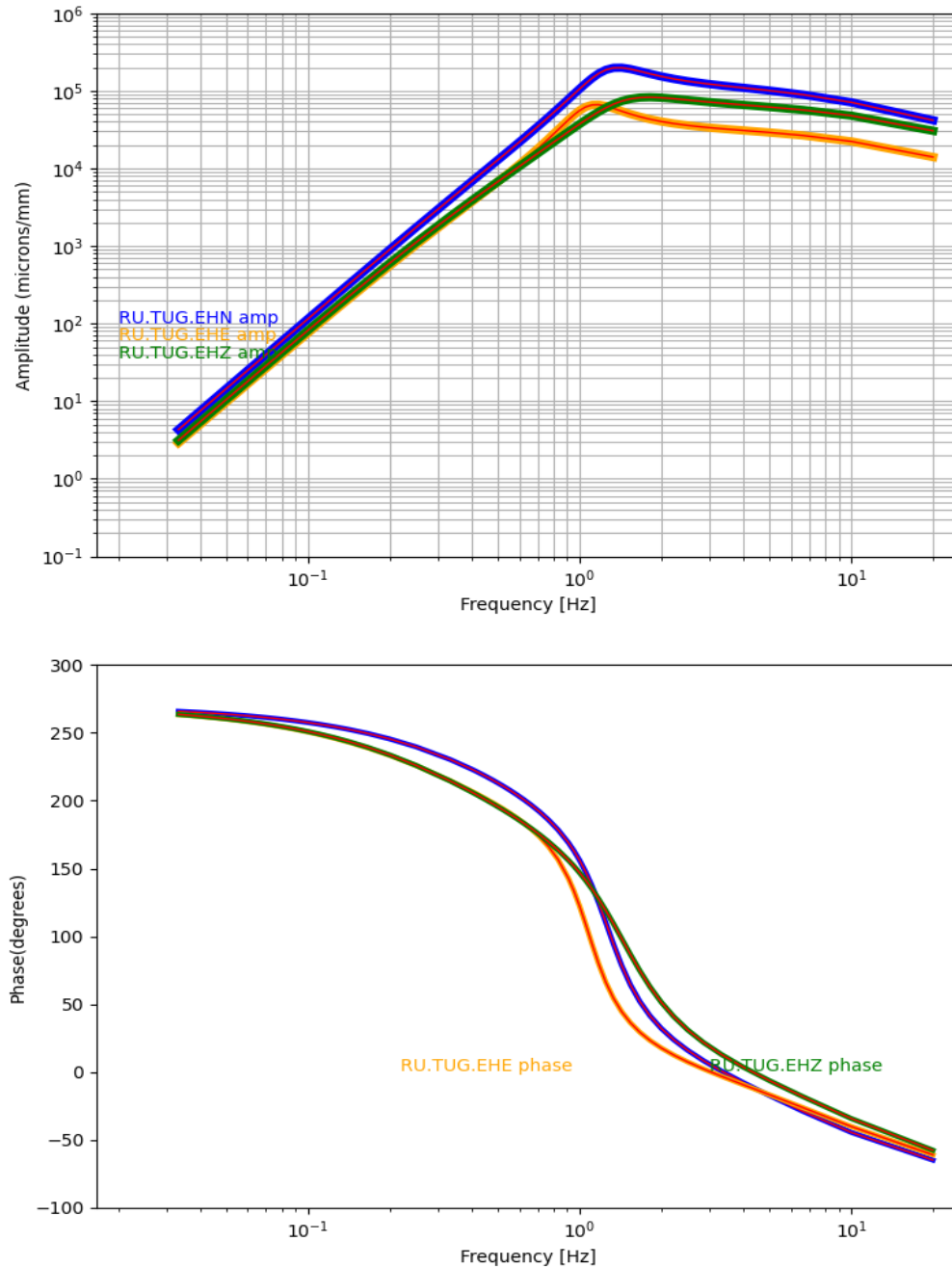


Figure 26. Variations in response from channel to channel. Station Tungurcha (TUG) in Russia, circa 1980. SKM instruments with variable response for the Z (green), N (blue), and E (orange) components in both amplitude and phase. A standardized response is insufficient to describe this station epoch.

Additional files that are included within the response folder accompanying this report are a text file representing the base calibration metadata from the original Soviet literature, a series of “SACPZ” files for each channel, along with response plots, .CSV representations of response and phase, and a .LOG file that documents the conversion of the base calibration file. The folder includes everything necessary for the examination (and re-generation) of the dataless SEED file, except for the PZCalc software itself.

2.7.7. Kyrgyz Republic Station Response Data

Many the seismic stations within the FSU used a “standardized” set of seismic systems that employed a standard series of calibration procedures. Moreover, these periodic calibrations were often recorded and published in annual metadata reports that contain the station name, code, coordinates, channel configuration, base calibration parameters, and a resulting channel response curve. One series of books published either in Moscow or Obninsk covers the calibration parameters of the Soviet ‘backbone’ network, which includes the main stations distributed across the Soviet Union (Glevskyy et al., 1984, and many others). We have completed a set (scanned or original) of these books spanning from 1963 to 1994. For the Kyrgyz Republic this set of books details the yearly calibrations conducted at stations Ala-Archa (AAK) and Frunzy (FRU). The calibration parameters in these books are used to calculate the specific response characteristics (poles and zeros) of each instrument for each seismogram digitized from these two stations. A complete set of scans of these parameter books accompanies the data submission of this report and is described in Appendix C, *Digitized Seismogram Library Description*.

The ISKR retains much station calibration information for the other legacy seismic stations of the Kyrgyz Republic. This information was used to generate the dataless SEED files that accompany the waveforms digitized in this study. For the years 1993-1995, the parameters for all stations are published in Prilozheniya (1996). A scan of this publication is included in the data submission that accompanies this report. The calibration parameters specific to the ISKR stations for other years are not formally published, though many remain held in the ISKR archive and utilized here. These unpublished calibration parameters can be found in the individual station ‘Passport’ files that are included in the data submission that accompanies this report. There are cases where the station parameters for some years are absent. In this situation, we generated the dataless SEED file using the parameters available for calibration that were nearest in time to the seismogram of interest.

The dataless SEED files are duplicated at two places within the collection: They accompany each digitized seismogram and are also found in a master Metadata folder grouping all dataless SEED files by year and station. See Appendix C, *Digitized Seismogram Library Description* for additional information.

2.7.8. Data Accuracy

2.7.8.1. Demonstration of amplitude and phase accuracy: Co-located Stations

Two co-located seismic instruments, one analog SKM-3 short period sensor and one digitally recorded broadband STS-1 sensor, from Ala-Archa (AAK), Kyrgyz Republic were

compared against one another to examine the trustworthiness of digitized analog seismograms with equivalent digital data. The seismic data for this comparison were from several Chinese Lop Nor nuclear test events from the early 1990's. A map of station AAK relative to the detonation site is shown in Figure 27. The analog data was digitized from the paper seismograms and the broadband data was downloaded from the Incorporated Research Institutions for Seismology (IRIS) digital seismogram database.

Figure 28 displays a comparison between the co-located instruments in the frequency domain for one of the events, CHIC39. Both PSDs of the co-located instruments match well with one another between 0.5 - 5 Hz as shown in the yellow highlighted region on the PSD. Within this region, both waveforms fall within 3db of each other; however, above 5 Hz the broadband waveform takes a sharp decline. This roll off is due to a 5 Hz lowpass filter applied to the data at the time of original recording. Due to this application, it is unknown whether the analog data continues to correlate with the digital data at higher frequencies. Another difference between the two waveforms is the sample rate. The digital waveform has a sample rate of 20 samples per second (sps), thought to be adequate at the time. The digitized waveform was a 600 DPI scan with a 100 sps sample rate. Even with these small differences, both waveform frequencies match well and show that the digitization of analog seismograms agrees with digital acquired data.

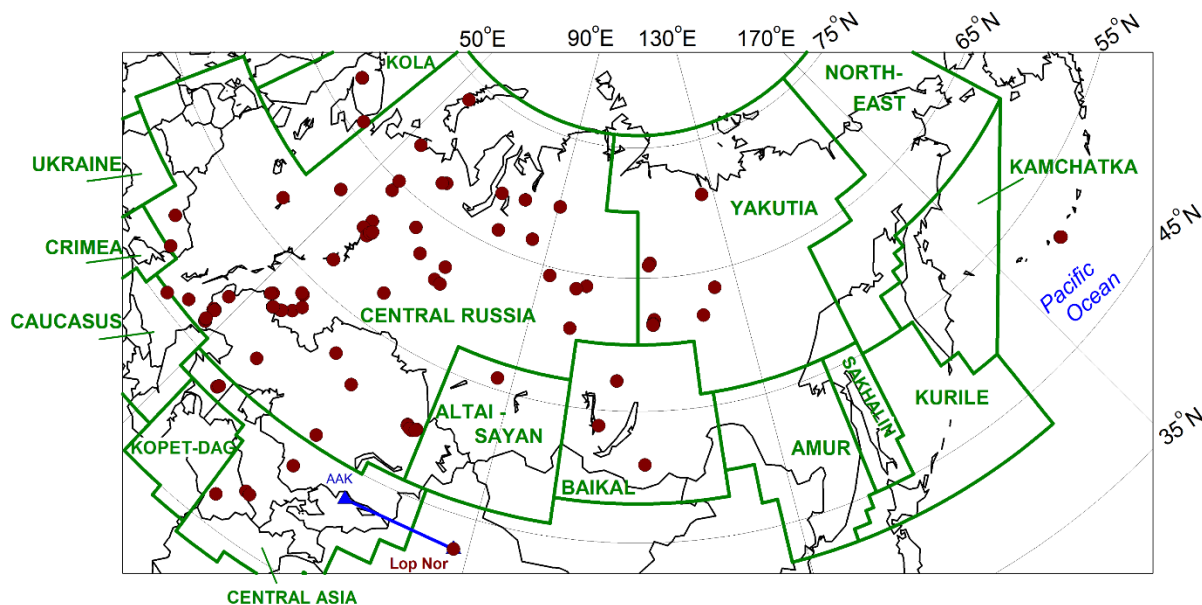


Figure 27. Location for station AAK with co-located instruments relative to the seismic event at the LNTS used for comparison analysis. The blue triangle is the seismic station Ala-Archa (AAK), Kyrgyz Republic and the Lop Nor detonation site is the red triangle. Additional detonation sites for Soviet and United States nuclear tests are shown as red circles.

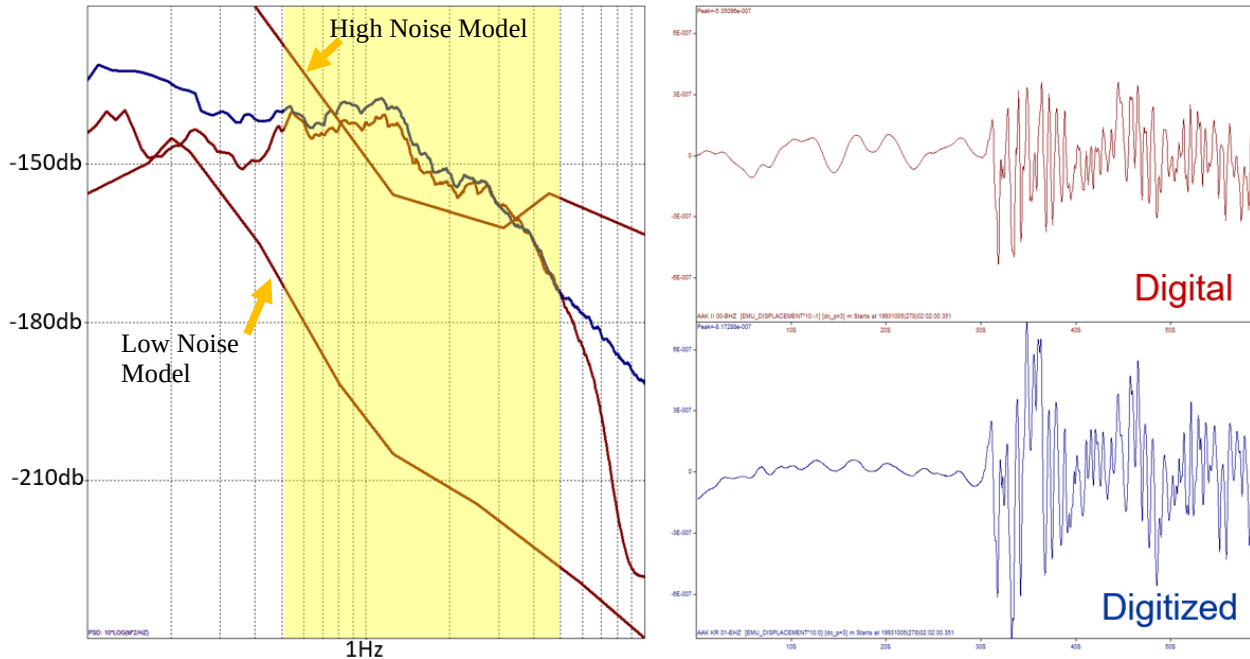


Figure 28. CHIC39 Chinese Lop Nor Nuclear Test of 5 October, 1993. PSD comparison of a broadband STS-1 BHZ component (red) and an analog SKM-3 EHZ component (blue) at station Ala Archa (AAK) in the Kyrgyz Republic. The High and Low Noise Models illustrate the bounds of seismic noise relative to the world's seismic stations. The yellow region highlights the frequencies where the two PSD curve waveforms fall within 3db of one another between 0.5 – 5 Hz. The broadband (red) signal roll-off observed at 5Hz is due to the antialiasing filter on the broadband sensor.

2.7.8.2 Estimate of timing accuracy

The timing of the stations can be estimated by understanding the technique used for maintaining timing on the analog station. There are also several examples of co-located analog stations that operated at the same time on the same pier as modern broadband stations. We can therefore infer timing accuracy from the co-located arrivals that come from tests that occur after 1993, assuming that the timing of the early 1990's digital station can be trusted.

2.7.8.2.1 Time synchronization Soviet stations

The time-base used on Soviet seismograms was derived from hourly timing signals that were broadcast on Soviet, and later Russian, standard public radio programming through the station Mayak (translates to 'Lighthouse'). The timing signals consist of a sequence of 6 short tone pulses on 1 second intervals. The beginning of each short pulse represented the start of seconds 55, 56, 57, 58, and 59 preceding a new hour, and the 6th pulse marking the beginning of an hour (Figure 29). The audio tones can be heard from 15-20 seconds in the audio recording at <https://www.youtube.com/watch?v=WMPJ5R1ajbc> (accessed February 2024). The Mayak station remains in existence and timing signals are still included in their programming to mark the beginning of every hour. However, their broadcasts are now via internet streaming where delays would be expected, thus reducing the accuracy of the signal on the receiver end.

The Mayak timing signals are no longer used for seismogram timing in the former Soviet republics.

Some networks and stations also utilized electronic circuits that would strip out specific tones from the radio broadcast. When the frequency of the broadcast timing code was detected, the light beam of the recording system would momentarily cut out. Figure 29 is representative of a seismogram that used frequency stripping to synchronize timing. It is noted that on this seismogram a sequence of 5 pulses precedes every hour mark, which is diagnostic of the automatic routine being used. The sixth pulse is not visible as it is within the beginning of the hour mark. It should be noted that the automatic routine for the application of the timing pulses does not correct the chronometer that applies the time marks. The station operator utilized the pulses as reference but manually adjusted the chronometer, either speeding it up or slowing it down slightly to maintain accurate timing.

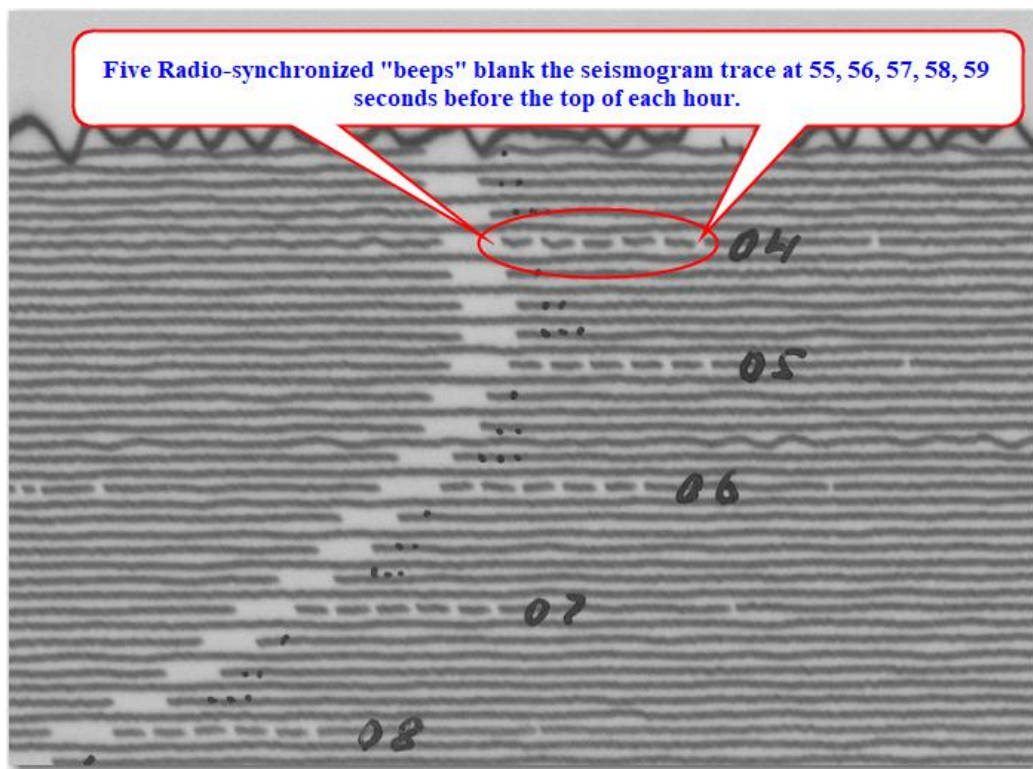


Figure 29. Automatically generated timing pulses preceding the top of each hour. The sixth pulse corresponds to the beginning of the hour, indicating a time correction of 0.0 s. The seismogram reads right to left.

In most stations, when using these codes, the timing pulses were manually synchronized by the station operator who would briefly push a button that momentarily interrupted the light beam recording the seismogram. This makes a series of short 1/10 – 1/2 second waveform gaps on the record (Figure 30). The station operator would generally synchronize timing at the beginning and ending hour on a newly installed seismogram paper roll.

The radio timing signal is believed to be fundamentally accurate to ± 0.1 s, as per discussion with the National Institute of Standards and Technology (NIST; pers comm. ~1996). Allowing for slight errors in the original manual correlation of the timing pulses (± 0.1 s) and the original interpretation and calculation of the time correction based on these marks (± 0.1 s), and placement of clickpoints at the beginning of time marks in the digitization process, errors in timing on the original paper seismograms should normally be less than 0.2 seconds.

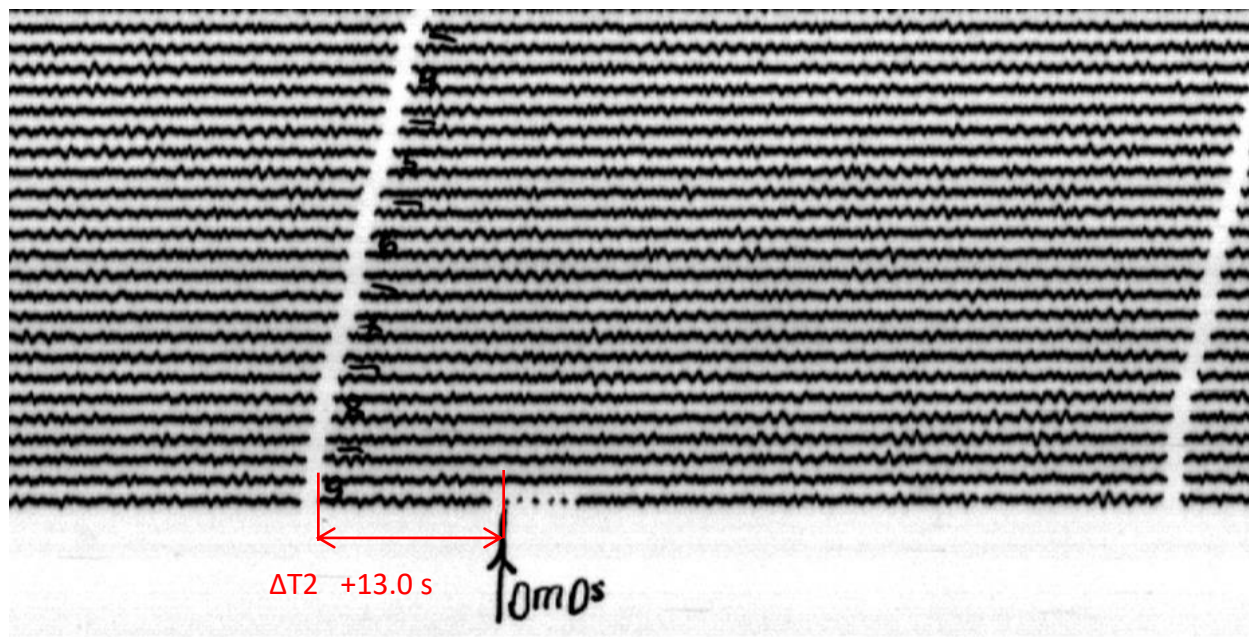


Figure 30. Manually generated timing pulses preceding the top of the hour. These were generally only input just before or just after the paper was changed. The $\Delta T2$ time correction calculation of +13.0 s is shown. This seismogram reads right to left.

With a set of accurate time pulses, the interpolated timing drift as a function of hour is calculated and applied to seismic arrivals found on the paper record (Figure 31). This is determined by establishing the timing correction factors $\Delta T1$ and $\Delta T2$ for the beginning and ending of the record, which is 12 hours in length for most seismograms.

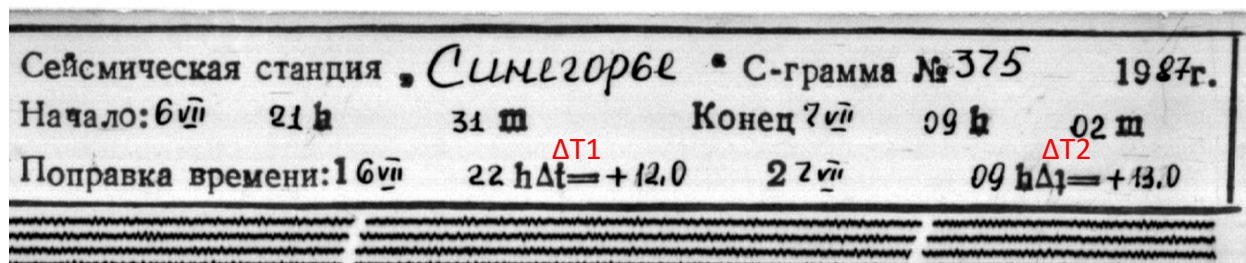


Figure 31. Timing Deviation at the beginning and ending of the seismogram. The “slew” between these two Δt values is calculated, and then the minute/hour Δt is interpolated to the minute preceding the arrival, for a calculation within 0.1 seconds. On this image, $\Delta T1$ is +12.0 s and $\Delta T2$ is +13.0 s. This $\Delta T2$ is shown on Figure 30. See Appendix D for a description of the parameters shown on the seismogram stamps.

The interpolated timing correction ΔT_c is calculated from the following formula:

$$\Delta T_c = (\text{hevent} - h_1) * (\Delta T_2 - \Delta T_1) / (h_2 - h_1) \quad (2)$$

Which is the time since the first timing measurement, multiplied by the rate of timing drift for the duration of the seismogram, where,

h_1 = beginning hour

h_2 = ending hour

ΔT_1 = timing correction at hour h_1

ΔT_2 = timing correction at hour h_2

hevent = Elapsed time of the event, as referenced from h_1 , in fractions of an hour.

The seismograms within the library contain these timing tone pulse marks, providing a way to optically check the accuracy of the original operator's calculation of ΔT_1 and ΔT_2 (Figures 30 and 31). It is likely easier with a scan of a seismogram than it was for the original station operator, who would have used a magnifying glass and a transparent template to overlay on the seismogram to recover time. Appendix F illustrates the measurement technique used in the original seismogram analysis to recover the time correction as well as determine the time of arrivals.

With digital scans, determination of the time correction can be checked by first measuring the number of pixels from the onset of the nearest minute, to the end of the minute, and then dividing by sixty to arrive at the number of pixels per second. Then, count the number of pixels from the beginning of the last "beep" mark to the onset of the new minute to understand the length of the offset in seconds. The Note that the last "beep" mark could precede or follow the minute mark depending on whether the time correction is positive or negative.

Based on our experience, the timing on a good quality scan can be picked to the nearest two pixels. From Figure 32, a 600 dpi scan of a 120 mm/min scanned seismogram, each pixel will represent 0.021 sec, so +/- 2 pixels is +/- 0.042 s. For a standard 60mm/second seismogram, the time interval uncertainty is doubled to +/- 0.084 s. These recording speed values represent the two common variations of the short-period seismograms that were digitized. The long period seismograms are generally recorded at 30 mm/min, thus their timing errors, based on +/- 2 pixels, is +/- 0.168 s. Of course, the timing measurements on the seismogram will also have larger errors if the light beam is out of focus as it is difficult to see the edges of the traces. The ability to select the beginning and end of the timing marks is also dependent on being able to see where the marks start, which is hard when it resides on a high amplitude signal that is faded into the background. There is also a potential timing error associated with the length of the minute on the paper seismogram. Theoretically, the minutes are 30, 60, or 120 mm in length depending on the instrumentation and original set-up of the station, however, recording speed was not always well regulated and the length of a minute can vary +/- 1-2 mm. However, the Wavetrack software interpolates between the identified minute marks, cancelling out meaningful effects of variation in minute length.

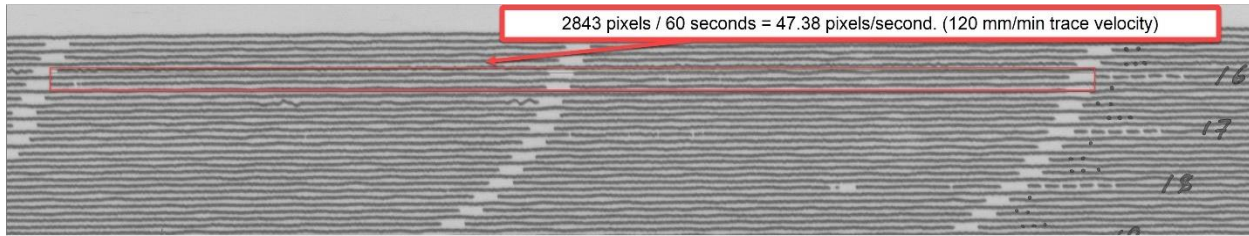


Figure 32. Scanned 600 dpi seismogram with 120 mm/second trace velocity. Note that one minute of time-history, 120mm-worth, is represented by 2843 pixels of scanned image. $2843 \text{ pixels} / 60 \text{ seconds} = 47.4 \text{ pixels per second}$, which is 21 milliseconds per pixel. A 60mm/second seismogram will represent 42 milliseconds per pixel.

2.7.8.2.2 Timing Study using co-located analog and digital stations at Ala-Archa (AAK)

For several years, station Ala-Archa (AAK) operated as an analog station for the Institute of Seismology and remained co-located alongside the GSN broadband station. During the first few years of station II.AAK operation, from 1993 through 1996, the last series of Chinese nuclear tests occurred, offering us a chance to directly compare the response of the broadband station against the analog station. Section 2.7.8.1 compared seismic energy common to both co-located stations to verify instrument response calculations. However another type of study can also be accomplished to evaluate timing accuracy. Since both sensors are mounted in the same tunnel on adjacent piers, their phase arrivals should be almost identical. Thus, by comparing waveforms in the same time domain, either displacement or velocity, we should be able to estimate timing differences between the two systems. Any discrepancies will either be a function of timing accuracy of the digital station or accuracy within the analog system, either during the inception of data creation, or during the digitalization process.

To compare the waveforms to the broadband, it is necessary to download them from IRIS (now Earthscope). The station components are II.AAK.00.BHx, where the channel assignments are BHZ, BHN and BHE. These channels represent a 20 sps waveform from a Streckeisen STS-1 broadband seismometer. The channels employed a 5 Hz anti-aliasing filter, which implies that it may not be possible to pick arrival times on the GSN to better than 200 milliseconds.

The analog and digital stations were co-located for a time spanning 7 detonations at Lop Nor (CHIC 39 through CHIC 45; Table 3), though no digitized signal is available for CHIC40 and CHIC 41. For each event, the onset of the P-wave arrival time was measured on both the digitized analog station and the digitally recorded GSN station. Of the 5 direct comparisons, the P-wave arrivals differ from 10 to 818 milliseconds.

In principle, we would like to use the GSN station as a baseline reference to evaluate the timing quality of the digitized analog seismograms. Unfortunately, it has been shown through prior studies that records from GSN station II.AAK (1993 – 2017) have their own inherent timing problems, with timing inaccuracy estimates sometimes exceeding one second (Yang, et al., 2022), and up to 7.3% of studied events possibly exceeding 500 milliseconds. This is attributed to issues related to flaws in the digitizer timing method that was used within the early GSN network. With this in consideration and the pick resolution on the GSN station having a 200ms uncertainty, we cannot provide a meaningful evaluation of timing for the digitized waveforms.

It is conceivable that the arrival time differences between the stations result more from errors in the GSN station and less from the analog station. Therefore, unless new research can correct the broadband station timing, there is no way to know whether our “reference” station or the analog record is the source of any timing differences. In summary, we believe that arrival times taken from analysis of the digitized analog station are probably of similar quality to times taken from the early operating years of the GSN station AAK.

Table 3. Tabulation, by event, of timing differences between digitized waveforms and the GSN station waveforms for co-located stations at Ala Archa.

Event	II.AAK Digital – Analog Time Difference
CHIC39	407 milliseconds
CHIC40	No analog signal available.
CHIC41	No analog signal available.
CHIC42	818 milliseconds
CHIC43	10 milliseconds
CHIC44	360 milliseconds
CHIC45	100 milliseconds.

3. WAVEFORMS DIGITIZED

3.1. Introduction

This project dealt with seismograms containing arrivals from 28 Chinese nuclear explosions detonated at the LNTS, as received by stations in the now Kyrgyz Republic. Accompanying this report is a library containing completed digitizations from 258 seismograms representing seismic arrivals from these nuclear explosions. The library also contains seismograms from 2 PNE’s detonated in Kazakhstan (Manglyshak-2 and Azgir-A-4), but these will not be discussed within this report. Most of the seismograms have all three components digitized, and there are 773 individual waveforms within this collection. Figure 14 shows the ray paths of the digitized Lop Nor events and Table 4 summarizes the events and number of related digitized seismograms that were found within the archive.

The completed digitization has passed three levels of quality control and the digitalized waveforms are a faithful representation of the signal visible on the original analog records (Figure 32). Appendix A summarizes the digitization completed in this project and displays select waveforms from each. To maintain quality and consistency in the digitization of seismograms, each component included in the data submission is accompanied by a quality control (QC) sheet (Appendix E). Each QC sheet was a working document that accompanied each seismogram digitization from initial scan to waveform completion. The QC sheet has metadata about the digital seismogram such as station name and code, date, sensor, time correction, etc. Additionally, the QC sheet tracks the digitization process variables such as scan resolution, image manipulation that that occurred, and the notes from digitalization process and QC certifications. The notes included may indicate that waveforms are off-scale or indicate

image processing to the scan was undertaken, such as an image rotation to correct asymmetry, or merging traces that span the end of the paper on the drum. Each QC sheet is included in the library of digitized waveforms.

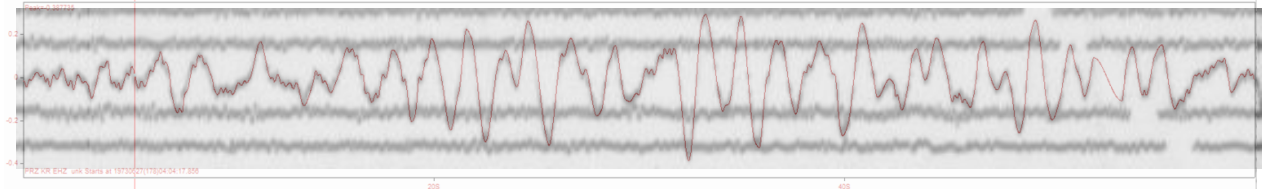


Figure 32. Overlay of relatively low amplitude (~7mm peak to peak on the original paper) digitized waveform (in red) from the miniseed file onto the original seismogram scan. The scan and waveform are a 60s portion of the vertical component of the CHIC15 (27 June 1973) nuclear explosion at station Prjevalsk (PRZ). This was an atmospheric test and the signals observed here are due to seismic coupling of the blast wave to the ground.

Following the digitization procedure using the Wavetrack software, the seismograms are converted into both miniseed and Seismic Analysis Code (SAC) format using the MSU developed PNE2SAC code (Burk, 2021). PNE2SAC extracts click-points from the Wavetrack ascii output file, and vectorizes the waveform using a PCHIP interpolation algorithm to maintain the appropriate amplitude scaling for the seismogram. It also applies the time correction to the waveform such that timing of the digital signal now matches UTC. **It is important to clarify that the miniseed and SAC waveform files accompanying this report have the time corrections already applied.** Because of this, time marks visible in the digitized seismogram may not correspond to the start of minutes based on the converted seismogram's UTC time base. The time correction offset can be verified on the QC sheets and seismogram scans that accompany the digitization.

Table 4. Seismograms and components digitized.

Event Date	Event Name	Station Name	ISC CODE	Inst Type	Component	CHANNEL GAIN	Image Type	DPI	Sample interval	QC passed?	Dataless SEED complete?
09-May-66	CHIC03	Prjevalsk	PRZ	SKM	EHE,EHN,EHZ	15000	BMP	600	0.01	Yes	Yes
28-Dec-66	CHIC05	Bishkek	FRU	SKM	EHE,EHN,EHZ	26000	BMP	600	0.01	Yes	Yes
17-Jun-67	CHIC06	Naryn	NRN	SKD	HLN,HLE HLZ	1000 500	BMP	600	0.01	Yes	Yes
27-Dec-68	CHIC08	Bishkek	FRU	SKM	EHE,EHN,EHZ	26000	BMP	600	0.01	Yes	Yes
27-Dec-68	CHIC08	Naryn	NRN	SKD	HLZ,HLN,HLE	1000	BMP	600	0.01	Yes	Yes
27-Dec-68	CHIC08	Prjevalsk	PRZ	SKM	EHE,EHN,EHZ	2250	BMP	600	0.01	Yes	Yes
14-Oct-70	CHIC11	Bishkek	FRU	SKM	EHE,EHN,EHZ	26000	BMP	600	0.01	Yes	Yes
14-Oct-70	CHIC11	Naryn	NRN	SKD	HLZ,HLN,HLE	1000	BMP	600	0.01	Yes	Yes
12-Dec-70	Manglyshak-2	Naryn	NRN	SKD	HLZ,HLN,HLE	1000	BMP	600	0.01	Yes	Yes
12-Dec-70	Manglyshak-2	Aral	ARLS	SKD	HLZ,HLN,HLE	1000	BMP	600	0.01	Yes	Yes
12-Dec-70	Manglyshak-2	Prjevalsk	PRZ	SKD	HLZ,HLN,HLE	1000	BMP	600	0.01	Yes	Yes
27-Jun-73	CHIC15	Ananievo	ANVS	SKD	HLZ,HLN,HLE	1000	BMP	600	0.01	Yes	Yes
27-Jun-73	CHIC15	Prjevalsk	PRZ	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
17-Jun-74	CHIC16	Erkin-Say	EKS	SKD	HLZ,HLN,HLE	1000	BMP	600	0.01	Yes	Yes
17-Jun-74	CHIC16	Prjevalsk	PRZ	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
17-Jun-74	CHIC16	Kaji-Say	KDJ	SKD	HLZ,HLN,HLE	1040	BMP	600	0.01	Yes	Yes
29-Jul-76	AZGIR-A4	Ananievo	ANVS	SKD	HLZ,HLN,HLE	1040	BMP	600	0.01	Yes	Yes
29-Jul-76	AZGIR-A4	Aral	ARLS	SKD	HLZ,HLN,HLE	1000	BMP	600	0.01	Yes	Yes
29-Jul-76	AZGIR-A4	Arkit	ARK	SKD	HLZ,HLN,HLE	1040	BMP	600	0.01	Yes	Yes
17-Nov-76	CHIC21	Boom	BOOM	SKM	EHE,EHN,EHZ	not recorded	BMP	600	0.01	Yes	Yes
17-Nov-76	CHIC21	Prjevalsk	PRZ	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
17-Nov-76	CHIC21	Kadji-Say	KDJ	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
14-Oct-78	CHIC24	Ananievo	ANVS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
16-Oct-80	CHIC27	Prjevalsk	PRZ	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
05-Oct-82	CHIC28	Ananievo	ANVS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
05-Oct-82	CHIC28	Boom	BOOM	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes

Table 4. Continued

Event Date	Event Name	Station Name	ISC CODE	Inst Type	Component	CHANNEL GAIN	Image Type	DPI	Sample interval	QC passed?	Dataless SEED complete?
05-Oct-82	CHIC28	Kadji-Say	KDJ	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
05-Oct-82	CHIC28	Ken-Suu	KNSU	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
05-Oct-82	CHIC28	Naryn	NRN	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
05-Oct-82	CHIC28	Prjevalsk	PRZ	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
05-Oct-82	CHIC28	Sary-Dzhaz	SRDZ	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
04-May-83	CHIC29	Ananievo	ANVS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
04-May-83	CHIC29	Boom	BOOM	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
04-May-83	CHIC29	Djergalan	DJN	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
04-May-83	CHIC29	Kadji-Say	KDJ	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
04-May-83	CHIC29	Ken-Suu	KNSU	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
04-May-83	CHIC29	Prjevalsk	PRZ	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
06-Oct-83	CHIC30	Kadji-Say	KDJ	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
06-Oct-83	CHIC30	Ananievo	ANVS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
06-Oct-83	CHIC30	Boom	BOOM	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
06-Oct-83	CHIC30	Aral	ARLS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
06-Oct-83	CHIC30	Saruu	SARY	SKM	EHE,EHN,EHZ	12271	BMP	600	0.01	Yes	Yes
06-Oct-83	CHIC30	Sary-Dzhaz	SRDZ	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
06-Oct-83	CHIC30	Prjevalsk	PRZ	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
03-Oct-84	CHIC31	Ala-Archa	AAK	SKM	EHE,EHN,EHZ	80000	BMP	600	0.01	Yes	Yes
03-Oct-84	CHIC31	Aral	ARLS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
03-Oct-84	CHIC31	Arkit	ARK	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
03-Oct-84	CHIC31	Boom	BOOM	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
03-Oct-84	CHIC31	Chumysh	CHMS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
03-Oct-84	CHIC31	Djergalan	DJN	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
03-Oct-84	CHIC31	Erkin-Say	EKS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
03-Oct-84	CHIC31	Kadji-Say	KDJ	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
03-Oct-84	CHIC31	Prjevalsk	PRZ	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
03-Oct-84	CHIC31	Saruu	SARY	SKM	EHE,EHN,EHZ	11325	BMP	600	0.01	Yes	Yes
03-Oct-84	CHIC31	Shaty	SHAT	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes

Table 4. Continued

Event Date	Event Name	Station Name	ISC CODE	Inst Type	Component	CHANNEL GAIN	Image Type	DPI	Sample interval	QC passed?	Dataless SEED complete?
03-Oct-84	CHIC31	Sufi-Kurgan	SFK	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
19-Dec-84	CHIC32	Boom	BOOM	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
19-Dec-84	CHIC32	Djergalan	DJN	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
19-Dec-84	CHIC32	Kadji-Sai	KDJ	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
19-Dec-84	CHIC32	Kara-Say	KRSY	SKM	EHE,EHN,EHZ	26514	BMP	600	0.01	Yes	Yes
19-Dec-84	CHIC32	Ken-Suu	KNSU	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
19-Dec-84	CHIC32	Sary-Dzhaz	SRDZ	SKM	EHN EHZ	25000 10000	BMP	600	0.01	Yes	Yes
05-Jun-87	CHIC33	Ala-Archa	AAK	SKD	HLZ,HLN,HLE	1000	BMP	600	0.01	Yes	Yes
05-Jun-87	CHIC33	Arkit	ARK	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
05-Jun-87	CHIC33	Aral	ARLS	SKD	HLZ,HLN,HLE	1000	BMP	600	0.01	Yes	Yes
05-Jun-87	CHIC33	Batken	BTK	SKD	HLZ,HLN,HLE	1040	BMP	600	0.01	Yes	Yes
05-Jun-87	CHIC33	Bishkek	FRU	SKM	EHE,EHN,EHZ	26000	BMP	600	0.01	Yes	Yes
05-Jun-87	CHIC33	Chauvai	CHVK	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
05-Jun-87	CHIC33	Chumysh	CHMS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
05-Jun-87	CHIC33	Kadji-Say	KDJ	SKD	HLZ,HLN,HLE	1040	BMP	600	0.01	Yes	Yes
05-Jun-87	CHIC33	Manas	MNAS	SKD	HLZ,HLN,HLE	1040	BMP	600	0.01	Yes	Yes
05-Jun-87	CHIC33	Naryn	NRN	SKM	EHE,EHN,EHZ	26750	BMP	600	0.01	Yes	Yes
05-Jun-87	CHIC33	Osh	OHH	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
05-Jun-87	CHIC33	Prjevalsk	PRZ	SKD	HLZ,HLN,HLE	1040	BMP	600	0.01	Yes	Yes
05-Jun-87	CHIC33	Sufi-Kurgan	SFK	SKD	HLZ,HLN,HLE	1040	BMP	600	0.01	Yes	Yes
29-Sep-88	CHIC34	Ala-Archa	AAK	SKM	EHE,EHN,EHZ	50000	BMP	600	0.01	Yes	Yes
29-Sep-88	CHIC34	Aral	ARLS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
29-Sep-88	CHIC34	Kensuu	KNSU	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
29-Sep-88	CHIC34	Kungey	KUNG	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
29-Sep-88	CHIC34	Terskey	TERK	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
29-Sep-88	CHIC34	Yrevka	YRV	SKM	EHE,EHN,EHZ	10000	BMP	600	0.01	Yes	Yes
29-Sep-88	CHIC34	Ak-Kiya	AKIA	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
26-May-90	CHIC35	Ala-Archa	AAK	SKM	EHE,EHN,EHZ	50000	BMP	600	0.01	Yes	Yes

Table 4. Continued

Event Date	Event Name	Station Name	ISC CODE	Inst Type	Component	CHANNEL GAIN	Image Type	DPI	Sample interval	QC passed?	Dataless SEED complete?
26-May-90	CHIC35	Ak-Kiya	AKIA	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
26-May-90	CHIC35	Alay-Kuu	ALKU	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
26-May-90	CHIC35	Ananievo	ANVS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
26-May-90	CHIC35	Arkit	ARK	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
26-May-90	CHIC35	Aral	ARLS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
26-May-90	CHIC35	Arslanbob	ARSB	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
26-May-90	CHIC35	Belogorka	BGK	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
26-May-90	CHIC35	Bishkek	FRU	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
26-May-90	CHIC35	Boom	BOOM	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
26-May-90	CHIC35	Chumysh	CHMS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
26-May-90	CHIC35	Manas	MNAS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
26-May-90	CHIC35	Erkin-Say	EKS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
26-May-90	CHIC35	Naryn	NRN	SKM	EHE,EHN,EHZ	27800	BMP	600	0.01	Yes	Yes
26-May-90	CHIC35	Osh	OHH	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
26-May-90	CHIC35	Prjevalsk	PRZ	SKM	EHE,EHN,EHZ	5400	BMP	600	0.01	Yes	Yes
26-May-90	CHIC35	Sufi-Kurgan	SFK	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
26-May-90	CHIC35	Terskey	TERK	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
16-Aug-90	CHIC36	Ala-Archa	AAK	SKD	HLZ,HLN,HLE	1000	BMP	600	0.01	Yes	Yes
16-Aug-90	CHIC36	Ala-Archa	AAK	SKM	EHE,EHN,EHZ	50000	BMP	600	0.01	Yes	Yes
16-Aug-90	CHIC36	Ak-Kiya	AKIA	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
16-Aug-90	CHIC36	Alay-Kuu	ALKU	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
16-Aug-90	CHIC36	Ananievo	ANVS	SKD	HLZ,HLN,HLE	1040	BMP	600	0.01	Yes	Yes
16-Aug-90	CHIC36	Ananievo	ANVS	SKD	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
16-Aug-90	CHIC36	Aral	ARLS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
16-Aug-90	CHIC36	Arslanbob	ARSB	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
16-Aug-90	CHIC36	Batken	BTK	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
16-Aug-90	CHIC36	Belogorka	BGK	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
16-Aug-90	CHIC36	Biskek	FRU	SKD	HLZ,HLN,HLE	1040	BMP	600	0.01	Yes	Yes
16-Aug-90	CHIC36	Boom	BOOM	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes

Table 4. Continued

Event Date	Event Name	Station Name	ISC CODE	Inst Type	Component	CHANNEL GAIN	Image Type	DPI	Sample interval	QC passed?	Dataless SEED complete?
16-Aug-90	CHIC36	Chumysh	CHMS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
16-Aug-90	CHIC36	Chauvai	CHVK	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
16-Aug-90	CHIC36	Daraut-Kurgan	DRK	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
16-Aug-90	CHIC36	Erkin-Sai	EKS	SKD	HLZ,HLN,HLE	1040	BMP	600	0.01	Yes	Yes
16-Aug-90	CHIC36	Kaji-Say	KDJ	SKD	HLZ,HLN,HLE	1040	BMP	600	0.01	Yes	Yes
16-Aug-90	CHIC36	Sufi-Kurgan	SFK	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
16-Aug-90	CHIC36	Manas	MNAS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
16-Aug-90	CHIC36	Naryn	NRN	SKM	EHE,EHN,EHZ	27800	BMP	600	0.01	Yes	Yes
16-Aug-90	CHIC36	Salom-Alik	SALK	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
16-Aug-90	CHIC36	Toktogul	TOKL	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
16-Aug-90	CHIC36	Yrevka	YRV	SKM	EHE,EHN,EHZ	10000	BMP	600	0.01	Yes	Yes
21-May-92	CHIC37	Ak-Kiya	AKIA	SKD	HLZ,HLN,HLE	1040	BMP	600	0.01	Yes	Yes
21-May-92	CHIC37	Ala-Archa	AAK	SKD	HLZ,HLN,HLE	1000	BMP	600	0.01	Yes	Yes
21-May-92	CHIC37	Ananievo	ANVS	SKD	HLZ,HLN,HLE	1040	BMP	600	0.01	Yes	Yes
21-May-92	CHIC37	Arkit	ARK	SKD	HLZ,HLN,HLE	1040	BMP	600	0.01	Yes	Yes
21-May-92	CHIC37	Aral	ARLS	SKD	HLZ,HLN,HLE	1040	BMP	600	0.01	Yes	Yes
21-May-92	CHIC37	Arslanbob	ARSB	SKD	HLZ,HLN,HLE	1040	BMP	600	0.01	Yes	Yes
21-May-92	CHIC37	Daraut-Kurgan	DRK	SKD	HLZ,HLN,HLE	1040	BMP	600	0.01	Yes	Yes
21-May-92	CHIC37	Erkin-Say	EKS	SKD	HLZ,HLN,HLE	1040	BMP	600	0.01	Yes	Yes
21-May-92	CHIC37	Bishkek	FRU	SKD	HLZ,HLN,HLE	1040	BMP	600	0.01	Yes	Yes
21-May-92	CHIC37	Kaji-Say	KDJ	SKD	HLZ,HLN,HLE	1040	BMP	600	0.01	Yes	Yes
21-May-92	CHIC37	Manas	MNAS	SKD	HLZ,HLN,HLE	1040	BMP	600	0.01	Yes	Yes
21-May-92	CHIC37	Osh	OHH	SKD	HLZ,HLN,HLE	1040	BMP	600	0.01	Yes	Yes
21-May-92	CHIC37	Prjevalsk	PRZ	SKD	HLZ,HLN,HLE	1050	BMP	600	0.01	Yes	Yes
21-May-92	CHIC37	Sufi-Kurgan	SFK	SKD	HLZ,HLN,HLE	1040	BMP	600	0.01	Yes	Yes
25-Sep-92	CHIC38	Ala-Archa	AAK	SKM	EHE,EHN,EHZ	50000	BMP	600	0.01	Yes	Yes
25-Sep-92	CHIC38	Ananievo	ANVS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
25-Sep-92	CHIC38	Aral	ARLS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
25-Sep-92	CHIC38	Boom	BOOM	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes

Table 4. Continued

Event Date	Event Name	Station Name	ISC CODE	Inst Type	Component	CHANNEL GAIN	Image Type	DPI	Sample interval	QC passed?	Dataless SEED complete?
25-Sep-92	CHIC38	Erkin-Say	EKS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
25-Sep-92	CHIC38	Bishkek	FRU	SKM	EHE,EHN,EHZ	28500	BMP	600	0.01	Yes	Yes
25-Sep-92	CHIC38	Kaji-Say	KDJ	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
25-Sep-92	CHIC38	Ken-Suu	KNSU	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
25-Sep-92	CHIC38	Kungey	KUNG	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
25-Sep-92	CHIC38	Prjevalsk	PRZ	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
5-Oct-93	CHIC39	Ala-Acha	AAK	SKD	HLZ,HLN,HLE	1000	BMP	600	0.01	Yes	Yes
5-Oct-93	CHIC39	Aral	ARLS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
5-Oct-93	CHIC39	Arslanbob	ARSB	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
5-Oct-93	CHIC39	Chauvay	CHVK	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
5-Oct-93	CHIC39	Erkin-Sai	EKS	SKD	HLZ,HLN,HLE	1040	BMP	600	0.01	Yes	Yes
5-Oct-93	CHIC39	Biskek	FRU	SKD	HLZ,HLN,HLE	1000	BMP	600	0.01	Yes	Yes
5-Oct-93	CHIC39	Kaji-Say	KDJ	SKD	HLZ,HLN,HLE	1040	BMP	600	0.01	Yes	Yes
5-Oct-93	CHIC39	Manas	MNAS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
5-Oct-93	CHIC39	Naryn	NRN	SKM	EHE,EHN,EHZ	27800	BMP	600	0.01	Yes	Yes
5-Oct-93	CHIC39	Sufi-Kurgan	SFK	SKD	HLZ,HLN,HLE	1040	BMP	600	0.01	Yes	Yes
5-Oct-93	CHIC39	Terek-Say	TRKS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
10-Jun-94	CHIC40	Ak-Kiya	AKIA	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
10-Jun-94	CHIC40	Ananievo	ANVS	SKD	HLZ,HLN,HLE	1040	BMP	600	0.01	Yes	Yes
10-Jun-94	CHIC40	Arslanbob	ARSB	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
10-Jun-94	CHIC40	Belogorka	BGK	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
10-Jun-94	CHIC40	Boom	BOOM	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
10-Jun-94	CHIC40	Chumysh	CHMS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
10-Jun-94	CHIC40	Chauvay	CHVK	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
10-Jun-94	CHIC40	Erkin-Say	EKS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
10-Jun-94	CHIC40	Bishkek	FRU	SKM	EHE,EHN,EHZ	28500	BMP	600	0.01	Yes	Yes
10-Jun-94	CHIC40	Ken-Suu	KNSU	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
10-Jun-94	CHIC40	Manas	MNAS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes

Table 4. Continued

Event Date	Event Name	Station Name	ISC CODE	Inst Type	Component	CHANNEL GAIN	Image Type	DPI	Sample interval	QC passed?	Dataless SEED complete?
10-Jun-94	CHIC40	Naryn	NRN	SKM	EHE,EHN,EHZ	27800	BMP	600	0.01	Yes	Yes
10-Jun-94	CHIC40	Prjevalsk	PRZ	SKM	EHE,EHN,EHZ	27000	BMP	600	0.01	Yes	Yes
10-Jun-94	CHIC40	Sufi-Kurgan	SFK	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
10-Jun-94	CHIC40	Terskey	TERK	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
7-Oct-94	CHIC41	Ala-Archa	AAK	SKM	EHE,EHN,EHZ	50000	BMP	600	0.01	Yes	Yes
7-Oct-94	CHIC41	Ak-Kiya	AKIA	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
7-Oct-94	CHIC41	Alay-Kuu	ALKU	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
7-Oct-94	CHIC41	Arkit	ARK	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
7-Oct-94	CHIC41	Aral	ARLS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
7-Oct-94	CHIC41	Arslanbob	ARSB	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
7-Oct-94	CHIC41	Belogorka	BGK	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
7-Oct-94	CHIC41	Batken	BTK	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
7-Oct-94	CHIC41	Erkin-Say	EKS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
7-Oct-94	CHIC41	Bishkek	FRU	SKM	EHE,EHN,EHZ	28500	BMP	600	0.01	Yes	Yes
7-Oct-94	CHIC41	Manas	MNAS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
7-Oct-94	CHIC41	Naryn	NRN	SKM	EHE,EHN,EHZ	27800	BMP	600	0.01	Yes	Yes
7-Oct-94	CHIC41	Osh	OHH	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
7-Oct-94	CHIC41	Sufi-Kurgan	SFK	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
7-Oct-94	CHIC41	Terek-Say	TRKS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
7-Oct-94	CHIC41	Yurevka	YRV	SKM	EHE,EHN,EHZ	10000	BMP	600	0.01	Yes	Yes
15-May-95	CHIC42	Ala-Archa	AAK	SKM	EHE,EHN,EHZ	50000	BMP	600	0.01	Yes	Yes
15-May-95	CHIC42	Ak-Kiya	AKIA	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
15-May-95	CHIC42	Alay-Kuu	ALKU	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
15-May-95	CHIC42	Ananievo	ANVS	SKD	HLZ,HLN,HLE	1040	BMP	600	0.01	Yes	Yes
15-May-95	CHIC42	Arkit	ARK	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
15-May-95	CHIC42	Arslanbob	ARSB	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
15-May-95	CHIC42	Belogorka	BGK	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
15-May-95	CHIC42	Boom	BOOM	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
15-May-95	CHIC42	Batken	BTK	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes

Table 4. Continued

Event Date	Event Name	Station Name	ISC CODE	Inst Type	Component	CHANNEL GAIN	Image Type	DPI	Sample interval	QC passed?	Dataless SEED complete?
15-May-95	CHIC42	Chumysh	CHMS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
15-May-95	CHIC42	Chauvay	CHVK	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
15-May-95	CHIC42	Erkin-Say	EKS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
15-May-95	CHIC42	Bishkek	FRU	SKM	EHE,EHN,EHZ	28500	BMP	600	0.01	Yes	Yes
15-May-95	CHIC42	Kadji-Say	KDJ	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
15-May-95	CHIC42	Kungey	KUNG	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
15-May-95	CHIC42	Manas	MNAS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
15-May-95	CHIC42	Osh	OHH	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
15-May-95	CHIC42	Sufi-Kurgan	SFK	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
15-May-95	CHIC42	Toktogul	TOKL	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
15-May-95	CHIC42	Torkent	TORK	SKM	EHE,EHN,EHZ	10000	BMP	600	0.01	Yes	Yes
15-May-95	CHIC42	Terek-Say	TRKS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
15-May-95	CHIC42	Yurevka	YRV	SKM	EHE,EHN,EHZ	10000	BMP	600	0.01	Yes	Yes
17-Aug-95	CHIC43	Ala-Archa	AAK	SKM	EHE,EHN,EHZ	50000	BMP	600	0.01	Yes	Yes
17-Aug-95	CHIC43	Ak-Kiya	AKIA	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
17-Aug-95	CHIC43	Alay-Kuu	ALKU	SKM	EHE,EHN,EHZ	15000	BMP	600	0.01	Yes	Yes
17-Aug-95	CHIC43	Arkit	ARK	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
17-Aug-95	CHIC43	Aral	ARLS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
17-Aug-95	CHIC43	Arslanbob	ARSB	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
17-Aug-95	CHIC43	Boom	BOOM	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
17-Aug-95	CHIC43	Chumysh	CHMS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
17-Aug-95	CHIC43	Chauvay	CHVK	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
17-Aug-95	CHIC43	Erkin-Say	EKS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
17-Aug-95	CHIC43	Kaji-Say	KDJ	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
17-Aug-95	CHIC43	Kyzyl-Djar	KZD	SKM	EHE,EHN,EHZ	10000	BMP	600	0.01	Yes	Yes
17-Aug-95	CHIC43	Manas	MNAS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
17-Aug-95	CHIC43	Naryn	NRN	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
17-Aug-95	CHIC43	Ohh	OHH	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
17-Aug-95	CHIC43	Prjevalsk	PRZ	SKD	HLZ,HLN,HLE	1040	BMP	600	0.01	Yes	Yes

Table 4. Continued

Event Date	Event Name	Station Name	ISC CODE	Inst Type	Component	CHANNEL GAIN	Image Type	DPI	Sample interval	QC passed?	Dataless SEED complete?
17-Aug-95	CHIC43	Salom-Alik	SALK	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
17-Aug-95	CHIC43	Terskey	TERK	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
17-Aug-95	CHIC43	Toktogul	TOKL	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
17-Aug-95	CHIC43	Terek-Say	TRKS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
17-Aug-95	CHIC43	Yurevka	YRV	SKM	EHE,EHN,EHZ	10000	BMP	600	0.01	Yes	Yes
8-Jun-96	CHIC44	Ala-Archa	AAK	SKM	EHE,EHN,EHZ	50000	BMP	600	0.01	Yes	Yes
8-Jun-96	CHIC44	Ananievo	ANVS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
8-Jun-96	CHIC44	Aral	ARLS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
8-Jun-96	CHIC44	Boom	BOOM	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
8-Jun-96	CHIC44	Bishkek	FRU	SKM	EHE,EHN,EHZ	28500	BMP	600	0.01	Yes	Yes
8-Jun-96	CHIC44	Kaji-Say	KDJ	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
8-Jun-96	CHIC44	Kungey	KUNG	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
8-Jun-96	CHIC44	Prjevalsk	PRZ	SKD	HLZ,HLN,HLE	1050	BMP	600	0.01	Yes	Yes
8-Jun-96	CHIC44	Terskey	TERK	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
8-Jun-96	CHIC44	Terek-Say	TRKS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
29-Jul-96	CHIC45	Ala-Archa	AAK	SKM	EHE,EHN,EHZ	50000	BMP	600	0.01	Yes	Yes
29-Jul-96	CHIC45	Alay-Kuu	ALKU	SKM	EHE,EHN,EHZ	15000	BMP	600	0.01	Yes	Yes
29-Jul-96	CHIC45	Ananievo	ANVS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
29-Jul-96	CHIC45	Aral	ARLS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
29-Jul-96	CHIC45	Boom	BOOM	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
29-Jul-96	CHIC45	Batken	BTK	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
29-Jul-96	CHIC45	Erkin-Say	EKS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
29-Jul-96	CHIC45	Bishkek	FRU	SKM	EHE,EHN,EHZ	28500	BMP	600	0.01	Yes	Yes
29-Jul-96	CHIC45	Kadji-Say	KDJ	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
29-Jul-96	CHIC45	Ken-Suu	KNSU	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
29-Jul-96	CHIC45	Kungey	KUNG	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
29-Jul-96	CHIC45	Prjevalsk	PRZ	SKM	EHE,EHN,EHZ	27000	BMP	600	0.01	Yes	Yes
29-Jul-96	CHIC45	Sufi-Kurgan	SFK	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
29-Jul-96	CHIC45	Terek-Say	TRKS	SKM	EHE,EHN,EHZ	25000	BMP	600	0.01	Yes	Yes
29-Jul-96	CHIC45	Yurevka	YRV	SKM	EHE,EHN,EHZ	10000	BMP	600	0.01	Yes	Yes

3.2. Use of digitized analog seismograms and understanding their limitations.

The seismograms that accompany this report are faithful digital representations of the original analog seismograms (Figure 32). When viewing and processing the data files, many are of high quality. Our goal in this project is to digitize seismograms that can be utilized in modern quantitative processing. However, there are some waveforms that will appear distorted, or contain artifacts when removing instrument response, filtering, or convolving from displacement to velocity or velocity to acceleration. These are generally a result of problems or characteristics of the original analog seismograms.

To aid future evaluation of the accompanying seismograms, the original scans and quality control documents are provided with each digital waveform accompanying this report. It is important that any user of this data understands its limitations and should always review the individual analog seismogram scans before use.

3.2.1. Timing Mark distortions, full-scale clipping, and signal dropouts.

One of the largest sources of distortion within this collection that impacts the quality of digitizations are time marks on the original photopaper records.

Time marks on the analog Soviet seismograms are represented by a one-second gap in the seismic trace every minute. This results in a 1 second loss of data. During the digitization process, the option chosen was to simulate a signal dropout by connecting the end of the signal at the beginning of the time mark with the beginning of the reappeared signal at the end of the time mark with a straight line (Figure 33).

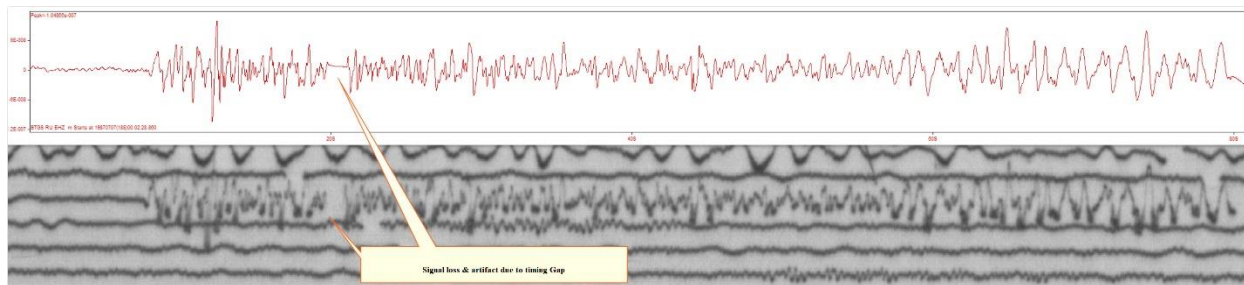


Figure 33. Example of how the digitized waveform bridges the indicated time marks.

Figure 34 shows an example of a digitized seismogram with the time mark locations indicated. Note that the raw digitization matches the analog seismogram signal, even though the time mark creates a long-period pulse. Unfortunately, when the instrument response is removed, the wider pulse from the time mark is amplified as a long period pulse artifact. In analysis, this artifact could be interpreted as a phase arrival, or have other undesirable effects, such as phantom low-frequency energy on a frequency domain FFT plot. The artifacts are generally less apparent when filtering the instrument corrected seismograms to frequencies above 1 Hz. The artifacts are also much less apparent on long period seismograms (SKD instrument) as the time mark is often superimposed on part of a single waveform cycle and can fall within the normal click-point intervals.

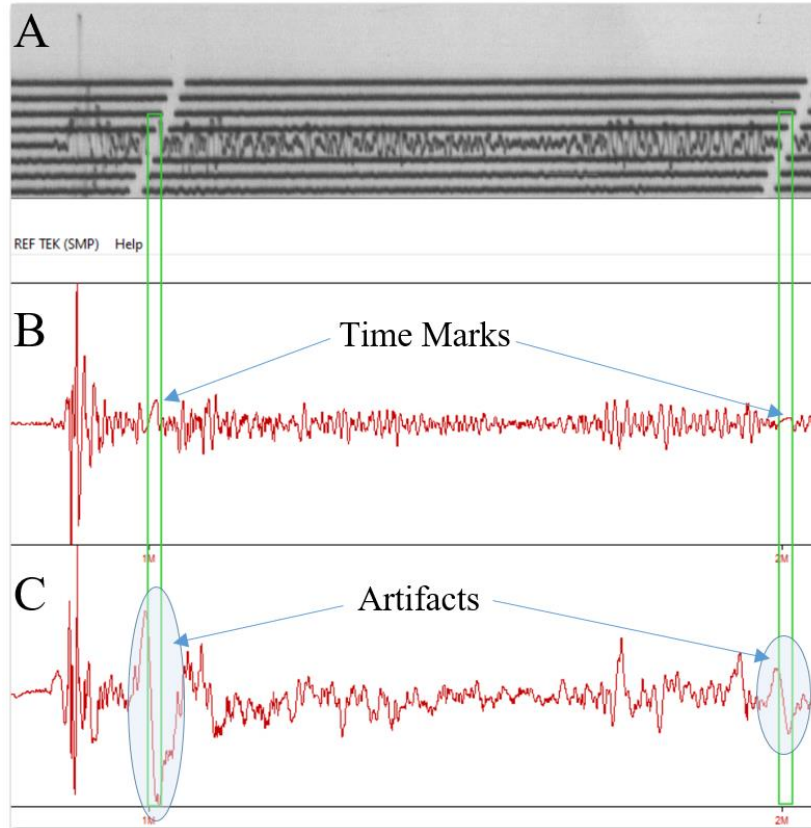


Figure 34. Digitization of a short-period component with time marks indicated by green boxes. A - Scan of the original seismogram showing the waveform. B - Raw digitization of the waveform. C – Displacement seismogram after removal of instrument response, which can sometimes result in large artifacts at the bridged time marks.

A potential solution to timing mark artifacts is the insertion of a short segment of “neutral waveform” within the space of the time mark. The neutral waveform must match the amplitude and frequency content of the signal immediately preceding and following the time mark, and it must match the preexisting trend of the signal at the beginning and end of the time mark.

It is important to note that we do not suggest an attempt to recover the original signal that is missing in the time mark gap, but to rather insert what we term as ‘neutral waveform’ that does not result in interpretable artifacts when data are filtered or processed. An example of the insertion of manually generated neutral signal to eliminate artifacts is shown in Figure 35. In this example, the time mark is not discernable in the manually modified files. MSU has conducted some background research into an automated process for generation and insertion of neutral waveform into the time mark gaps, but the solution must be developed during future research efforts as it is beyond the current scope.

Within the digitized seismograms, there are sometimes other signal dropouts that we must bridge when digitizing the seismogram. Some examples might include off-scale waveforms, high-velocity traces where the trace fades into invisibility, interruptions in the light beam when generating a series of time correction pulses, and blocking/refraction of the light

beam due to the plastic strip that held the photopaper onto the recording drum. Figure 12 shows an example seismogram where the timing marks and multiple other small data gaps result in a difficult seismogram with significant interpretation issues in terms of understanding what is really signal and what is a figment of the digitalization process (Figure 36). Hence, it is advisable to consult the original seismogram scan when any question arises concerning artifacts.

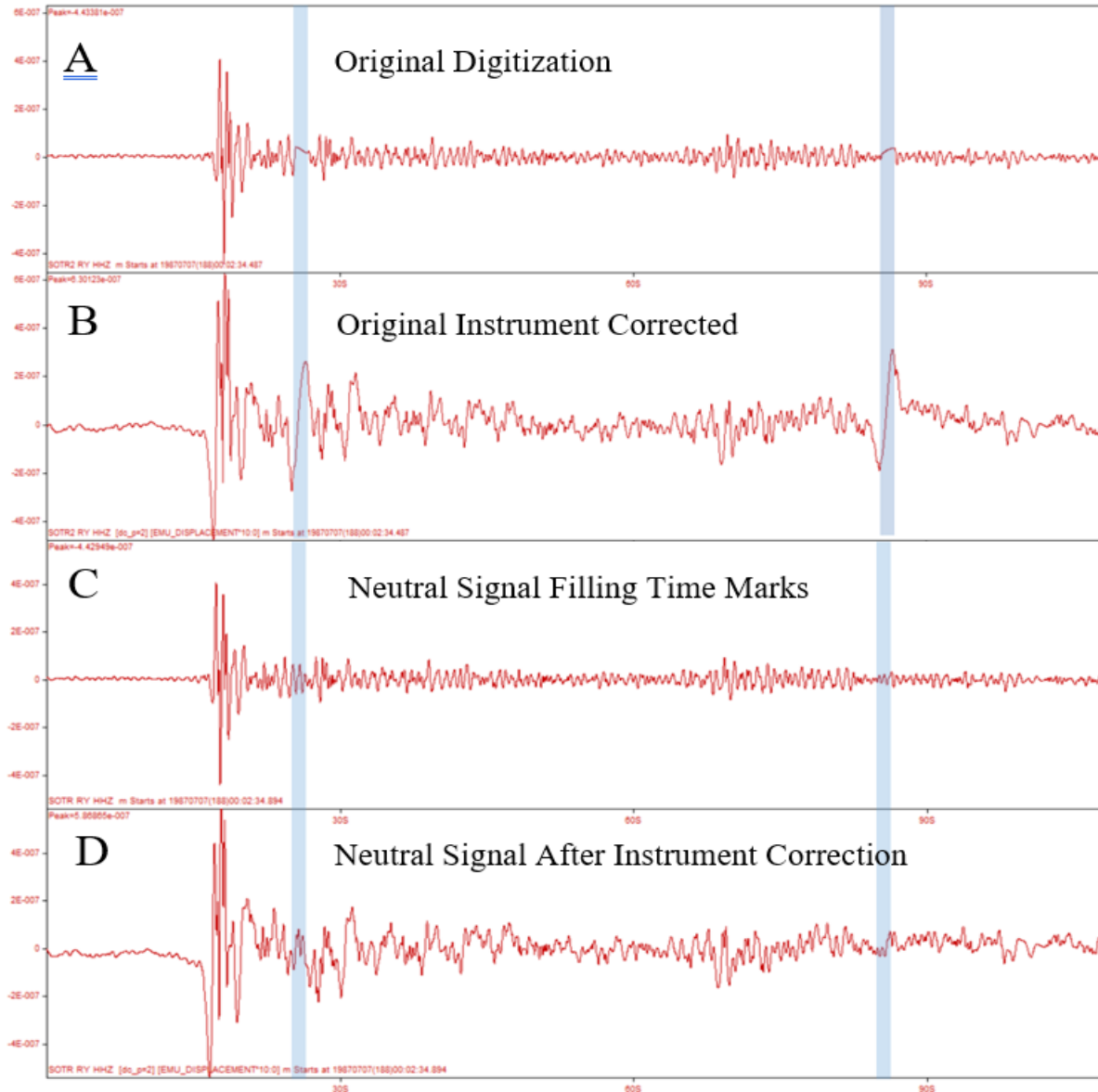


Figure 35. Digitization of the vertical component with time marks indicated by blue boxes. A - Scan of the original seismogram showing the waveform. B – Displacement seismogram after removal of instrument response, which results in large artifacts at the bridged time marks. C – Neutral signal added to span the time marks. D – Instrument corrected waveform of the seismogram containing the neutral signal spanning the time marks. Note removal of the artifacts apparent in B.

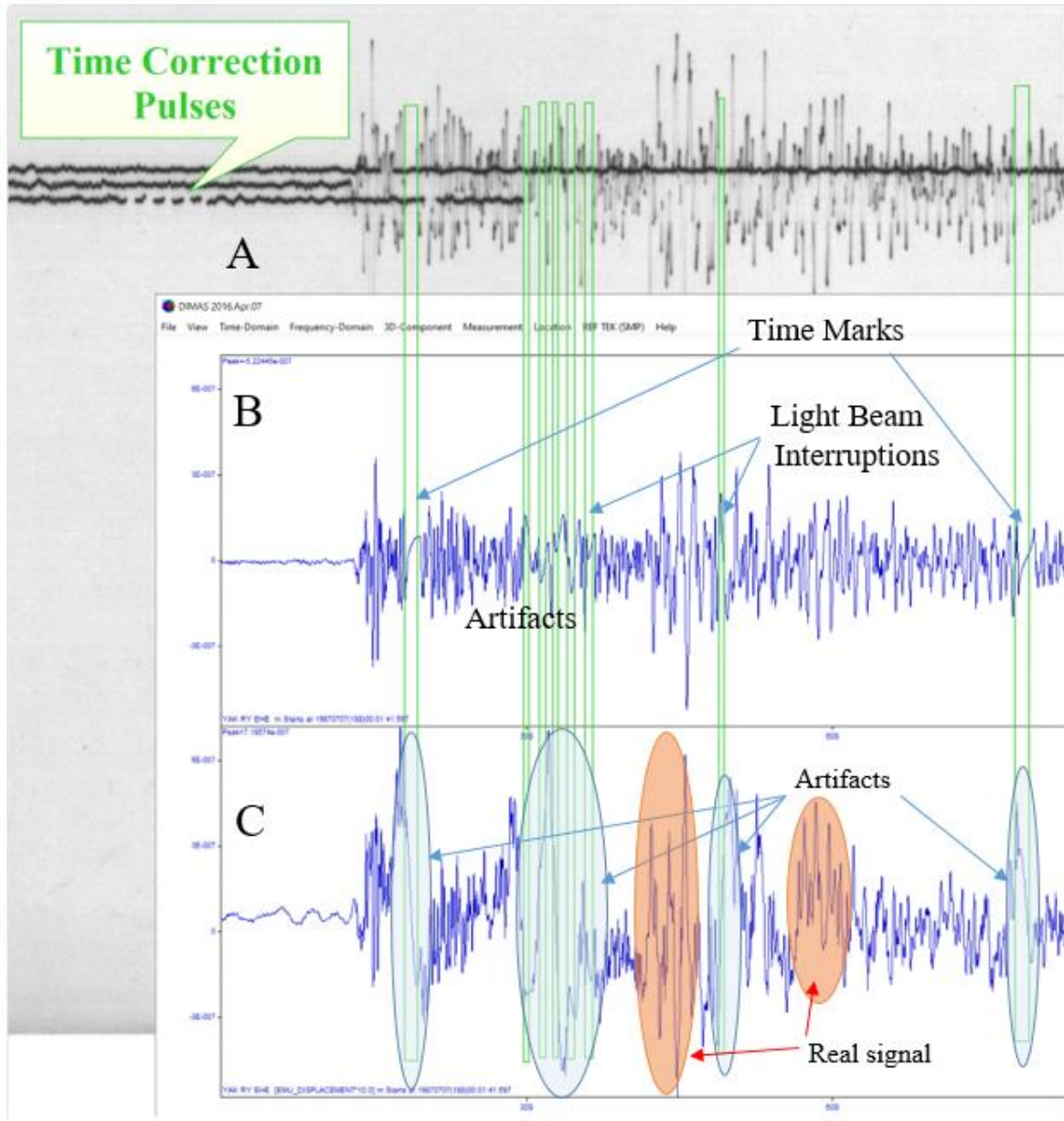


Figure 36. Seismogram illustrating the difficulty in waveform interpretation when there are interruptions in the light beam, as shown by the green boxes. Note the series of gaps are similar in character to the indicated set of time correction pulses. A – Scan of original seismogram. B – Original digitization matching scan. C. Displacement seismogram with instrument response removed with artifacts resulting from light beam interruptions (blue ovals), that can look like real seismic arrivals (red ovals).

3.2.2. Distortions due to low amplitude signals

Digitization of low amplitude seismograms also have some characteristics that result from difficulty in choosing click points that accurately represent the trace. Even with a scan resolution of 600 dpi, variation in signal amplitude may only be a few pixels wide, resulting in a difficult waveform recovery. Figure 37 shows the digitization of a long period vertical component seismogram. In this example, when the amplitude of the digital waveform is expanded, it is apparent that peaks follow along certain discrete levels, because of limited choices within the pixels. With very low amplitudes, they become apparent even when using a 600 dpi scan. The plane of distorted peaks may be parallel to the time axis, or it may be angled, which results when the amplitude of the pixels representing the waveform are not orientated exactly perpendicular to the horizontal axis of the scanned image (Figure 37). The apparent discretization is masked when the waveforms are instrument corrected, or filtered, and it does not seem to significantly affect PSD plots of the waveforms.

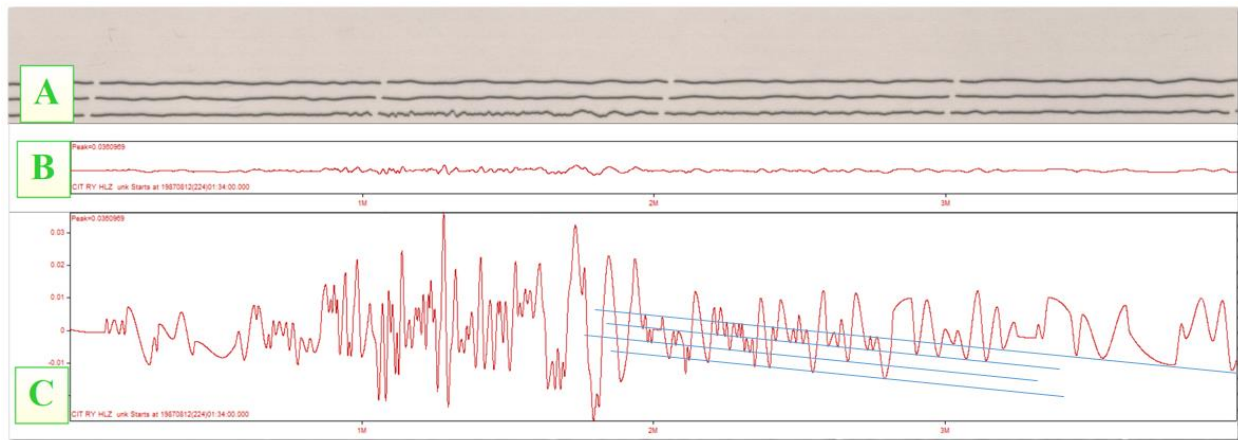


Figure 37. Scan and digitization of a low amplitude vertical component long-period seismogram. A – 600 dpi scan of the seismogram where maximum amplitude is only a few pixels tall. B – Original digitization matching the waveform from the scan. C – Amplified version of the original digitization. Note the apparent signal degradation of waveform when digitizing a very low amplitude signal. Blue lines denote the discretization of peaks corresponding to pixels from the scanned seismogram image.

4. ESTABLISHMENT OF THE GT CALIBRATION EXPLOSION WORKING GROUP

Seismologists work to understand the tectonic setting of the world. The necessary tasks of the work include an understanding of active faulting and where earthquakes occur, measurements of the size of earthquakes, the evaluation of seismic hazards, the ability to discriminate between earthquakes and explosions, etc. These goals can be achieved through collaboration and the conduction and use of regional seismic calibration experiments. In this project, MSU, working with the International Science and Technology Center (ISTC) hosted a workshop titled “Seismic Calibration Events in Eurasia: Past, Present, and Future” in Almaty, Kazakhstan, on 28-29 March 2023 (Figure 38).

The workshop was hosted by Dr. Kevin Mackey, Associate Professor at Michigan State University; Dr. Kanatbek Abdrakhmatov, Professor and President of the National Academy of Sciences of the Kyrgyz Republic, and Mr. Daniel Burk, Chief Seismological Engineer at Michigan State University. The workshop was attended by the directors and leading scientists of seismic institutions from nine different countries: Armenia, Azerbaijan, Republic of Georgia, Kazakhstan, Kyrgyzstan, Mongolia, Tajikistan, Ukraine, United States. These institutions represent diverse backgrounds from Research Universities, Ministries of Emergency Services, National Data Centers in support of CTBTO, National Seismic Research institutes, Government, and Military (Figure 39).

The goal of the workshop was to form an international coalition of institutions that advocate the advancement of seismic calibration events throughout the region, with the goal of improving network accuracy when locating and classifying seismic events.

Traditionally, seismology has been one of the more ‘open’ scientific fields, with data shared between organizations and countries without restrictions. Unfortunately, this is not always the case among the independent states of the former Soviet Union. Since the break-up of the Soviet Union, the scientific communities of the former republics have become more isolated and seismological capability and exchange has suffered. MSU began seismological research in the Soviet Union in the 1980s. Over the past decades, MSU has worked to build and facilitate collaboration between the now independent seismological networks in the region. Along this line, the workshop created a common theme for the efforts and participation of multiple countries. At the conclusion of the workshop, a Protocol of Intent was jointly drafted to facilitate future seismic calibration experiments (Appendix G). Although the current political climate in the region may preclude an active large calibration explosion, there is a significant amount of legacy explosion data held in the regional archives that can be utilized to improve the regional calibration.



Figure 38. Screenshot from the workshop titled “Seismic Calibration Events in Eurasia: Past, Present, and Future” held in Almaty, Kazakhstan, on 28-29 March 2023



Dana Mubarakova, ISTC, Kazakhstan, Chimed Odonbaatar, Mongolian National Data Center, Josh Stachnik, Lehigh University, USA, Olexandr Haniiev, Subbotin Institute of Geophysics, Ukraine, Kanatbek Abdrakhmatov, Academy of Sciences, Kyrgyz Republic, Hektor Babayan, Institute of Geology, Armenia, Daniel Burk, Michigan State University, USA, Biembet Ashimov, Seismological Expedition, Kazakhstan MES, Tea Godoladze, Ilia State University, Republic of Georgia, Natalia Mikhailova, KNDC, Kazakhstan, Irina Aristova, KNDC, Kazakhstan, John Nabelek, Oregon State University, USA, Albert Buzaladze, Ilia State University, Republic of Georgia, Anna Berezina, Institute of seismology, Kyrgyz Republic, Natalia Silicheva, Institute of Seismology, Kazakhstan, Aidyn Muikambayev, KNDC, Kazakhstan, Aizhan Zhunosova, Seismological Expedition, Kazakhstan MES, Evgeniy Kozakov, KNDC, Kazakhstan, Ruslan Gashimov, Seismological Expedition, Kazakhstan MES, Sabina Kazimova, Republican Seismological Survey, Azerbaijan, Viktor Shaytorov, KNDC, Kazakhstan, Pulod Aminzoda, Institute of Geology, Earthquake Engineering, and Seismology Tajikistan.

Figure 39. Names and organizations of participants (L to R) at the workshop titled “Seismic Calibration Events in Eurasia: Past, Present, and Future” held in Almaty, Kazakhstan, on 28-29 March 2023.

5. ENGAGEMENT IN UZBEKISTAN

5.1. Introduction

Uzbekistan has historically had few regional connections with the seismological community. One task in this project was to engage with the seismologists in Uzbekistan to develop cooperation with the goal of assisting them with developing their seismological networks and increasing regional and global collaborations. To this end, we visited and engaged with Uzbekistan within the scope of this project.

5.1.1. National University of Uzbekistan

We met with the Department of Geosciences at the National University of Uzbekistan (NUU) in Tashkent. They are eager to increase their international collaboration between universities. They specifically requested a cooperative agreement and requested assistance with the deployment of a teaching seismic station at their university. We visited the NUU geological field camp base as a potential station site and found it to be acceptable. From an understanding of the NUU needs, MSU will continue this effort under the auspices of the Seismic Cooperation Program (SCP) of DoE/NNSA NA-243 as that program is in good alignment.

5.1.2. Ministry of Emergency Situations

MSU also engaged with the Uzbekistan Ministry of Emergency Situations (MES), who operates the national seismological network. Through a DoS project, the Incorporated Research Institutions in Seismology (IRIS) is coordinating with the ESTH office at the US Embassy in Tashkent and the MES to install a broadband seismic station at Karasai. MSU was asked to provide an evaluation of the station site and existing infrastructure, as well as verify tunnel measurements and conditions. The general tasks are:

- Provide an opinion as to utilization of the wagon on site for recording equipment.
- Evaluate the distance to the nearest fiber optic line.
- Evaluate the presence and location of water in the tunnel.
- Evaluate and measure the long tunnel that branches to the left.
- Verify distance from the tunnel entrance to the sensor site.
- Review the overall site and comment.

5.1.2.1 Evaluation of Wagon Infrastructure at Karasai

The wagon was inspected. The wagon, or ‘Vagonchik’ is essentially an outbuilding on a skid or wheels that is towed into place for use. These are common in the Former Soviet Union as out buildings, camp housing, construction site trailers, etc. This particular wagon has been permanently mounted onto a concrete foundation.

In MSU’s opinion, the wagon is not ideal in its current state to house the recording equipment. The concrete foundation it is mounted on prevents airflow under the building. This can result in the wagon being hotter during the summer months, which would require more air conditioning to keep the building and servers inside cool. This increases the power

requirements of the installation. Secondly, the lack of airflow under the building and the linoleum floor installed in the wagon trap moisture in the wood floor. This has already caused much of the floor to rot away and the floor is not structurally sound. There are several sections that appear to have rotted away based on the observation of soft and spongy depressions in the floor. Figure 40 shows sinking floor sections that are soft, indicative of rot. One source of the incoming water may be the adjacent window, as evidenced by water stains on the wall below the window and on the baseboard. This may also indicate rot in the wall compromising its integrity as well. Although MES indicated that the wagon could be rebuilt, our experience is that such repairs are often more work than anticipated.



Figure 40. Left – Overview of the wagon building. The tunnel entrance is behind the wagon and under the solar panels. Right - Evidence of water ingress and rot in the collapsing floor of the wagon.

5.1.2.2. Internet/Data availability

Fiber optic cable is available at the site. From the vicinity of the main road until a few hundred meters from the station site, the cable is buried. Closer to the station it is strung between utility poles. The fiber connects to the Wagon and subsequently enters the tunnel. It extends to the first alcove on the left where the MES short period station is operating. Figures 41-43 below provide detail on the fiber optic line.



Figure 41. Fiber optic cable entering the tunnel. The red arrow shows the line. The blue arrow shows an undesirable sharp bend in the cable.



Figure 42. Close-up of the fiber cable with identification markings. The cable appears to read 'CPC NXTCS -6B1.3 (1.7 mm) 2020.08'



Figure 43. Fiber cable with junction box (left and Center) and switch (right). Cable is incoming at the bottom left of the image at right.

The measurements on the initial site plan diagram appear to be correct (Figure 44). We took measurements along the wall from the entrance to the pier marked #3 and from pier #3 to the end of the tunnel behind the pier marked #5. Fundamentally, the measurements follow the green line on this diagram.

From Pier #3 to wall behind Pier #5 = 20.7m +/- 0.2m

[illegible]

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5.1.2.4. Tunnel Discussion

For the purposes of the tunnel discussion, we used the engineering diagram below for reference (Figure 45). Note that measurements on this image are NOT all correct as metric and English units are mixed. This image is used simply for clarity to add notes.

The color scheme indicates the treatment of the tunnel walls. Yellow indicates concrete walls where formers were used (Figure 46). There is rebar in the concrete. Purple indicates walls that are encased in shotcrete (Figure 47). In most places, the ceilings of the shotcrete sections have a steel mesh imbedded and rockbolts were used. The steel mesh is often deteriorated due to rust. Note that there were no observations of any breaks in the shotcrete, places where rocks had fallen, etc., and the shotcrete and concrete appear 100% intact. The concrete and shotcrete were installed when the tunnel was built in 1985. From this observation, the tunnel appears stable and safe, though note that the MSU evaluation was not conducted by a licensed engineer who can provide a legal opinion on this.

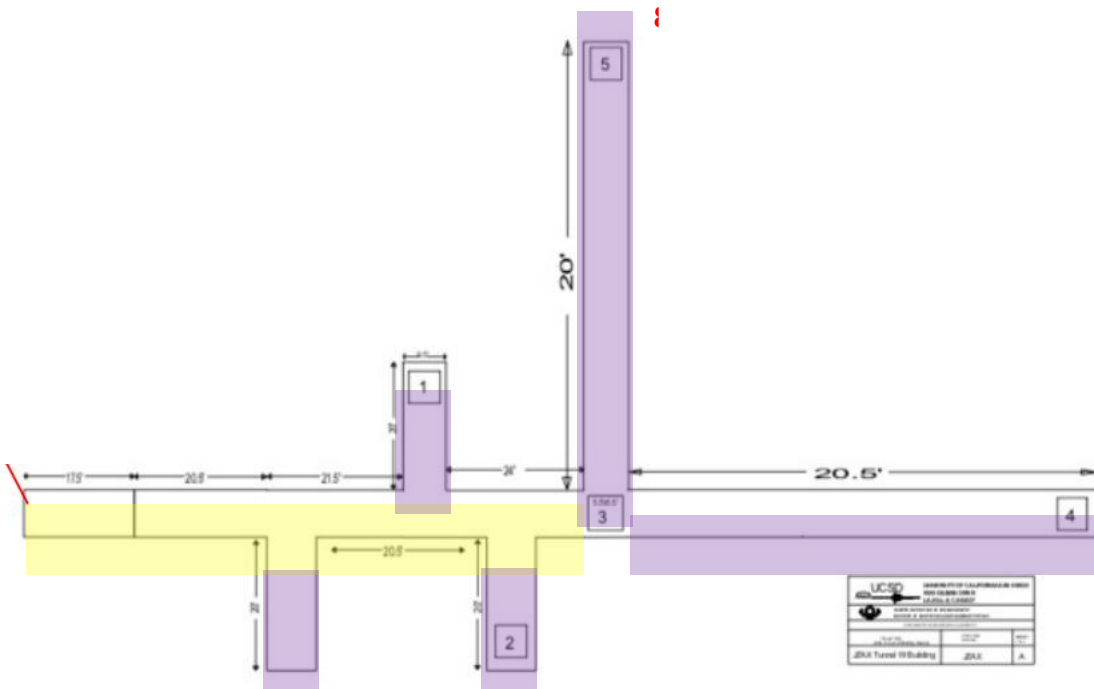


Figure 45. Engineering diagram of the tunnel. Yellow denotes tunnel sections with formed concrete walls while purple denotes areas where walls have shotcrete and wire mesh with rockbolts. Note that measurements on this diagram are NOT correct. Numbers indicate concrete instrumentation piers and correspond with Figures 46 and 47.



Figure 46. Left – Looking into the tunnel from near the entrance and showing formed concrete walls. Right – The current instrument rack on the pier at point 1.



Figure 47. Left – looking down the tunnel to the pier at point 5. Right – The pier at point 5. Note the shotcrete walls and rockbolts with mesh on the ceiling.

5.1.2.5. Water Ingress

Generally, the tunnel is dry. There are areas where the floor is damp, but there is no evidence of current or previous puddles or flowing water. As the construction plan anticipates installation of concrete floor for the first several meters of the tunnel, there should be a pipe under the concrete or a trench along the side just to be safe in case there is more that water than expected. Throughout the various photos, dark areas of the floor indicate damp ground while light areas are completely dry. The extension of the tunnel to point 4 is overall dryer than the tunnel branch to the left going to point 5. There are water seeps on the wall on either side of the alcove containing pier 2 (Figure 48).



Figure 48. Water seeps on the wall to either side of the entrance to pier 2.

5.1.2.6. Conclusions

The tunnel appears to be very suitable site for the installation of a seismic station. The previous engineering plan details doors, electrical requirements, etc. and I am not fully reviewing those other than they look quite reasonable. In the tunnel, cable trays are planned to hold cabling. This is better than hanging the cables from hooks. Outside the tunnel, we suggest to clean up the wiring as it is currently hanging in rather haphazard ways.

There are bats in the tunnel (Figure 49). We suggest that a small access hole be available for them to enter the tunnel at the entrance. Such a hole is not needed at the door to the vault with the sensor.



Figure 49. A bat in the tunnel.

6. CONCLUSIONS

The majority of the world's seismograms of nuclear explosions reside on analog media such as photopaper. Since the recording of these seismograms, the technology for signal processing and seismic processing has grown by orders of magnitude. New insights and research are now possible for these collections of important signals if they are converted into digital waveforms. This project focuses on the digitization of nuclear explosions conducted at the LNTS in the Peoples Republic of China and recorded at seismic stations in the Kyrgyz Republic at regional distances (9-16 arc degrees). We have included the original seismogram scans and associated project files used for recovery and digitization of the waveform in the data delivery that accompanies this report. Clickpoint files represent a vectorized version of the waveform and are included so that future researchers may apply their own unique interpolation algorithms to the signals. A PCHIP interpolated waveform is also included in the form of both miniseed and SAC data format. We have recovered original station calibration parameters where possible and converted them into modern poles and zeros and embedded them into corresponding dataless SEED files. We include the QC document governing the digitization for each seismogram. We also have included a comprehensive series of station "passports" that gather as much information about the site as could be found, in some cases, including scans of station calibration parameters, or photographs of the installation. Converting historic analog records into research quality digital seismograms is a complex and tedious process that requires attention to innumerable details. However, the resulting waveforms represent unique travel paths for seismic energy from nuclear tests that likely will never be duplicated again.

7. ACKNOWLEDGEMENTS

We would like to thank the staff at the Institute of Seismology, Academy of Sciences of the Kyrgyz Republic in Bishkek for their generous assistance, fastidious attention to detail when digitalizing, and of course, for the access to these valuable historical seismograms.

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9. LIST OF ABBREVIATIONS

A	Atmospheric test
AS	Atmospheric at Surface test
AS	Academy of Science
AS-T	Atmospheric Tower test
A-R	Atmospheric – Rocket or Missile test
cm	centimeter
CTBTO	Comprehensive Nuclear-Test-Ban Treaty Organization
CSE	Complex Seismological Expedition
CSS3.0	A standard format for digital seismic data
db	Decibel
DoE	Department of Energy
DoS	Department of State
dpi	Dots-Per-Inch (related to resolution of scanned images)
E	East
ESTH	Environment, Science, Technology, and Health
EW	East-West
FDSN	Federation of Digital Seismograph Networks
f_N	Normalization frequency where peak amplitude response is set to unity
FSU	Former Soviet Union
GB-4	Type of Galvanometer used in Soviet photopaper recording seismic stations
GT	Ground Truth
GMT	Greenwich Mean Time
G_d	Galvanometer damping ratio
G_s	Galvanometer Free Period
GSN	Global Seismic Network
Hz	Hertz
IDA	International Deployment of Accelerometers
IMS	International Monitoring System
IPE	Institute of the Physics of the Earth
IRIS	Incorporated Research Institutions in Seismology
ISC	International Seismological Centre
ISKR	Institute of Seismology, Academy of Science of the Kyrgyz Republic
ISTC	International Science and Technology Centre
km	kilometer
km ²	square kilometers
KNDC	Kazakhstan National Data Center
KNET	Kyrgyz Seismic Telemetry Network (contemporary)
KSE	Type of short period seismometer
KRNET	Kyrgyz Republic Digital Network (contemporary)
K	Thousand
kt	kiloton
LN	Lop Nor

LN-A	Lop Nor, area A
LN-B	Lop Nor, area B
LN-C	Lop Nor, area C
LN-D	Lop Nor, area D
LNTS	Lop Not Test Site
m	meter
M	Magnitude (generic)
MES	Ministry of Emergency Situations
mm	millimeter
MSU	Michigan State University
Mt	Megaton
N	North
NIST	National Institute of Standards and Technology
NNC	National Nuclear Center
NNSA	National Nuclear Security Agency
NORSAR	Norwegian Seismological Service
NS	North-South
PNE	Peaceful Nuclear Explosion
PRC	People's Republic of China
RK	Republic of Kazakhstan
RS RAS	Research Station of the Russian Academy of Sciences
s	second
S_c	Sensitivity constant
SAC	Seismic Analysis Code
SGKD	Horizontal component SKD
SGKM-3	Horizontal component SKM-3
SK	Type of intermediate period seismometer with $T_0=12.5$ s
SKD	Type of long period seismometer
SKD-1	Configuration of SKD with $T_0=20$ s
SKD-2	Configuration of SKD with $T_0=25$ s
SKM-3	Type of short period seismometer
SNR	Signal to Noise Ratio
SP	Short Period
sps	Samples per Second
STS	Semipalatinsk Test Site
STS-1	Streckeisen broadband seismometer
SVKD	Vertical component SKD
SVKM-3	Vertical component SKM-3
T	Period
T_d	Seismometer damping ratio
T_s	Seismometer free period
UG	Underground
UG-S	Underground in Shaft test
UG-T	Underground in Tunnel test

USA	United States of America
UTC	Coordinated Universal Time
USSR	Union of Soviet Socialist Republics
v_o	Magnification ratio
V_m	Velocity amplification
Y	Yield
Z	Vertical
σ^2	Coupling Coefficient

10. APPENDICES

APPENDIX A. LOP NOR EVENT OVERVIEWS REPRESENTED BY THIS LIBRARY

A1. Introduction

The tests at the LNTS (Table 2) occurred within 18 arc degrees of the analog stations found within the territory of the Kyrgyz Republic. Of these events, the library contains digitalized waveforms from 28 of the 45 named tests, as well as two PNEs from Kazakhstan. Many additional seismograms were found in the archive, however the initial digitizations completed here focused on the higher quality records of those that were available. Some issues from non-digitized seismograms include lack of signal in the seismogram, station outage, or seismogram contrast/quality. The station coverage for these events range from one to over twenty stations (Table 3). This appendix provides representative graphical snapshots of each event found within this library to assist with selection of research events, though not all digitized components are shown.

This library also includes several digitalized signals from the Soviet PNEs Manglyshak-2 and Azgir-A-4 and these are included in the following pages in the proper chronological sequence relative to the Lop Nor tests.

A2. Lop Nor Event Overviews

The following event overviews are quick, one-page summaries of the events found within the library. Each one contains a single screenshot of the event, encompassing a good portion of the event. It may show the representative shape of the waveforms, but does not, with very few exceptions, “zoom” in to show the waveforms in detail. In some cases, some commentary has been included during the initial inspection of the time-history data, detailing how the author attempted to enhance signal clarity. Any filters applied to the waveform are described, along with any unique features observed during the initial analysis.

A2.1. CHIC03: 09 MAY 1966 – Event Overview

One station (PRZ) represents this event. Very low SNR. Try bandpass filtering 0.125 Hz to 2.5 Hz. Signal uncertainty is compromised by low amplitude.

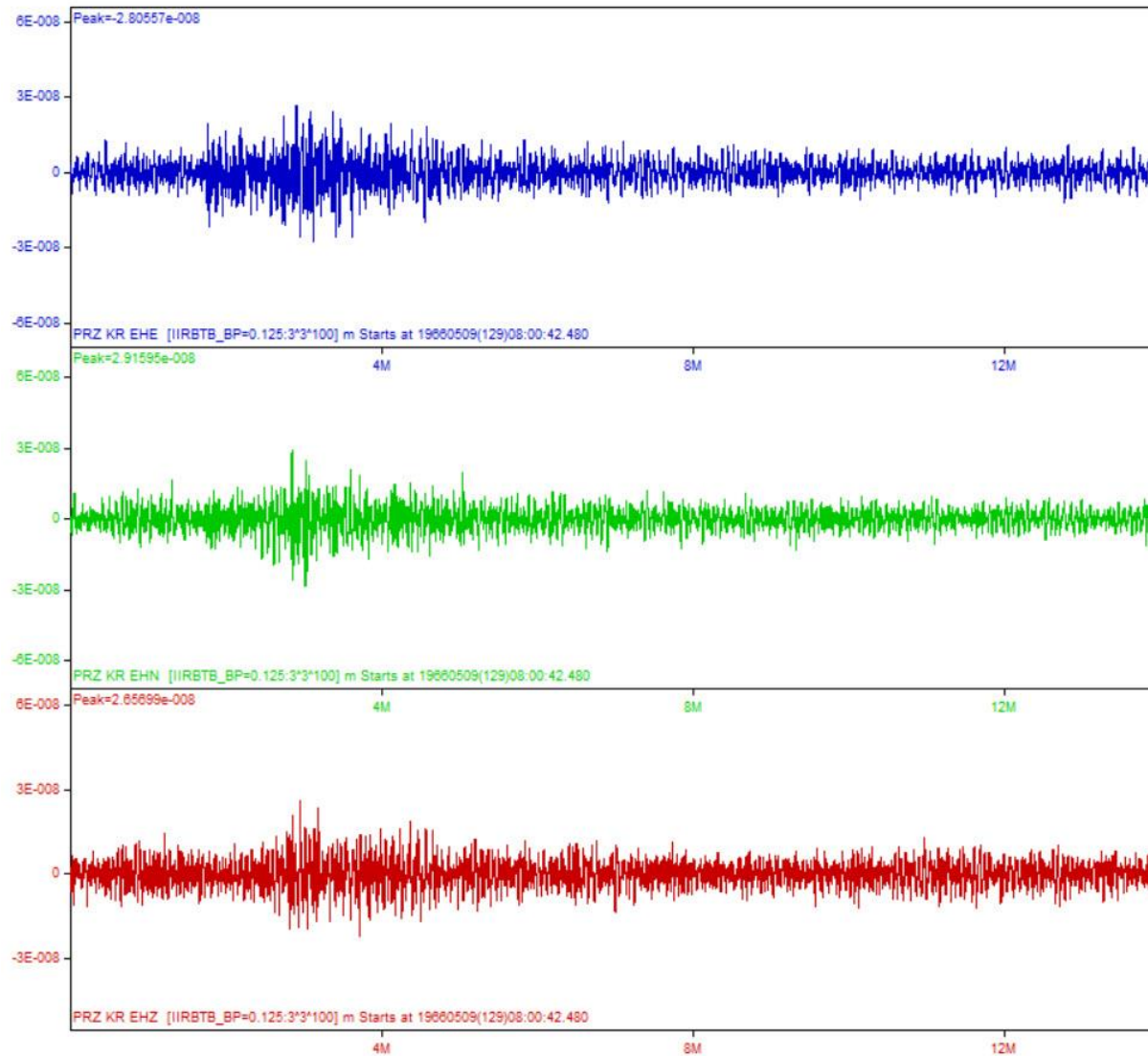


Figure A-1. CHIC03 Event overview. Station PRZ with a 0.125 - 3 Hz band pass filter applied is displayed. Local scaling per channel is shown.

A2.2. CHIC05 28 DEC 1966 – Event Overview

One Station (FRU) represents this event. Very low SNR. Try bandpass filtering 0.125 Hz to 3 Hz. Signal uncertainty is compromised by low amplitude. Quality Control document states that the station was “recording against the background of strong urban noise.”

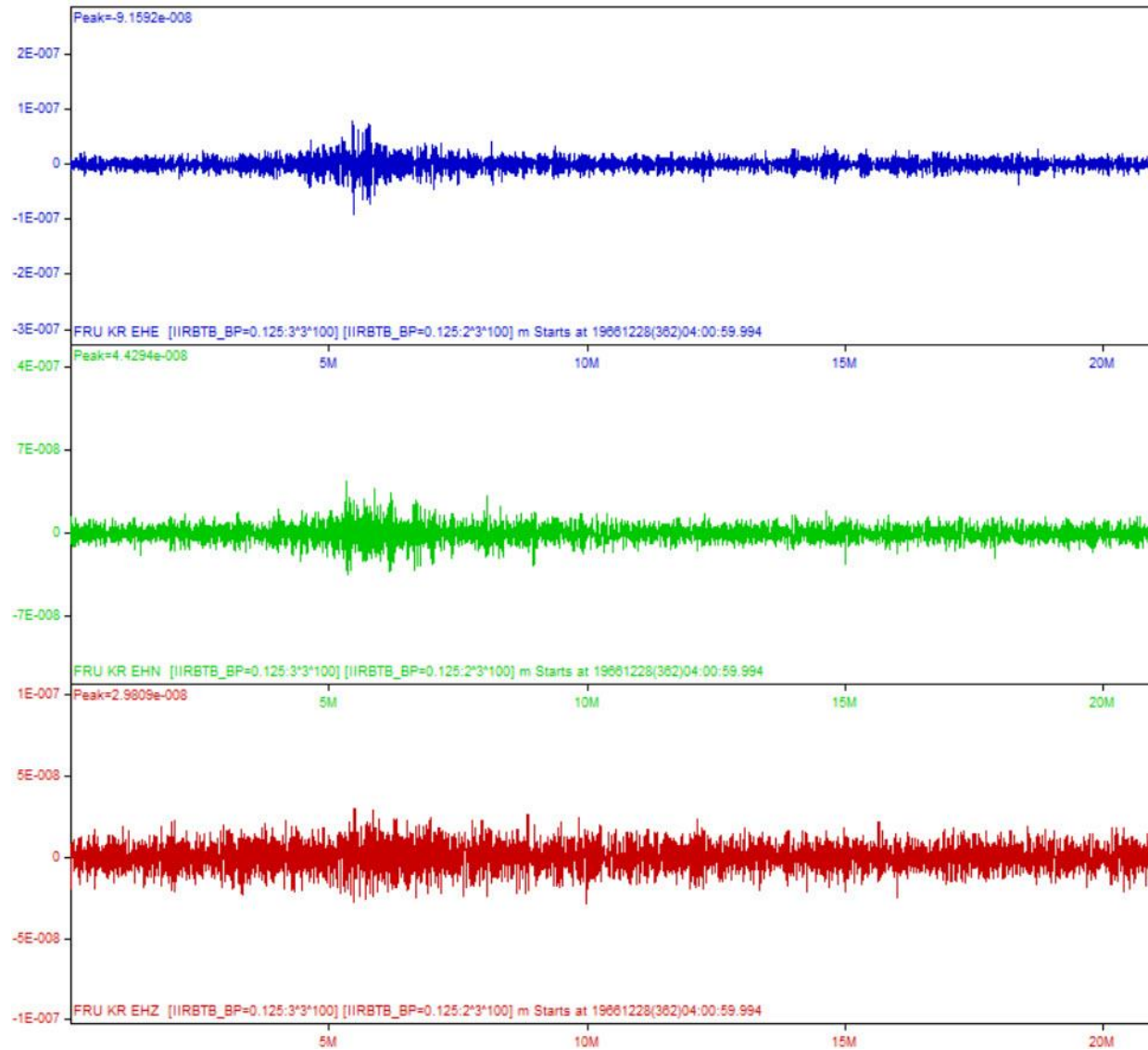


Figure A-2. CHIC05 Event Overview. Station FRU with a 0.125 – 3 Hz, 3-pole Butterworth bidirectional filter applied. Local scaling per channel is shown.

A2.3. CHIC06: 17 JUN 1967 – Event Overview

One Station (NRN) represents this event. This is a long-period SKD seismogram. Highly emergent arrival, it is difficult to catch the start time at 00 hours, 21 minutes. High-pass filter at 0.033 Hz to remove DC offsets.

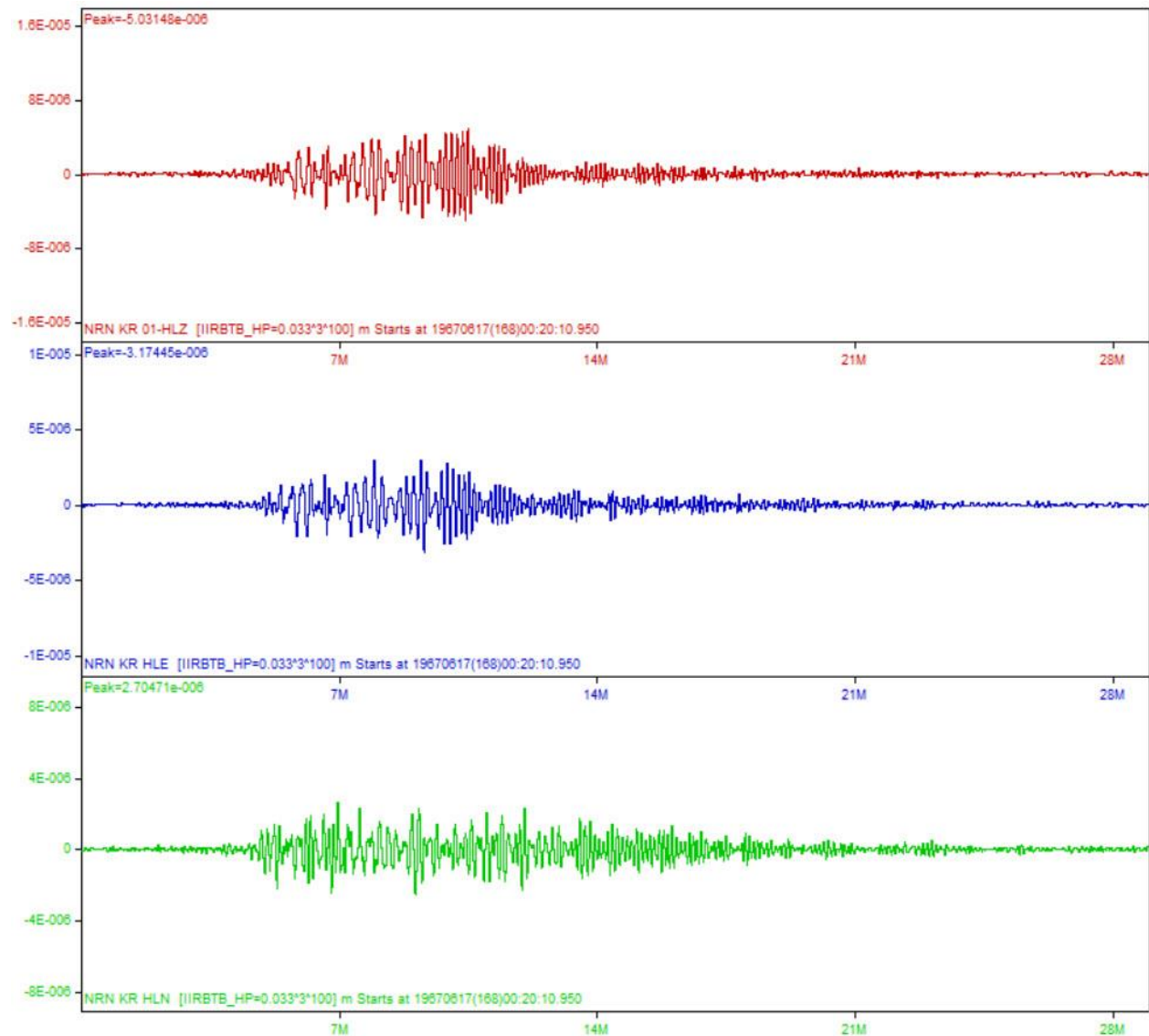


Figure A-3. CHIC06 Event Overview. Station NRN SKD long-period records with 0.033 Hz high-pass filter applied to correct offsets are displayed. Local scaling per channel is shown.

A2.4. CHIC08: 27 DEC 1968 – Event Overview

Three Stations (FRU, NRN, PRZ) represent this event. Stations FRU and PRZ use SKD short-period seismometers whereas NRN record is long-period from the SKD instrument. As such, they have different bandwidth in regards to their response. Apply a 0.033 Hz to 5 Hz bandpass filter to the short period channels, and a 0.033 Hz high pass filter to the long period channels. Low SNR makes onset of arrival difficult to pick.

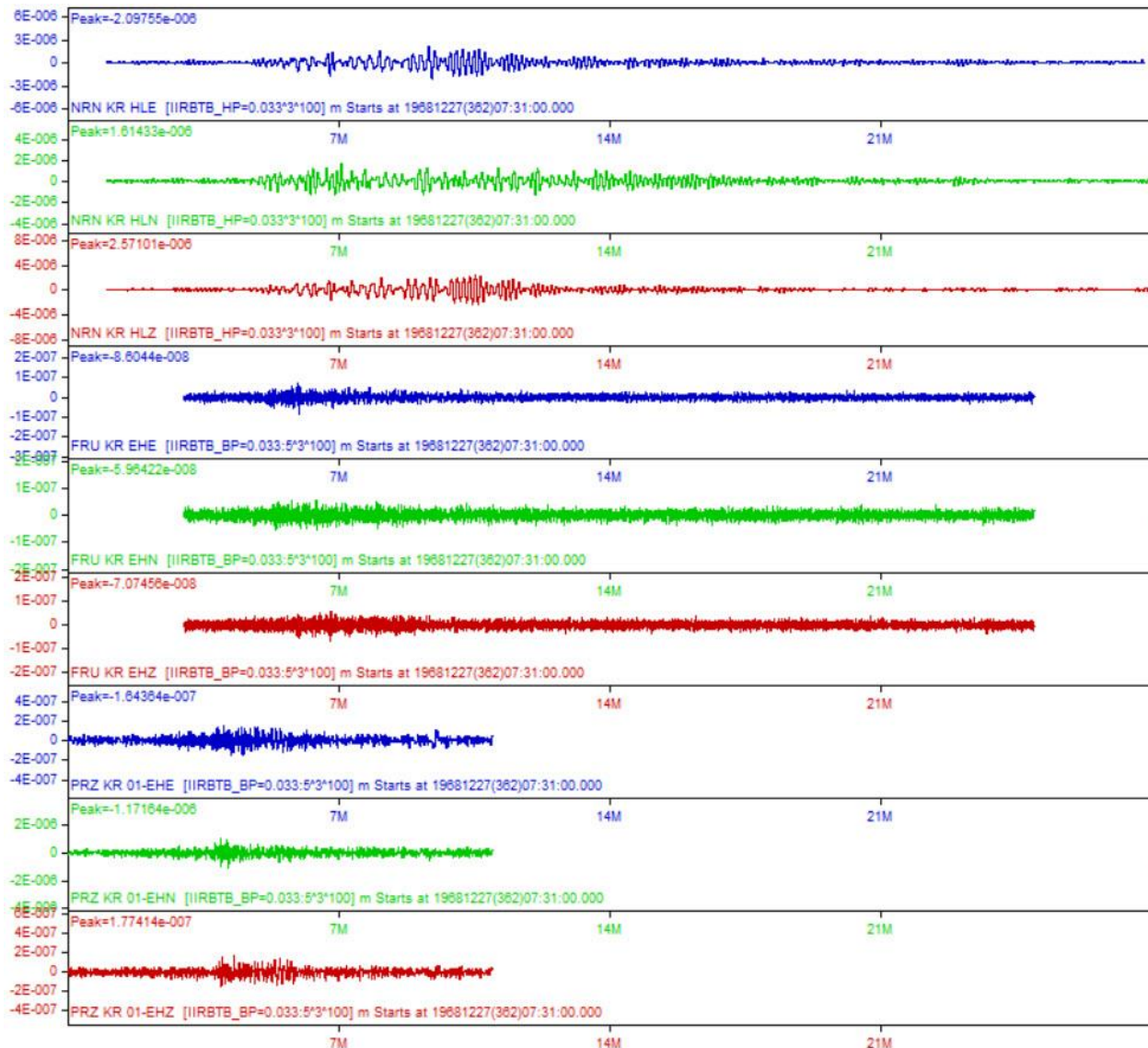


Figure A-4. CHIC08 Event Overview. Station NRN, FRU and PRZ, are shown with all components having a 0.033 Hz to 5Hz filter applied. Local scaling per channel is shown.

A2.5. CHIC11: 14 OCT 1970 – Event Overview

Two Stations (FRU, NRN) represent this event. Station FRU features a SKM short-period seismometer whereas NRN record is long-period from the SKD instrument. As such, they have different bandwidth in regards to their response. A 0.033Hz to 1 Hz band pass filter appears to provide a good compromise to urban noise in finding signal, especially on station FRU. Emergent arrivals could not be picked in the original analysis on the paper seismogram. Urban noise masks the initial arrival.

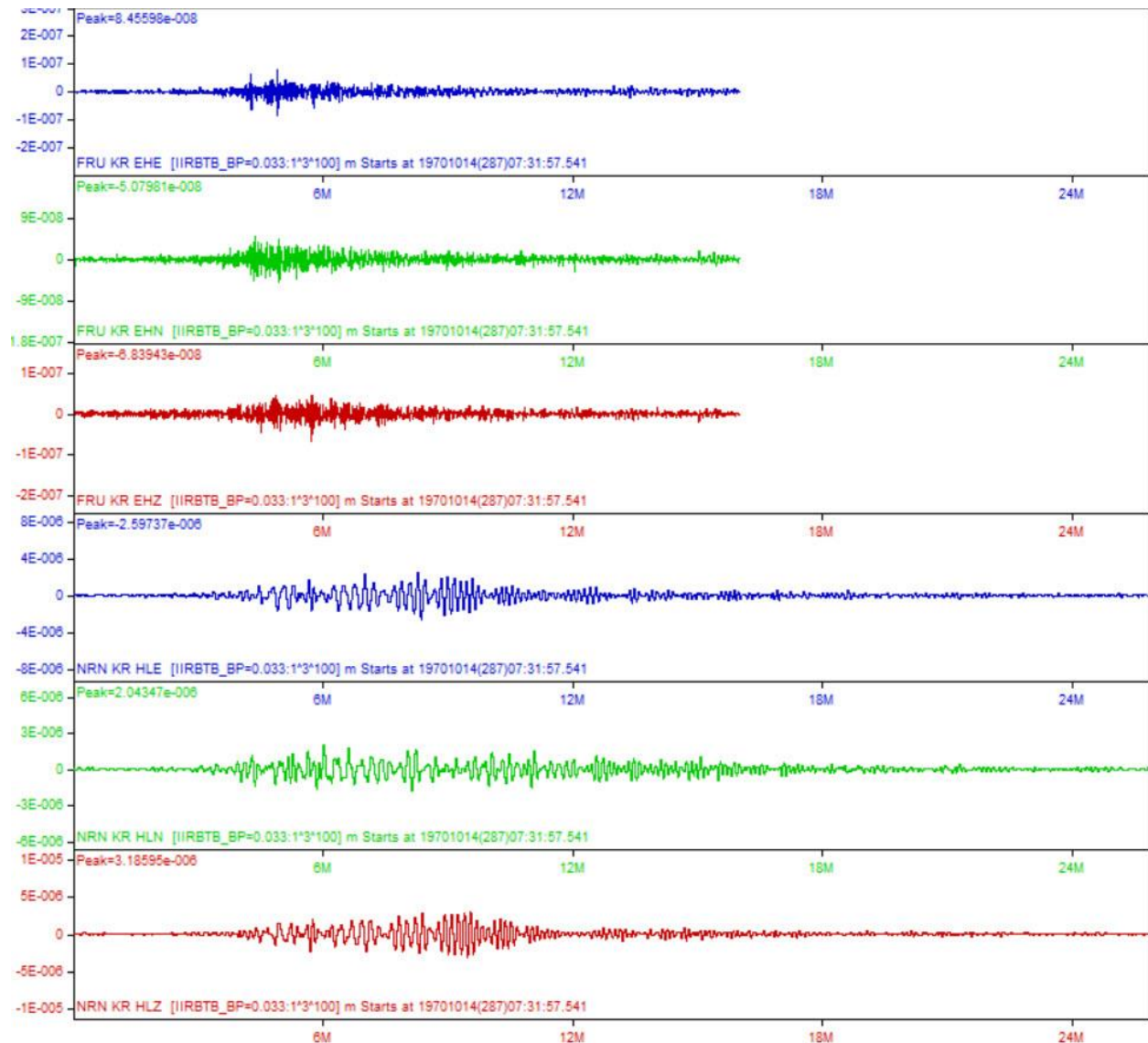


Figure A-5. CHIC11 Overview. Station FRU, NRN, All components. 0.033Hz to 1 Hz bandpass filter applied. Local scaling per channel is shown.

A2.6. Manglyshak-2: 12 DEC 1970 – Event Overview

Three stations (ARLS, NRN, PRZ) represent this event using SKD long-period seismometers. Filters are not necessary for picking start times for this event, with impulsive + arrivals at all three stations.

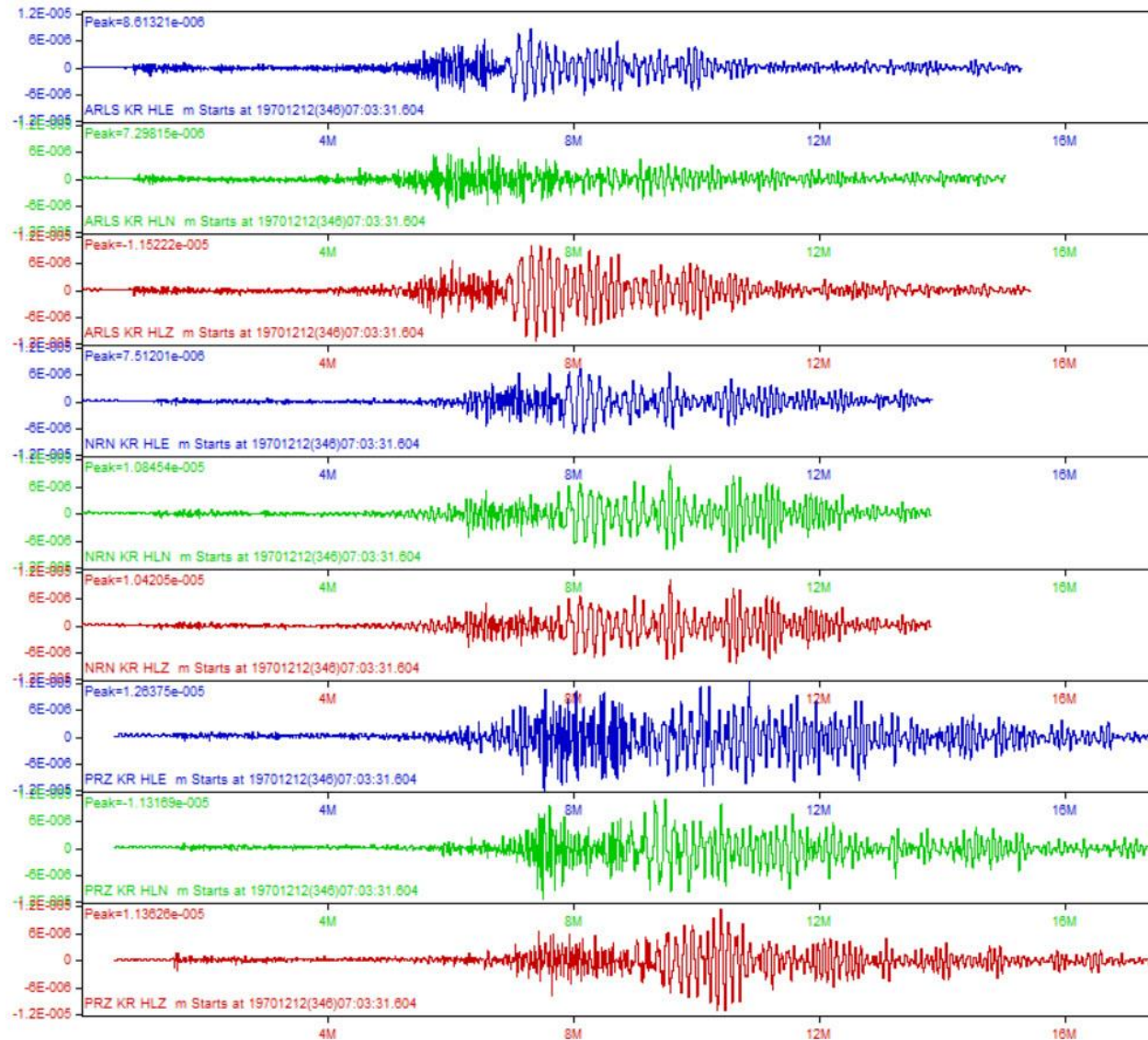


Figure A-6. Manglyshak-2 Overview. Station ARLS,NRN,PRZ, All components. No filter, Global scaling applied.

A2.7. CHIC15: 27 JUN 1973 – Event Overview

Two stations (ANVS, PRZ) represent this atmospheric detonation. Station ANVS features a SKD long-period seismometer whereas PRZ record is a short-period SKM instrument. As such, they have different bandwidth in regards to their response. A 0.033Hz to 1 Hz band pass filter enhances the fairly clear arrival on both instruments and corrects DC offsets from the paper record.

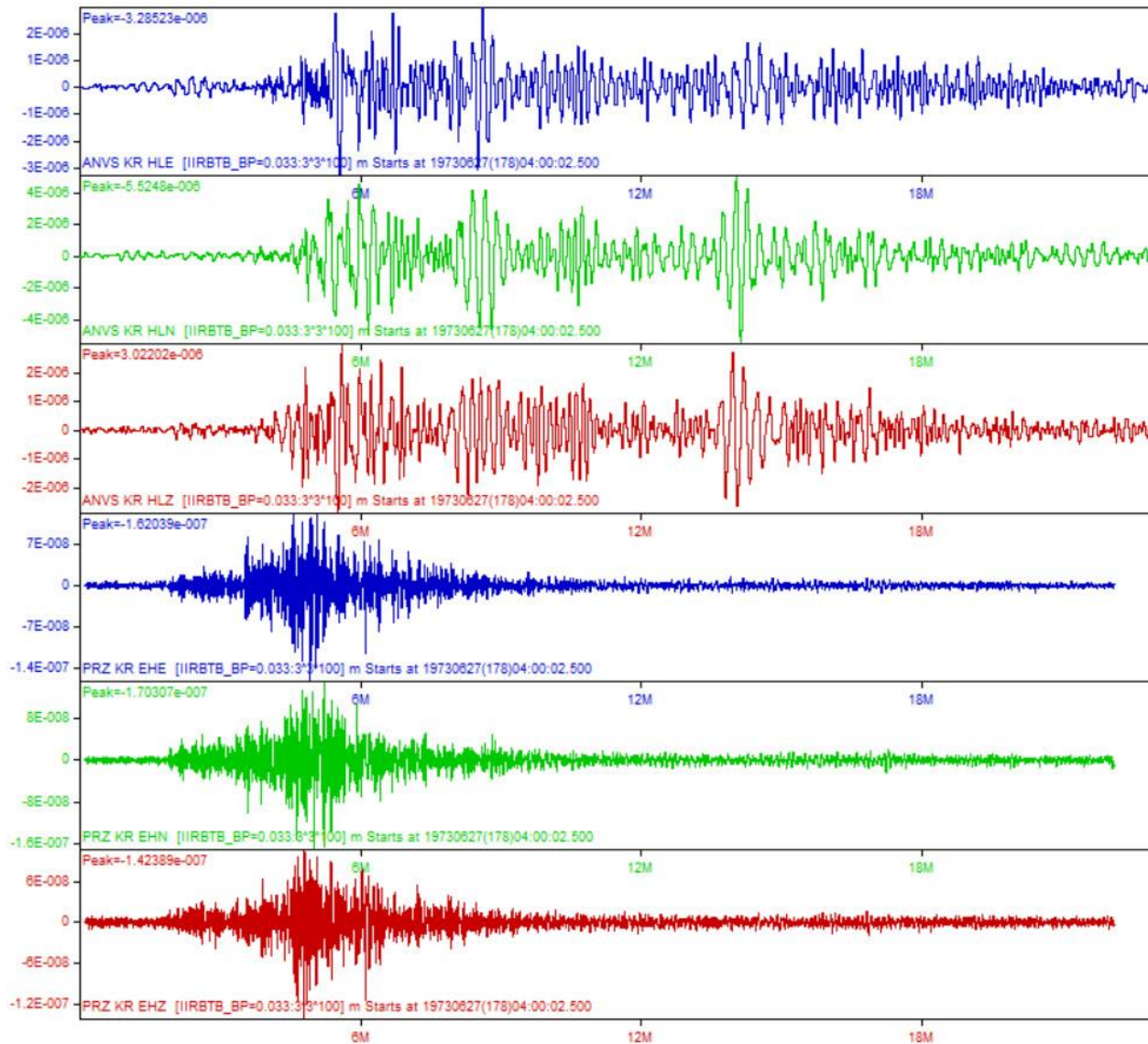


Figure A-7. CHIC15 Event overview. Stations ANVS (top), PRZ (bottom) all components. 0.033Hz to 3Hz bandpass filtered. Local scaling per channel applied.

A2.8. CHIC16: 17 JUN 1974 – Event Overview

Three stations (EKS, KDJ, PRZ) represent this event. Station EKS and KDJ feature a SKD long-period seismometer whereas PRZ record features a short-period SKM instrument. As such, they have different bandwidth in regards to their response. A 0.033Hz to 3 Hz band pass filter helps these somewhat emergent arrivals to be seen, although no pick was made in the initial paper seismogram analysis.

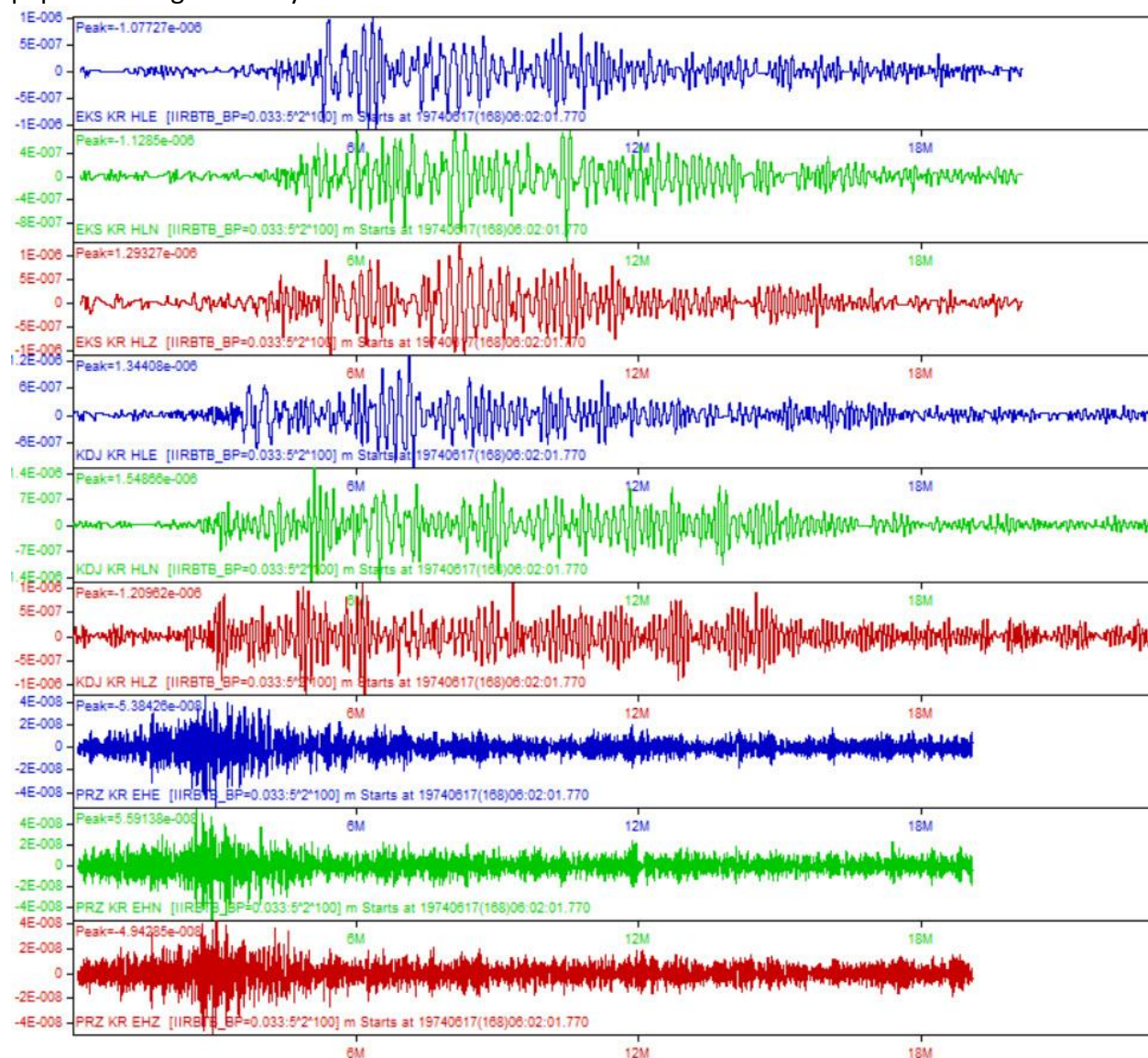


Figure A-8. CHIC16 Event Overview. Stations EKS,KDJ,PRZ, all components. 0.033 Hz to 5Hz bandpass filtered. Local scaling per channel applied.

A2.9. Azgir-A-4: 29 JUL 1976 – Event Overview

Three stations (ARK, ARLS, ANVS) represent this event. Station ARK features only the vertical component, although the other two components are present on the paper record. All three stations have good impulsive arrivals from these long-period SKD instruments.

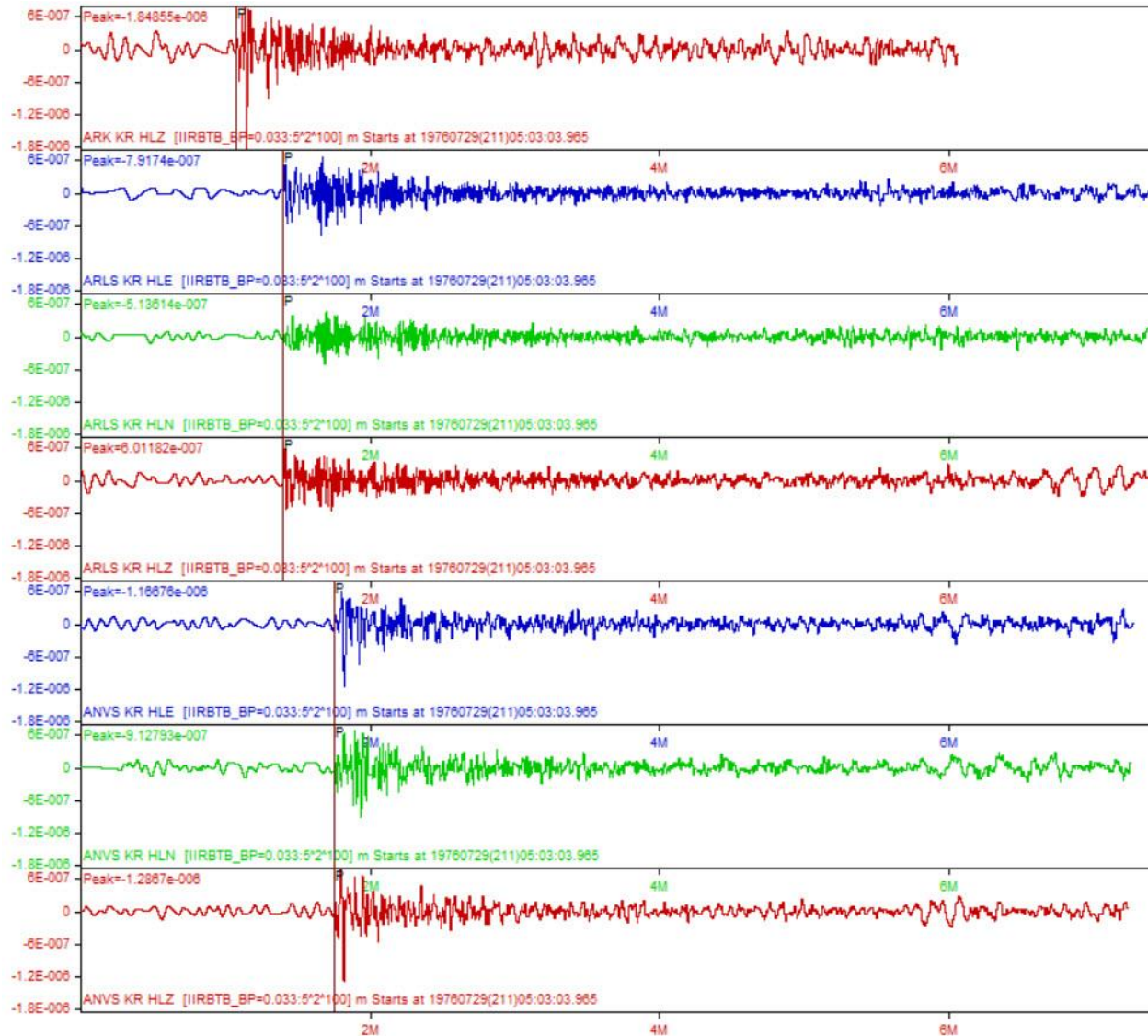


Figure A-9. Azgir-A4 Event Overview. Stations ARK, ARLS and ANVS SKD long-period shown. ARK contains only one digitized component. 0.033 – 5Hz bandpass filtered, global scaling per channel applied.

A2.10. CHIC21: 17 NOV 1976 – Event Overview

Three Stations (PRZ, KDJ, BOOM) represent this event with short-period SKM seismometers. SNR is low on this event, with emergent arrivals. No arrival picks are shown in the initial paper record analysis for these stations.

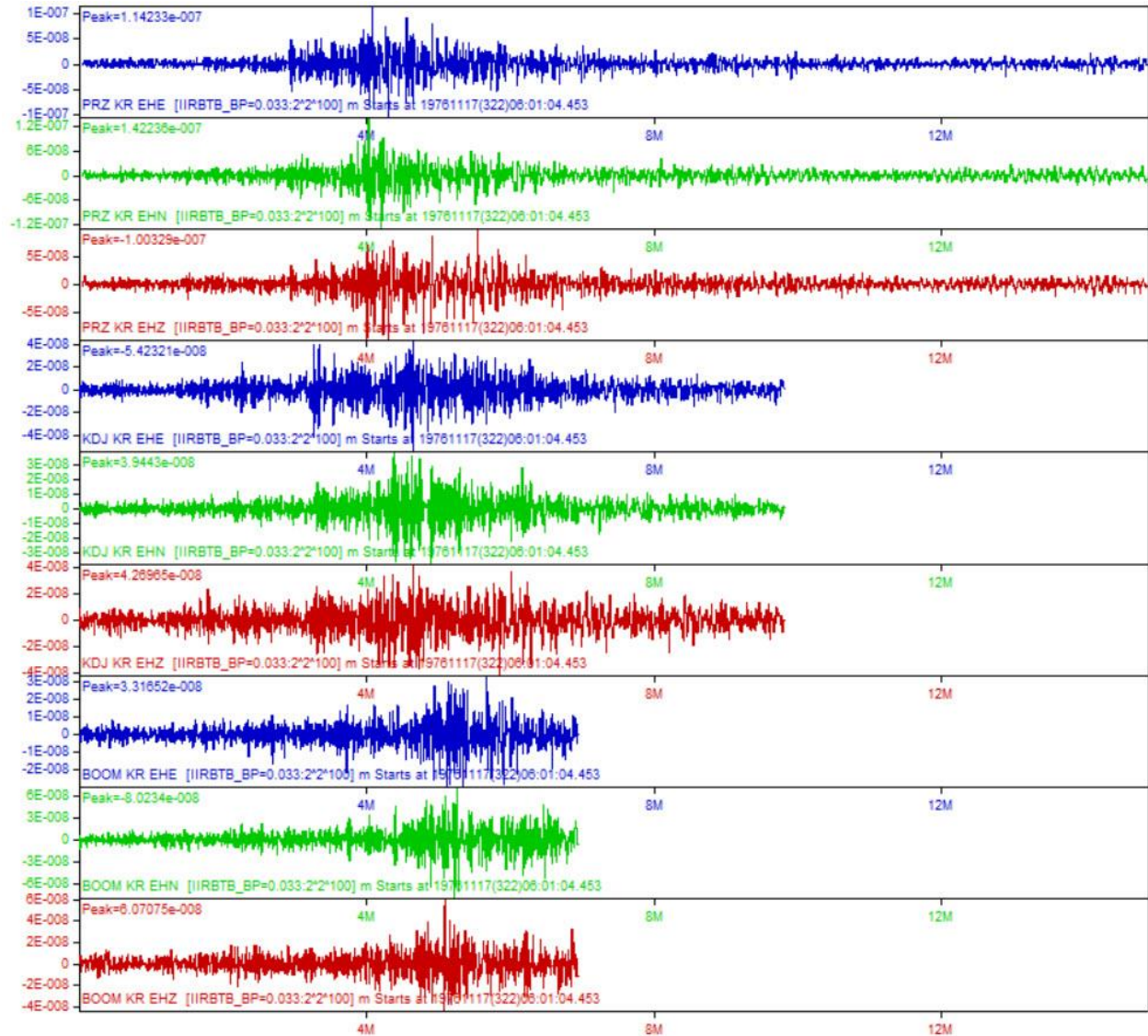


Figure A-10. CHIC21 Event Overview. Stations PRZ, KDJ and BOOM SKM short-period instruments shown. 0.033 Hz – 2 Hz bandpass filtered, local scaling per channel applied.

A2.11. CHIC24: 14 OCT 1978 – Event Overview

One station (ANVS) represents this event with a short-period SKM instrument. A very nice, clear arrival is shown with several subsequent phases.

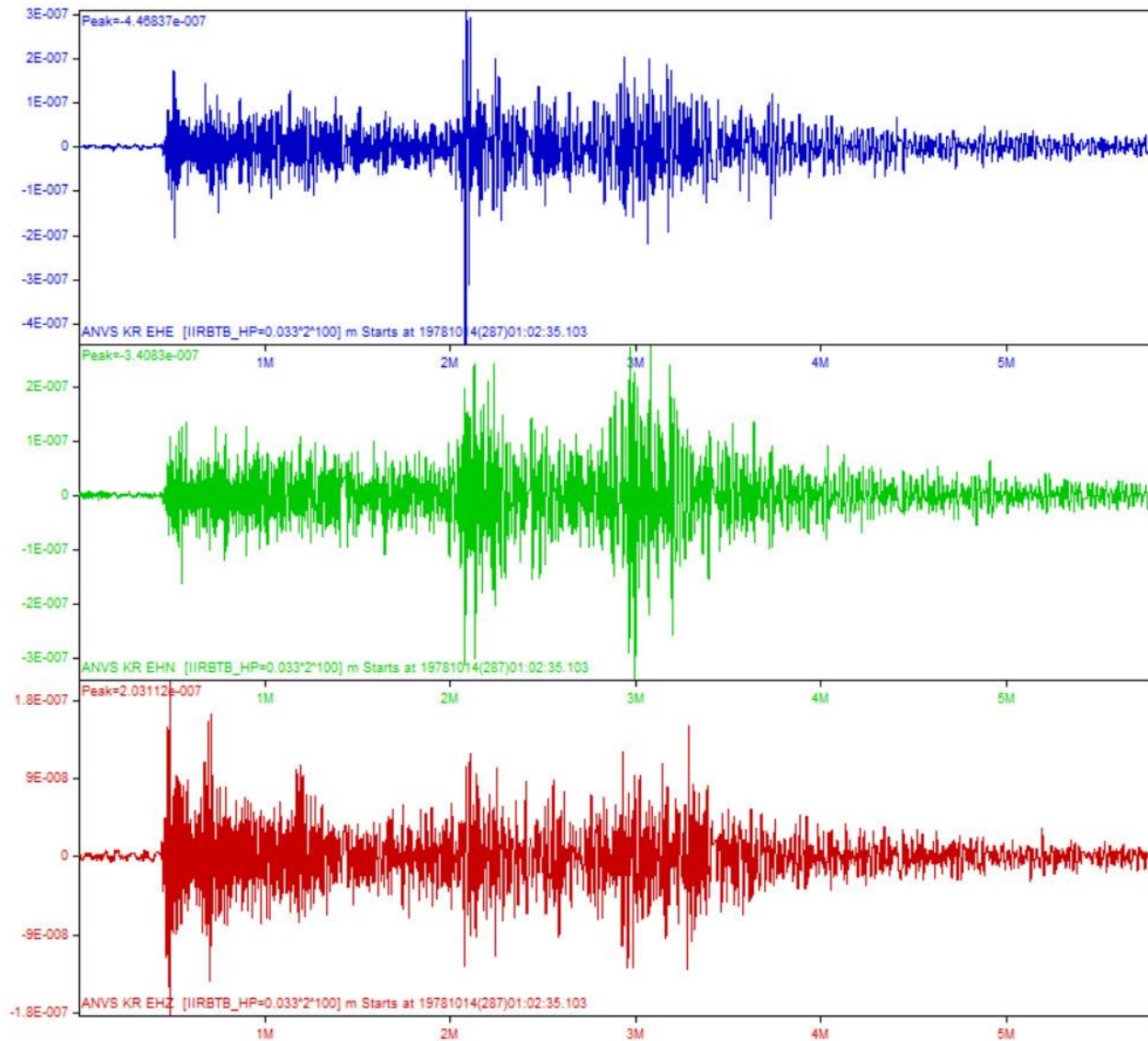


Figure A-11. CHIC24 Event Overview. Station ANVS, SKM short-period instrument. 0.033 Hz high-pass filtered, local scaling per channel applied.

A2.12. CHIC27: 16 OCT 1980 – Event Overview

One station (PRZ) represents this event with a short-period SKM instrument. The arrival is very emergent without a well-defined P, but there is significant surface wave energy. If the instrument response is removed from the signal, the surface wave energy is enhanced and visible within this digitalized signal.

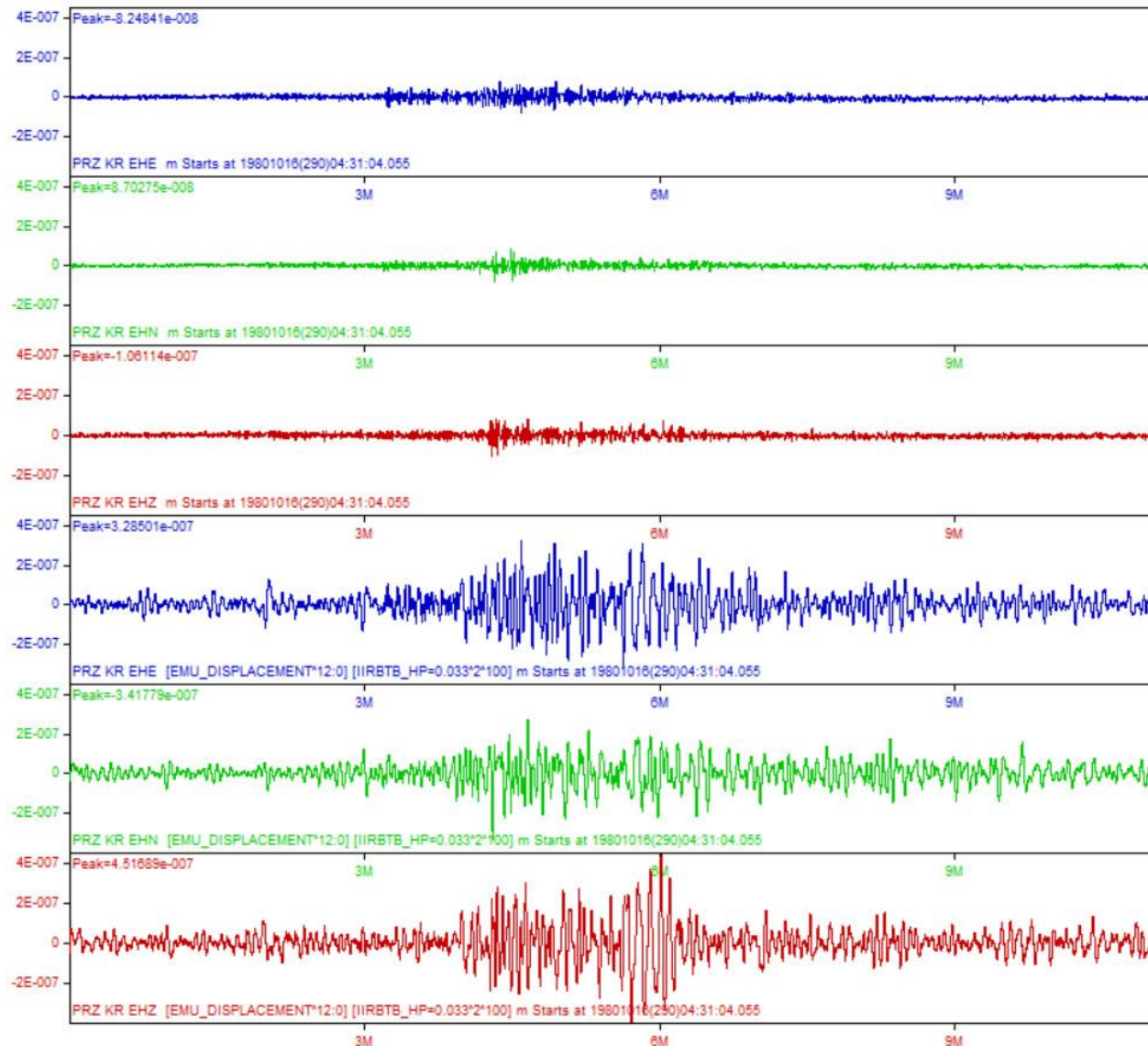


Figure A-12. CHIC27 Event Overview. Station PRZ Short-period SKM instrument. Top traces are unfiltered. Bottom traces have had instrument response removed, and 0.033Hz high-pass filtered applied, which enhances the surface wave in this digitized signal.

A2.13. CHIC28: 05 OCT 1982 – Event Overview

Seven stations represent this event, with three components each. SNR varies greatly, with impulsive arrivals on KNSU and SRDZ, to almost invisible arrivals on NRN, which require filtering to see.

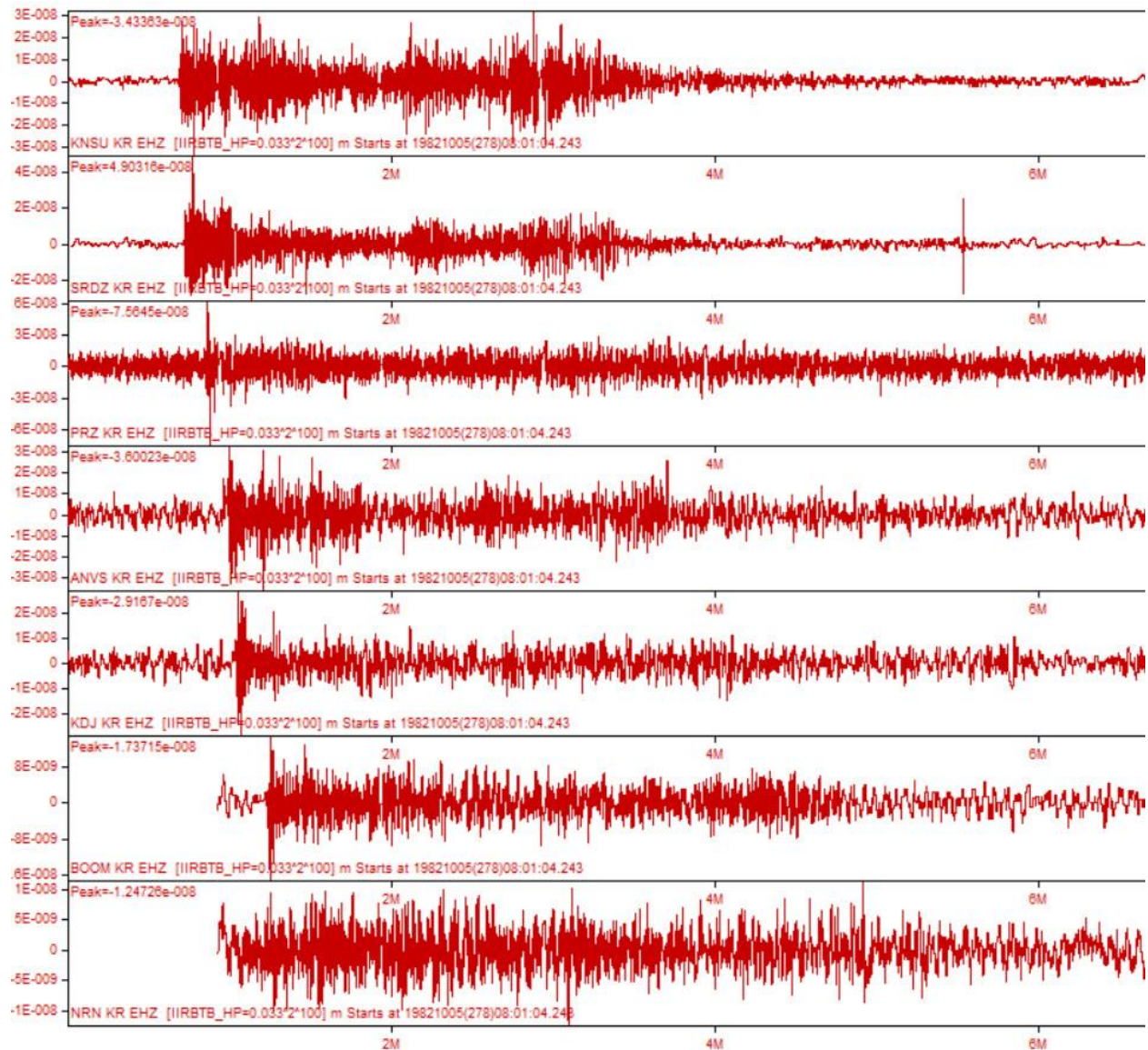


Figure A-13. CHIC28 Event Overview. 7 stations. Z axis shown. 0.033Hz high-pass filtered, local scaling per channel. Z axis components are shown on this plot.

A2.14. CHIC29: 04 MAY 1983 - Event Overview

Six stations represent this event (KNSU, DJN, PRZ, ANVS, KDJ, BOOM) with three short-period SKM components each. There is good SNR on all channels. A bandpass filter, 0.5 – 5 Hz appears to help reduce teleseismic noise.

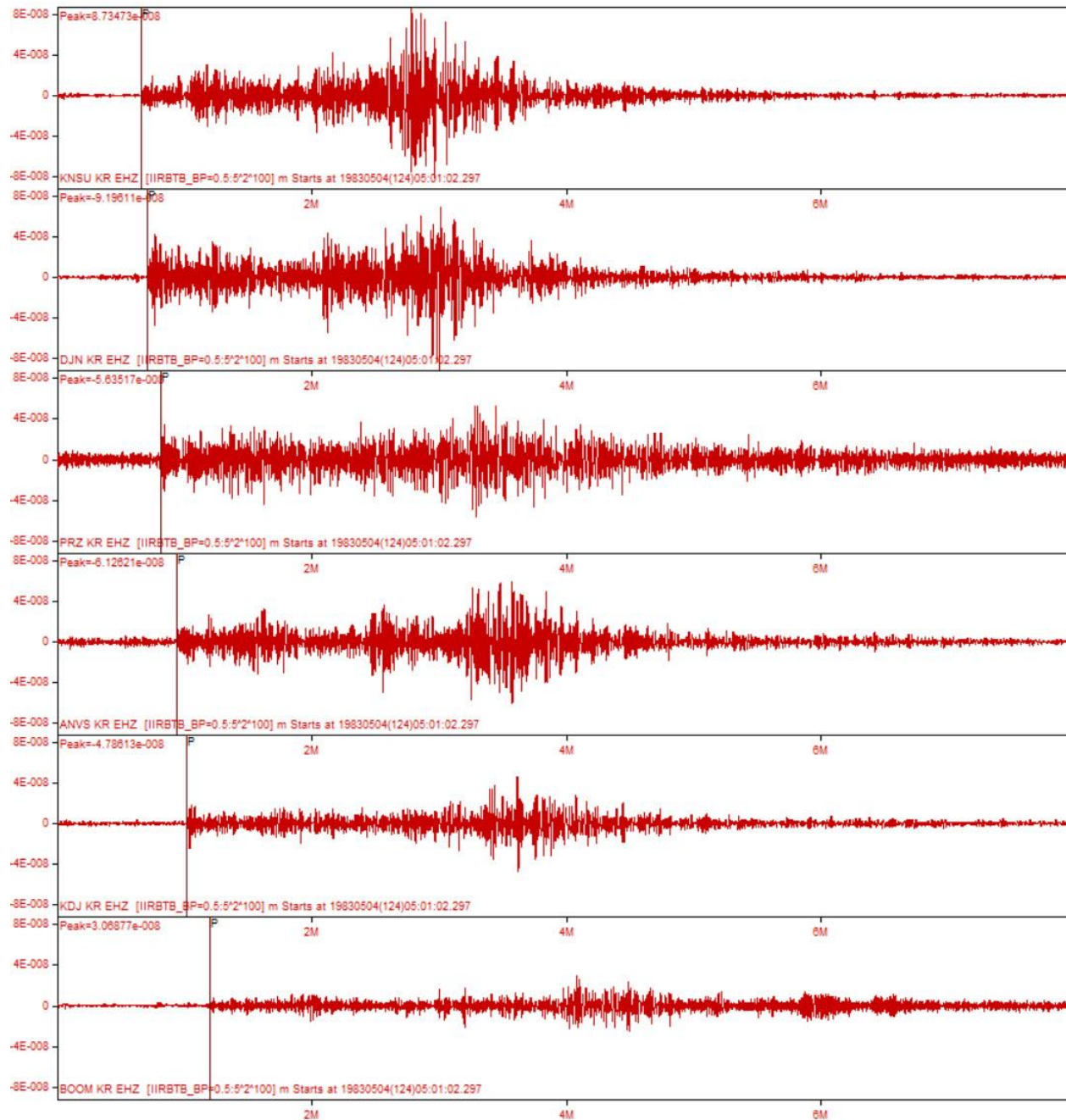


Figure A-14. CHIC29 Event Overview. Good SNR on all channels. 0.5 – 5Hz bandpass filtered. Global scaling on this plot shows consistent energy dissipation with respect to distance. Z axis components are shown on this plot.

A2.15. CHIC30: 06 OCT 1983 – Event Overview

Seven stations represent this event (ARLS, SRDZ, PRZ, SARY, BOOM, ANVS, KDJ). All seismograms have good SNR. Notes for BOOM indicate the arrival time hit on the minute mark, when there was blank signal due to the time marks. Gain for BOOM in metadata has been verified. There may be a local event superimposed over CHIC30 (Figure A.15 inset).

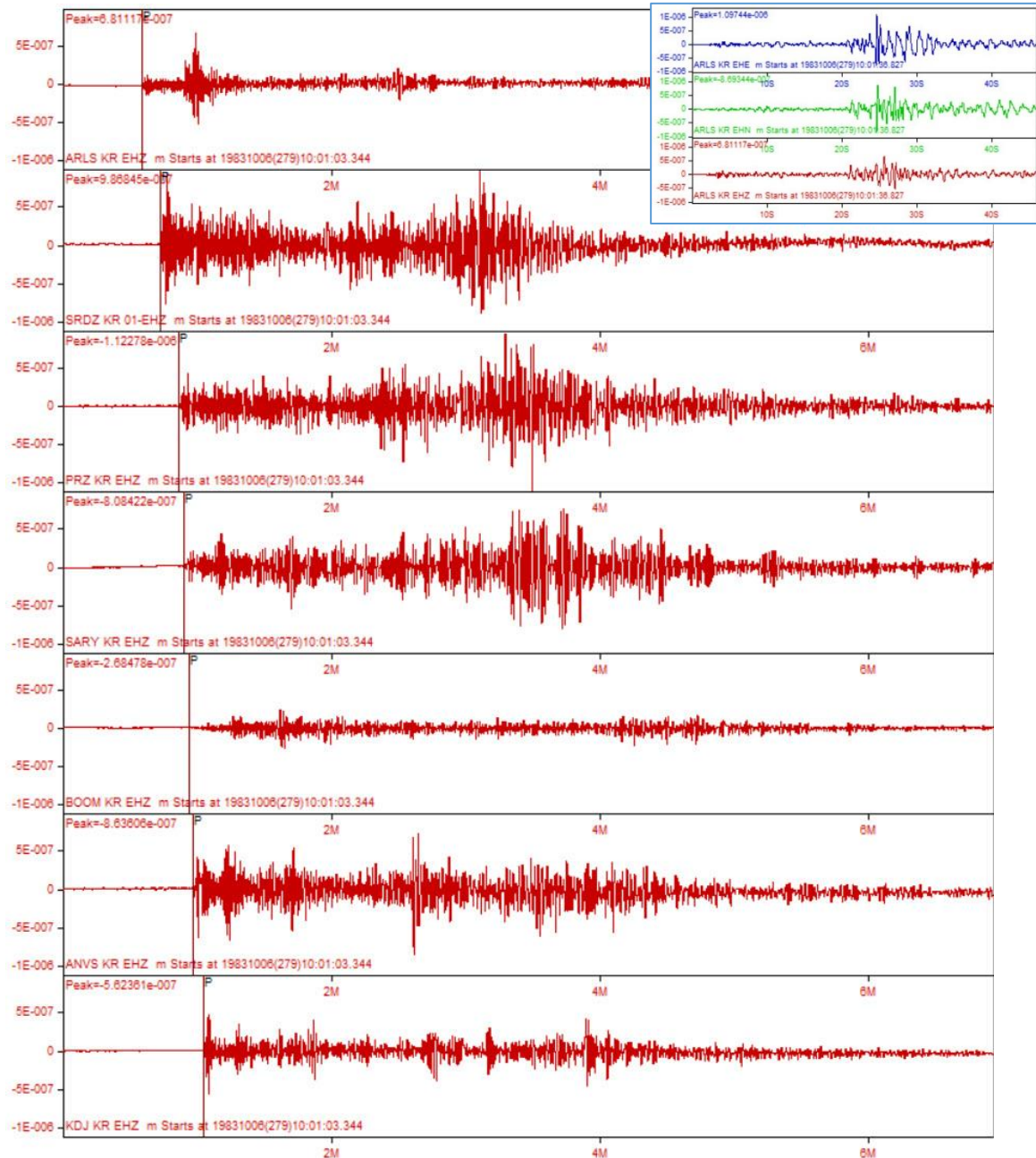


Figure A-15. CHIC30 Event Overview. Good SNR on all channels. No filtering, Global scaling on main plot. Inset of ARLS shows what may be another event superimposed over the arrival of CHIC30. Only Z-axis is shown on the main plot.

A2.16. CHIC31: 03 OCT 1984 – Event Overview

Twelve stations represent this event. All seismograms feature good SNR, and in some cases, additional phase arrivals are clear, especially on the horizontal channels. Energy dispersion is consistent with distance. DJN has its initial arrival masked by a timing mark.

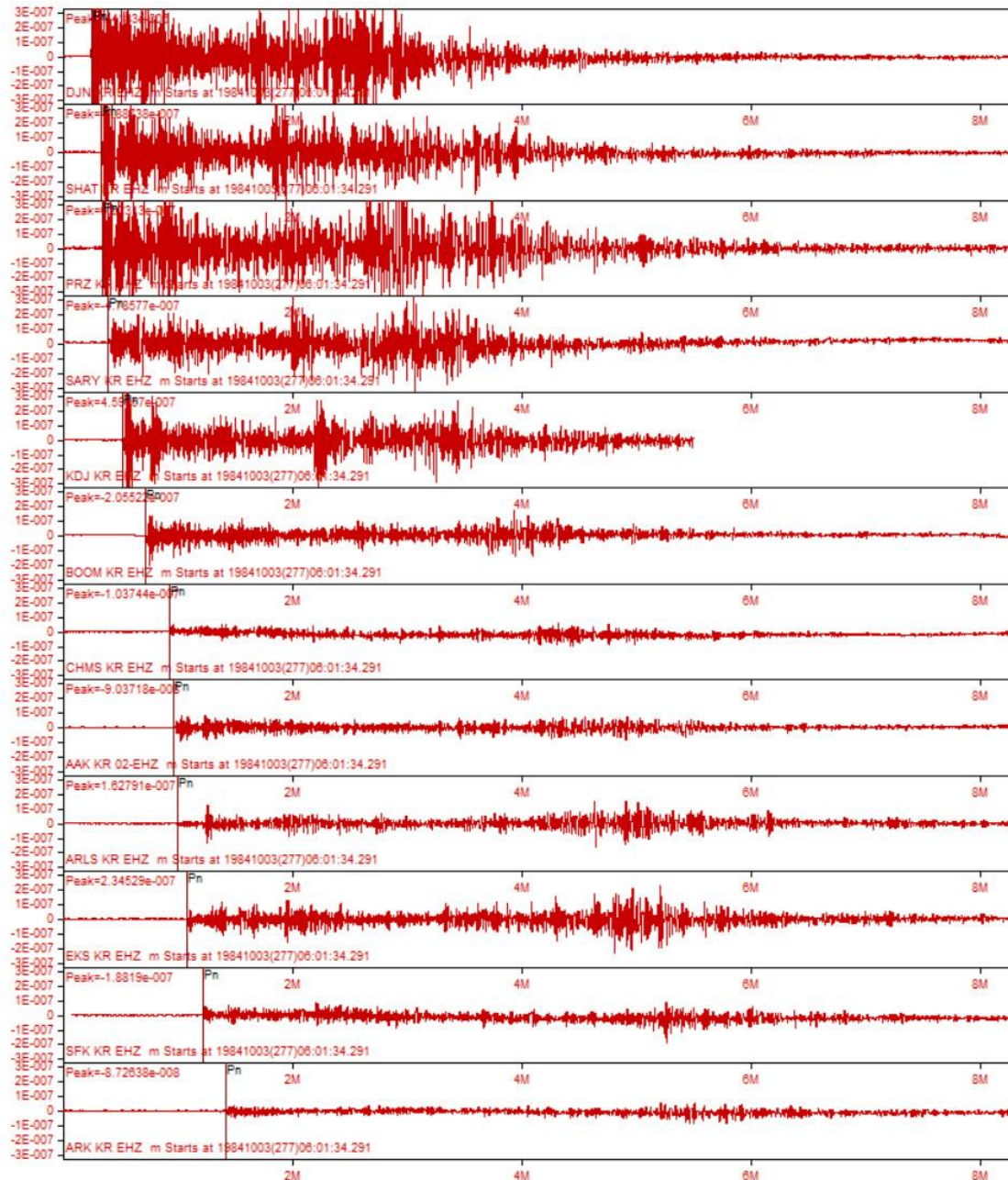


Figure A-16. CHIC31 Event Overview. No filtering, Global scaling. Good clear arrivals on all channels. Only Z-axis is shown on this plot.

A2.17. CHIC32: 19 DEC 1984 – Event Overview

Six stations represent this event. All seismograms feature good SNR, and in some cases, additional phase arrivals are clear, especially on the horizontal channels. Energy dispersion is consistent with distance. SRDZ is missing EHE because of a channel outage on original seismogram.

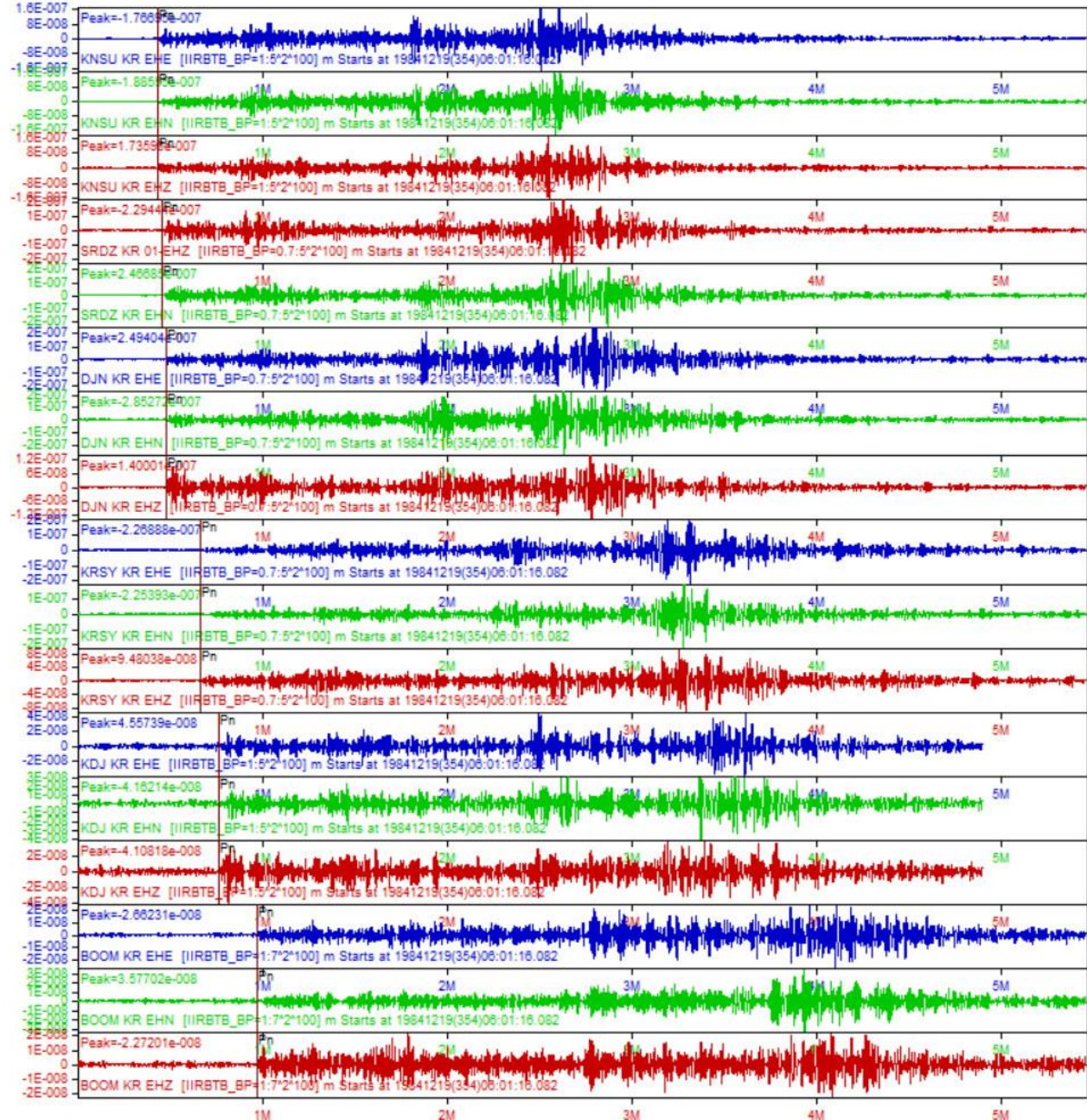


Figure A-17. CHIC32 Event Overview. All channels, Various bandpass filters. Local scaling. Station SRDZ has a dead channel EHE that was not digitized for this event.

A2.18. CHIC33: 05 JUN 1987 – Event Overview

This event contains a mixture of long-period SKD and short-period SKM instruments. Each of the stations has good signal to noise ratio. The SKD instruments feature a clear surface wave that is not seen on the short-period record. When instrument response is removed from the signal across all channels, the surface wave is enhanced on short period, and can be partially seen on the SKM channels.

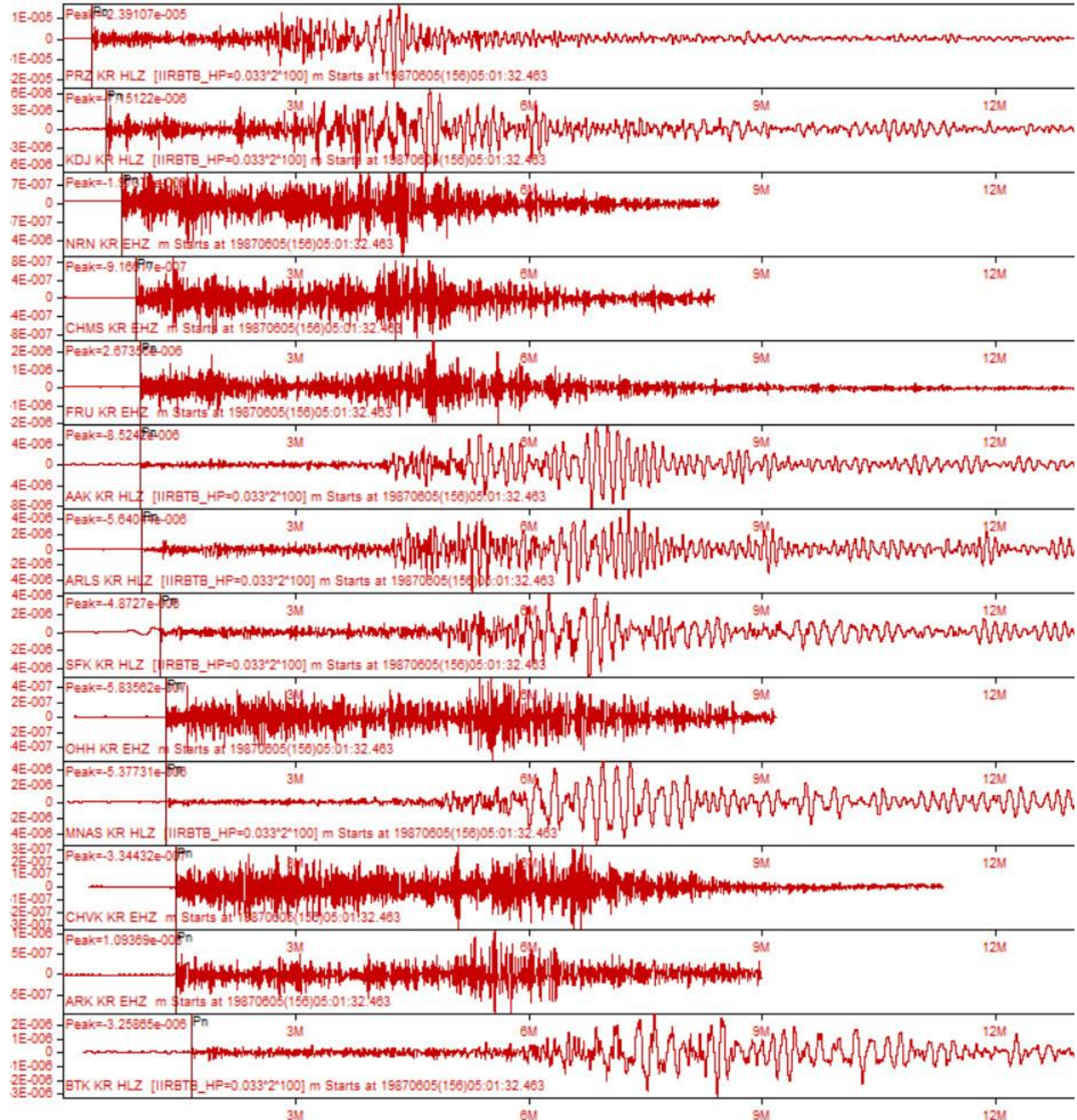


Figure A-18. CHIC33 Event Overview. 13 stations, only Z-axis shown. SKD records are 0.033Hz high-pass filtered to remove low-frequency signal offsets. Clear surface wave.

A2.19. CHIC34: 29 SEP 1988 – Event Overview

Seven stations (KNSU, KUNG, TERK, YRV, AAK, ARLS, AKIA) represent this event. The closer stations have clear arrivals, but quality degrades with distance due to ground attenuation. ARLS and AKIA have very low SNR, but initial P arrival can be observed with 0.033 – 3Hz bandpass filtering.

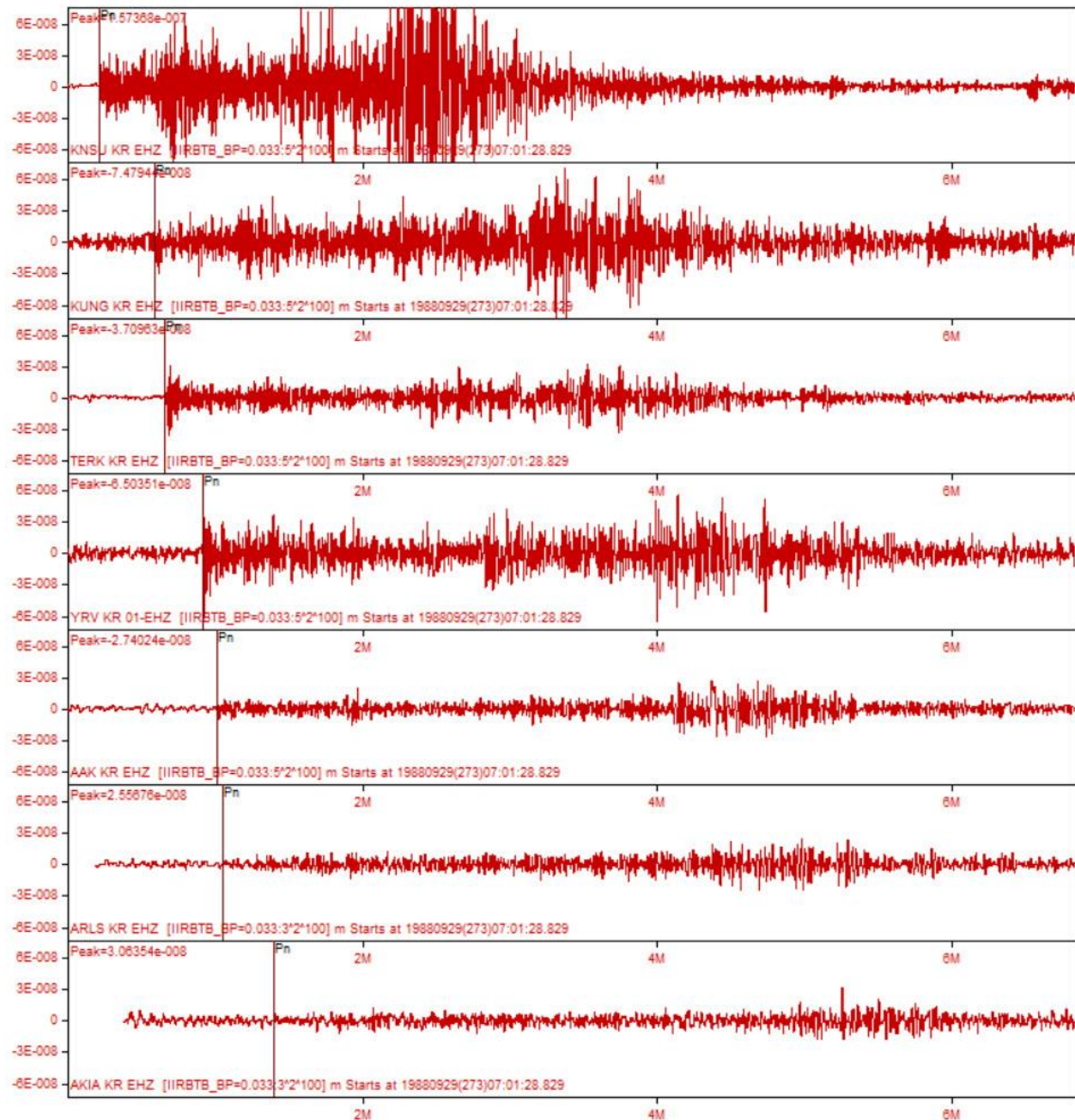


Figure A-19. CHIC34 Event Overview. Z-axis shown, various bandpass filters applied. Global scaling shown, with subsequent loss of signal fidelity due to ground attenuation with distance.

A2.20. CHIC35: 26 MAY 1990 – Event Overview

18 stations have been digitized for this event, and include all three components, except station BOOM that had the EHN component inoperable for this time. There is excellent SNR for all traces, and ground attenuation can be easily seen with increasing distance from the event.

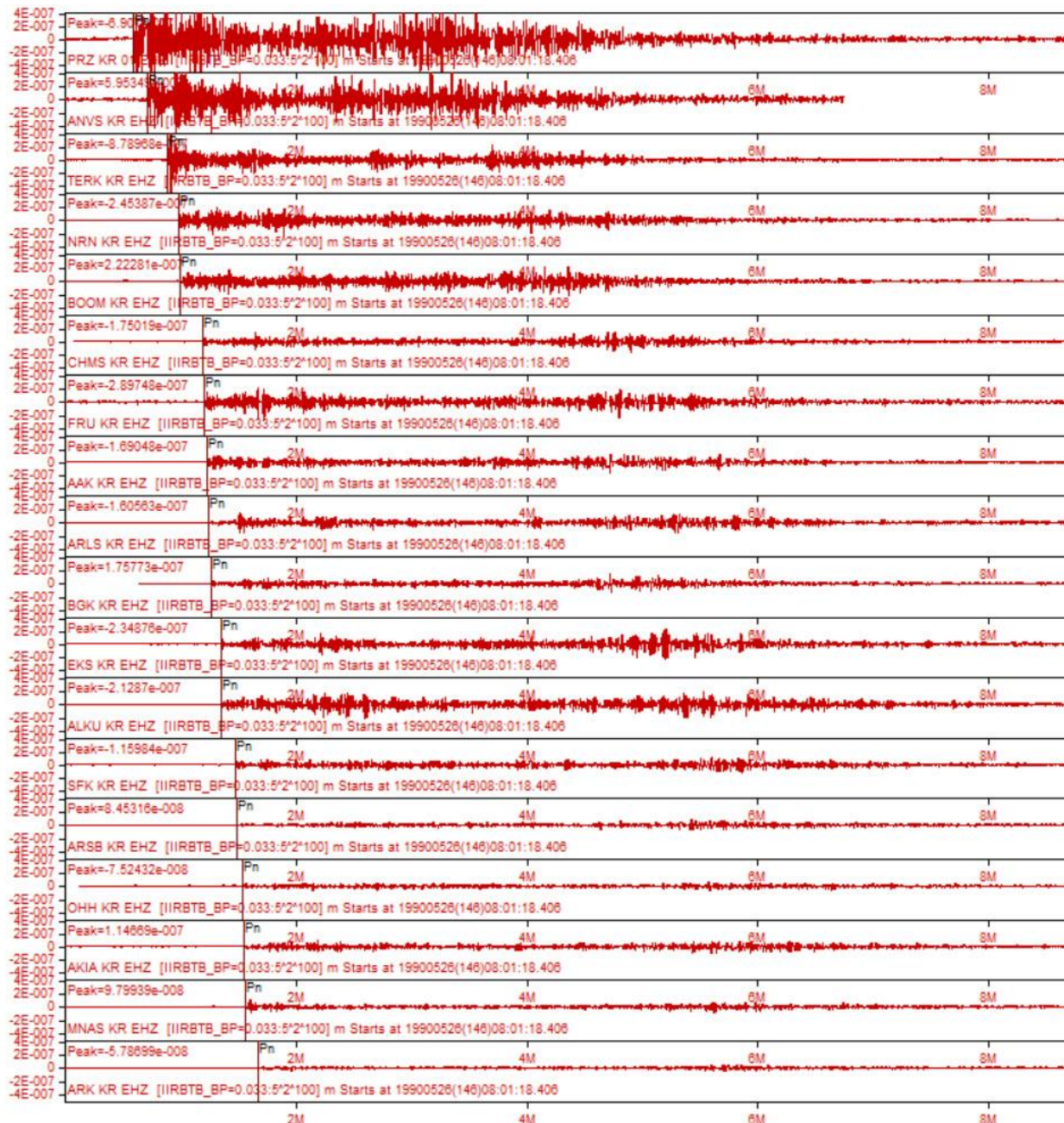


Figure A-20. CHIC35 Event Overview. Z-axis shown. 0.033-5Hz band pass filter applied, global scaling shown, with subsequent amplitude reduction due to ground attenuation with distance.

A2.21. CHIC36: 16 AUG 1990 – Event Overview

This event is represented by 22 stations, 3 components each. This event has signal dropouts due to paper change operations on several stations. There is a mixture of short-period SKM and long-period SKD instruments.

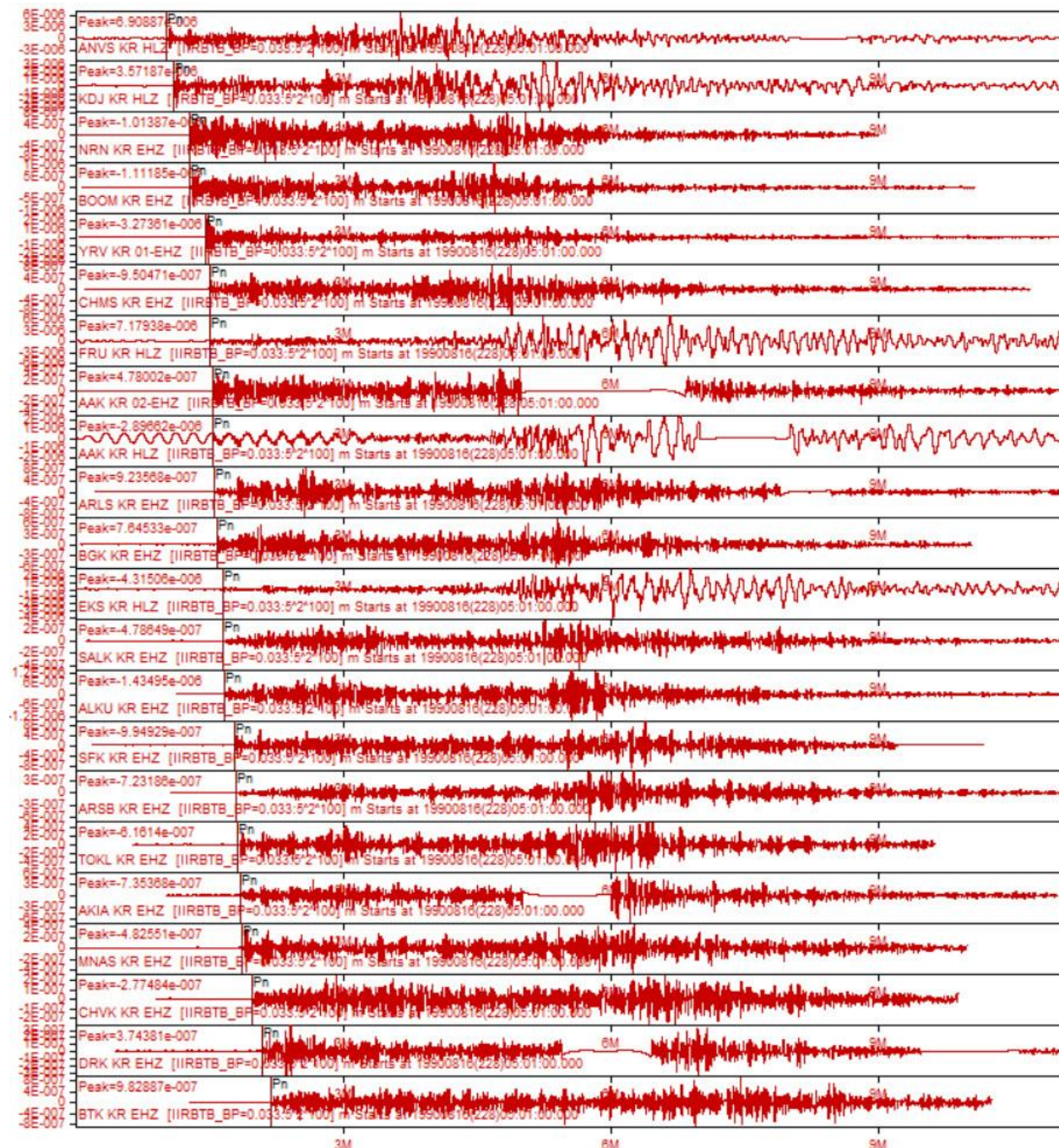


Figure A-21. CHIC36 Event Overview. 0.033Hz – 5Hz Bandpass filtered, local scaling shown, Z axis shown. Signal gaps present due to paper change operations.

A2.22. CHIC37: 21 MAY 1992 – Event Overview

This event is represented by 15 stations, 3 long-period components each. Station FRU contains two sets of signals, from the standard gain seismograms and the “Kpch” Low-gain channels, offering insight into how channel gain affects digitization accuracy. DRK shows unusually large Lg, and the gain on paper seismogram has been verified to match the metadata.

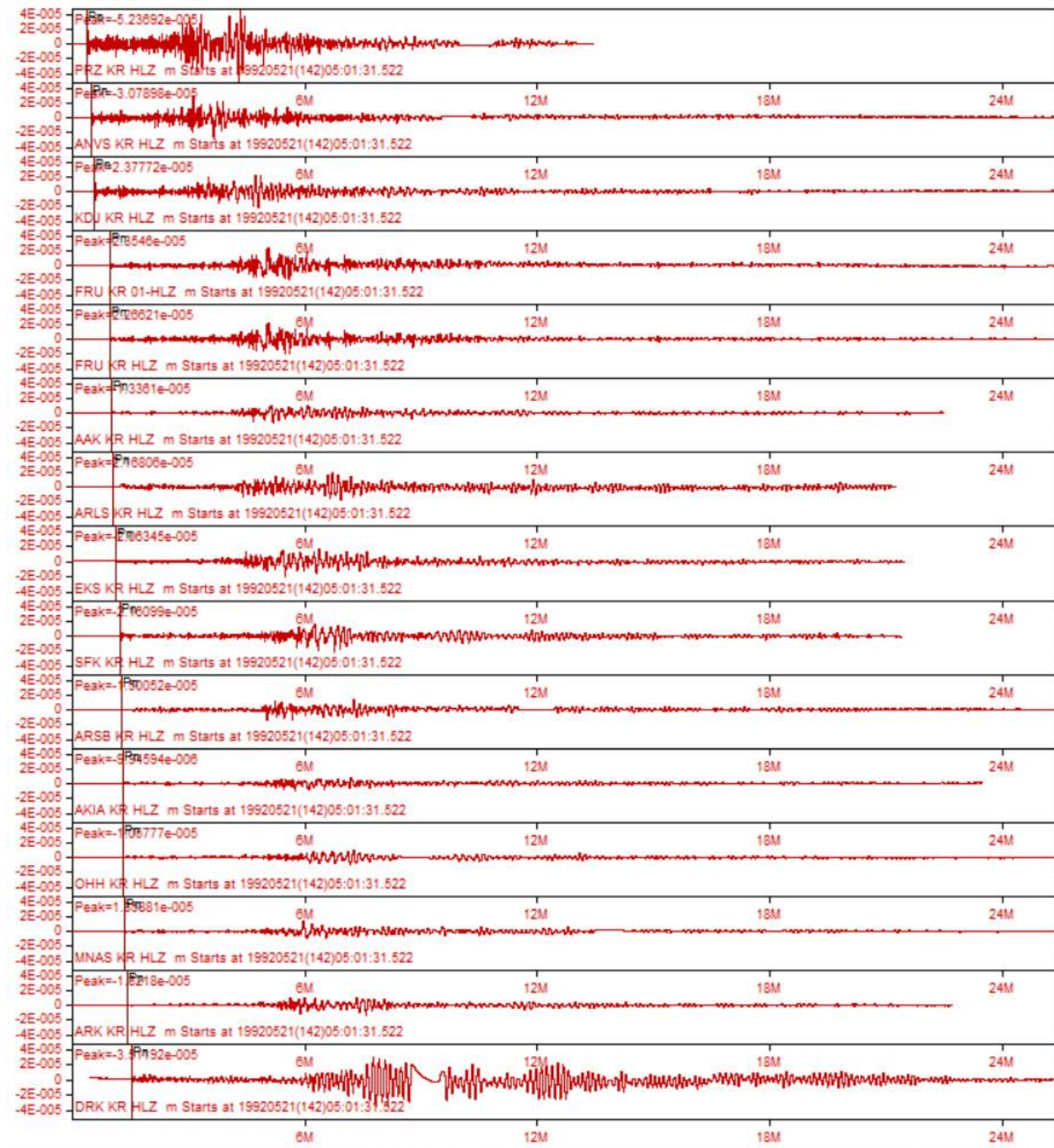


Figure A-22. CHIC37 Event Overview. LP channels, No filter, Global scaling applied. Z axis shown.

A2.23. CHIC38: 25 SEP 1992 - Event Overview

11 stations represent this event. Each station features SKM short-period instruments on all channels. Good SNR on all channels.

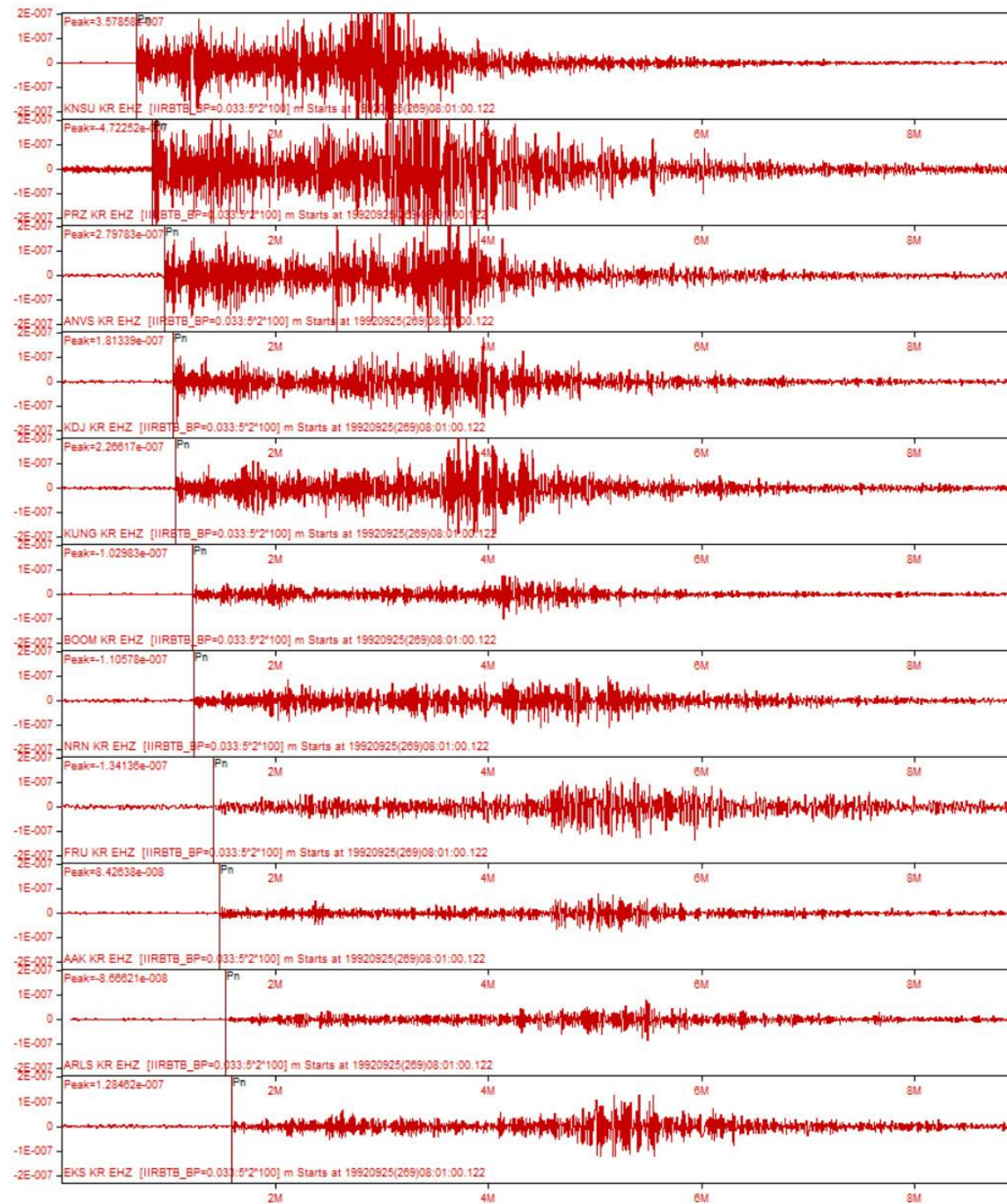


Figure A-23. CHIC38 Event Overview. 0.033 – 5Hz bandpass filtered, global scaling. Z axis shown.

A2.24. CHIC39: 05 OCT 1993 - Event Overview

Eleven stations represent this event. Seven SKD long-period instruments are digitized, along with six short-period SKM instruments. Stations NRN and ARLS contain both the SKM and SKD record, presumably co-located on the same pier. Power Spectral Density plots show that within the common passband, between 0.3 – 2Hz, energy is within 3db between for both instruments at both stations. Co-located seismic data from II.AAK is available for downloaded from Earthscope DMC for colocation studies at this station.

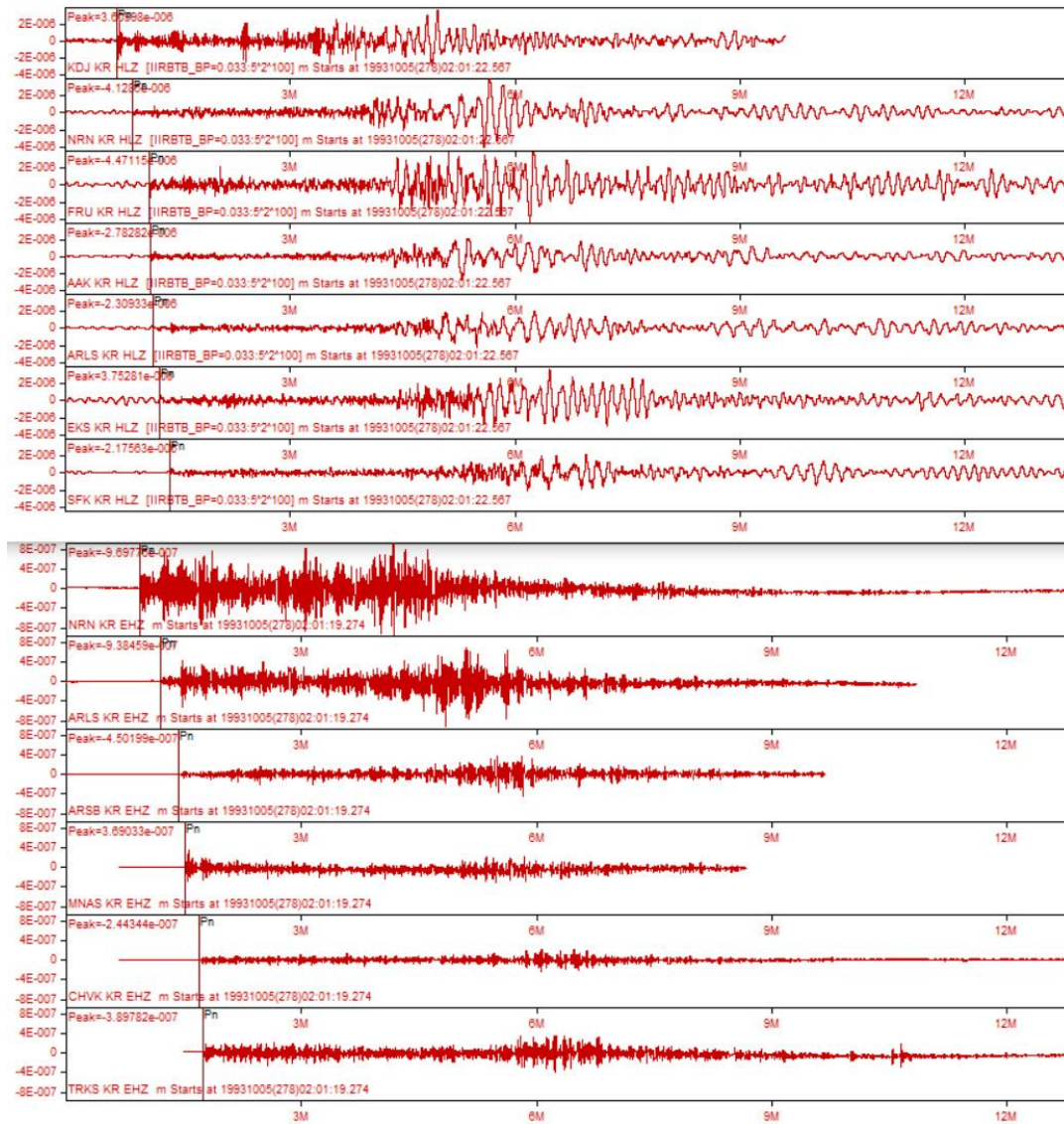


Figure A-24. CHIC39 Event Overview. Both SKD Long-period and SKM short-period instruments are represented in this event. 0.033-5Hz bandpass filter applied to SKD channels only. Global scaling for each set of channels. Stations NRN and ARLS feature seismograms from both instruments.

A2.25. CHIC40: 10 JUN 1994 - Event Overview

Sixteen stations represent this event. CHIC40 shows good SNR, with clear arrivals at all stations. Station ANVS features long-period SKD instruments whereas remaining stations utilize SKM short-period instruments. CHIC40 can be supplemented with broadband data from II.AAK which is located at Earthscope DMC.

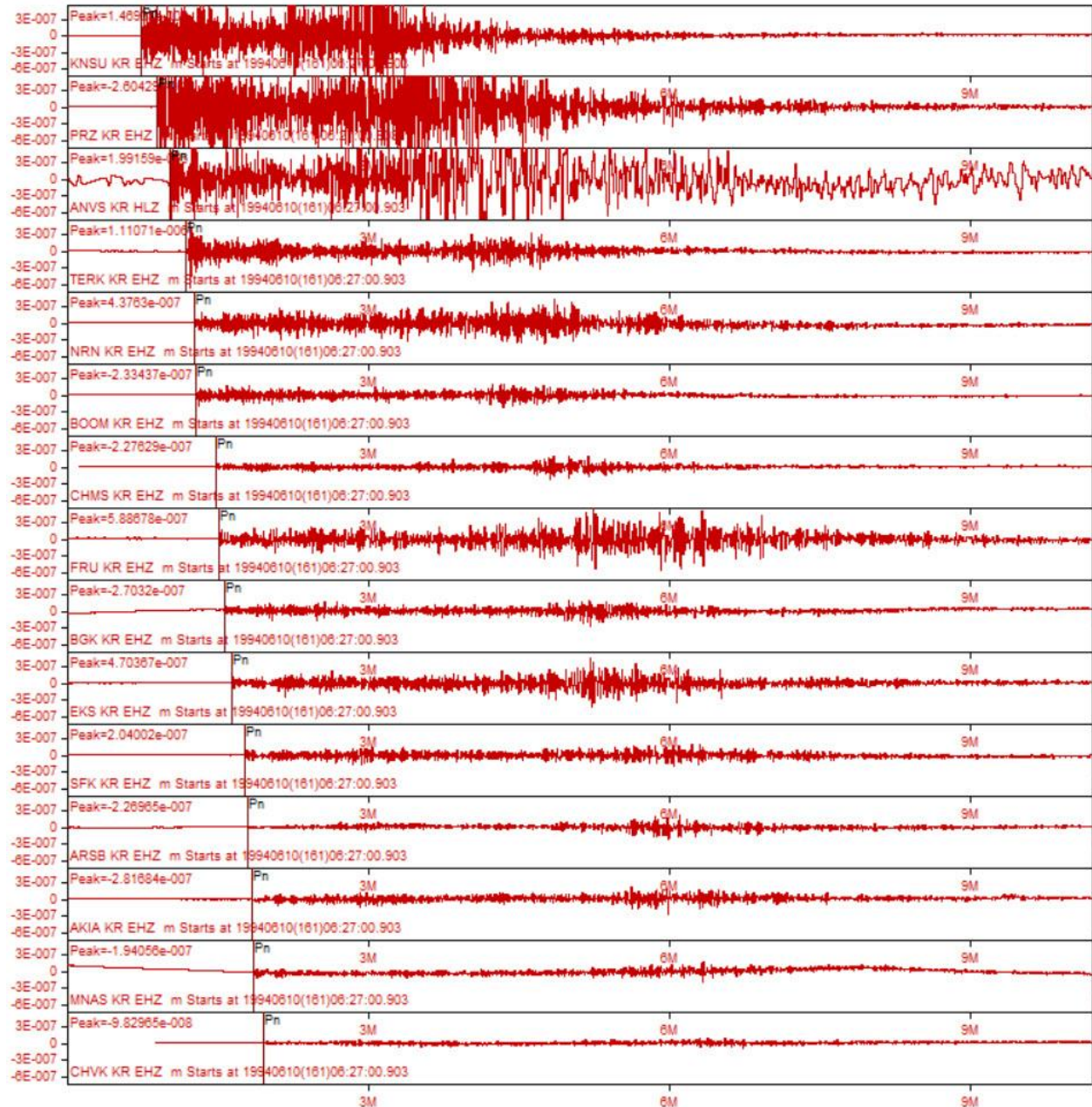


Figure A-25. CHIC40 Event overview. No filter, global scaling is set and illustrates seismic energy attenuation as a function of distance.

A2.26. CHIC41: 07 OCT 1994 – Event Overview

Sixteen Stations represent this event. CHIC41 is reported to have similar yield as CHIC40 but has almost double the amplitude as CHIC40. Station NRN has good cross correlation between both events.

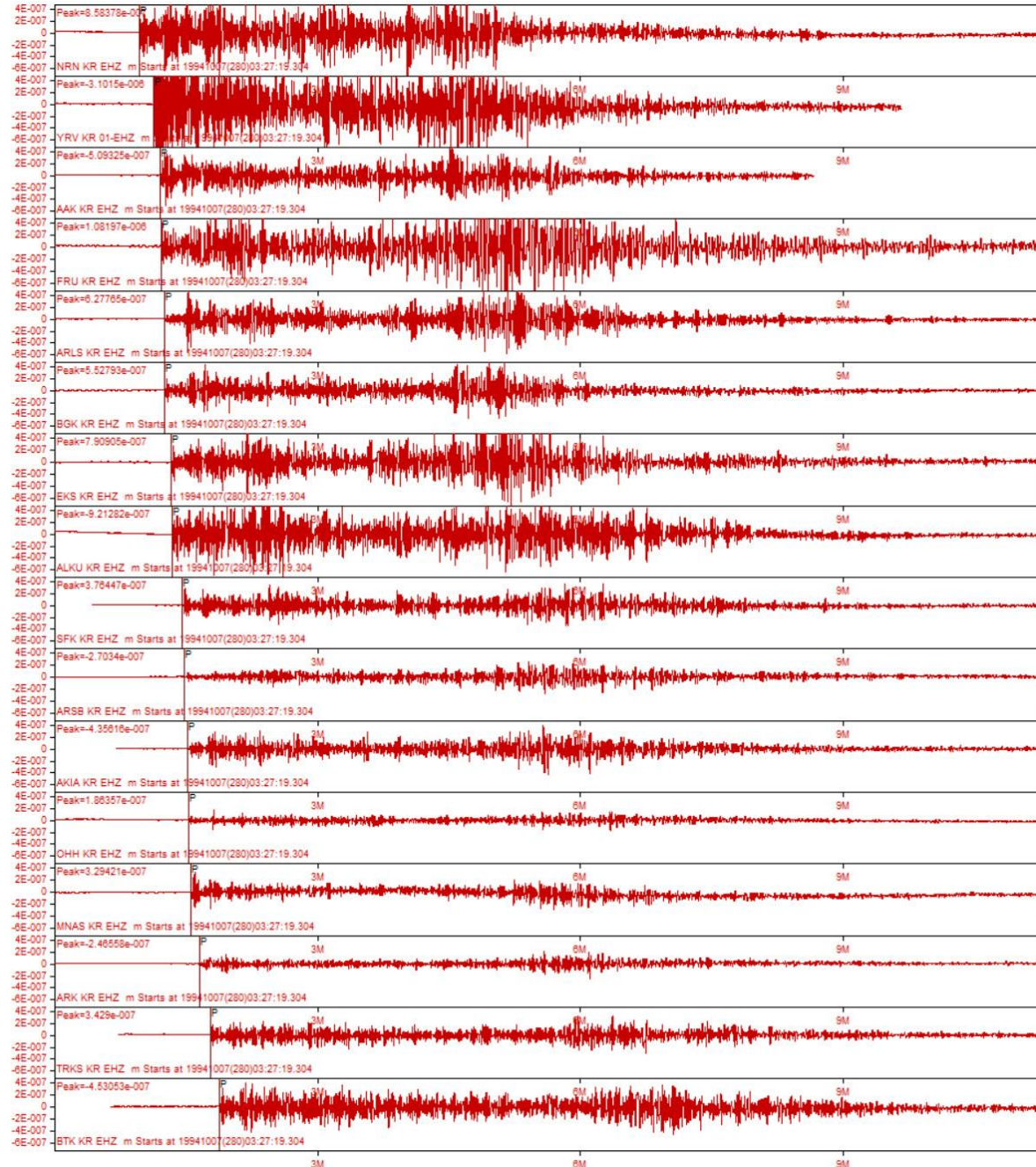


Figure A-26. CHIC41 Event Overview. No filter, Global scaling applied. Z axis shown. Amplitudes are significantly larger than CHIC40.

A2.27. CHIC42: 15 MAY 1995 – Event Overview

22 stations represent this event. The closest station to CHIC42 is ANVS, and this is the one station out of this series that features the long-period SKD seismometer, with a good representative Lg. The remaining stations utilize the short-period SKM. Station KR.AAK is represented for this event. Seismic data from II.AAK is available for download from Earthscope DMC for colocation studies at this station.

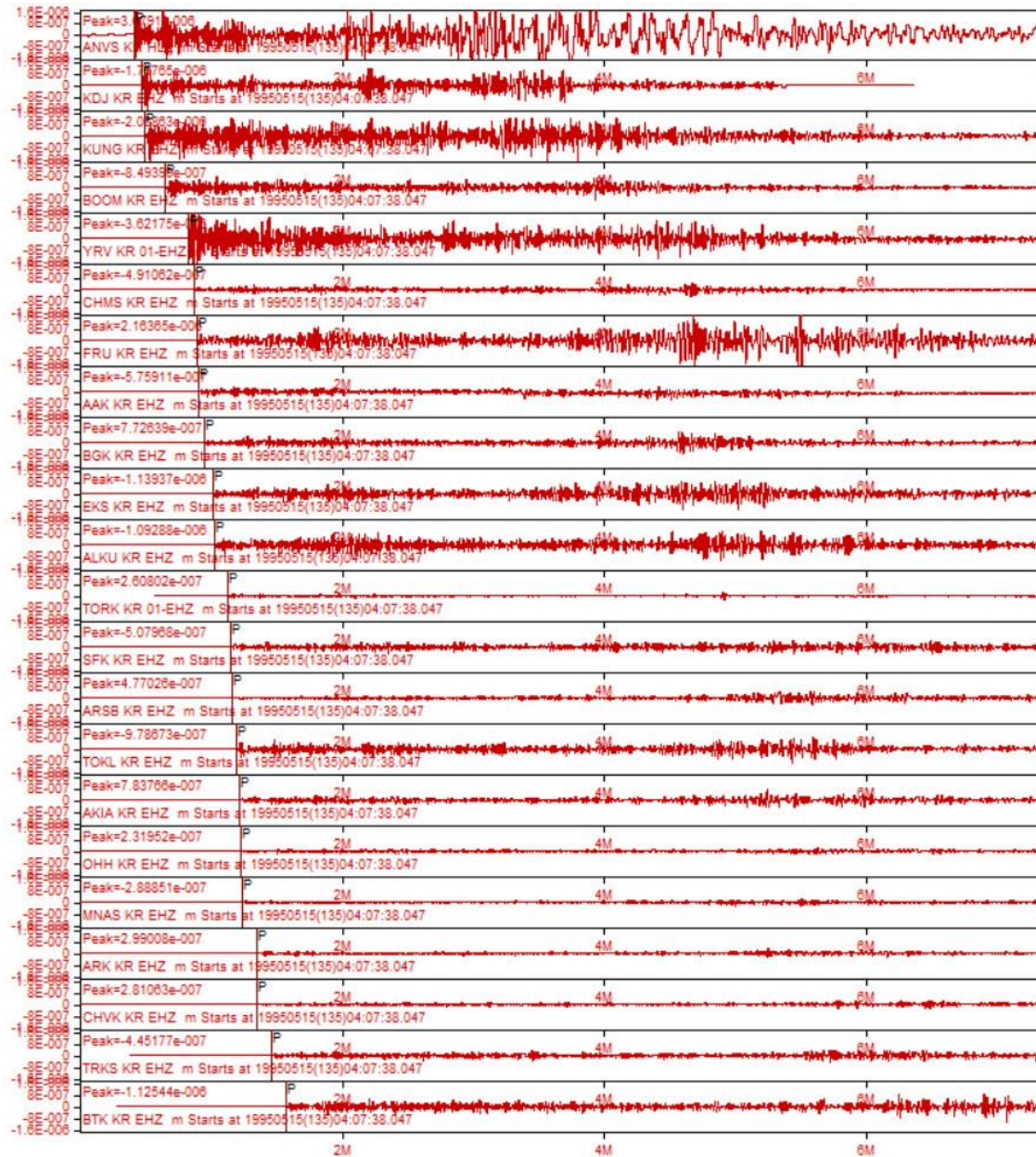


Figure A-27. CHIC42 Event Overview. There is no filter and global scaling applied. Only Z axis are shown.

A2.28. CHIC43: 17 AUG 1995 – Event Overview

This event is represented by 20 stations. PRZ utilizes SKD long-period seismometer whereas the rest are SKM short period. KR.AAK is represented for this event, and co-located seismic data from IL.AAK is available for download from Earthscope DMC for colocation studies at this station. Arrivals are clear and range from impulsive to emergent.

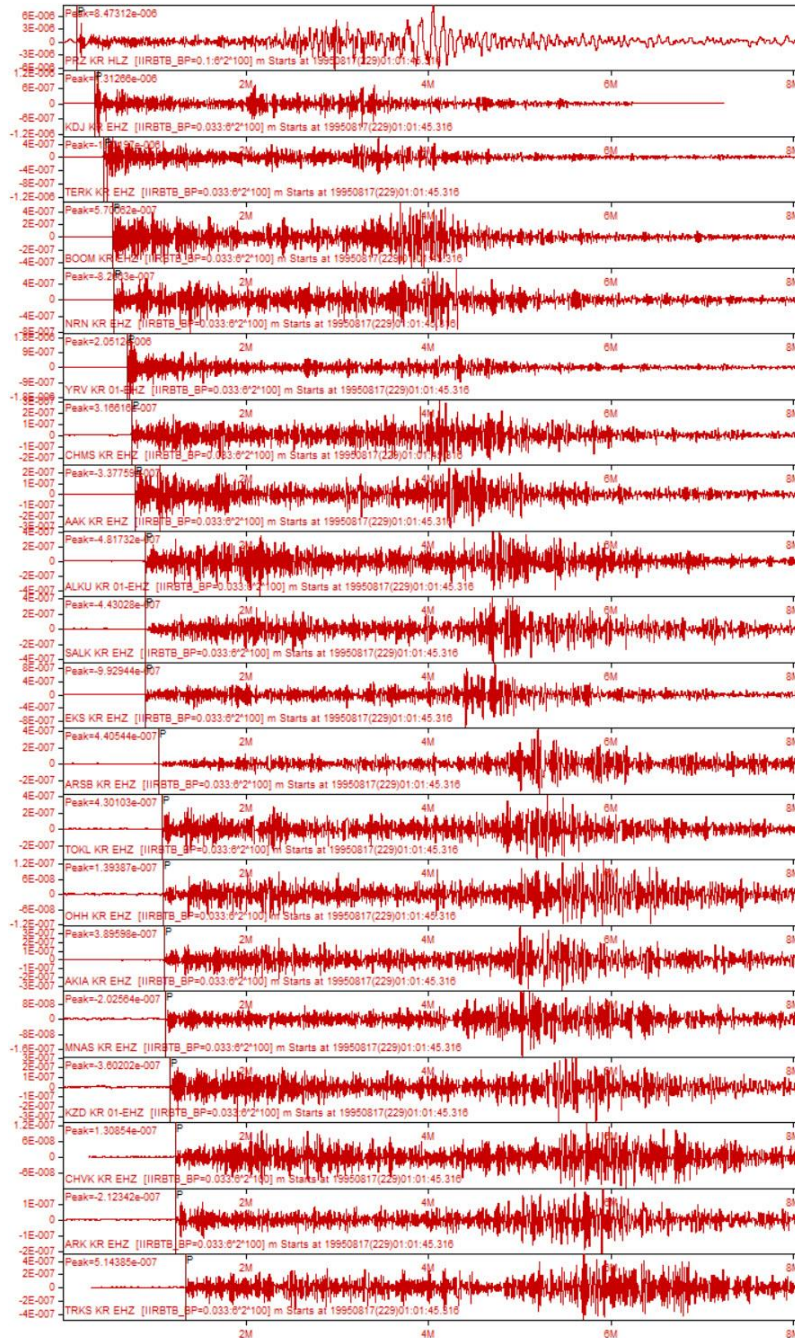
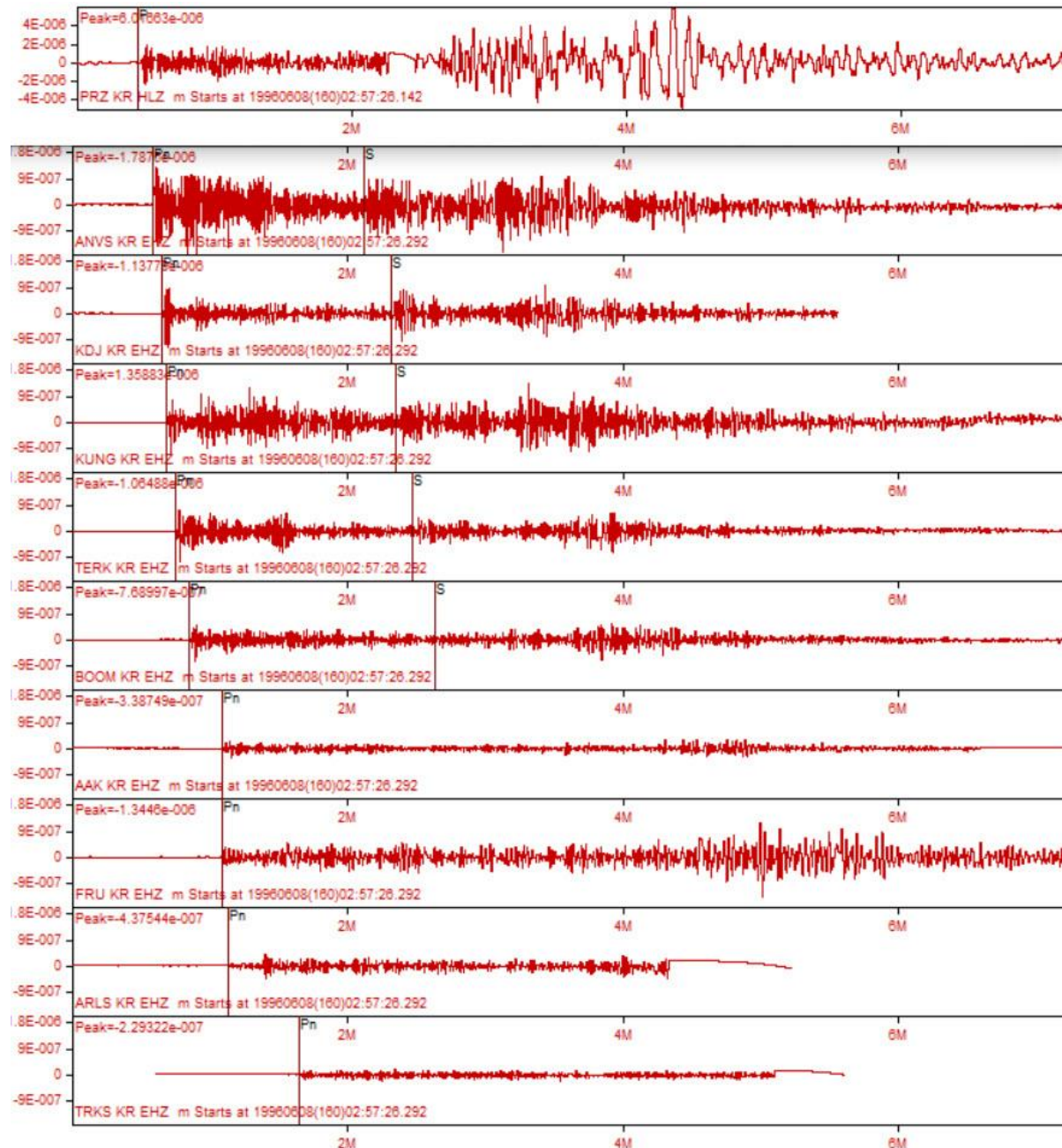


Figure A-28. CHIC43 Event Overview. LP filtered 0.1Hz – 6Hz., SP filtered 0.033 – 6Hz. Locally scaled. Z axis shown.

A2.29. CHIC44-1, CHIC44-2: 08 JUN 1996– Event Overview

CHIC44 is a double event, reported as two simultaneous detonations. PRZ, ANVS, KDJ, ERK, and BOOM all show clear S phase arrivals. KR.AAK is represented for this event and co-located seismic data from II.AAK is available for download from Earthscope DMC for colocation



studies at this station.

Figure A-29. CHIC44 Event Overview. Local scale on PRZ, Global scaling on remaining short period stations. No filters. Clear S arrival on five stations. Co-located II.AAK time-history data is also available from Earthscope DMC for this event. Z axis shown.

A2.30. CHIC45: 29 JUL 1996 – Event Overview

14 stations represent this event. Several of the close stations exhibit clear S-phase arrivals. KR.AAK is present for this event and co-located seismic data from II.AAK is available for download from Earthscope DMC for colocation studies at this station.

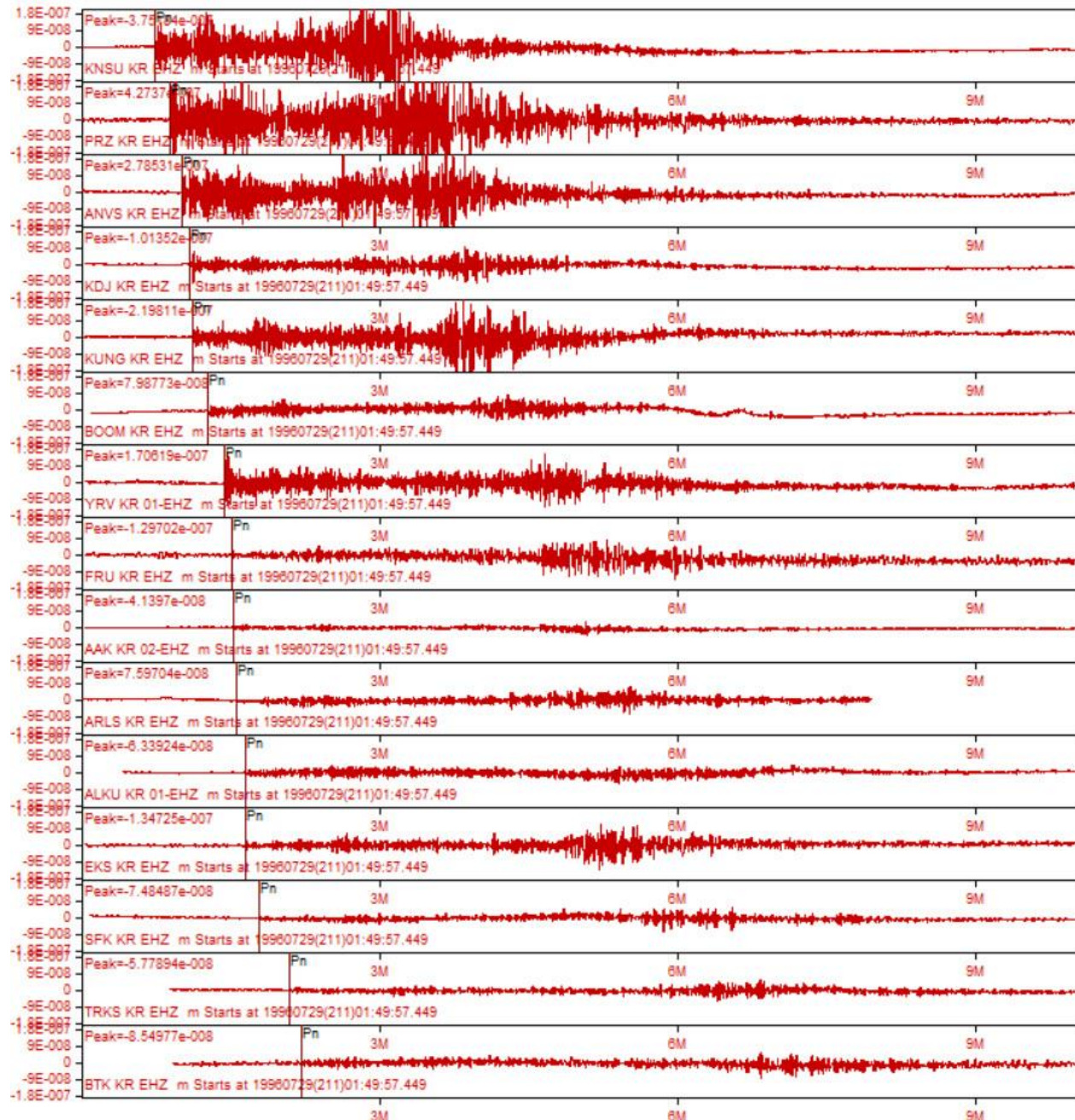


Figure A-30. CHIC45 Event Overview. Z axis shown. Global scaling, no filter. Several close stations exhibit clear S-phase arrival. Co-located II.AAK time-history data is also available from Earthscope DMC for this event.

APPENDIX B. METADATA: DATALESS SEED AND THE STATION PASSPORT FILES.

B1. Introduction

The station passports are a collection of Microsoft documents that describe the station site, the station equipment history, and any collected station calibration parameters information that could be found. They are located within accompanying data deliverable with metadata, under the subfolder 'passports'. The files themselves vary in terms of content, from a single page of text to an exhaustive collection of station installation photographs, channel response graphs, and other ancillary information. These response graphs and parameters have been used generate a dataless SEED file that encompasses the various epochs for the station. Some stations have a sparse record of calibration and will have a long-term epoch covering their entire operating timeframe, whereas some stations will have a record of many calibrations embedded within their dataless SEED. These 35 dataless SEED files are also found within the subfolder called 'metadata' and contain the calibration information that covers all of the generated miniseed waveform files needed to apply the gain and response for the channel for that given epoch. Some station passports include additional data that falls outside of the epochs covered by this report, and thus the dates within the passport may not match the epochs listed within the provided dataless SEED files. Table B-1 provides a basic parameter station list for seismograms digitized in this project. The filename for each station's passport file is also included in the table.

Table B-1. Station code, coordinates, epochs in dataless SEED file, channel type, and passport document name as found in metadata>passports within the data library.

STATION	STATION NAME	LAT.	LON.	ELEV.	EPOCHS COVERED	CHANNELS	PASSPORT FILENAME
AAK	Ala-Archa	46.6375	74.4942	1633	1983-1996	SP,LP	KR.AAK.docx
AKIA	Ak-Kiya	41.6192	72.6833	960	1987-1996	SP,LP	KR.AKIA.docx
ALKU	Alay-Kuu	40.4167	74.1167	2040	1970-1996	SP	KR.ALKU.docx
ANVS	Ananievo	42.7861	77.6672	1864	1973-1996	SP,LP	KR.ANVS.docx
ARK	Arkit	41.7995	71.9667	1280	1976-1996	SP,LP	KR.ARK.docx
ARLS	Aral	41.846	74.324	1640	1968-1996	SP,LP	KR.ARLS.docx
ARSB	Arslanbob	41.3233	72.9811	1440	1983-1996	SP,LP	KR.ARSB.docx
BGK	Belogorka2	42.6400	74.2383	1300	1980-1996	SP	KR.BGK.docx
BOOM	Boomskiye	42.4922	75.9422	1737	1973-1996	SP	KR.BOOM.docx
BTK	Batken	40.0575	70.8181	980	1983-1996	SP,LP	KR.BTK.docx
CHMS	Chumysh	42.9917	74.7539	655	1968-1996	SP	KR.CHMS.docx
CHVK	Chauvay	40.1447	72.2167	2120	1987-1996	SP	KR.CHVK.docx
DJN	Djergalan	42.6097	79.0217	2120	1987-1996	SP	KR.DJN.docx
DRK	Daraut-Kurgan	39.4808	71.805	2320	1987-1996	LP	KR.DRK.docx
EKS	Erkin-Say	42.6689	73.785	1180	1966-1996	SP,LP	KR.EKS.docx
FRU	Bishkek (Frunze)	42.8411	74.6128	830	1966-1996	SP,LP	KR.FRU.docx
KDJ	Kadji-Say	42.1272	77.1944	1880	1973-1996	SP,LP	KR.KDJ.docx
KZD	Kyzyl-Djar	41.275	72.2467	660	1976-1996	SP	KR.KZD.docx
KNSU	Ken-Suu	42.315	79.245	3018	1982-1996	SP	KR.KNSU.docx
KRSY	Kara-Say	41.575	77.9061	3360	1984-1996	SP	KR.KRSY.docx
KUNG	Kungey	42.6672	76.935	2050	1987-1996	SP	KR.KUNG.docx
MNAS	Manas	42.4894	72.5067	1465	1987-1996	SP,LP	KR.MNAS.docx
NRN	Naryn	41.4167	75.9667	2120	1968-1996	SP,LP	KR.NRN.docx
OHH	Osh	40.5244	72.7847	980	1983-1996	SP,LP	KR.OHH.docx
PRZ	Prjevalsk	42.4735	78.4004	1727	1968-1996	SP,LP	KR.PRZ.docx
SALK	Salom-Alik	40.871	73.804	1710	1992-1996	SP	KR.SALK.docx
SARY	Saruu	42.2214	77.9764	2060	1982-1987	SP	KR.SARY.docx
SFK	Sufi-Kurgan	40.0128	73.503	2160	1976-1996	SP,LP	KR.SFK.docx
SHAT	Shaty	42.775	78.375	2170	1973-1996	SP	KR.SHAT.docx
SRDZ	Sary-Dzhaz	41.989	79.084	2600	1973-1996	SP	KR.SRDZ.docx
TERK	Terksey	42.0639	76.5706	2200	1987-1996	SP	KR.TERK.docx
TOKL	Toktogul	41.925	72.869	1097	1982-1996	SP	KR.TOKL.docx
TORK	Torkent	41.933	73.21	1400	1992-1996	SP	KR.TORK.docx
TRKS	Terek-Say	41.4625	71.1733	1640	1987-1996	SP	KR.TRKS.docx
YRV	Yur'evka	42.6889	75.0508	1180	1987-1996	SP	KR.YRV.docx

APPENDIX C. DESCRIPTIONS AND STRUCTURE OF THE ACCOMPANYING DATA DELIVERY

C1. Introduction

This document accompanies the library of deliverables for the MSU/Kyrgyz Republic Seismogram digitization project. It describes the data folder layout, as well as a description of the products that are found within the library. This document is to be used in association with the Digitalization of Seismograms from the Archives of the Kyrgyz Republic, representing selected nuclear explosions from Lop Nor, which are also located within the library. At the time of delivery, the library consists of over 14,000 files, 1400 folders, and a size in excess of 217 Gigabytes.

C2. File Folders Found Within the Library

C2.1. Main Folder "Digitalized_Historical_Seismograms_Of_Kyrgyzstan".

The main folder contains the library subfolders, along with some supplemental files such as this document. It also includes the spreadsheet "Digitization_Оцифровка.xlsx" that served as the working index for the seismograms digitalization project, organized by event.

C2.2. Supporting Documents

This subfolder contains supplementary training documents that were generated for use by digitization personnel. These files provide insight into the technique used for the hand-digitization of the seismograms as they are converted from scanned photocopies into an accurate digital seismogram.

C2.3. Software

This subfolder contains the python-based software tools that are used for converting the initial Wavetrack digitization output into miniseed files. It also contains the tool necessary for converting the published station calibration parameters and station metadata into a dataless SEED file. Although the project uses a digitization tool called Wavetrack, that software is not included in the deliverables. It is managed and distributed by the Trofimuk Institute of Petroleum-Gas Geology and Geophysics, of the Siberian Branch of the Russian Academy of Geophysics, located in Novosibirsk, Russia. Please contact Michigan State University for additional information if needed.

C2.3.1. PNE2SAC

PNE2SAC is the software that is used for conversion of the Wavetrack output files into a miniseed file. It is dependent on the Obspy software package and a functional python development environment. Also located within the folder are a user manual and a basic instruction file.

C2.3.2. PZCALC

PZCALC is the software used for building the metadata files that accompany the PNE2SAC miniseed output files. The dataless SEED file is created from a template and a .CAL

input file. These files are present within this folder, so that dataless SEED files, as found within this library, can be duplicated by the user of this library. Documentation is located within the source file PZCALC.py along with a README.txt file.

C2.3.3. MERGE

Merge is the software used to merge two miniseed files representing two digitized traces from the same seismogram. Sometimes the event runs over onto adjacent traces on the paper drum, and the two adjacent traces must be digitized. Once completed, Merge will combine the two miniseed files into a single trace representing the entire event.

C2.4. “Metadata” Folder

Metadata contains all of the generated dataless SEED files that accompany the digitizations found within this library.

C2.4.1. Individual Compiled Dataless SEED Files

Located in main metadata folder are the compiled dataless SEED files that cover the thirty stations used within this library. Each compiled dataless SEED file covers all the epochs for which the station has digitized waveforms. As gains and responses change with published information for a given channel, the changes are tracked within these files. They enable appropriate instrument response removal for each channel for each station, across all periods represented within this library.

C2.4.2. Calbooks Folder

This ‘calbooks’ subfolder contains the assembled library of station parameters booklets currently found within the Michigan State University archives. These station parameters cover several different networks, from the original USSR “backbone” network, from 1963 through 1993, and books for several regional networks. These are supplemented with published parameters from the local Kyrgyz network starting in 1990. The specific calibration is referenced within the “Digitization_Оцифровка.xlsx” spreadsheet as such : “Filename.Pagenumber.stationnumber”. Thus, you should be able to reference the original calibration for a given digitized calibration. These parameters are then transcribed into the .CAL file, as found within the station folder for its given year.

The calibration books provide a detailed overview of station channel calibrations on a yearly basis. The response graphs and parameters found within these scanned station parameter booklets were used to generate dataless SEED files that encompass the various epochs for the stations. Some stations have a sparse record of calibration and will have a long-term epoch covering their entire operating timeframe, whereas some stations will have a record of many calibrations embedded within their dataless SEED. There are 35 dataless SEED files within the subfolder called ‘metadata’, and they contain the calibration information necessary to cover all the generated miniseed waveform files within the library. These dataless SEED files enable the researcher to correctly apply the gain and response for the channel for that given epoch.

C2.4.2.1. *qbstations.mdb* file

This is a MS access database containing station coordinates for over 25,000 stations from around the world, and is based on the master station list from the International Seismological Centre. This database is supplemented with local station information from states of the former Soviet Union (FSU) and is used for looking up station coordinates, as well as verification of station code for a given station within the library.

C2.4.3. *Passports Folder*

Passports contains individual dossiers for each station involved within the digitization project. The content of each passport file varies, depending on what material was found for the station. The passport always include station coordinates as a function of time, station opening and closing years, and station codes. The passport might also include station calibration parameters if these documents were found. In some cases, station site photographs exist within the passport, along with GPS verified coordinates, where site visits occurred or where good coordinates were available from geolocation on satellite imagery. In some older cases, the station no longer exists, so the passport may be abbreviated. Clues into the station operating parameters exist within these files to assist future researchers with context in regards to the seismograms. Some station passports include additional data that falls outside of the epochs covered by this report, and thus the dates within the passport may not match the epochs listed within the provided dataless SEED files. The passport files were compiled by ISKR through a different project supported by the National Nuclear Security Administration, the International Science and Technology Center, Lawrence Livermore National Laboratory, and Michigan State University.

C2.4.4. *Year Folder*

This folder contains the individual calibration files for each of the epochs for the stations, organized by epoch. These files are generated, and used to form the compiled dataless SEED files found within the above folder. Metadata for a given station are organized by the year in which they are valid. They are presented here for diagnostic purposes only. It is recommended that the main compiled dataless SEED files be used with the library.

C2.4.4.1. *NN.SSS Station Folder*

Located in each Year subfolder, are the subfolders containing the metadata for a single station for that particular epoch. Located within the subfolder are various files dealing with the integration and generation of the metadata.

C2.4.4.1.1. *YYYY.NN.SSS.CAL*

The station subfolder contains a .CAL file, that contains the base metadata for the station, including the station coordinates, the station channel calibration parameters, and more. This is the input file for PZCALC.py which will then generate all subsequent files found within the subfolder.

C2.4.4.1.2. *YYYY.NN.SSS.LOG*

This is the log file that was generated at the time of metadata file creation by PZCALC. It is created by piping the text output from pzcalc from the screen into the file.

C2.4.4.1.3. dataless.NN_SSS_INST_DD_MM_YYYY.seed

This is the resulting dataless SEED file. This file is then copied into the digitized seismogram folder and accompanies the digitized seismogram for proper gain control, station location, and instrument removal of each digitized channel.

C2.4.4.1.4. NN.SSS.CHN.DD_MM_YYYY.sacpz

This is a SAC compliant SAC pole-zero file for use with SAC files of the digitized wave forms. It contains similar metadata as the dataless file.

C2.4.4.1.5. NN.SSS.CHN_DD_MM_YYYY.csv

This comma-separated file represents the amplitude and phase output as a function of frequency for each channel that is represented in the metadata.

C2.4.4.1.6. NN.SSS.CHN_DD_MM_YYYY_paz.txt

This text file contains the poles and zeros output calculations for all of the channels within the metadata .CAL file.

C2.4.4.1.7. NN.SSS.CHN_MM_DD_YYYY_response.png

This illustration plots all channels representing station response. It plots amplitude as a function of frequency, as well as a separate plot of phase in terms of degrees versus frequency. This is a more modern interpretation of instrument response that is more recognizable to instrumentation engineers.

C2.4.4.1.8. NN.SSS.CHN_MM_DD_YYYY_response_period.png

This illustration plots all channels representing station response on a graph format that duplicates the graphs as found within the original Soviet literature. It plots amplitude as a function of period in seconds, as well as phase as a function of seconds vs. seconds.

C2.5. Seismograms

The Seismograms folder contains 31 event folders, including a waveform summary folder and one folder for each event held in the seismogram library. The folder called Event_mseed_compilations contains a summary of digitized miniseed files that are grouped by event. The individual event folders are named first by the date of the test, followed by the popular name. Within each folder are subfolders representing each station for which there is a seismogram. Nested within each station folder will be the scanned seismogram, and subfolders containing the working files for each individual component.

C2.5.1. Event_mseed_compilations Folder

This is a self-contained folder containing all essential data necessary for utilizing the library for research. Located within the folder are thirty subfolders representing digitalized seismograms for thirty different events: 28 Lop Nor explosions, and 2 USSR PNE's detonated in

Kazakhstan for which there are clear arrivals at the Kyrgyz Stations. There is also a subfolder called `dataless_SEED_files` that contains DUPLICATE compiled dataless SEED files from the metadata subfolder of this library. It is placed here for convenience, to provide a self-contained, compact research product. ***It is important to clarify that the miniseed waveform files accompanying this report have the time corrections already applied.***

C2.5.2. Event Folders

There exists 30 folders, each of which represent a single event. The name of the folders follows the format `YYYYMMDD_EVNAME`, with date followed by the popular name of the event. Located within each subfolder are subfolders representing each contributing station to this event. The subfolders are named by the ISC station code.

C2.5.2.1. Scanned Seismogram File

Located within each station folder is a scanned copy of the seismogram that was used for the digitization. Most, but not all seismograms have viable (i.e. legible) traces. This image is the source material, and is used in conjunction with Wavetrack for vectorizing the click points for each digitized component. In some cases, a supplementary image may exist of the backside, and contain additional information about the scan such as time, date, trace gain, time corrections, etc. In most cases, this information is recorded on the front of the seismogram. ***The scan is provided because it is an important reference that connects the digitization to the original data. The scan should be referenced to verify quality of the digitization or address other questions that arise.***

C2.5.2.2. SKD (LP) or SKM(SP) Seismogram Folder

In some cases, there exist seismograms for both a short-period and long-period instrument at the station. In these cases, the station will contain multiple subfolders to separate the long-period from the short-period seismograms. Located within this folder will be the scanned copy of the seismogram, for when there exists more than one seismogram for a given station.

C2.5.2.3. Channel Folder

Within each station (or optionally, SP/LP subfolder) subfolder there are eight distinct file types that each provide different information related to the digitization. Typically, there will only be one of each of these files, however if the component was digitized in two parts and merged, there will be two files for each extension besides “.docx” due to there being two separate digitizations for that channel. One for each partial digitization. The two miniseed files generated will then have been run through the “merge” program within PNE2SAC and combined into one file. When merging, the final sample of the first file is used to form a DC baseline for the second file, in order to avoid DC level shifts when the files are combined. The merged file of the full waveform will then exist as a final miniseed file and be the product of the two smaller files. ***This merged file is also provided in the Event_mseed_compilations folder (section 2.5.1).***

C2.5.2.3.1. .mseed File

Files with the extension “.mseed” are the main output file generated by the PNE2SAC program. This file is the final digitized waveform for use in analysis. This digitization file represents the Wavetrack trace output data integrated with GMT timing as well as station and channel information, which then has a curve fitting algorithm applied to it by PNE2SAC. This file can be used in conjunction with the corresponding dataless seed file to remove instrument response and provide a digital record of true ground motion. File names that include Part1 and Part2 in the naming convention represent partial traces, that run to the end of the paper seismogram drum, requiring two separate digitization operations. Accompanying these two files should exist a third seismogram, representing the merged file. ***You can identify this .mseed file by it's size, which should be approximately the sum of the two previously mentioned segments. It is important to clarify that the miniseed waveform files accompanying this report have the time corrections already applied.***

C2.5.2.3.2. .sac File

Similar to miniseed files are those with “.sac” extensions. These files also consist of the final digitized waveform similarly to “.mseed” files in content however they are generated by PNE2SAC for use in SAC Software to provide additional analysis options. The .sacpz response files for the .sac files are not included within this folder, but are found within the Metadata “Year” subfolder for the appropriate epoch, or can be extracted from the dataless SEED file (See sec. C2.4.4.1.6). ***It is important to clarify that the SAC waveform files accompanying this report have the time corrections already applied.***

C2.5.2.3.3. .png File

Image files ending in “.png” are generated by PNE2SAC as a snapshot of the final waveform the program has generated. If there are discontinuity errors in timing where one clickpoint is backwards in time compared to a previous clickpoint, the program will report it as an error and generate a vertical green bar at the location of the error to help identify that the issue needs to be fixed. This line is also generated if two clickpoints share the same GMT coordinate. This was part of the error checking routines in place during the digitization process. The identified errors were corrected, so no .png images should retain vertical green bars.

Within the “.png” file are three channels. The top channel shows an overlay of the original Wavetrack clickpoints, the PCHIP interpolated waveform, and the optimized waveform. The middle channel contains just the optimized waveform, which will only differ from the PCHIP interpolated waveform if the optimizer is activated. Finally, the bottom channel is a trigger channel which reports frequency discrepancies as a way to determine potential skew issues within the waveform. This reports both the initial waveform data as well as the data after the optimizer has adjusted clickpoints to verify that the optimizer has adequately reduced skewness.

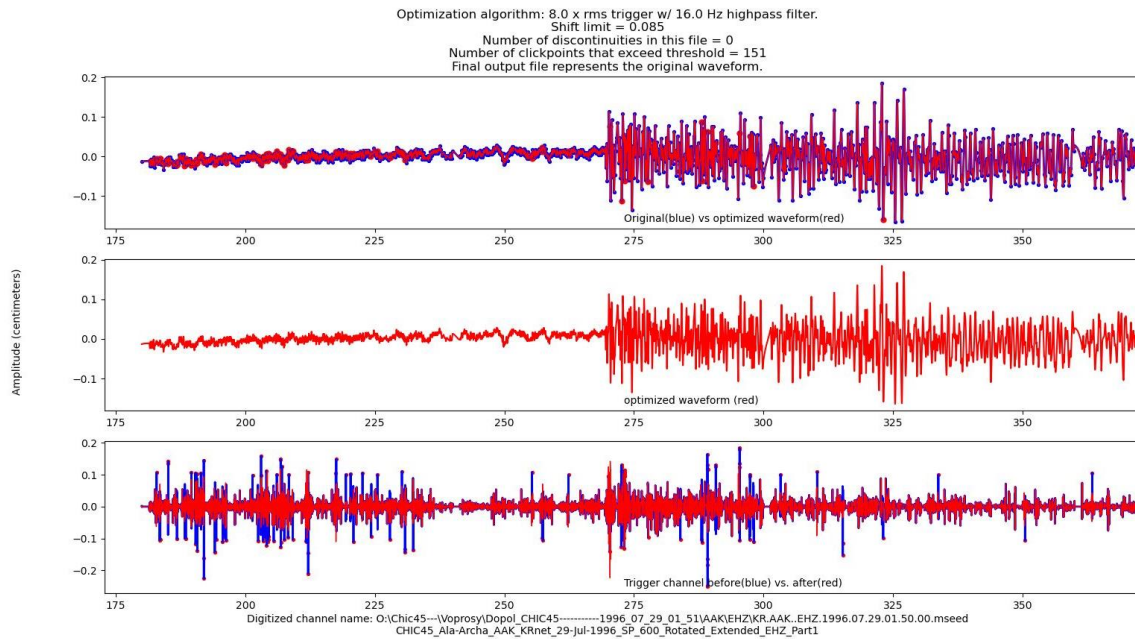


Figure C-1. PNE2SAC output file example. Station AAK, CHIC45, Z component, part one. Top trace contains three traces: Original wavetrack linear output (in black), Blue unoptimized PCHIP interpolated, red optimized PCHIP interpolated, and calculated clickpoint positions as blue dots. Middle Trace is the potentially optimized trace. Bottom trace is the trigger channel used during optimization.

C2.5.2.3.4. .log File

Files with “.log” extensions are a record the outputs of PNE2SAC during sac and miniseed generation which are created during the process of running “.txt” files through the code. This provides a helpful diagnostic tool to ensure that the code is properly reading the headers and correctly integrating important channel data into the files. Timing discrepancies are also reported in this file to help operators find and correct the issues more easily, rather than having to manually search for them based on the “.png” file image. Adjustments made by the optimizer are also reported in this file. These adjustments are listed by which clickpoint was adjusted, how much it was adjusted by, and the new value of that clickpoint.

C2.5.2.3.5. clickpoints.csv File

Physical clickpoints are logged in the “.csv” files within the component subfolder. These files are generated by PNE2SAC at the same time as miniseed and sac files. This list provides the vectorized clickpoints, allowing for further flexibility in generating a digital waveform from the manual trace. Future researchers can then apply their own interpolation methods if so desired without re-digitalizing the scanned seismogram.

C2.5.2.3.6. .wsp Project File

Files with the extension “.wsp” contain the wavetrack project data for the physical digitization. This file is generated when the digitization process is started and is used to create

the digital waveform. This file incorporates the grid which is used to set the timing and physical scale for the digitization, as well as the manually selected clickpoints placed onto the grid that make up the digitized waveform. This project file is associated with the seismogram scan and is loaded into Wavetrack when digitizing the desired trace.

C2.5.2.3.7. PNE2SAC .txt Input File

Files with the extension “.txt” are the output files from Wavetrack of the digitization. Where the “.wsp” files represent physical digitization data, the “.txt” files contain a raw coordinate output of that physical data. The first column in this file lists the number of seconds beyond the start of the digitization, recorded at the desired sample rate. The second column records the displacement within the grid at that given slice of time. This format allows for the digital waveform to be generated with PNE2SAC by combining time slices into a linear trace.

Channel information is also present in this file allowing for integration into the digital waveform by PNE2SAC. This includes station information such as the station code and network as well as seismogram information such as component, amplification, and time correction. Additionally, GMT information is added to provide a framework for PNE2SAC to convert from a chronologically isolated set of seconds in the raw output to the corresponding real time on the original paper seismogram. The line “REFTIME” lists the date and time in GMT of the first minute mark on the digitization grid. The line “STARTTIME” is the date and time in GMT where the first manual point was selected. This allows PNE2SAC to know when in time to correlate the digitization data while also cutting out time where no signal has been traced from the final output to provide a cleaner file output.

C2.5.2.3.8. QC.DOC file – Quality Control Worksheet

The final file type is “.doc” which represents the quality control sheet for the listed component. The purpose of this document is to amalgamate all relevant seismogram information into one document as well as track the digitization process for a given seismogram component. During the digitization process, this document acts as a checklist for the digitizer when they review their work to ensure parameters are set properly. Then as the waveform passes through the QC process it creates a record of what has been checked and allows future reviewers to potentially locate the source of errors. Once it has been filled in its entirety and the digitization has passed the final QC check, it acts as a reference sheet which confirms that the value of each parameter of the waveform has been verified and provides access to the metadata of the original paper seismogram to limit the need to access additional files. A sample QC worksheet is shown in Appendix E below.

C2.5.2.4. *Archive Folder*

The Archive folder is present in most of the seismogram station folders and contains the original, unmodified scan of the seismogram. The scan sometimes has rotation issues, or needs to be processed (trace merging) in order to be properly digitized. To preserve signal fidelity, the original scan is placed within the archive folder.

APPENDIX D. INFORMATION FOUND ON SEISMOGRAM STAMPS

Soviet seismograms will typically have several stamps on them that provide information about the station, instrumentation, dates, and timing. Typical stamps are depicted below with explanations of their meaning.

D1. Station, Date and Time Block.

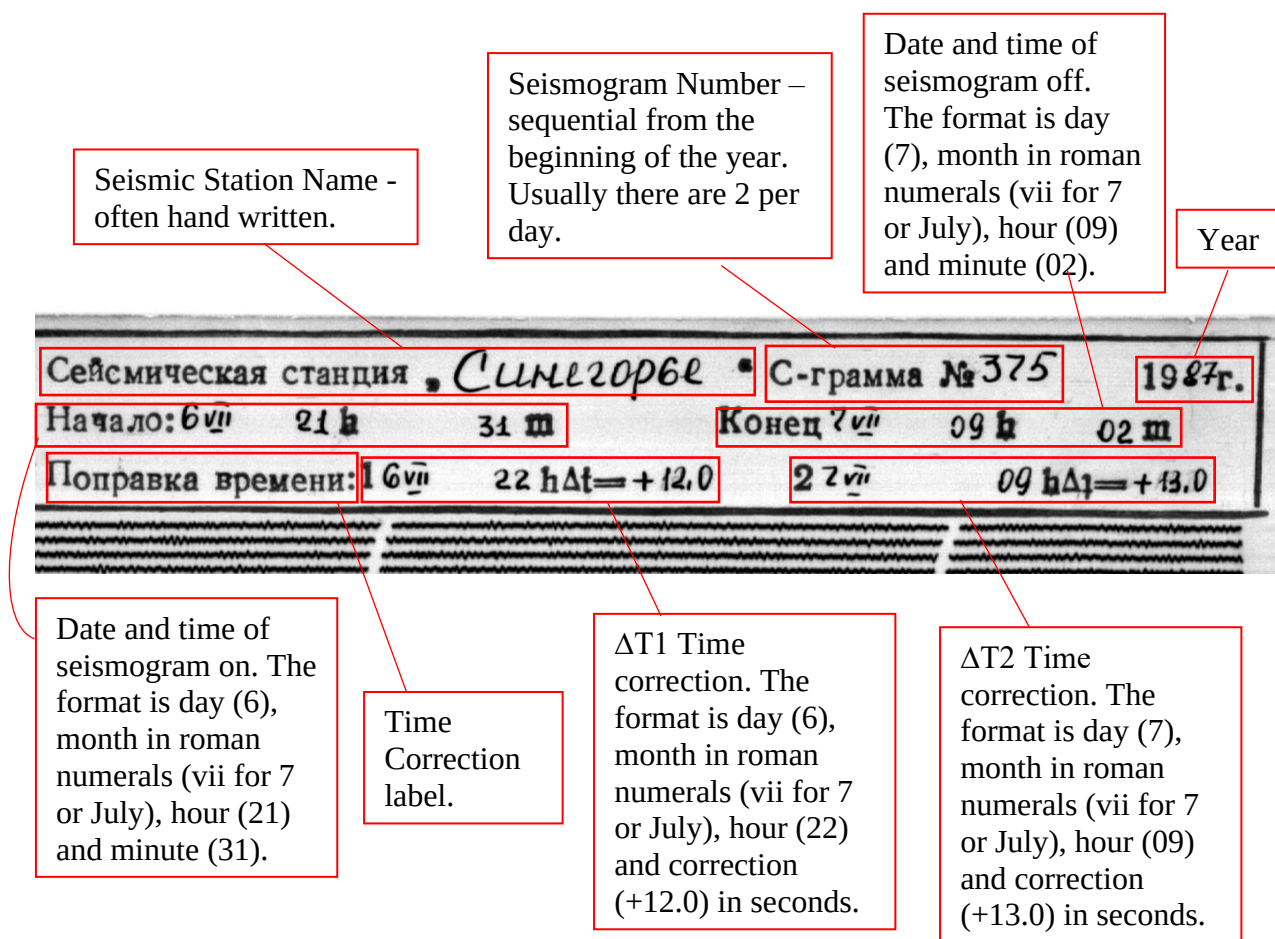


Figure D-1. Explanation of fields in the seismogram basic information stamp.

D2. Seismic Station Name.

This stamp reads **Seismic Station** and the name of the station is in quotes. This is from station "ARSLANBOB"

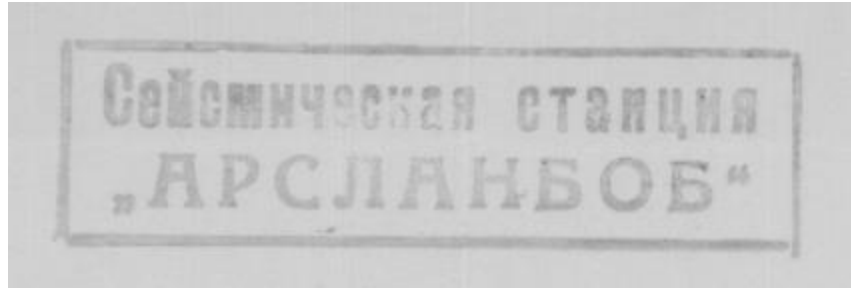


Figure D-2. Example of the seismic station name stamp. This stamp says “Seismic Station Arslanbob”.

D3. Channel Information

In most instances, each channel on a seismogram has a stamp that contains information on the instrument and component. Note that these stamps depict the component orientation using English nomenclature, where N-S is North-South, E-W is East-West, and Z is Vertical. These stamps are usually on the right end of the seismogram off the end of the relevant component. In many cases, the seismogram as digitized used a spliced image to extend the waveform being digitized. This would cover up these stamps. However, the stamps are visible on the original scanned image that is found within the Archive folder of each station digitized. Two stamp examples are shown below:

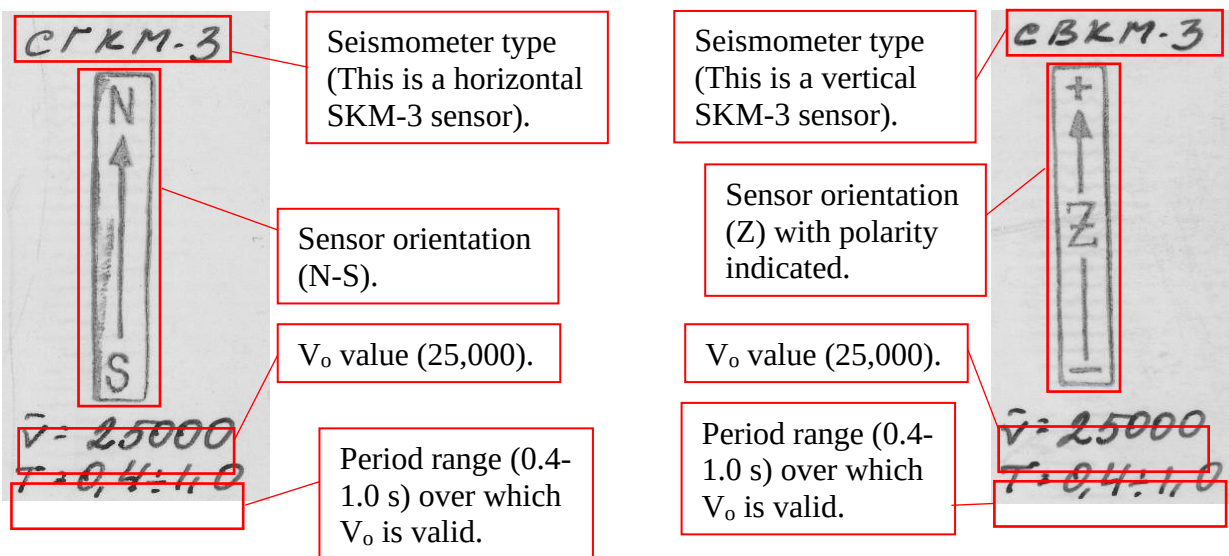


Figure D-3. Explanation of fields in the seismogram component information stamp.

APPENDIX E. QUALITY CONTROL SHEET

Each seismogram digitized in this project was accompanied by a Quality Control (QC) sheet that documented all aspects of the digitization process. The sample below is the QC sheet for the vertical component of station AAK for CHIC36.

MSU DIGITIZATION SHEET			
For use with Wavetrack and PNE2SAC digitizations			
METADATA			
Station	Ala-Archa	Network ID	KRNET
Code	AAK	ISC Station Code	AAK
Date	1990-Aug-16	Event	CHIC 36
Component	EHZ		
SEISMOGRAM DETAILS			
Instrument Type:	SKM	Magnification (CF)	50000
T _m	1.64		
Time Correction # 1: @ Date	Aug-16 03 h	T.C.=	00.0 s
Time Correction # 2: @ Date	Aug-16 06 h	T.C.=	00.0 s
Interpolated Time Correction for event (TC): @ Date	Aug-16 05 h	T.C.=	00.0 s
Signal Polarity:	Positive, N, E ☒	Negative, S, W ☐	VERIFIED ? ☐
Trace Velocity:	120	mm/minute	
SCAN AND IMAGE DETAILS			
Original Resolution (dpi)	600	Image Format	BMP (BMP/TIFF/JPG/PNG)
File Combined from Multiple Images?	☐	If yes, from Multiple Files?	☐ and/or Waveform Extension? ☒
Up Sampled Resolution (dpi)	N/A	Image Format	N/A (BMP/TIFF/JPG/PNG)
Image Rotation = [-]	0.647 °	See Image Processing Guide for calculation	
File Name	CHIC36_Ala-Archa_AAK_KRNETnet_16-Aug-1990_1_SP_Rotated_Extended.bmp (Ns455)		
	CHIC36_Ala-Archa_AAK_KRNETnet_16-Aug-1990_2_SP_Rotated_Extended.bmp (Ns455a)		
Scan Condition and Image Processing Notes			
Image rotated on -0.647°.			
Scan is good quality and the waveform is very clear.			
Seismic event are included in 2 separate images (seismogram Ns455, 455a)			
Image Processed By	Omukeyeva Baktygul	DATE	2023-Mar-22
WAVETRACK PASS #1			
Digitized Trace Start time (REFTIME)	04:58:00.000 (Part1);05:05:00.000 (Part2);		
MSEED Export Start time (STARTTIME)	05:01:00.000 (Part1); 05:05:00.000 (Part2);		
Template used	600dpi_7min (Part1,Part2)	Amplitude Interval	0-28
Resampling Interval	0.01	(seconds)	
File Component	EHZ (HHZ, HHN, HHE, etc.)		
.wsp file name	CHIC36_Ala-Archa_AAK_KRnet_16-Aug-1990_1_SP_600_Rotated_Extended_EHZ_Part1; CHIC36_Ala-Archa_AAK_KRnet_16-Aug-1990_1_SP_600_Rotated_Extended_EHZ_Part2;	Export file name	CHIC36_Ala-Archa_AAK_KRnet_16-Aug-1990_1_SP_600_Rotated_Extended_EHZ_Part1_0-420.txt; CHIC36_Ala-Archa_AAK_KRnet_16-Aug-1990_1_SP_600_Rotated_Extended_EHZ_Part2_0-120.txt
DIGITIZED BY	Kiselev Evgeniy	DATE	2023-Aug-16
EDIT EXPORT FILE (to prepare file for PNE2SAC conversion – Record actual header information here)			
STATION	AAK		
NETWORK	KR		
COMPONENT	EHZ		
CF(from above)	50000		
TC(Time Correction from above)	00.0s		
REFTIME(from above)	04:58:00.000 (Part1);05:05:00.000 (Part2);		
STARTTIME(from above)	05:01:00.000 (Part1); 05:05:00.000 (Part2);		
COMMENT	The amplitudes of Z component is out of tape edge.		
EXPORT EDITED BY	Kiselev Evgeniy	DATE	2023-Aug-16
PNE2SAC Conversion			
.log file name	CHIC36_Ala-Archa_AAK_KRnet_16-Aug-1990_1_SP_600_Rotated_Extended_EHZ_Part1_0-420.log; CHIC36_Ala-Archa_AAK_KRnet_16-Aug-1990_1_SP_600_Rotated_Extended_EHZ_Part2_0-120.log;	.mseed file name	KR.AAK.02.EHZ.1990.08.16.05.01.00_Part1.mseed KR.AAK.02.EHZ.1990.08.16.05.05.00_Part2.mseed
All time discrepancies repaired?	☒		

Turn Page Over

Last Updated 2020-08-11(PM)

Station Name **AAK** Component **EHZ** Seismogram Time & Date **03h:03m 1990-Aug-16_05h:06m 1990-Aug-16**

Wavetrack .wsp file edited & re-exported ☒

PNE2SAC discrepancy graph file name **KR.AAK.02.EHZ.1990.08.16.05.01.00_Part1.png** **KR.AAK.02.EHZ.1990.08.16.05.05.00_Part2.png**

.mseed file checked for asymmetry in DIMAS ☒

Event arrival time from paper seismogram **05:02:32.3** GMT

Event arrival time from Miniseed file **05:02:32.169** GMT Do they match? ☐

CONVERTED BY **Kiselev Evgeniy** DATE **2023-Aug-16**

WAVETRACK PASS # 2 (Second Person Edit)

.mseed file checked for waveform and asymmetry in DIMAS? ☒

Are discrepancies found? ☐ Comment:

Wavetrack .wsp file edited & re-exported ☒ If Yes, Why?

Correction of amplitude peaks.

File: CHIC36_Ala-Archa_AAK_KRnet_16-Aug-1990_1_SP_600_Rotated_Extended_EHZ_Part1.wsp;

CHIC36_Ala-Archa_AAK_KRnet_16-Aug-1990_1_SP_600_Rotated_Extended_EHZ_Part2.wsp;

Export file: CHIC36_Ala-Archa_AAK_KRnet_16-Aug-1990_1_SP_600_Rotated_Extended_EHZ_Part1_0-420.txt;

CHIC36_Ala-Archa_AAK_KRnet_16-Aug-1990_1_SP_600_Rotated_Extended_EHZ_Part2_0-120.txt;

Final .log file **CHIC36_Ala-Archa_AAK_KRnet_16-Aug-1990_1_SP_600_Rotated_Extended_EHZ_Part1_0-420.log;**
CHIC36_Ala-Archa_AAK_KRnet_16-Aug-1990_1_SP_600_Rotated_Extended_EHZ_Part2_0-120.log;

Final .mseed file name **CHIC36_Ala-Archa_AAK_KRnet_16-Aug-1990_1_SP_600_Rotated_Extended_EHZ.mseed**

Final PNE2SAC discrepancy graph file name **CHIC36_Ala-Archa_AAK_KRnet_16-Aug-1990_1_SP_600_Rotated_Extended_EHZ.png**

Quality of digitization **good**

Event arrival time from paper seismogram **05:02:32.3** GMT

Event arrival time from Miniseed file **05:02:32.169** GMT Do they match? ☐

QC CHECK BY **Sokolova Nadejda** DATE **2023-Aug-22**

FINAL QC

Is recorded information from seismogram accurate ☒ Comment **Accurate**

Is the Scan of seismogram of good quality at maximum DPI? ☒ Comment **600 dpi**

Did PNE2SAC export .mseed waveform with no errors or time discrepancies? ☒ Comment **No errors**

Does .mseed file arrival time match the original paper seismogram? ☐ Comment **No, it differs by 0.031 s.**

Does .mseed station name comply with ISC station code name? ☒ ISC station code name **AAK**

Does .mseed channel name comply with FDSN/IRIS naming standards? ☒ Channel name **EHZ**

WAVEFORM QUALITY

On scale of 1(poor) to 5(excellent, none observed), how bad is the skew? **5** require re-editing? ☐

How accurately does Waveform reflect the original seismogram in shape and amplitude? **good**

COMMENTS:

QC [**PASS** / FAIL]

Final QC performed by **Nikitenko Tatiana** Dat **2023-Aug-22**

APPENDIX F. ORIGINAL TECHNIQUE OF TIME DETERMINATION

The original analysis of the photopaper seismograms was primarily graphical. This presented challenges when determining time corrections as well as selecting arrival times, particularly when the rotation speed of the recording drum and thus length of a recorded minute was variable. This was made easy with the use of a graphical template that was configured to allow the reading of times for when the length of a minute varied. The template could be moved up and down on the seismogram to correct for slight variations in the length of a minute due to changes in the drum rotation speed. Figure F1 shows the template configuration. Figure F2 illustrates the use of the template on the Figure 30 image and the determination of the illustrated +13.0 s time correction. The 1 second intervals between the time correction pulses are also apparent. Note that this example shows that the minute under measurement is less than the nominal 60 mm in length.

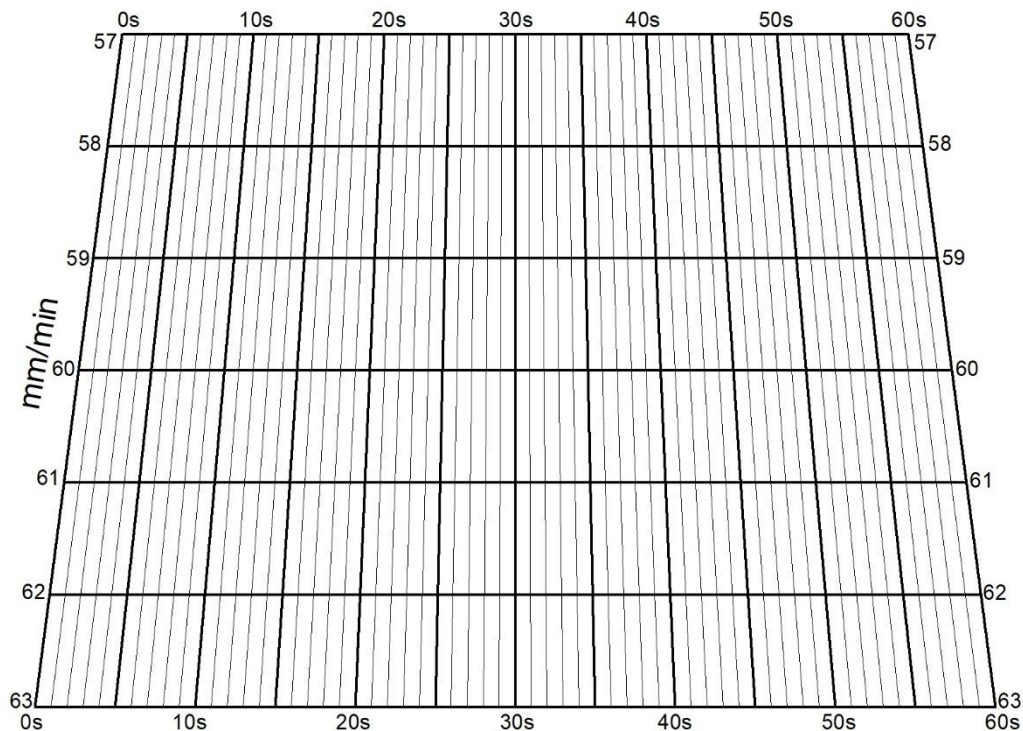


Figure F1. Template configuration used for the determination of times on Soviet photopaper seismograms.

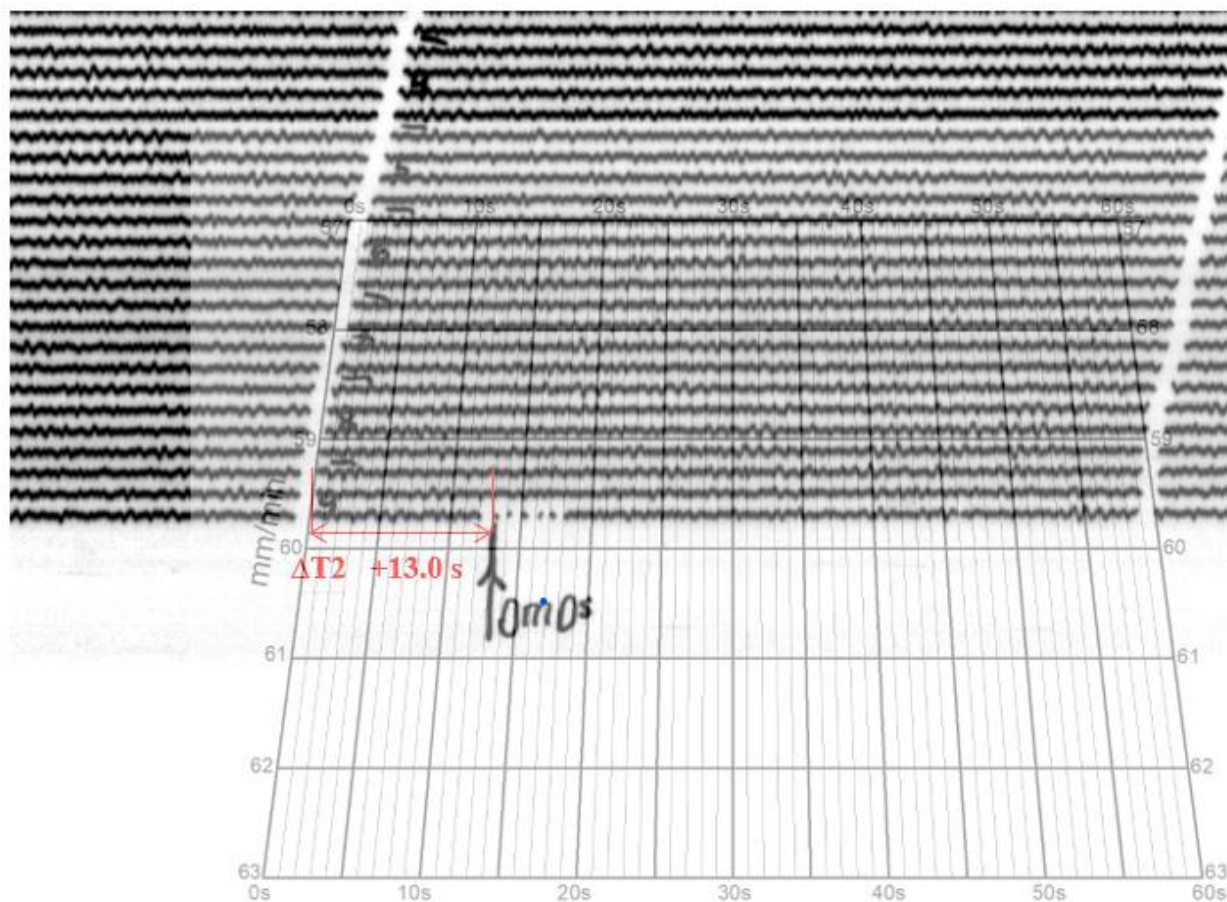


Figure F2. Illustration of the use of the template to determine time on a seismogram where the length of a minute is variable. The edges of the template are aligned with beginning of two consecutive minute marks, which corrects for the length. Seconds can be determined from the X axis. This example overlays the time correction image from Figure 30 and verifies the original $\Delta T2$ time correction of +13.0 s. This seismogram reads right to left.

APPENDIX G. PROTOCOL OF INTENTS DRAFTED BY THE SEISMIC CALIBRATION WORKING GROUP AT THE WORKSHOP IN ALMATY, KAZAKHSTAN, 28-29 MARCH, 2023.

Draft

Protocol of Intent

From the seismic calibration working group “Seismic calibration experiments in Eurasia – Past, Present and Future”, Almaty, Kazakhstan, March 28-29, 2023.

We, the participants from Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Mongolia, Tajikistan, Ukraine, and United States agree on the following

1. Seismologists work to understand the tectonic setting and processes occurring in the earth crust and mantle determining the seismic hazard. The important part of this work is installation and operation of seismic stations and networks, processing of its data for the accurate location of events and measurement of its size (strength). The results of seismic stations data processing are used in different sections of seismology including assessment of seismic hazard and seismic risk, discrimination between the earthquakes and explosions, study of velocity models and deep Earth structure.

To do our job, we collect and process data from our respective seismological stations and networks, compile seismic bulletins and earthquakes catalogues. The quality of our work depends on our ability to accurately process the data that we collect that, in turn, requires the detailed calibration of our seismic networks. The earthquakes do not respect political boundaries. An event occurred in one country is recorded by the stations of different countries. As such, the calibration of one seismic network requires data from adjoining regions. Because of this, we as an international group of seismologists express the need to improve the calibration of our respective seismological networks.

2. The following are the calibration needs:

- Calibration of travel-times on all possible paths to allow better location of seismic events;
- creation of Source Specific Station Corrections (SSSCs, source – seismic station) for each station and seismic array;
- Calibration of amplitude and attenuation models to allow the calculation of accurate magnitudes;
- Calibration of event back azimuth to improve location of events when using seismic arrays;
- calibration of stations on the seismic noise level to calculate the threshold magnitude level of detected seismic events at different distances.

3. Calibration can be conducted using the following:

- new calibration experiments;
- available materials from archives of historical seismograms;
- data records of mining and other industrial blasts, ground-truth earthquakes.

Calibration using new calibration experiments.

With no doubts, for new calibration experiments it is possible to plan the installation of temporary seismic stations at places selected for the investigation, create necessary configuration of networks to solve the set tasks on constructing travel-time curves, study of attenuation etc.

Need and reasons for new experiments are as follows:

- Historic events and other sources are not sufficient
- To calibrate new seismic infrastructure
- To allow an accurate assessment of seismic risk at a local, regional, and national level

Note that we are aware that the calibration experiment is a difficult, finance consuming activity. It should be supported by the national structures to ensure the safety of population and infrastructure, and environment protection.

Calibration using existing archive materials and contemporary commonly available sources:

For this purpose, historic materials of different seismological organizations from different countries that were not originally used for seismic calibration purposes can be used.

Data Types:

- Industrial explosions
- PNEs and other nuclear tests
- Reference Earthquakes

The approach to use the historical materials should be developed:

- criteria for event selection as reference;

Create a consolidated and comprehensive database of reference events to include seismograms, seismic bulletins, events metadata, stations metadata, data processing for calibration.

Commonly available seismic sources are quarry, mine, research, construction explosions.

The approach to use commonly available sources for calibration should be developed.

- Criteria to select events as calibration;
- Create a database of potential sources;
- Acquisition and evaluation of each source parameters (origin time by nearby station, data on explosion location, its yield etc. independently on seismic calculation);
- Record signals on temporary and permanent stations;
- Creation of seismic bulletins by all stations recorded the event;
- Collection of events metadata;
- Collection of stations metadata;
- Data processing for calibration.

Process data for calibration purposes

Resuming the workshop work, we, the workshop participants, hope that the first meeting will allow for further proposals on new joint projects on seismic networks calibration in Eurasia aimed at improving the seismic data quality.