EVALUATION OF A SEISMIC EVENT, 12 MAY 2010, IN NORTH KOREA

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for presentations in October, 2015

From Lars-Erik De Geer, published in 2012:

Figure 1: The Korean peninsula seen from northwest and the stations where radioxenon and radioxenon daughters were detected in mid-May 2010 (color figure available online).

Table 1: Xenon and barium isotopes detected at Geojin, Takasaki, Okinawa and Ussuriysk in May 2010. The hours, upper levels and uncertainties at Geojin are given in italics to indicate that they are estimates based on good experience from similar SAUNA spectra. Uncertainties are given for k = 1 and upper levels are based on a risk level for first kind errors of 5 percent. All concentrations refer to an assumed constant value during the collection time, which is the standard way adopted by the CTBTO[23]

Station	Collection start UTC	Collection stop UTC	^{131m}Xe mBq/m^3	^{133m}Xe mBq/m^3	^{133}Xe mBq/m^3	^{135}Xe mBq/m^3	^{140}Ba $\mu Bq/m^3$
Geojin	13 May *11:00*	13 May *23:00*	*<0.2*	*<0.2*	2.45 ± *0.2*	10.01 ± *0.6*	
Takasaki	15 May 06:46	15 May 18:46	<0.02	<0.06	<0.10	<0.61	
Takasaki	15 May 18:46	16 May 06:46	0.04 ± 0.03	<0.09	0.16 ± 0.07	<0.57	
Takasaki	16 May 06:46	16 May 18:46	0.05 ± 0.03	<0.08	0.23 ± 0.06	<0.47	
Takasaki	16 May 18:46	17 May 06:46	0.16 ± 0.07	<0.09	1.49 ± 0.11	<0.20	
Takasaki	17 May 06:46	17 May 18:46	<0.04	<0.05	0.52 ± 0.07	<0.06	
Takasaki	17 May 18:46	18 May 06:46	<0.11	0.10 ± 0.06	0.79 ± 0.09	<0.58	
Takasaki	18 May 06:46	18 May 18:46	0.06 ± 0.03	<0.02	<0.10	0.42 ± 0.23	
Takasaki	18 May 18:46	19 May 06:46	<0.07	<0.05	0.18 ± 0.06	<0.52	
Okinawa	15 May 00:23	16 May 00:23					81.9 ± 3.6
Okinawa	16 May 00:23	17 May 00:23					22.7 ± 2.2
Okinawa	17 May 00:23	18 May 00:23					27.5 ± 2.2
Okinawa	18 May 00:23	19 May 00:23					28.1 ± 2.3
Okinawa	19 May 00:23	20 May 00:23					50.8 ± 2.9
Okinawa	20 May 00:23	21 May 00:23					43.8 ± 2.8
Okinawa	21 May 00:23	22 May 00:23					5.2 ± 1.6
Okinawa	22 May 00:23	23 May 00:23					5.0 ± 1.5
Ussuriysk	15 May 01:44	16 May 01:44					4.1 ± 1.4
Ussuriysk	16 May 01:44	17 May 01:40					<15
Ussuriysk	17 May 01:40	18 May 01:40					12.2 ± 2.3
Ussuriysk	18 May 03:44	19 May 01:49					5.3 ± 1.6

De Geer wrote (his page 15):

"The May 2010 test was not detected by any seismic station or network and must therefore have been quite low-yield (less than 50 ton TNT equivalent or possibly up to some 200 ton if some decoupling is assumed)."

(this conclusion, was based on advice received via a phone call to NORSAR…)

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Routledge
Taylor & Francis Group

Seismological Constraints on Proposed Low-Yield Nuclear Testing in Particular Regions and Time Periods in the Past, with Comments on "Radionuclide Evidence for Low-Yield Nuclear Testing in North Korea in April/May 2010" by Lars-Erik De Geer

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We have attempted to detect seismic signals from small explosions in North Korea on five specific days in 2010 that feature in scenarios proposed by De Geer. We searched the seismic data recorded by station MDJ in northeastern China, applying three-component cross-correlation methods using signals from known explosions as templates. We assess the capability of this method of detection, and of simpler methods, all of which failed to find seismic signals that would be expected if De Geer's scenarios were valid. We conclude that no well-coupled underground explosion above about a ton occurred near the North Korea test site on these five days and that any explosion would have to be very small (local magnitude less than about 2) to escape detection.

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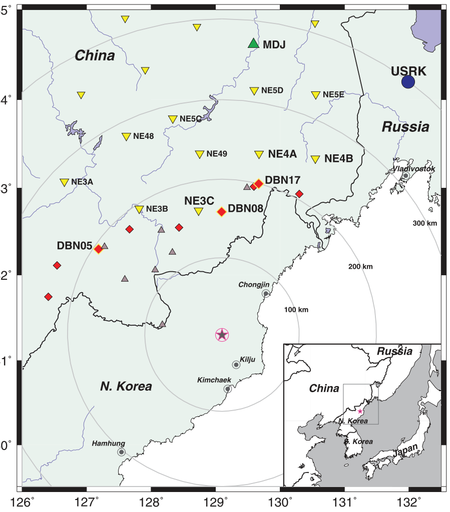
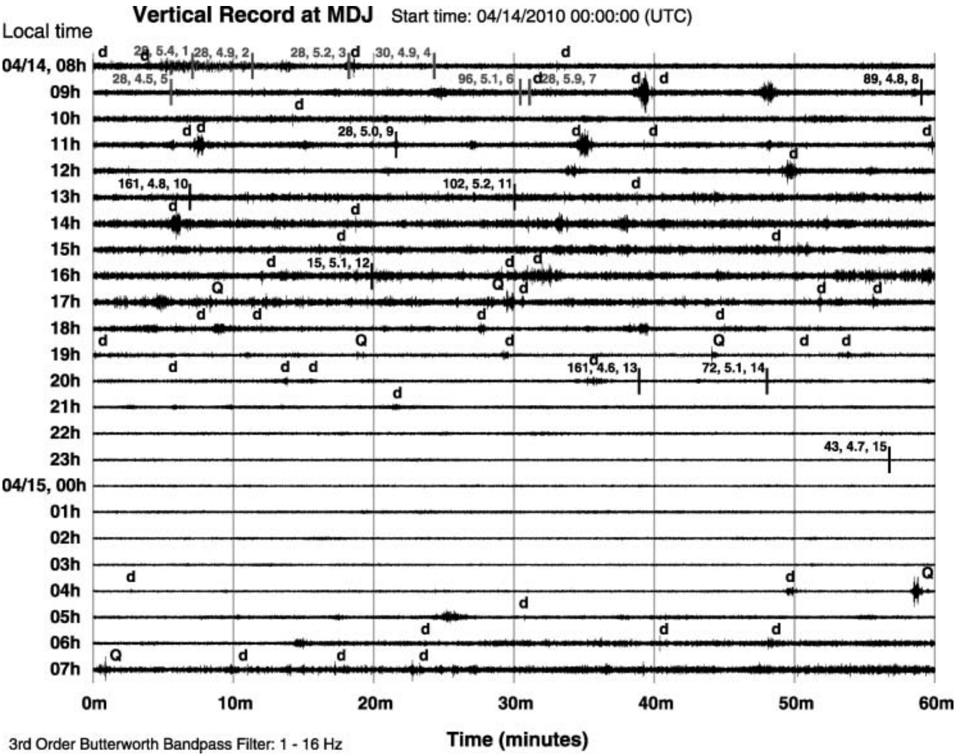


126° 127° 128° 129° 130° 131° 132°
45° 44° 43° 42° 41° 40°
China
MDJ
USRK
Russia
NE5D
NE5E
NE5C
NE48
NE49
NE4A
NE4B
NE3A
Vladivostok
DBN17
NE3C
DBN08
NE3B
300 km
DBN05
200 km
Chongjin
100 km
Kilju
Kimchaek
N. Korea
Hamhung
Russia
China
N. Korea
S. Korea
Japan



Vertical Record at MDJ
Start time: 04/14/2010 00:00:00 (UTC)
Local time
04/14, 08h
09h
10h
11h
12h
13h
14h
15h
16h
17h
18h
19h
20h
21h
22h
23h
04/15, 00h
01h
02h
03h
04h
05h
06h
07h
28, 5.4, 1
28, 4.9, 2
28, 5.2, 3
30, 4.9, 4
28, 4.5, 5
96, 5.1, 6
28, 5.9, 7
89, 4.8, 8
28, 5.0, 9
161, 4.8, 10
102, 5.2, 11
15, 5.1, 12
161, 4.6, 13
72, 5.1, 14
43, 4.7, 15
0m
10m
20m
30m
40m
50m
60m
Time (minutes)
3rd Order Butterworth Bandpass Filter: 1 - 16 Hz

The main conclusions of our analysis in 2012 were that

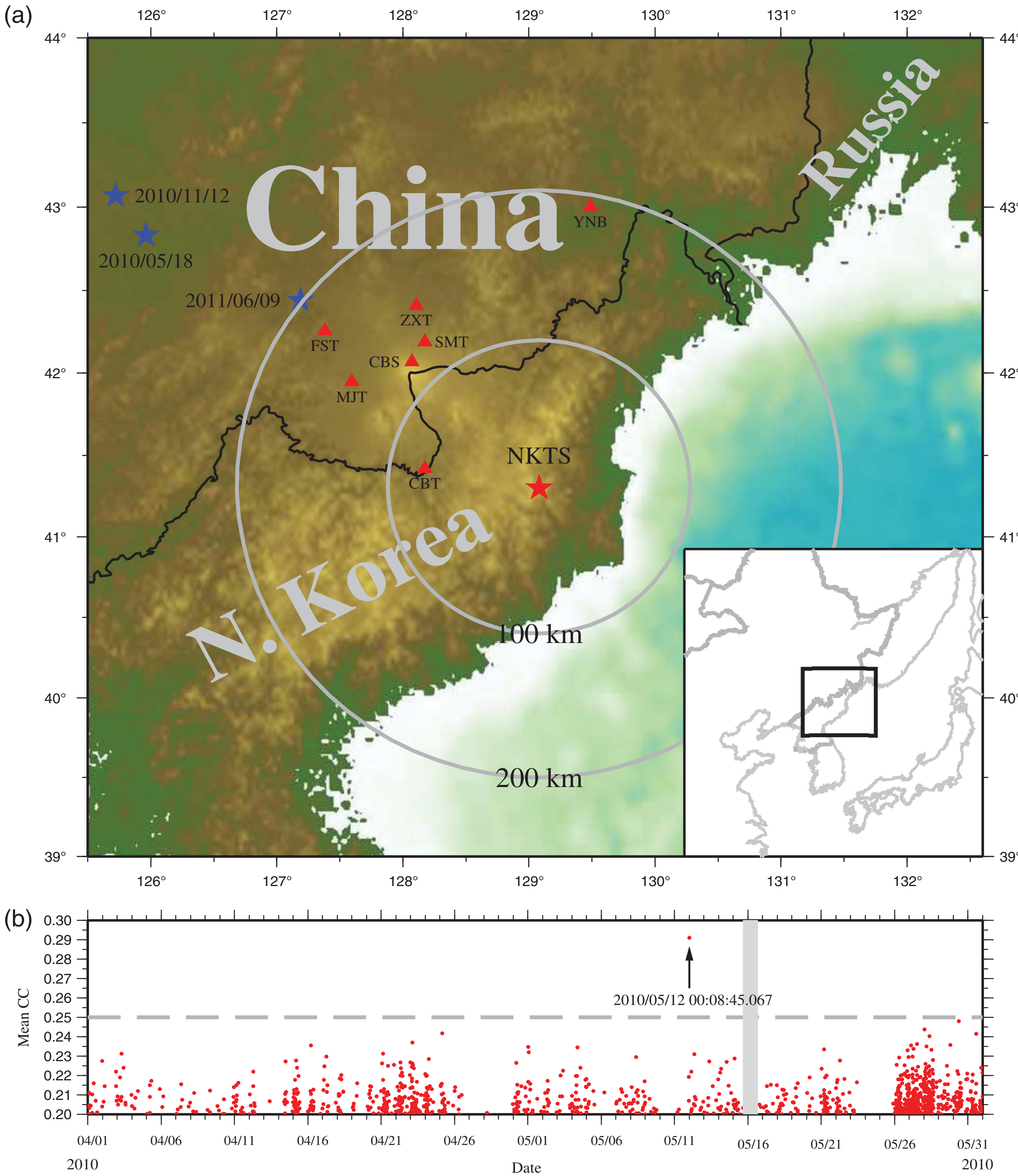
- no well-coupled underground explosion above about a ton occurred near the North Korea nuclear test site in the year 2010 on the five days hypothesized by De Geer (i.e., on 2010 April 14 – 16, and May 10 – 11); and that

- any explosion would have to be very small (local magnitude less than about 2) to escape detection.

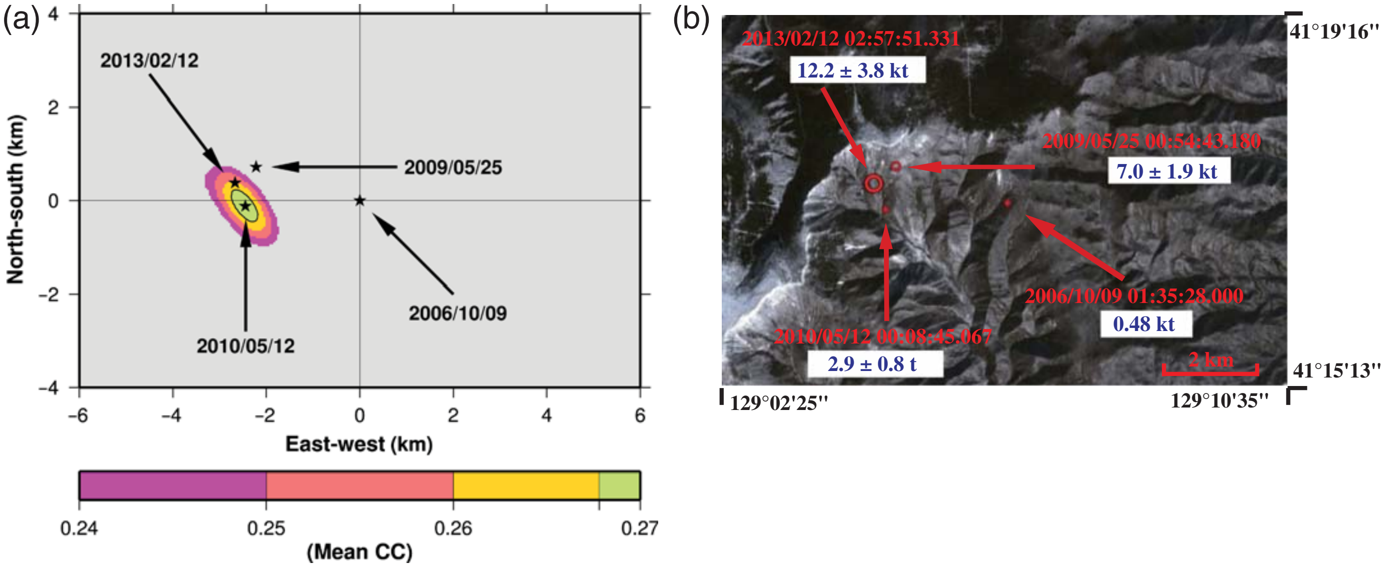
Ⓔ

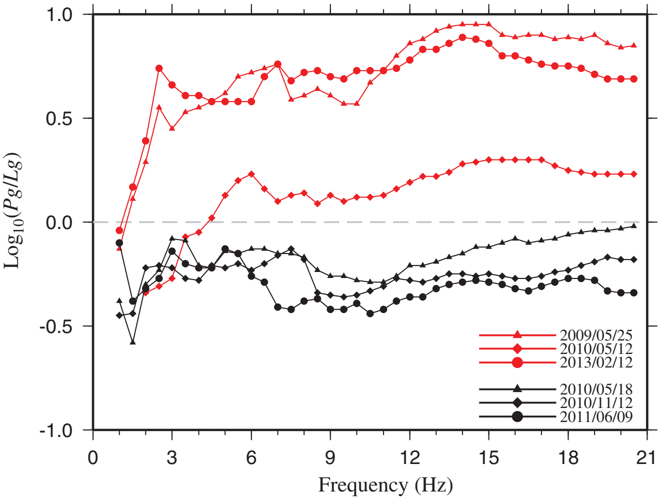
Seismological Evidence for a Low-Yield Nuclear Test on 12 May 2010 in North Korea

by Miao Zhang and Lianxing Wen

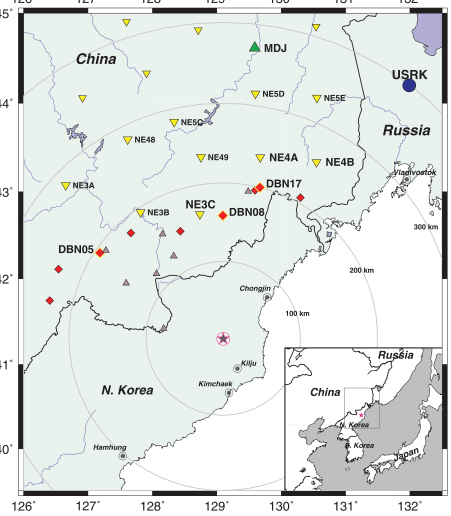


▲ **Figure 1.** (a) Location of North Korea's nuclear test site (NKTS, red star), seven seismic stations (red triangles) within 200 km of the test site, and three nearby earthquakes (blue stars) used in event type comparison. (Inset) A regional map of eastern Asia in which the black rectangle indicates the study area. (b) Maximal values of the stacked cross correlograms for every 0.001 s time interval (red dots) from 1 April 2010 to 31 May 2010 (only the values greater than 0.2 are plotted) and a detected event at 00:08:45.067 UTC on 12 May 2010 (dot labeled by the event origin time). Gray dashed line stands for the mean CC threshold of 0.25. Gray area indicates the time window of data gap (from 16:00 UTC on 15 May 2010 to 16:00 UTC on 16 May 2010).


(a)
2013/02/12
2009/05/25
2006/10/09
2010/05/12
North-south (km)
East-west (km)
0.24
0.25
0.26
0.27
(Mean CC)
(b)
2013/02/12 02:57:51.331
12.2 ± 3.8 kt
2009/05/25 00:54:43.180
7.0 ± 1.9 kt
2006/10/09 01:35:28.000
0.48 kt
2010/05/12 00:08:45.067
2.9 ± 0.8 t
2 km
41°19'16''
41°15'13''
129°02'25''
129°10'35''



▲ **Figure 5.** *Pg*/*Lg* spectral ratios of three nuclear tests (red symbols) and three nearby earthquakes (black symbols) (shown as blue stars in Fig. 1a, Ⓔ Table S1 in the electronic supplement) for the seismic data recorded at borehole station SMT.



126°
127°
128°
129°
130°
131°
132°
45°
44°
43°
42°
41°
40°
China
Russia
N. Korea
MDJ
USRK
NE5D
NE5E
NE5C
NE48
NE49
NE4A
NE4B
NE3A
NE3B
NE3C
DBN17
DBN08
DBN05
Vladivostok
Chongjin
Kilju
Kimchaek
Hamhung
100 km
200 km
300 km
Russia
China
N. Korea
S. Korea
Japan

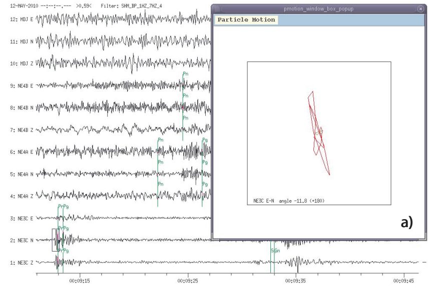
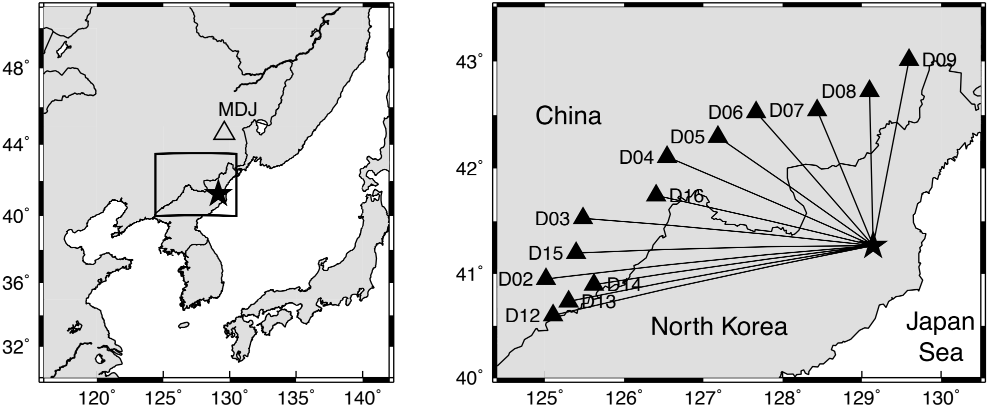
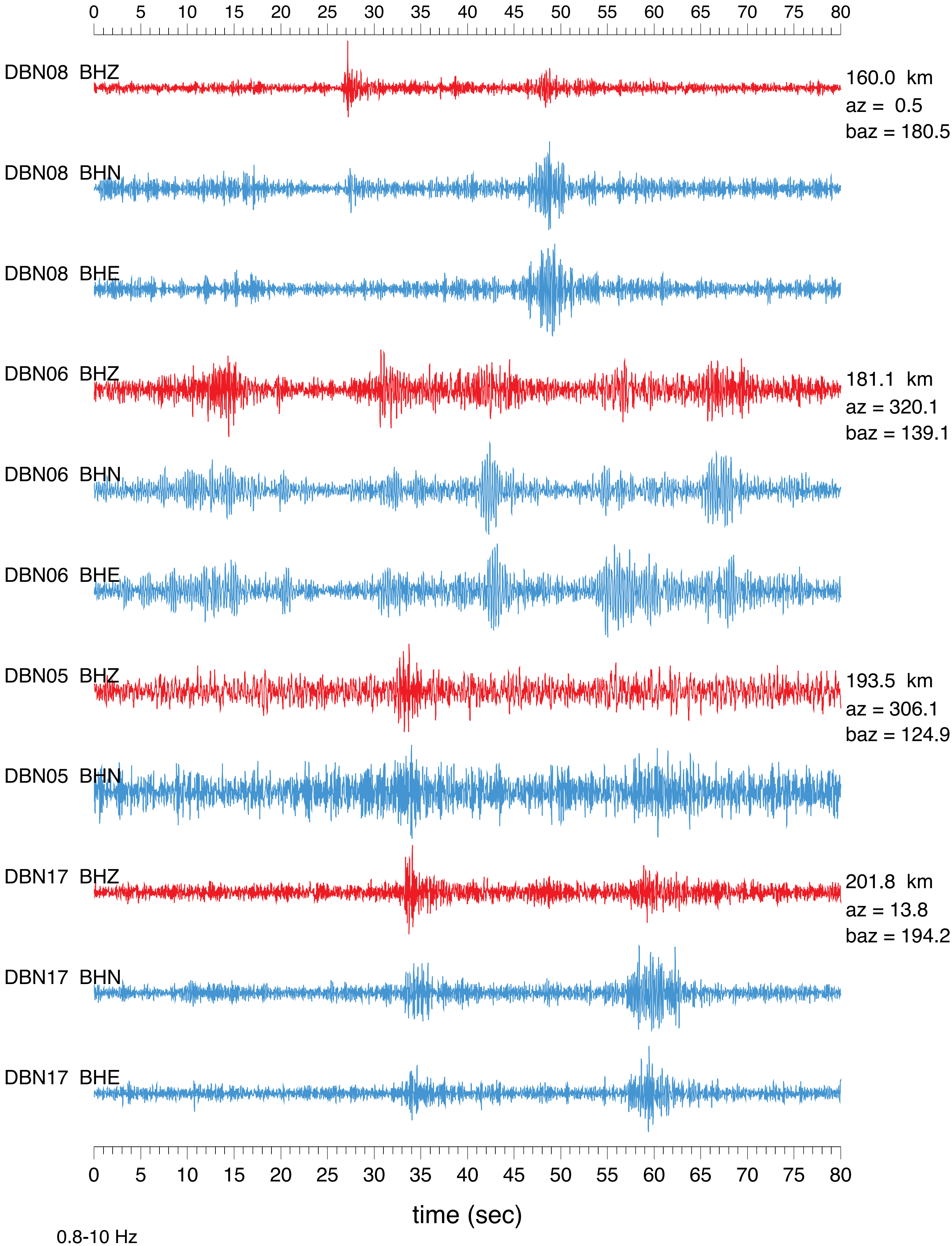


Fig.4: Particle motion analysis of the P wave arrival at NE3C which showed a good signal-to-noise ratio. The resulting polarization direction is consistent with an event occurring on or near the DPRK test site.


48°
44°
40°
36°
32°
120°
125°
130°
135°
140°
MDJ
43°
42°
41°
40°
125°
126°
127°
128°
129°
130°
China
North Korea
Japan Sea
D09
D08
D07
D06
D05
D04
D16
D03
D15
D02
D14
D13
D12

2010 May 12, 00:08:45.07, Lat = 41.286°, Lon = 129.079° (Zhang & Wen, SRL 2015)



Statement from David Schaff, made on the basis of using Lg-wave cross-correlation measurements on data from Dongbei stations:
****

We are able to detect a similar Lg-wave as the maximum correlation at the expected arrival time of the 2010 event for two stations searching 10 minutes of data.

Performing an association of detections at five of the Dongbei stations for *Lg*-waves validates this detection with a high degree of confidence with greater statistical significance than the detection found by Zhang and Wen using 2 months of data.

Our location estimate has poorer quality data than we typically use for *Lg* and shows less confidence than either the detection or association step. **But we are reasonably certain that the 2010 event occurs no more than 4 km to the SW of the 2009 event with estimated 3 km 95% error ellipses.**

- Open source seismic data from the NECESSArray network, and additional regional data from the DBSN network, support a seismic event on 12 May 2010, on or near the DPRK test site. Its magnitude is about 1.5.

- We were able to apply modern methods of cross- correlation to *Lg* signals from the Dongbei network. These methods are superb for co-located events, even if they differ significantly in magnitude. But these methods can degrade as distance between event pairs increases.

- Our observations and those of Ford & Walter (2015) can be explained if the 12 May 2010 event is somewhat further from the known 2009 UNT, than claimed by Zhang & Wen.

Results presented so far, were obtained
by June 2015 and presented at a
CTBTO workshop in Vienna,
as can be seen on YouTube — go to

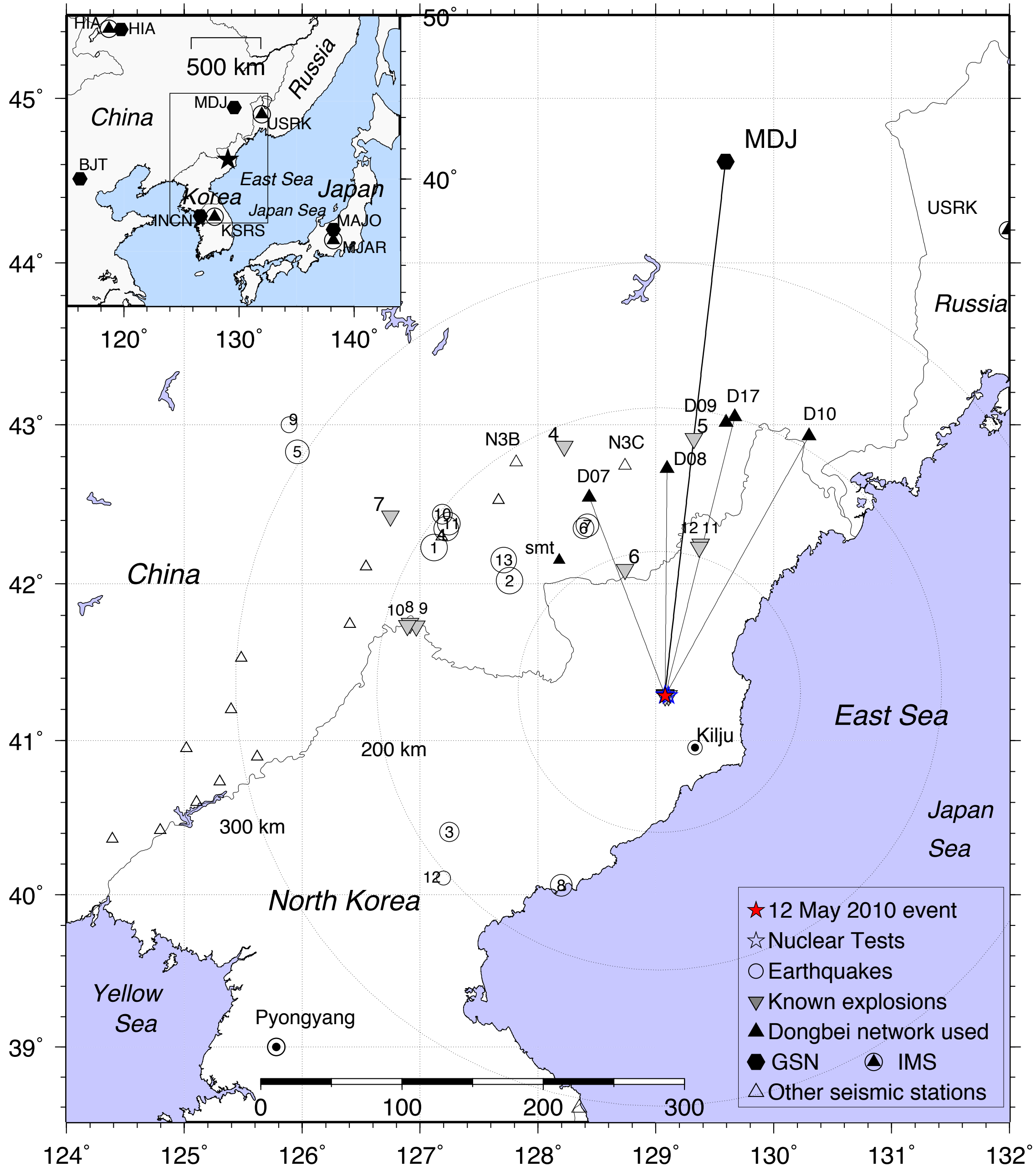
— —

https://www.youtube.com/watch?v=vPRJ8lPNSbo

— —

Next, let’s look at work we’ve done
at Lamont since June 2015
(work done largely by Won-Young Kim):

North Korean Nuclear Tests and Seismic Events



3-component records at MDJ and other stations from;

(a) UNTs

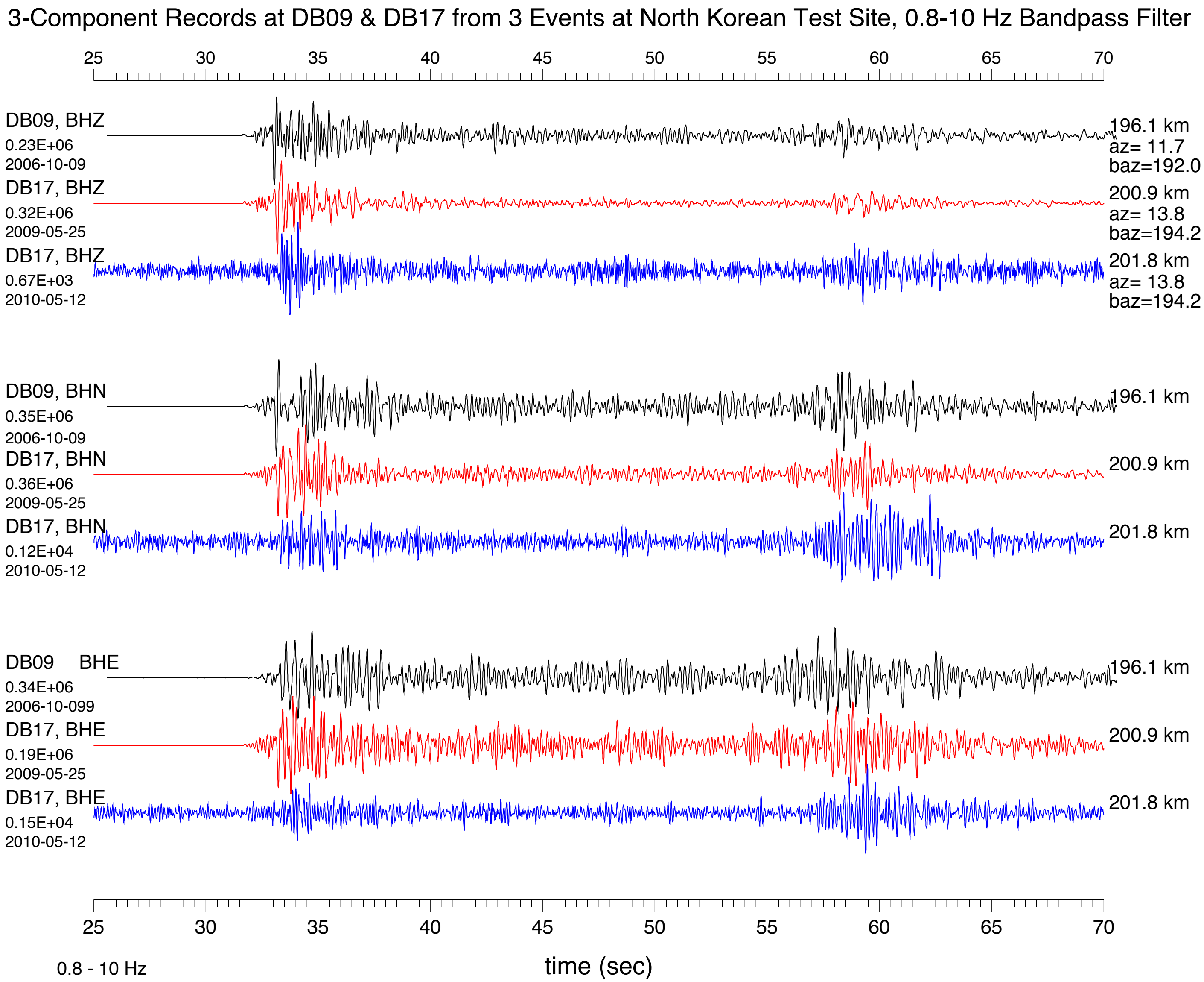
(b) earthquakes, and

(c) Single-hole explosions,

(d) Large industrial chemical explosions.

(e) Weak suspected events.

Comparison of 3-component records. S waves from May 12 are relatively stronger than P waves .



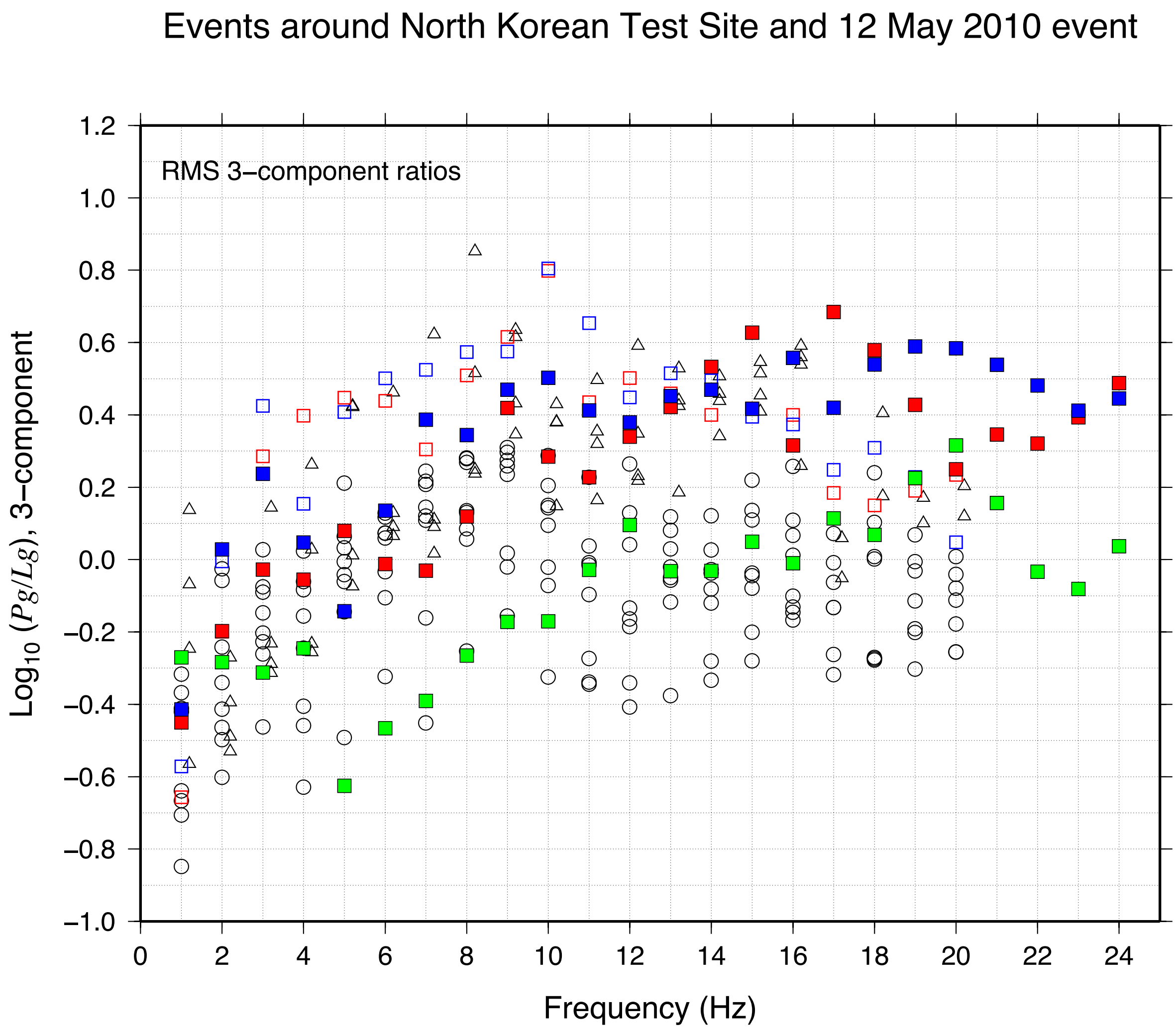
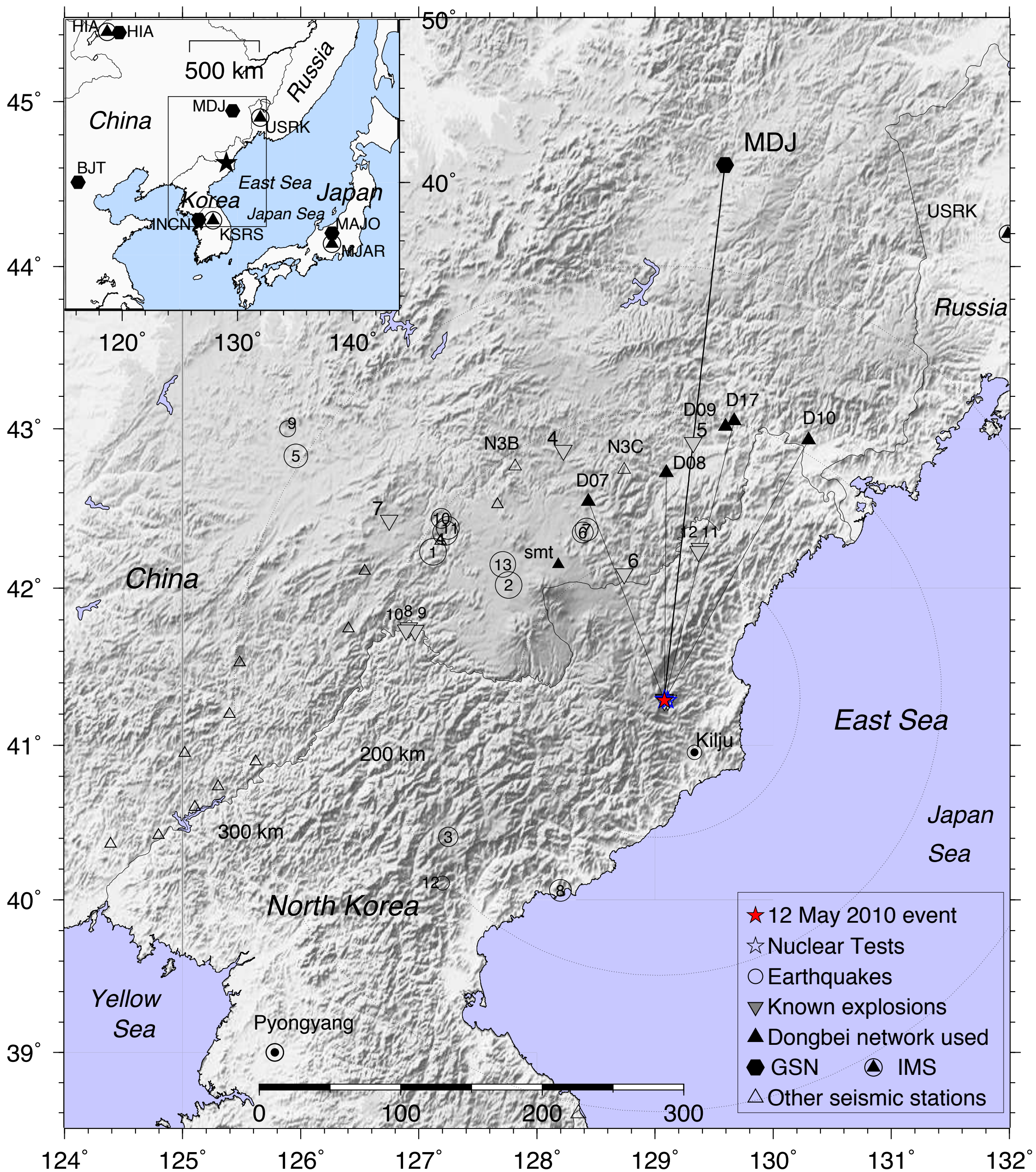


Figure 6. Three-component $\mathrm{Log}_{10}(Pg/Lg)$ spectral amplitude ratios at frequency range 1 to 24 Hz used in discrimination analysis are plotted for earthquakes (*circles*), chemical explosions (*triangles*), and nuclear test (*squares*). The data for the earthquakes and chemical explosions are from a GSN station MDJ, and two underground explosions (2006 and 2009) and 12 May 201 event are from Dongbei network data (see Figure 1) – stations DB07, DB08, DB09 and DB17 are used for the analysis. Newly acquired data from Dongbei Network in NE China along the North Korean border region recorded at 100 samples/second, and hence, provided spectral ratios up to about 35 Hz.

Seismic Events & Stations Around North Korean Nuclear Test Site



3-component records at MDJ from

(a) UNE,

(b) earthquake, and

(c) chemical explosion.

- P and S waves are strong on T-component from explosion sources (EW records),

- Rayleigh on vertical- & radial (NS) records from the explosion (~3s period),

- Strong Lg on T-component from the earthquake (EW).

Details on 12 explosions (used with MDJ data to characterize P/S spectra from explosions)

id	Date (year-mo-dy)	Time (hh:mm:s)	Lat (°N)	Long (°E)	Dep (km)	Mag (M_L)	Agency
				Underground Nuclear Tests			
1	2006-10-09	01:35:27.9	41.277	129.114	0.5	4.2	PDE
2	2009-05-25	00:54:43.3	41.306	129.029	0.6	4.7	PDE
3	2012-02-12	02:57:51.49	41.2990	129.029	0.6	5.1	PDE
				Single Hole Explosions			
4	1998-08-12	15:00:08.10	42.865	128.223	0	1.0	Wu
5	1998-08-18	14:00:06.69	42.914	129.324	0	2.0	Wu
6	1998-08-19	15:00:07.79	42.091	128.739	0	1.9	Wu
7	1998-08-25	15:00:07.46	42.427	126.748	0	1.0	Wu
				Chemical Explosions			
8	2010-01-15	06:18:01.44	41.7488	126.9143	0.0	2.9	ISC
9	2011-01-05	05:46:05.66	41.7317	126.9674	0.0	2.8	ISC, KIGAM
10	2011-02-18	15:25:58.15	41.7345	126.8917	0.0	3.5	ISC
11	2011-05-19	09:38:21.58	42.2512	129.3803	0.0	2.6	ISC
12	2012-01-21	07:54:45.59	42.2306	129.3680	0.0	2.6	ISC

Details on 12 earthquakes (used with MDJ data to characterize P/S spectra from explosions)

id	Date (year-mo-dy)	Time (hh:mm:s)	Lat (°N)	Long (°E)	Dep (km)	Mag (M_L)	Agency
1	1994-01-25	08:51:38.2	42.23	127.12	04	4.0	NK
2	2004-12-16	18:59:14.5	41.79	127.94	10	4.0	PDE
3	2007-12-31	21:33:38.0	40.41	127.25	0	3.2	
4	2009-08-05	12:08:12.6	42.349	127.223	10	3.8	
5	2010-05-18	04:08:10.3	42.83	125.96	10	3.7	
6	2010-10-09	05:45:14.7	42.352	128.388	10	3.4	
7	2010-10-09	06:07:09.2	42.370	128.420	5	3.6	
8	2010-11-07	11:11:39.74	40.0623	128.1985	17.6	3.5	kigam
9	2010-11-12	02:10:44.8	43.00	125.89	7	2.8	
10	2011-06-09	01:10:35.1	42.44	127.19	6	3.3	
11	2011-12-26	13:34:08.6	42.381	127.246	0	3.6	
12	2014-08-04	21:16:36.0	40.110	127.200	0	2.5	

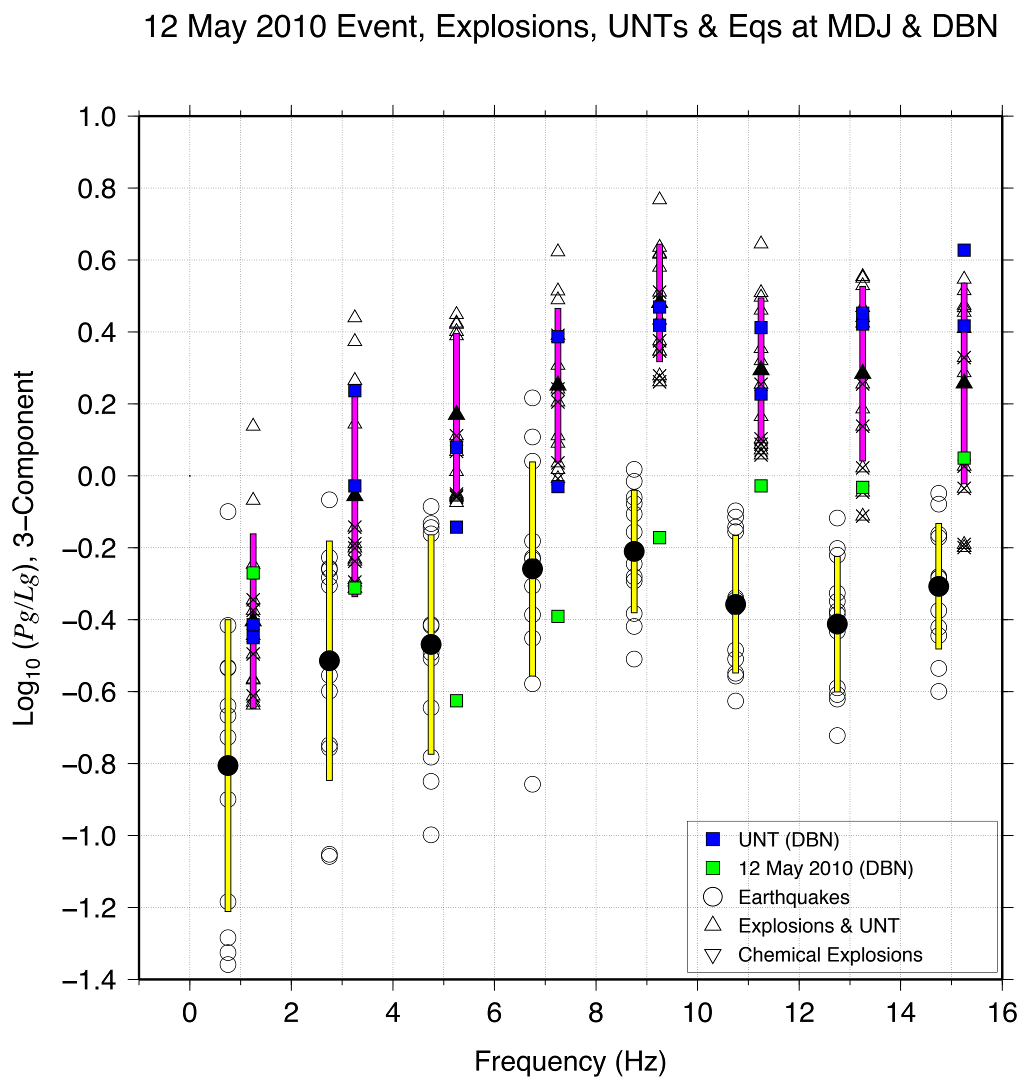
Test events

2010-05-12						
2002-04-16	22:52:38.6	40.66	128.65	10	4.1	ISC
2005-04-15	06:34:15.4	42.15	127.71	10	3.9	BJI

P/S spectral ratios of rotated 3-component records.

Define 3-component ratio as: $P/S = (P_z^2 + P_R^2)^{½} / (S_z^2 + S_R^2 + S_T^2)^{½}$

where subscripts indicate the component: Z= vertical, R= radial and T= transverse components.



3-component records at MDJ from:

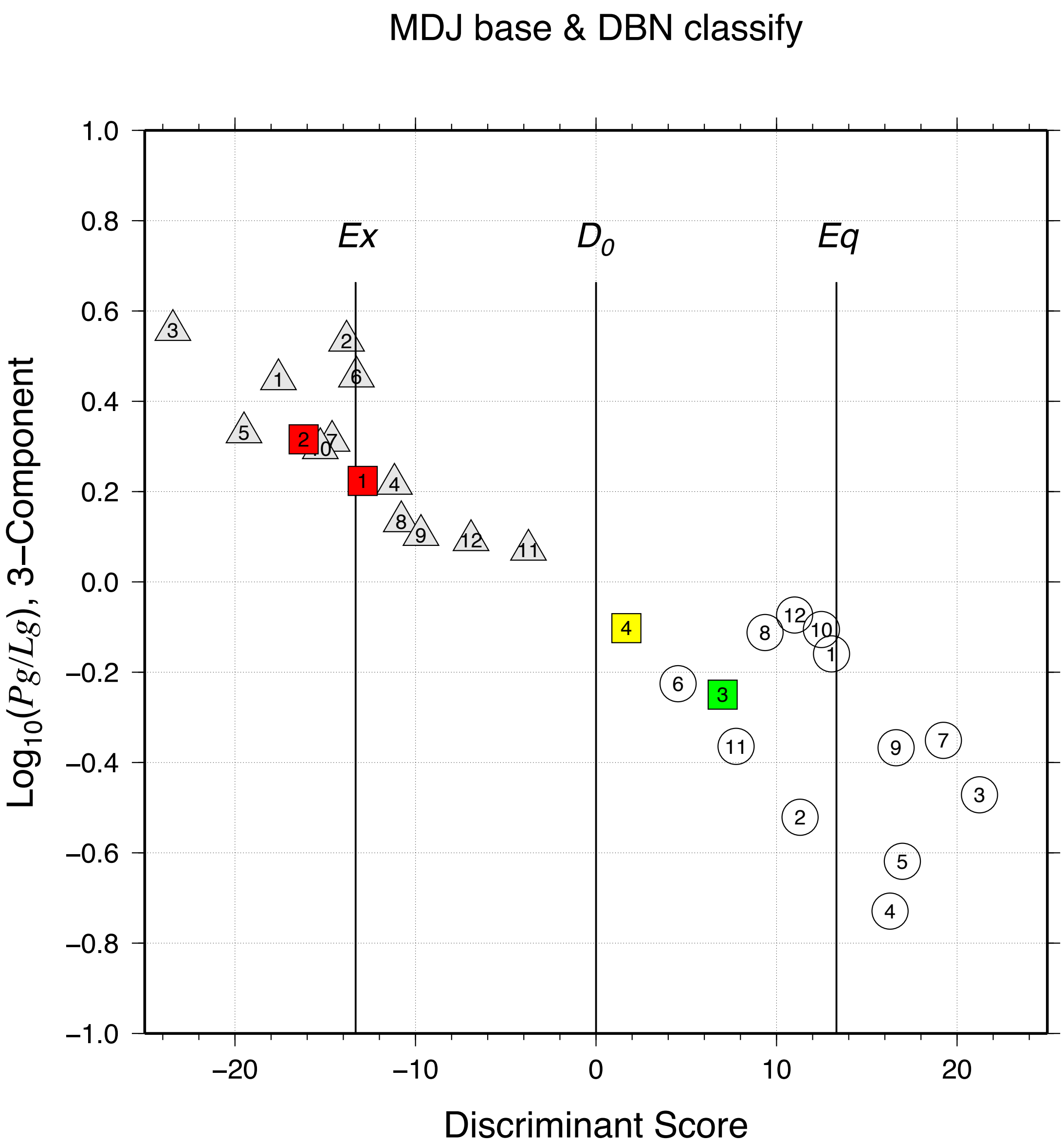
- 12 earthquakes (M 2.5 – 4.0)

- 12 explosions (UNT, single- & multiple-hole explosions)

Two populations:
overlap at 1-4 Hz,
well separated at > 5 Hz.

MDAC (magnitude, distance, amplitude corrections) not applied.

Discrimination power of *Pg/Lg* ratio with the sample data of 12 Eqs and 12 Exs (3 UNE + 4 shots + 5 chemical).

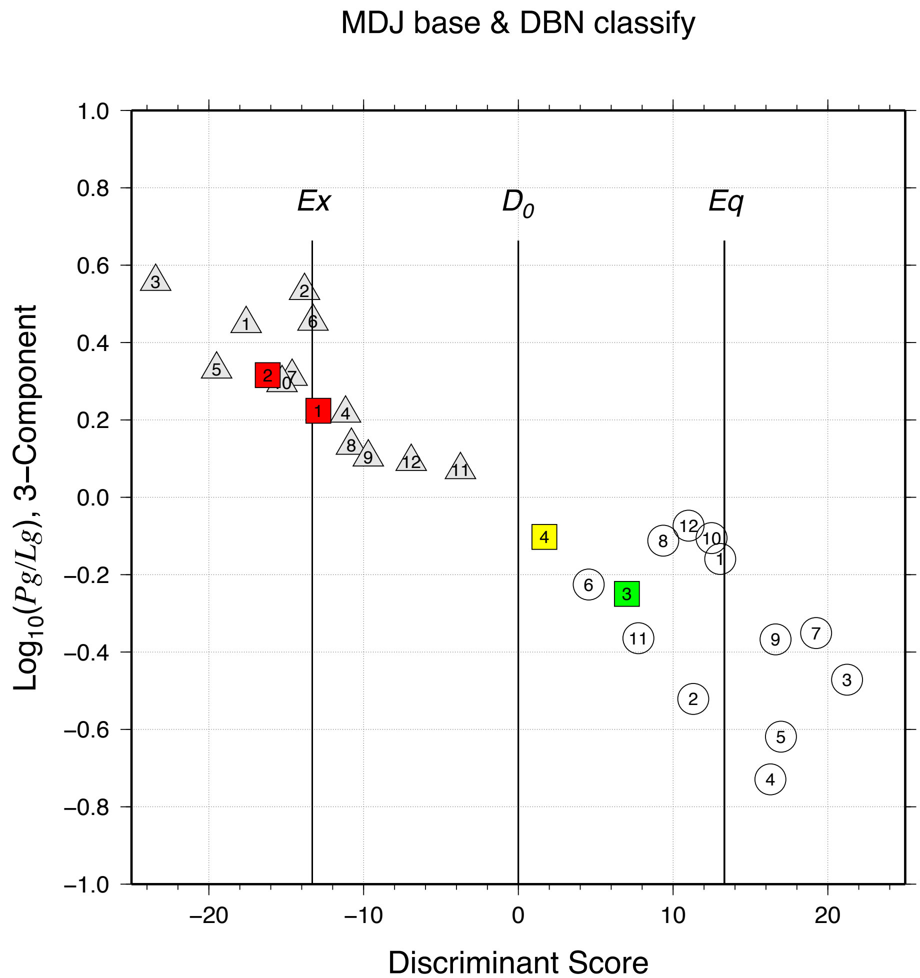


Pg/Lg spectral ratios in 5-13 Hz, at 5 discrete frequencies are used for linear discrimination analysis.

All events are correctly classified with a total misclassification probability of 0.5%.

Mahalanobis distance squared (Δ^2) measure is 26.6.

12 May 2010 event is classified as an earthquake.



Linear discriminant function analysis applied to the *P*/*S* spectral ratios of seismic events in and near northern North Korea. An explosion population (12 events, chemical and nuclear), is shown as triangles. An earthquake population (12 events), is shown as circles. **Data from a temporary network (DBN) provided signals for two nuclear explosions (red squares) and for the event of interest (May 12, 2010; green square). The event of interest falls in the earthquake population.** Key to our conclusions, is use of a method that analyzes all three components of recorded motion, not just the vertical component.

The ability to detect and analyze events as small as this one (magnitude ~ 1.5) is new, and raises new questions such:

- what stations are quiet and reliable?
- whose job is it to build relevant archives?
- how can we analyze many many events?

Extra images:

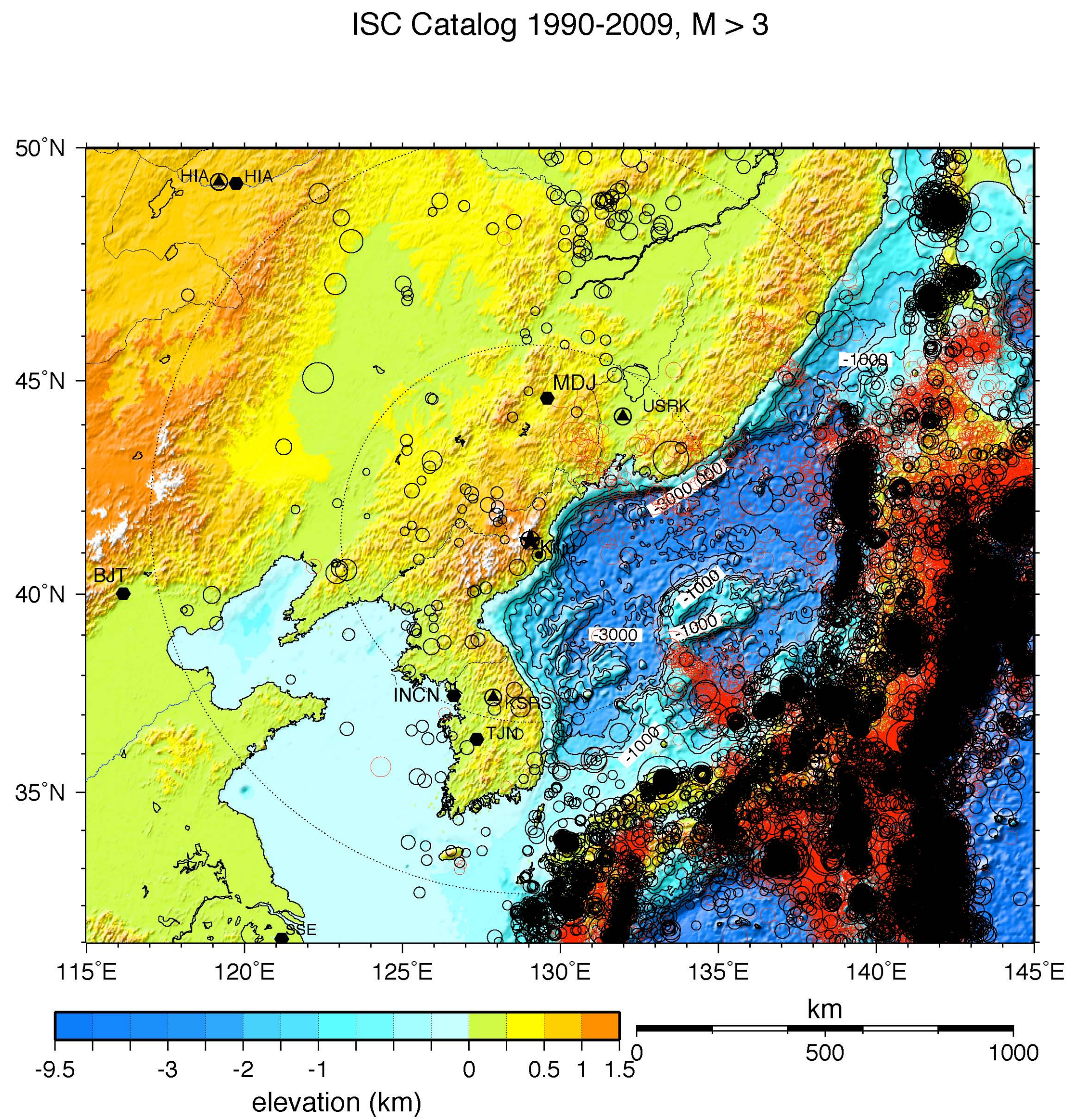
Seismicity around the nuclear test site in North Korea

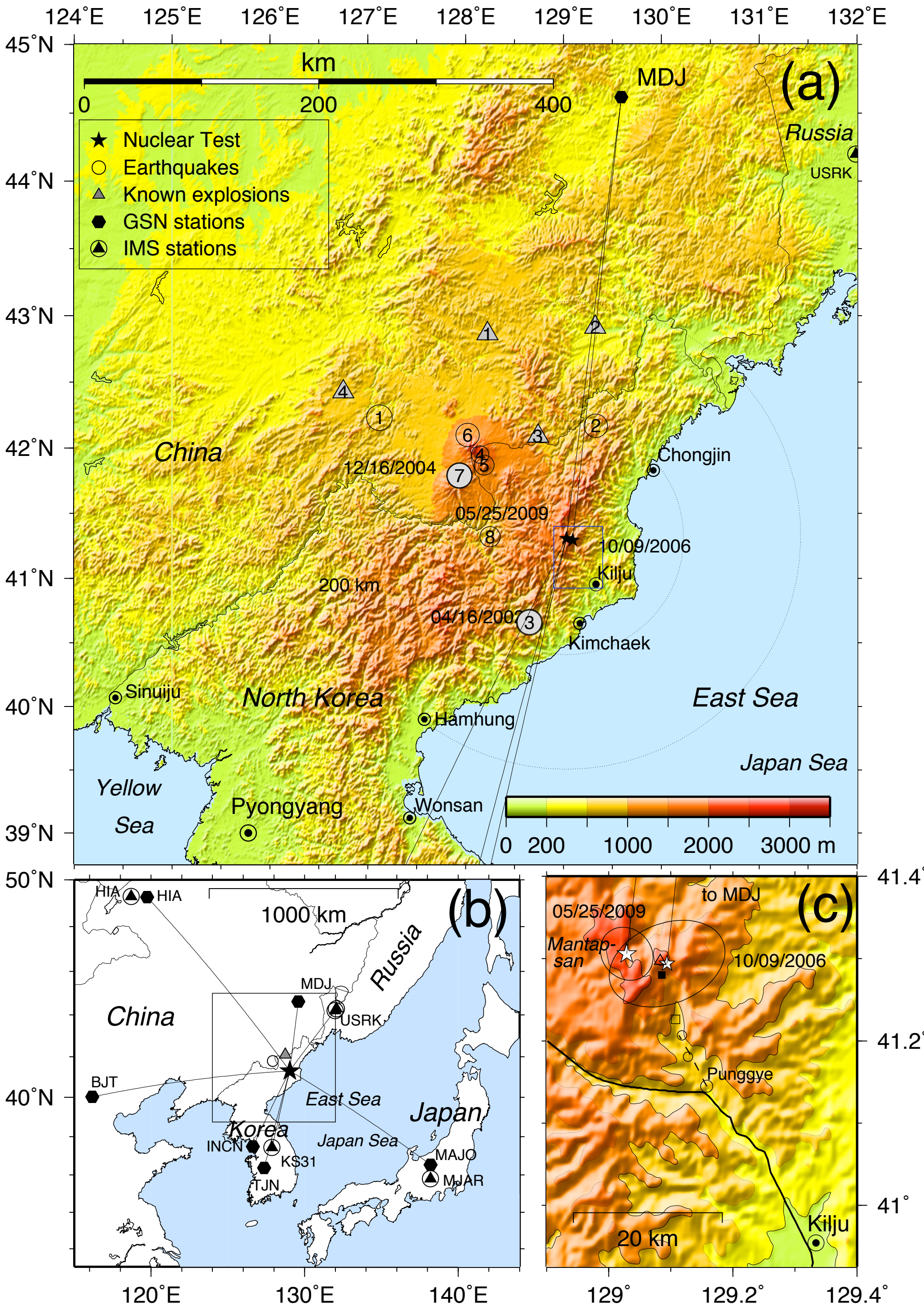
ISC Bulletin 1990-2009, M > 3, ~1,000 km.

- Much of the East Sea of Korea (Japan Sea) is probably oceanic crust,

- Crust around the volcanic Baekdu-san (Changbei-shan) may be highly attenuating,

- Relatively few events within 500 km from the test site.



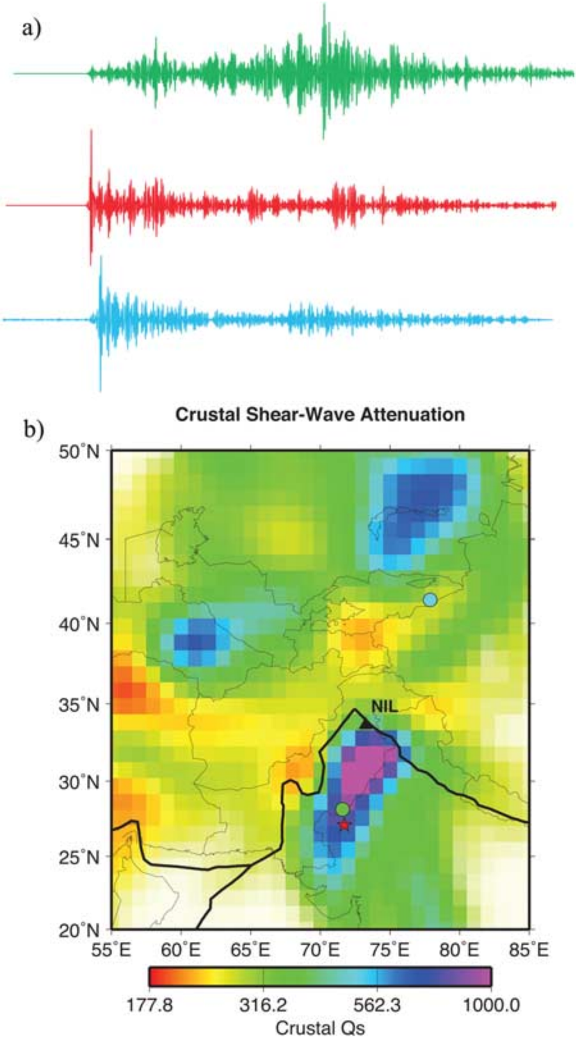


Events Selected for Discrimination Analysis

12 Earthquakes & 12 Explosions around NK test site

Up to ~200 km from the test site.

a)


b)
Crustal Shear-Wave Attenuation
50˚N
45˚N
40˚N
35˚N
30˚N
25˚N
20˚N
55˚E
60˚E
65˚E
70˚E
75˚E
80˚E
85˚E
NIL
177.8
316.2
562.3
1000.0
Crustal Qs