SnT 2019 NUCLEAR TESTS AT THE PUNGGYE-RI TEST SITE ACCORDING TO THE KNET NETWORK DATA

CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

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In September 1991, a modern digital telemetric network of seismic stations KNET was installed on the territory of Kyrgyzstan and Kazakhstan. At present it includes 10 stations, transmitting data in real time mode to the Institute of Seismology of the National Academy of Sciences of Kyrgyz Republic (IS NAS KR) and the Research Station of the Russian Academy of Sciences (RS RAS) (Table 1, Figure 1).

Seismic stations of the KNET network are equipped with three-component broadband sensors STS2 and digitizers REFTEK-72 A. The sample rate is 40 Hz for BHZ, BHE, BHN channels, 100 Hz for HHZ, HHE, HHN channels and 1 Hz for LHZ, LHE, LHN channels. Figure 2 shows their instrument responses.

Data of the KNET network is used by regional and international seismological centers for the compilation of bulletins of seismic events of various nature and scientific research. During the long period of its operation, practically 30 years, the KNET network recorded nuclear tests on regional and teleseismic distances conducted at the Test Sites: Nevada, Mururoa and Fangataufa, Lop Nor, Pokharan, Chagay and Punggye-ri.

The North Korean nuclear test site Punggye-ri is located at teleseismic distances from the KNET network, with range of distances 4302-4513 km, and the range of azimuths to the epicenter 71.78°-73.53° (Figure 3).

Table 1. KNET stations parameters.

Station	Code	Date of installation	Date of closing	φ°	λ°	h
Ala-Archa	AAK	01.09.1991		42.6333	74.4944	1680
Alma-Ashu	AML	07.09.1991		42.1311	73.6941	3400
Belogorka	BGK2	01.09.1991	11.09.1993	42.6451	74.2274	1640
Chumysh	CHM	01.09.1991		42.9986	74.7513	655
Erkin-Say	EKS2	01.09.1991		42.6615	73.7772	1360
ERPT	ERPT	08.08.1999	14.06.2000	42.6011	76.0735	3790
Karagay-Bulak	KBK	01.09.1991		42.6564	74.9478	1760
Kyzart	KZA	01.09.1991		42.0778	75.2496	3520
NRPT	NRPT	08.08.1999		42.6011	76.0735	3790
Tokmak	TKM	01.09.1991	30.08.1994	42.8601	75.3184	960.0
Tokmak2	TKM2	20.09.1994		42.9208	75.5966	2020
Uchtor	UCH	11.09.1991		42.2275	74.5134	3850
Ulahol	ULHL	11.09.1994		42.2456	76.2417	2040
Uspenovka	USP	01.09.1991		43.2669	74.4997	740.0

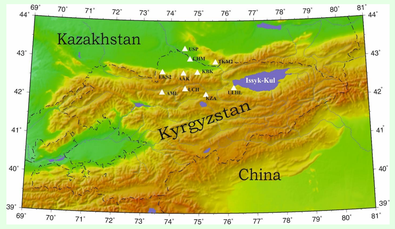


Figure 1. Map of KNET stations location.

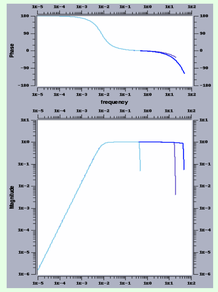


Figure 2. KNET stations responses.

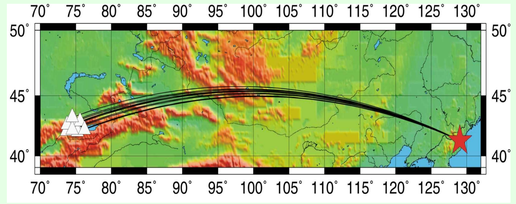


Figure 3. Location of KNET seismic stations and nuclear explosion of September 3, 2017.

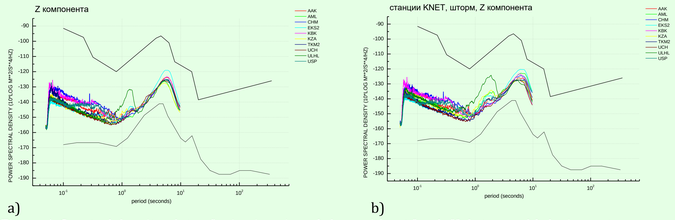
There are many factors which influence on the efficiency of seismic event recordings: seismic equipment parameters, station installation conditions, the geological structure, the presence of anthropogenic noises, remoteness of the oceans and seas, etc. At the KNET stations, the sensitive equipment with minimum level of instrument noise is installed. Stations are located far from the oceans and anthropogenic noises, at the outcrops of the bedrock. Most part of these one are installed in the tunnels. Figure 4a shows the spectral density plots of seismic noises of KNET stations during night time, they are close to the lower-level Peterson model .

However, the level of seismic noise for stations located in the Northern Tien Shan region is significantly affected by standing waves generated by the Issyk-Kul lake during storms. Such influence can be traced over a large area, right up to the Karatau (IGR RK) station, located on 400 km from the lake. KNET stations are located in a range of distances from 15 km (ULHL) to 200 km (AML). The spectral density plots of seismic noise for the days without Issyk-Kul lake storms and during storms are presented on the Figure 4. It is seen that for the ULHL station, the influence of the Issyk-Kul lake is observed at any time as a peak in the range of 0.7 - 1.9 s. During storms, the peak in the 0.7-2.3 s period range increases for most stations of the network.

Figure 5 shows the spectrum of P-waves of the North Korean nuclear test of January 1, 2016. It is clear that the spectrum of the explosion is limited by frequencies of 0.8-2.2 Hz (0.45-1.25 s), which related to the storm microseism periods generated by the Issyk-Kul lake. Therefore, the seismic effect of the North Korean nuclear explosions for KNET stations can be reduced during storms on the lake, and permanently for the ULHL station, which is located close to the lake, and for the best signals picking the using of narrowband filtering is necessary.

Figure 6 demonstrates the seismograms of the North Korean nuclear tests according to the KNET stations for the period of 2006-2017. Figure 6a presents a seismogram of the nuclear test on October 9, 2006. The event was weak, hardly picking at the background level after filtering. North Korean nuclear tests of 2009-2016 are picking well on the KNET network records after filtering, the seismic phases P, PP, PcP can be defined. Figure 6d demonstrates the seismogram of nuclear test of September 3, 2017, where the seismic phases P, PP, PcP, LQ and LR are well defined at all stations.

KNET data were used by various seismological agencies (ISC, USGS, GS RAS, EMSC, KNDC of IGR RK) for determination of the nuclear explosions parameters. In spite of the teleseismic distance of the explosions and KNET location in a narrow azimuth range according to the source (Figure 3), and the absence of seismic arrays in the network, the localization of the seismic event of September 3, 2017 was done urgently. Of course, the accuracy of localization was worse than for global seismic networks (Table 2), however, for an operative evaluation of the affiliation to the test site, time in the source and magnitude of the event, the result is not bad.



a) b)

Figure 4. Spectral density plots of seismic noise: a) days without Issyk-Kul storms; b) during a storm.

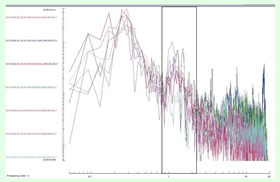
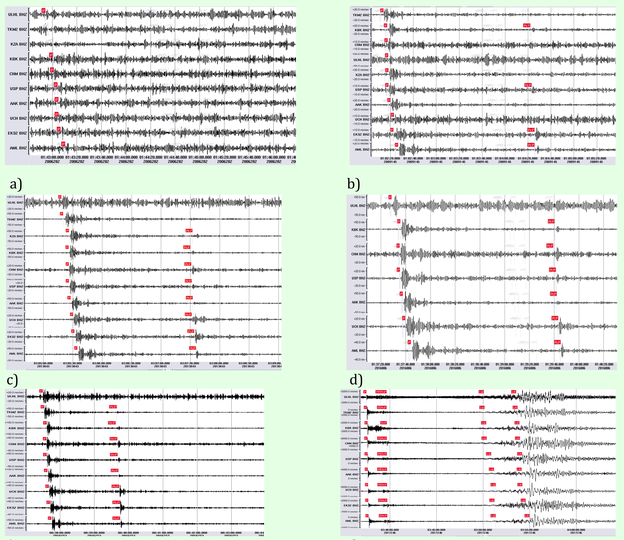


Figure 5. Spectrums of North Korean nuclear test of January, 1, 2016.



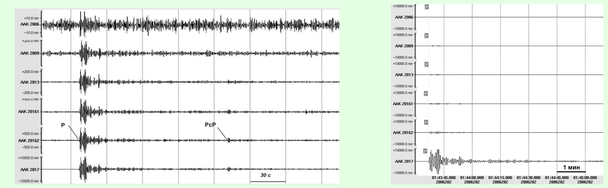
a) b) c) d) e) f)

Figure 6. Seismograms of North Korean nuclear tests according to the KNET stations records: a) October 9, 2006; b) May 25, 2009; c) February 12, 2013; d) January 6, 2016; e) September 9, 2016, filter 1.25 Hz; f) September 3, 2017 without filter. Z-component.

Table 2. Parameters of the North Korean nuclear test of September 3, 2017, according to the data of various seismic networks.

Date	Time in the source	Latitude	Longitude	mb	Ms	ML	Number of stations	Agency
2017/09/03	03:29:59	41.3000	129.1000	6.3			28	GS RAS
2017/09/03	03:30:01.1	41.3205	129.0349	6.1	4.9	5.2	189	IDC
2017/09/03	03:30:01.8	41.332	129.030	6.3	5.1		323	USGS
2017/09/03	03:30:03.4	41.3400	129.0700	5.7			30	GFZ
2017/09/03	03:29.59.5	41.0225	129.4348	6.0			7	KNET

Figure 7 presents the seismograms of six North Korean nuclear tests recorded by the AAK station (KNET) and normalized according to the maximum amplitude. It can be seen that the seismograms of all explosions are similar according to their waveforms, however, there is big difference in amplitude values.



a) b)

Figure 7. Seismograms of North Korean nuclear tests according to the AAK station records (top-down records: October 9, 2006; May 25, 2009; February 12, 2013; January 6, 2016; September 9, 2016; September 3, 2017). Z-component. Filter is 1.25 Hz. a) normalized according to the maximum of amplitudes; b) real scale.

In connection with this, amplitudes and periods for all records of explosions recorded by the KNET stations were measured, and mb magnitudes were calculated. Table 3 presents the results of magnitude measurements for each station, as well as the difference of station magnitudes with the magnitude of the NEIC catalog (USGS) and the average magnitude of the KNET network.

All magnitudes of the KNET stations have understated estimates with respect to NEIC (USGS) values, which can be explained by several facts (using the SKM filter for amplitude measurements, station conditions, amplitude attenuation at the trace of Punggye-ri - station). Figure 8 demonstrates the mb magnitudes of the North Korean nuclear tests according to the KNET data. The mb magnitudes according to the KNET network and the USGS data (USA) are presented in the Table 4. The mb magnitudes on the KNET network have understated estimates in average on 0.5 in comparison with the USGS values.

Table 3. Magnitudes of the North Korean nuclear tests according to the KNET data.

Time in the source	Station	Δ	mb_{AAK}	mb_{AAK} - mb	mb_{KNET} - mb	Time in the source	Station	Δ	mb_{AAK}	mb_{KNET} - mb	mb_{KNET} - mb
2006-10-09 01:35:28.0	AAK	4433	3,62	0,68	0,06	2016-01-06 01:30:01.5	AAK	4429	4,67	0,43	-0,15
2006-10-09 01:35:28.0	AML	4513	3,68	0,62	0,00	2016-01-06 01:30:01.5	AML	4509	4,7	0,40	-0,18
2006-10-09 01:35:28.0	CHM	4401	3,81	0,49	-0,13	2016-01-06 01:30:01.5	CHM	4397	4,41	0,69	0,11
2006-10-09 01:35:28.0	EKS2	4488	3,56	0,74	0,12	2016-01-06 01:30:01.5	KBK	4393	4,73	0,37	-0,21
2006-10-09 01:35:28.0	KBK	4397	3,66	0,64	0,02	2016-01-06 01:30:01.5	UCH	4441	4,4	0,70	0,12
2006-10-09 01:35:28.0	KZA	4393	3,96	0,34	-0,28	2016-01-06 01:30:01.5	ULHL	4305	4,65	0,45	-0,13
2006-10-09 01:35:28.0	TKM2	4338	3,73	0,57	-0,05	2016-01-06 01:30:01.5	USP	4408	4,38	0,72	0,14
2006-10-09 01:35:28.0	UCH	4445	3,35	0,95	0,33	2016-09-09 00:30:01.4	AAK	4432	4,89	0,41	-0,17
2006-10-09 01:35:28.0	ULHL	4309	3,81	0,49	-0,13	2016-09-09 00:30:01.4	AML	4512	4,93	0,37	-0,21
2006-10-09 01:35:28.0	USP	4412	3,6	0,70	0,08	2016-09-09 00:30:01.4	CHM	4400	4,65	0,65	0,07
2009-05-25 00:54:43.1	AAK	4428	4,42	0,28	-0,06	2016-09-09 00:30:01.4	EKS2	4487	4,55	0,75	0,17
2009-05-25 00:54:43.1	AML	4508	4,27	0,43	0,09	2016-09-09 00:30:01.4	KBK	4396	5,01	0,29	-0,29
2009-05-25 00:54:43.1	CHM	4397	4,28	0,42	0,08	2016-09-09 00:30:01.4	TKM2	4337	4,68	0,62	0,04
2009-05-25 00:54:43.1	EKS2	4483	4,25	0,45	0,11	2016-09-09 00:30:01.4	UCH	4444	4,55	0,75	0,17
2009-05-25 00:54:43.1	KBK	4392	4,49	0,21	-0,13	2016-09-09 00:30:01.4	ULHL	4308	4,45	0,85	0,27
2009-05-25 00:54:43.1	KZA	4388	4,4	0,30	-0,04	2016-09-09 00:30:01.4	USP	4411	4,74	0,56	-0,02
2009-05-25 00:54:43.1	TKM2	4333	4,44	0,26	-0,08	2017-09-03 03:30:01.8	AML	4506	5,98	0,32	-0,09
2009-05-25 00:54:43.1	UCH	4441	4,28	0,42	0,08	2017-09-03 03:30:01.8	AAK	4427	6,09	0,21	-0,20
2009-05-25 00:54:43.1	ULHL	4304	4,62	0,08	-0,26	2017-09-03 03:30:01.8	ULHL	4303	5,83	0,47	0,06
2009-05-25 00:54:43.1	USP	4408	4,19	0,51	0,17	2017-09-03 03:30:01.8	TKM2	4331	5,63	0,67	0,26
2013-02-12 02:57:51.5	AAK	4426	4,8	0,30	-0,12	2017-09-03 03:30:01.8	KBK	4391	6,16	0,14	-0,27
2013-02-12 02:57:51.5	AML	4506	4,8	0,30	-0,12	2017-09-03 03:30:01.8	CHM	4395	6,1	0,20	-0,21
2013-02-12 02:57:51.5	CHM	4394	4,58	0,52	0,10	2017-09-03 03:30:01.8	USP	4406	5,78	0,52	0,11
2013-02-12 02:57:51.5	EKS2	4481	4,43	0,67	0,25	2017-09-03 03:30:01.8	UCH	4439	5,6	0,70	0,29
2013-02-12 02:57:51.5	KBK	4390	4,92	0,18	-0,24	2017-09-03 03:30:01.8	EKS2	4482	5,87	0,43	0,02
2013-02-12 02:57:51.5	KZA	4385	4,78	0,32	-0,10						
2013-02-12 02:57:51.5	TKM2	4331	4,78	0,32	-0,10						
2013-02-12 02:57:51.5	UCH	4438	4,52	0,58	0,16						
2013-02-12 02:57:51.5	ULHL	4302	4,51	0,59	0,17						
2013-02-12 02:57:51.5	USP	4405	4,65	0,45	0,03						

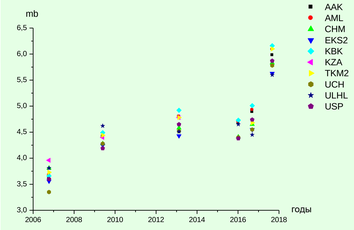


Figure 8. Mb magnitudes of the North nuclear tests according to the KNET data.

Table 4. Mb magnitudes of the North Korean nuclear tests according to the KNET and USGS data.

Date of explosion	mb (USGS)	mb(KNET)	mb (USGS) - $mb_{(KNET)}$
2006-10-09	4,3	3,7	0,6
2009-05-25	4,7	4,4	0,3
2013-02-12	5,1	4,7	0,4
2016-01-06	5,1	4,5	0,6
2016-09-09	5,3	4,7	0,6
2017-09-03	6,3	5,9	0,4

CONCLUSION

1. All six North Korean nuclear tests of 2006-2017 were successfully recorded by the KNET network at the teleseismic distances.
2. Mb magnitudes according to the KNET data have understated estimates in average on 0.5 in comparison with the NEIC USGS data.
3. It is necessary to conduct the work on the identification of azimuthal magnitude corrections for KNET stations for improvement of the quality of the catalogs of Kyrgyzstan and Central Asia.

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