CTBTO seismic processing and the announced DPRK nuclear test of October 9, 2006

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CTBTO PREPARATORY COMMISSION | preparatory commission for the comprehensive nuclear-test-ban treaty organization

Abstract

The Provisional Technical Secretariat (PTS) of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) has been ramping-up the installation of the International Monitoring System (IMS) consisting of a network of seismic, hydroacoustic, infrasound, and radionuclide stations, since its inception in March 1997. Data from these networks are automatically processed at the International Data Centre (IDC) to produce, within a few hours, a series of automatic bulletins called the Standard Event Lists (SEL1, SEL2, SEL3). After analyst review and correction as necessary the Reviewed Event Bulletin (REB) is produced. Additional information about characterization of an event as an earthquake or otherwise is also available in the Standard Event Bulletin (SEB) shortly after production of the REB. The overall process was successfully tested on October 9, 2006 when the Democratic People's Republic of Korea announced and conducted a nuclear test.

The standard SEL1 bulletin was routinely produced on the day of the event with good results. The event was available in the IDC database 1 hour and 46 minutes after its occurrence and consisted of 13 associated stations, all part of the primary seismic network and ranging in distance from 17 degrees to 151 degrees. The origin time of the event was 1:35:28 UT, the location at 41.28 North, 129.01 East, and depth 0 km. Subsequent SEL2 and SEL3 processing did not modify the composition or the location of the event. An additional 9 stations contributed to the event in the REB bulletin. The location of the event was moved slightly to 41.31 North and 129.02 East, the origin time being moved earlier by 0.7 seconds. The surface area of the error ellipse was reduced from 2391 km2 to 880 km2 after interactive analysis, and the event was not screened out as an earthquake (IDC does not perform discrimination per se but does screen out events with a high probability of being earthquakes.)

At the time of the event, and in addition to standard processing, the IDC was also experimenting with SEL0, a modified version of its processing sequence designed to produce an automatic global bulletin to the shortest possible time schedule. The purpose of this fast bulletin in a potential future operational context could be to supply additional information to tsunami warning organizations. The project was initiated following the disastrous Indian Ocean Tsunami of December 26, 2004. The experimental SEL0 bulletin detected the DPRK event with an epicentre at 41.13 North, 128.33 East, and included 12 primary stations. The event was in the database 19 minutes after its occurrence. Although the quality of the solution was not as good as the SEL1 solution - in particular the event was erroneously placed at depth - the SEL0 epicentre was close enough to the suspected test site to allow staff at the IDC to be alerted and start diligent work on the analysis before major news media publicly announced the event.

Conclusions and future work

The occurrence of the underground DRPK nuclear test on October 9th, 2006 provided the CTBTO with a unique opportunity to test the capability of the seismic network and detection software being installed since the organization's debut in 1997. The results show that, although the network is still being installed, tuned, and tested and is not yet complete (in particular the nearby station KSRS was not yet fully operational at the time of the event), the overall system performed well.

• The automatic system detected the event which was present in the SEL1, SEL2 and SEL3 automatic bulletins with an accurate location and within the expected time delay. The experimental SEL0 bulletin's results showed that the time delay between occurrence of the event and placement in the database could be further reduced to approximately 20 minutes.

• Analysis added stations to the solution for the event and was able to constrain the error ellipse to a surface area small enough to satisfy the guidelines to permit effective on-site inspection.

• The event was not screened-out as a natural event by the event screening software in place, although the regional data available to perform the screening was limited in quantity.

Future work will focus on improving the conditions under which event screening is applied. Another potentially interesting area to investigate as well is the introduction of a jack-knife type of algorithm to stabilize the location solution, particularly with depth, as the SEL0 solution suffered from an instability introduced by a single arrival.

Processing of seismic data at the International Data Centre

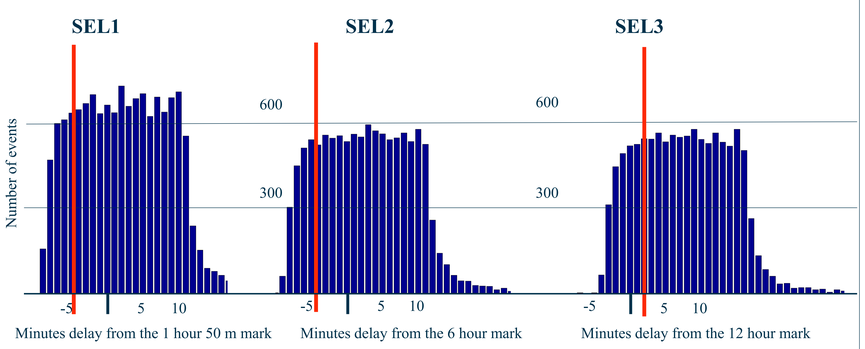
Primary seismic station data is delivered continuously by CD protocol via the VSAT-based GCI to the IDC. The waveforms are collected into 10 minute intervals which are then processed as soon as sufficient data is received.

The first level of automatic processing is Station processing which consists of two stages. The first stage forms detections and extracts features, such as arrival time, amplitude, period, azimuth and slowness from the waveforms. The second stage makes a preliminary, tentative identification of the extracted detections based on the value of their features, groups signals together that are likely to belong to the same source, and performs single-station locations based on groups of detections whenever possible.

The second level of automatic processing is Network processing. In contrast to Station processing, which processes data as soon as it is available, Network processing is triggered every 20 minutes, with fixed delays relative to real time to produce three automatic global Standard Event List bulletins. The first of these, or SEL1, is produced at approximately 1 hour 50 minutes after real time. At that stage, only primary seismic and hydroacoustic stations are used in the bulletin. The SEL1 bulletin is used to acquire additional data through requests to the auxiliary seismic network. Time segments to be requested are predicted based on the SEL1 events for stations within 30 degrees of the hypocentre and are processed through Station processing. The additional auxiliary station arrivals are included into the SEL2 and SEL3 bulletins, along with hydroacoustic and infrasound arrivals. The SEL2 and SEL3 are produced approximately 6 hours and 12 hours after real time (see actual time statistics in the figure below.)

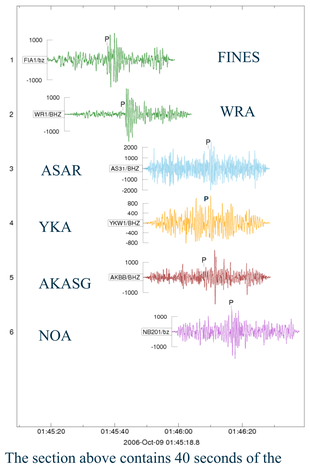
After the critical step of interactive analysis, which results in the production of the Reviewed Event Bulletin (REB), the events undergo Post analysis processing, including body and surface wave magnitude calculations, various waveform archiving activities, event characterization and event screening. Event screening attempts to positively identify natural phenomena, based on depth and P/S amplitude ratios (e.g. Fisk et al., 1999.)

Time statistic of standard automatic network processing at the International Data Centre of the CTBTO.



Automatic network processing at the IDC consists of three processing pipelines named SEL1, SEL2 and SEL3, at different time delays after real time. The graph above shows the distributions of events during a three-month period (October-December 2006) according to their delay in minutes with respect to the nominal time (shown below the graph) after which they should be present in the database. Note that the total number of events formed by the SEL1 pipeline is larger than the number of events formed by the SEL2 and SEL3 pipelines. This is due to a lower threshold for one of the acceptance criteria for automatic events. The red lines indicate, for each of the pipelines, the time at which the DPRK event of October 9, 2006 was written to the database.

Performance of the IDC system for the DPRK event of 9 October 2006



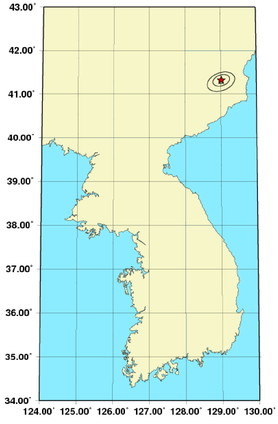
The section above contains 40 seconds of the broadband channel waveform segments and the automatic picks for stations between 60 and 70 degrees from the epicenter. The filter band used is 1.5 to 4.5 Hz, where a reasonable signal to noise ratio is obtained. The section illustrates the relatively low signal to noise ratios and the relative difficulty of performing automatic picking for an event in this magnitude range. The signal to noise ratio ranges from 4.6 at station NOA to 25.4 at station FINES.

The trace above shows 70 seconds of broadband waveform data for the station KSRS starting 10 seconds before the theoretical arrival for that station (which was not contributing to IDC operations at the time of the event.) Note the large amplitude P wave relative to the S arrivals. This is indicative of an explosion-like source and is one characteristic used to avoid screening out this event as a natural event.

The map to the right shows the location of the stations automatically associated in the SEL1, SEL2 and SEL3 bulletins. Note the good azimuthal (121 degrees of azimuthal gap) and distance coverage between 17.4 degrees and 151 degrees.

The map to the left shows the location of the stations included into the REB bulletin. The azimuthal gap is now reduced to 112 degrees, and the distance range is expanded to include stations between 8.3 degrees and 153.3 degrees.

The map to the right shows the Korean peninsula with the locations and error ellipses for the SEL1 event (green dot) and the REB event (red star). The semi-minor axis for the SEL1 error ellipse is 22.3 km and the semi-major axis 34.1 km. Note that the SEL1 event's location is quite close (3.6 km) to the analyst-reviewed location. The SEL2 and SEL3 event locations are the same as the SEL1 location, the association set being identical for all three automatic bulletins. The addition of 9 stations after analysis has led to a reduced error ellipse, with a semi-minor axis of 13.6 kilometers and a semi-major axis of 20.6 km. Its surface area is within the guidelines set for on-site inspection.



Disclaimer

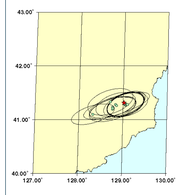
The views expressed in this paper are those of the authors and do not necessarily reflect the views of the CTBTO Preparatory Commission.

The SEL0 bulletin and the DPRK event

The SEL0 bulletin is an experimental bulletin which is being tested on the IDC development LAN. Its purpose is to explore which data and products beyond the raw waveform data from the IMS might be useful and could be provided by the PTS as input to tsunami warning centres (Le Bras et al, 2006.) The critical feature of such a product is the timeliness of the delivery of the product and we are routinely achieving a delivery time of approximately 20 minutes. The SEL0 bulletin was operating on the 9th of October 2006 and recorded the event. The event was formed automatically with twelve stations, a slightly different set than the standard bulletin station set (station HFS is used rather than station LPAZ), and the solution was placed at a depth of 411 km and 70 km away from the REB location of the event. Thus, the solution was not as good as with the standard processing.

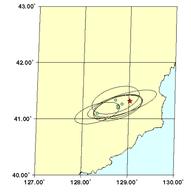
#	Origin Time (hum)	Origin Time (ep)	Orid	Latitude	Longitude	Depth	Magnitude	Nass	Ndef	Region	Delay(m)
9	2006-10-09 07:44:02	1160379842.2	292287	30.8237	56.6624	75.0	4.1	17	9	NORTHERN IRAN	16.22
10	2006-10-09 05:34:26	1160372066.0	292243	-2.7988	28.0311	0.0	4.0	10	6	LAKE TANGANYIKA REGION	15.80
11	2006-10-09 05:12:53	1160370773.5	292231	30.9200	67.9692	0.0	4.3	12	6	PAKISTAN	17.32
12	2006-10-09 04:38:52	1160368756.3	292214	56.1824	164.1964	12.0	3.8	7	7	KOMANDORSKIYE ISLANDS REGION	16.37
13	2006-10-09 01:36:12	1160357772.4	292132	41.1285	128.3304	411.0	3.3	12	12	NORTH KOREA	19.07
14	2006-10-09 01:09:14	1160357774.1	292128	40.8880	128.0165	431.1	3.3	6	6	NORTH KOREA	13.92
15	2006-10-09 00:10:07	1160352607.0	292098	-23.1267	-175.6596	65.0	4.0	20	10	TONGA ISLANDS REGION	20.12
16	2006-10-09 00:10:25	1160352625.5	292091	-23.3871	-175.8313	240.0	3.6	17	7	TONGA ISLANDS REGION	14.68
17	2006-10-08 22:32:31	1160346751.7	292045	35.7156	76.0717	130.0	3.6	8	6	EASTERN KASHMIR	17.60
18	2006-10-08 22:31:51	1160346711.2	292044	-8.2493	153.0189	0.0	4.4	16	10	DENTRECASTEAUX ISLANDS REGION	18.28
19	2006-10-08 21:30:46	1160343046.2	291994	-31.7874	-68.4322	171.4	3.4	12	8	SAN JUAN PROVINCE, ARGENTINA	19.85

An internal web page is available that displays the content of the database containing the SEL0 bulletin. A short time interval containing the DPRK event is displayed in the figure to the left. The last column shows the delay between occurrence of the event and time at which it is in the database. Note that there are two instances of the event visible on the page. The first instance was formed within about 14 minutes with 6 stations and the second within 19 minutes with 12 stations.



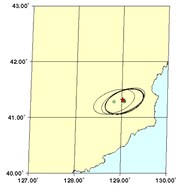
We analyzed the reasons why the SEL0 solution was not placed at the surface, by conducting a 'jack-knife' algorithm simulation. The simulation consisted in taking away one station at the time from the SEL0 simulation set and re-running the automatic association on the remaining stations. The resulting set of solutions is shown on the map to the left (green dots) along with the REB solution (red star). It is clear that there is a strong scatter depending on the inclusion or exclusion of a single arrival from the set available for association. The automatic arrival from HFS has the strongest influence on placing the event at depth and away from the actual location, but this influence is balanced when including station LPAZ in the solution as well. This is shown by the three figures below. The map to the left is for the solutions with HFS only and do not include LPAZ. The centre map shows the solutions when HFS is not associated and the map to the right shows the solutions with both HFS and LPAZ associated.

HFS - no LPAZ



No HFS

HFS and LPAZ



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