T2.1-P2

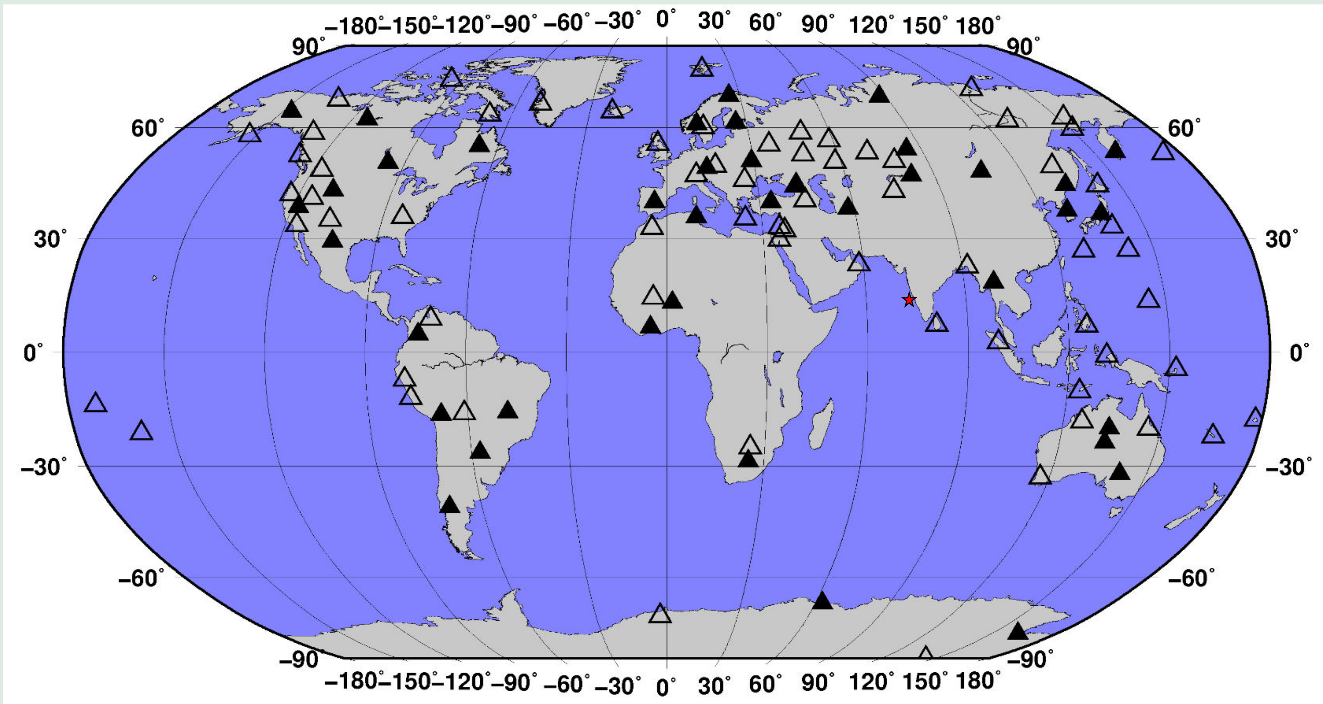
Absolute and relative body wave magnitudes of five DPRK events as measured by the IDC

Dmitry Bobrov, Ivan Kitov, and Mikhail Rozhkov

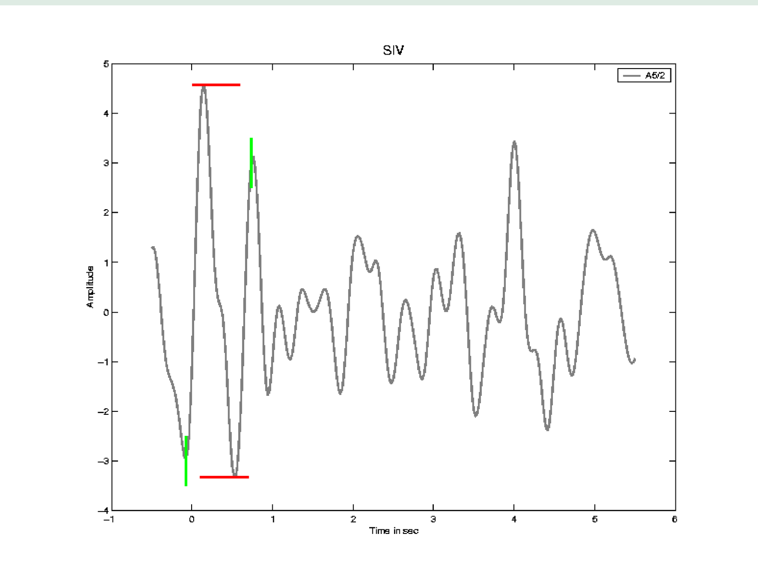
International Data Centre, Preparatory Commission for the Comprehensive Nuclear Test-Ban Treaty Organization

CTBTO PREPARATORY COMMISSION

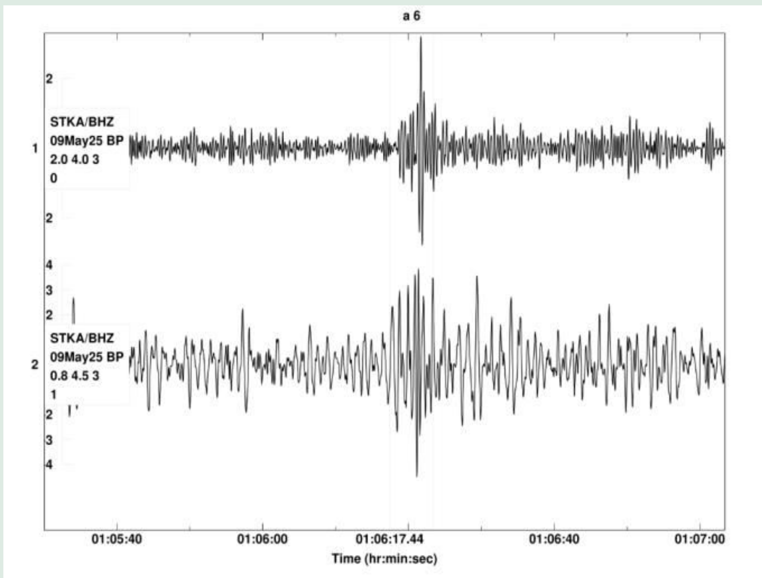
Abstract
The seismic network of the International monitoring system of the Comprehensive nuclear-test-ban Treaty Organization detected seismic signals from five declared underground tests conducted by the DPRK in October 2006, May 2009, February 2013, January and September 2016. These data allow thorough cross comparison of relative amplitudes and frequency content of detected signals as well as event locations, magnitudes and source mechanisms obtained using standard methods adapted at the International Data Centre (IDC) and several techniques based on waveforms cross correlation, which are under development at the IDC. Seismic signals from the bigger events provide high quality waveform templates for detection of missed arrivals from smaller events at less sensitive IMS stations and possible aftershocks with magnitudes by two-to-three units lower than the DPRK events themselves.



Primary station locations are shown in black, auxiliary station locations are shown as open triangles, the 9 SEP 2016 event location is shown in red. Only the primary arrays were used in this study.



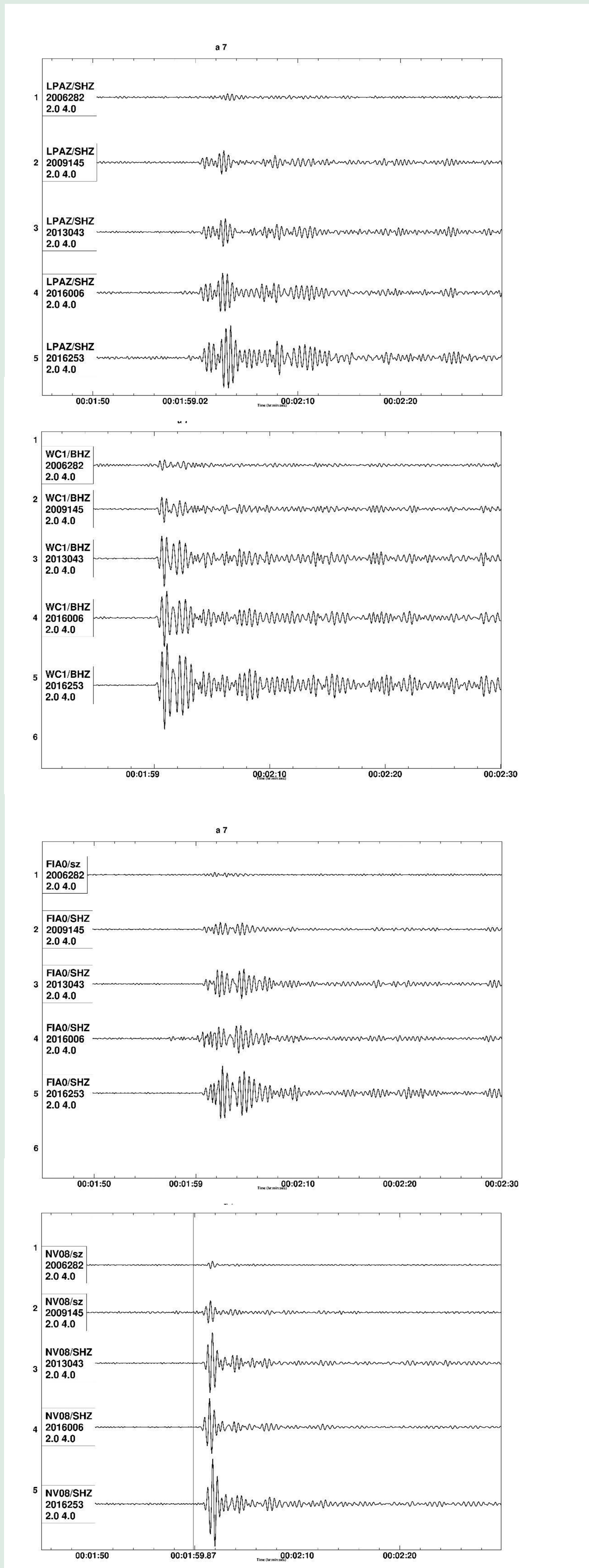
Example of IDC standard amplitude and period measurements. Seismogram is fileted by the 3rd order zero-phase filter between 0.8 Hz and 4.5 Hz.



The difference in signal SNR for the IDC standard amplitude and period measurement and that for the WCC-based dRM calculations at station STKA

Table. Comparison of station magnitude residuals for standard, dm_b, and WCC-based, dRM_{diff}, estimates. The dRM_{diff} residuals have much lower scattering. For 4 first events, the reference event is the DPRK5, for which the DPRK4 is the reference.

	DPRK1		DPRK2		DPRK3		DPRK4		DPRK5	
	dm_b	dRM_{diff}	dm_b	dRM_{diff}	dm_b	dRM_{diff}	dm_b	dRM_{diff}	dm_b	dRM_{diff}
AKASG	0.16	-0.08	0.41	0.03	0.39	-0.03	0.36	-0.03	0.37	0.03
ARCES			-0.15		-0.24		-0.41	-0.07	-0.31	0.04
ASAR	-0.18	0.11	-0.01	-0.01	0.06	0.08	-0.02	0.01	-0.04	-0.02
BRTR		-0.12	-0.17	0.00	-0.17	-0.04	-0.17	-0.01	-0.20	0.01
CMAR			0.10	0.02	0.09	0.05	0.08	0.01	-0.02	-0.01
ESDC			-0.41	0.20	-0.35	0.17	-0.32	-0.03	-0.36	0.03
FINES	0.19		0.47	-0.02	0.43	-0.08	0.47	-0.02	0.46	0.02
GERES	-0.34	-0.10	0.10	-0.01	0.11	-0.03	0.11	0.02	0.07	-0.02
GEYT					0.46	0.06	0.33	-0.03	0.40	0.03
ILAR			0.18	-0.04	0.16	-0.07	0.24	0.02	0.22	-0.02
KSRS		0.11		0.04		0.01		0.05		-0.05
MJAR						0.13		0.14		-0.14
MKAR	-0.50	-0.13	-0.16	0.01	-0.19	-0.04	-0.21	-0.08	-0.22	0.08
NOA	-0.09		0.16		0.17	0.01	0.06	-0.10	0.09	0.10
NVAR	0.29		0.50		0.52	0.00	0.54	0.04	0.48	-0.04
PDAR	-0.17		0.10		0.06	-0.05	0.06	0.03	0.04	-0.03
PETK			-0.56		-0.62		-0.87	-0.04	-0.85	0.06
SONM		0.03		-0.06	-0.46	0.02	-0.53	-0.04	-0.51	0.03
TXAR			-0.11	-0.05	-0.11	-0.06	-0.06	0.03	-0.09	-0.03
USRK				-0.06		-0.07		0.02		-0.02
WRA	0.29	0.20	0.36	-0.02	0.38	0.02	0.33	0.02	0.29	-0.02
YKA	-0.27		-0.27		-0.31		-0.27	0.01	-0.30	-0.02
ZALV			-0.29	-0.01	-0.33	-0.03	-0.35	-0.06	-0.31	0.06
st.dev	**0.27**	**0.12**	**0.30**	**0.06**	**0.32**	**0.07**	**0.35**	**0.05**	**0.34**	**0.05**



The difference in signal amplitudes of 5 DPRK events as measured at 4 IMS stations: LPAZ, WRA, FINES and NVAR. All signals are filtered from 2 Hz to 4 Hz. The estimate of *dRM* is obtained in the time window of cross correlation. The values of CC coefficients obtained for 4 events relative to the DPRK4 are shown in the table to the right.

Relative magnitude

$$dRM = \log(\,|\,M\,|\,/\,|\,S\,|\,) = \log|\,M\,| - \log|\,S\,|$$

The relative magnitude, d***RM***, is calculated as the logarithm of the ratio of L2-norms (lengths) of the slave, **S**, and master, **M**. For the former, the length of time window is the same as in the master, which found that slave. The length of master template depends on the frequency band with the highest SNR at the averaged CC-trace. Table 2 lists the d***RM*** estimates with the DPRK5 as a master event.

Using an event as a master or slave may result in different d***RM*** absolute values because of a slight difference in the travel time residuals between channels of an array station for different locations of master events. This difference in small, however.

The station d***RM*** estimates averaged over all available stations, ***RM***, provides an accurate and reliable estimate of the relative size of two measured events (see Table 3). The standard error of the mean value (given in brackets) is also calculated in order to illustrate the level of residual magnitude scattering over stations. The average ***RM*** estimates are compared with those calculated by standard procedure from station magnitudes. The difference of the network magnitudes are small except that for the 2006 event – its magnitude was likely overestimated by standard method.

Table. Comparison of absolute and relative magnitudes (with 9 Sep 2016 as a reference) for 5 DPRK tests

Date	RM	m_b IDC
9 OCT 2006	3.93 (0.14)	4.08
25 MAY 2009	4.54 (0.04)	4.51
12 FEB 2013	4.96 (0.07)	4.92
6 JAN 2016	4.85 (0.02)	4.82
9 SEP 2016	5.09 (REF)	5.09

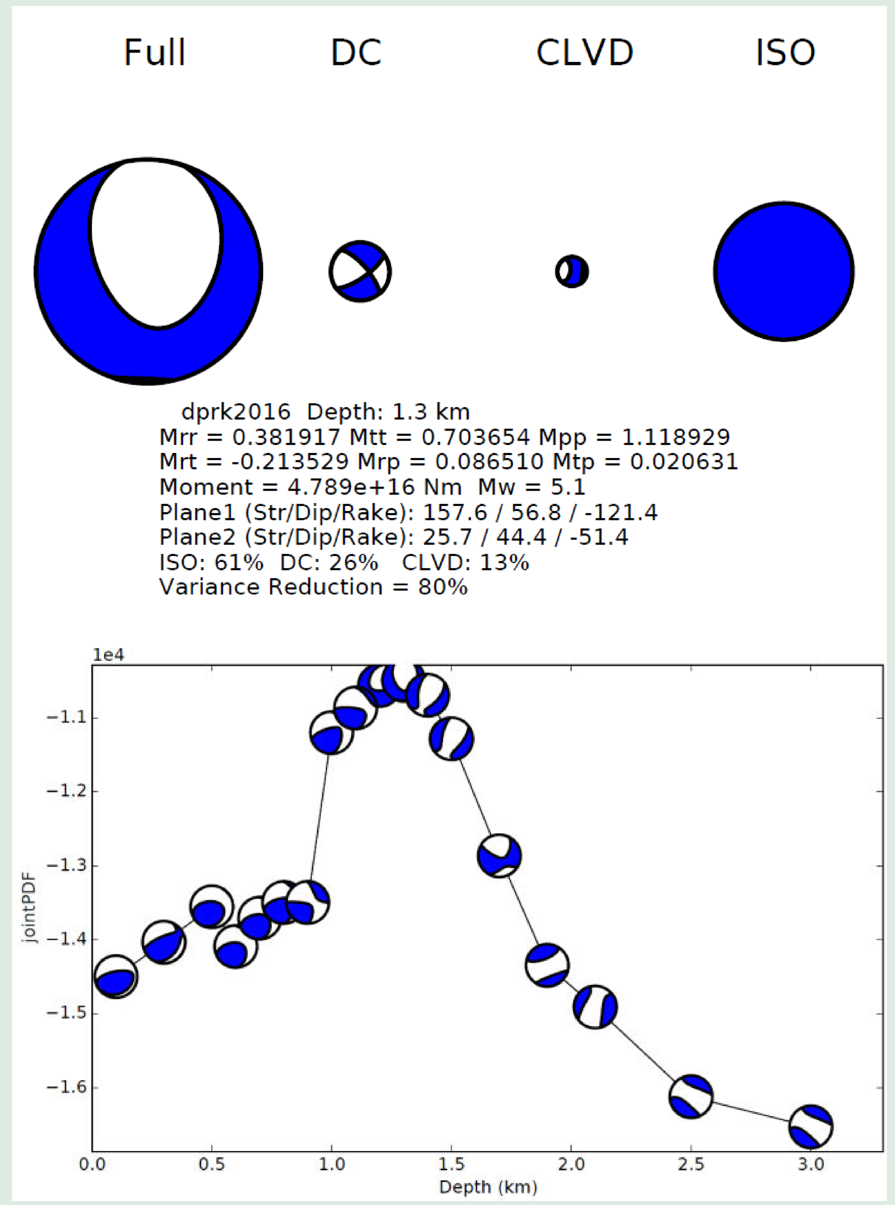
Table. Average CC and relative magnitude with 9 Sep 2016 as a reference

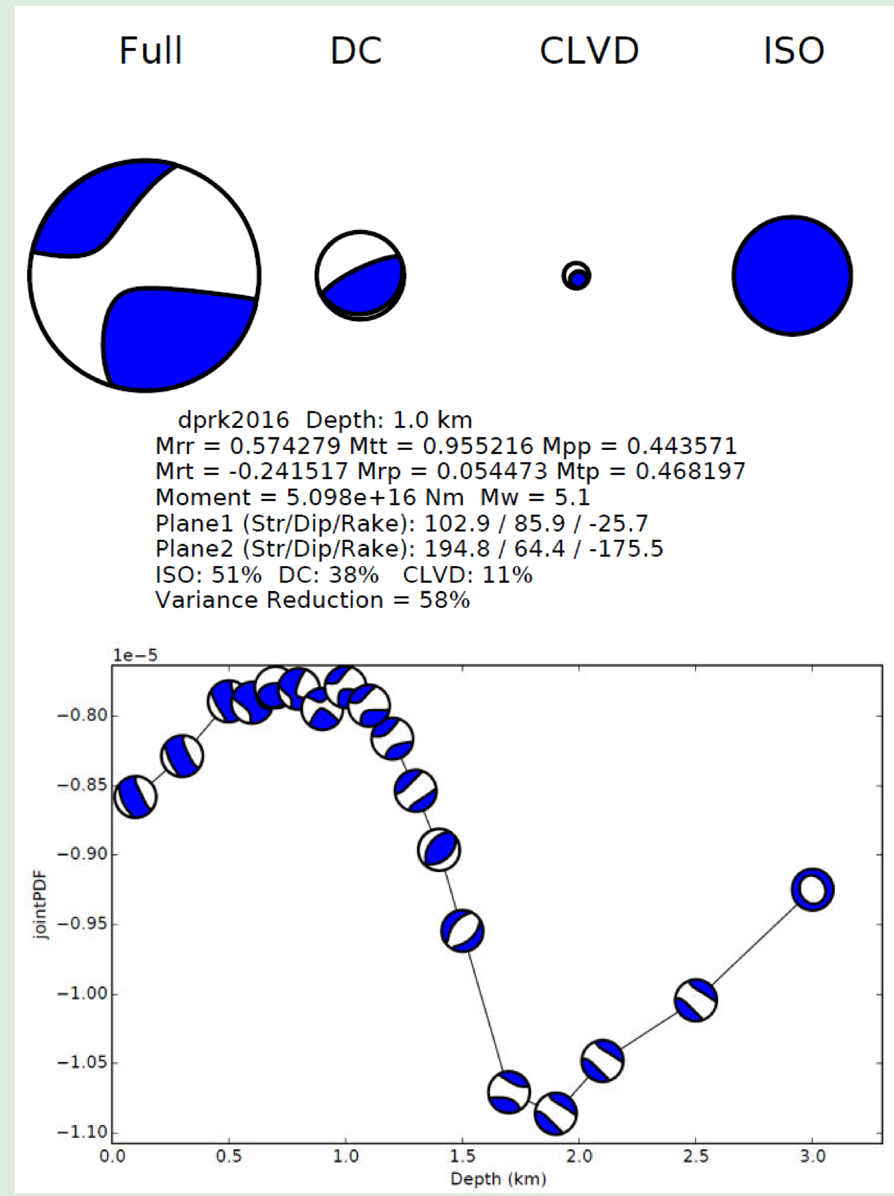
Sta	Dist	CC				dRM			
		2016	2013	2009	2006	2016	2013	2009	2006
USRK	3.6	0.97	0.97	0.97		0.22	0.20	0.61	
KSRS	4.0	0.97	0.94	0.95	0.62	0.19	0.12	0.51	1.08
MJAR	8.6	0.80	0.73	0.73	-0.52	0.10	0.01	-	-
SONM	17.4	0.92	0.95	0.93	0.62	0.27	0.12	0.54	1.13
ZALV	31.8	0.97	0.90	0.93		0.30	0.15	0.56	
MKAR	33.7	0.99	0.99	0.98	0.53	0.32	0.17	0.54	1.32
CMAR	34.4	0.97	0.96	0.89		0.23	0.08	0.53	
ILAR	51.1	0.99	0.99	0.99		0.22	0.20	0.59	
GEYT	53.3	0.98	0.97			0.27	0.07		
ARCES	56.4	0.94				0.28			
FINES	60.3	0.98	0.98	0.97		0.26	0.21	0.57	
WRA	61.1	1.00	0.92	0.90	0.89	0.22	0.11	0.57	0.99
YKA	64.7	0.76			0.76	0.22			1.27
ASAR	64.8	0.99	0.98	0.95	0.78	0.22	0.05	0.56	1.06
AKASG	64.8	0.92	0.94	0.94	0.76	0.27	0.15	0.52	1.27
NOA	66.2	0.85	0.86			0.34	0.11		
BRTR	68.7	0.89	0.97	0.98		0.25	0.17	0.55	
GERES	73.7	0.92	0.88	0.90	0.50	0.22	0.15	0.56	1.29
NVAR	79.7	1.00	0.99			0.20	0.13		
PDAR	81	0.99	0.98			0.21	0.18		
ESDC	88.8	0.74	0.77	0.68		0.27	-0.04	0.36	
TXAR	94.5	0.98	0.94	0.93		0.21	0.19	0.60	

Table. Station estimates of the empirical relative magnitudes, d***RM***, estimated using as pairs of DPRK events as as slaves and masters.

M/S	13/16	16/13	09/16	16/09	09/13	13/09	06/16	16/06	06/13	13/06	06/09	09/06
Sta	dRM	dRM	dRM	dRM	dRM	dRM	dRM	dRM	dRM	dRM	dRM	dRM
AKASG	-0.14	0.14	0.25	-0.25	0.44	-0.44	0.91	-0.90	1.05	-1.05	0.75	-0.75
ASAR	-0.23	0.23	0.28	-0.28	0.51	-0.50	0.84	-0.83	1.00	-1.01	0.51	-0.48
BRTR		0.17	0.27	-0.27	0.38	-0.38		-1.05		-1.13		-0.76
CMAR	-0.15	0.15	0.31	-0.30	0.46	-0.46						
ESDC	-0.30	0.30	0.08	-0.08	0.38	-0.38						
FINES	-0.06	0.05	0.29	-0.31	0.35	-0.36						
GERES	-0.09	0.09	0.34	-0.34	0.42	-0.42	1.04	-1.04	1.13	-1.12	0.75	-0.75
GEYT	-0.24	0.24										
ILAR	-0.04	-0.01	0.34	-0.34	0.39	-0.39						
KSRS	-0.09	0.09	0.30	-0.30	0.40	-0.40	0.95	-0.95	0.91	-0.97	0.52	-0.52
MKAR	-0.15	0.15	0.22	-0.22	0.37	-0.37	1.06	-0.92	1.21	-1.07	0.80	-0.80
NOA	-0.23	0.23										
NVAR	-0.09	0.09										
PDAR	-0.01	0.00										
PETK	-0.06				0.37	-0.34						
SONM	-0.18	0.18	0.29	-0.33	0.49	-0.52	0.87	-0.88	1.07	-1.06	0.58	-0.58
TXAR	0.00	-0.01	0.39	-0.39	0.41	-0.39						
USRK	-0.02	0.02	0.39	-0.39	0.41	-0.41						
WRA	-0.13	0.13	0.33	-0.33	0.43	-0.43	0.76	-0.76	0.84	-0.84	0.41	-0.41
ZALV	-0.15	0.15	0.26	-0.26	0.41	-0.41						
mean	-0.12	0.13	0.29	-0.29	0.41	-0.41	0.92	-0.92	1.03	-1.03	0.62	-0.63
stdev	0.09	0.09	0.08	0.08	0.04	0.05	0.11	0.10	0.13	0.09	0.15	0.15
mean REB	-0.13		0.28		0.40		0.97		1.09		0.56	
stdev REB	0.08		0.09		0.04		0.11		0.10		0.29	
REB mb diff	-0.10		0.31		0.41		0.74		0.84		0.43	

CHANGE IN MOMENT TENSOR ESTIMATION WITH THE DEPTH OF BURIAL : EVENTS 2016_1 (left) and 2016_2 (right)





Preliminary moment tensor estimation as a function of source depth. We are in a process of implementation of the method of Tape and Tape (2015) of uniform discretizing the moment tensor space with following determination of the optimal moment tensor and depth by comparing observed seismograms with synthetic waveforms. Teleseismic P waves are windowed around an analyst picked first arrival filtered at 0.6 - 4.5 Hz. Regional Rayleigh waves on the vertical component are selected in a 180 second window filtered 10-50 s period. Instrument responses are removed from observed signals prior to processing.

Teleseismic Green's functions are calculated with the stationary phase approximation using the AK135 velocity model for the propagation path and CRUST1.0 for the source and receiver locations, and the regional surface waves are synthesized with the wavenumber integration, using Robert Herrmann's code (CPS package).

Optimal solution shown as beachball at joint PDF/Depth plot corresponds to 1.3 km for Jan-6-2016 event and 1 km for the Sep-09-2016 event, with pre-dominant positive isotropic source (61% and 51%), accompanied by well pronounced DC component (26% and 38%) and 13% and 11% CLVD.

Preparatory Commission for the Comprehensive Nuclear-Test Ban Treaty Organization, Provisional Technical Secretariat, Vienna International Centre, P.O. Box 1200, A-1400 Vienna, Austria.
E-mail: ivan.kitov@ctbto.org

Disclaimer: The views expressed on this poster are those of the authors and do not necessary reflect the views of the PTS CTBTO