T4.-P19 Selected Research Activities of Turkish NDC

O. Necmioglu[1], K. Semin[1], M.U. Teoman[1], S. Altuncu Poyraz[2], S. Kocak[1], C.T. Destici[1]

[1] Boğaziçi University - Kandilli Observatory and Earthquake Research Institute - Belbasi Nuclear Tests Monitoring Center

[2] Boğaziçi University - Kandilli Observatory and Earthquake Research Institute – Regional Earthquake and Tsunami Monitoring Center

Abstract

Boğazici University - Kandilli Observatory and Earthquake Research Institute (KOERI) acts as the Turkish National Data Center (NDC) and is operating International Monitoring System (IMS) Primary Seismic Station BRTR (PS-43) under Belbasi Nuclear Tests Monitoring Center (Belbasi NTMC) for the verification of compliance with the Comprehensive Nuclear-Test-Ban Treaty since February 2000. The NDC is responsible for operating two arrays, which are part of the IMS, as well as for transmitting data from these stations to the International Data Centre (IDC) in Vienna. Selected capacity building activities of the Turkish NDC to be presented at SnT 2017 focus on i) A theoretical study to investigate the array response and gain for different array configurations in order to find the optimal placement of additional sites for a possible enlargement of BRTR from 6 SP-1 BB to 9 SP-1BB elements; ii) Comparison of CTBTO/IDC and KOERI/Regional Earthquake and Tsunami Monitoring Center (RETMC) earthquake bulletins for the first six months period of 2016, and iii) Analysis of DPRK events.

Theoretical Analysis of Expanding the Short - Period Keskin (BRTR) Array

Summary

Keskin (BRTR) array is one of most important seismic stations of IMS and AFTAC due to its location. BRTR array, which has the lowest number of elements among the other IMS seismic arrays is consists of 6 SP and 1 BB site at the moment. IMS requires a minimum of 9 elements size for new installed arrays. The number of sites in an array is important for detection capability, since Signal-to Noise improvement with array processing techniques increase with number of elements. Seismic arrays are defined as groups of closely located seismological stations. The detection capability for BRTR could be enhanced significantly by extending the current array configuration. Therefore, it is desired to find optimal configuration with minimum number of additional array sites.

1. CALCULATION OF ARRAY GAIN USING CROSS-CORRELATION.

Before calculating the expected gains for future additional elements to the BRTR array, we have calculated the current SNR Gain of the array. The SNR gain G for seismic arrays can be expressed by

$$G^2 \frac{\sum_{ij} C_{ij}}{\sum_{ij} N_{ij}}$$

where *Cij* is the signal cross-correlation and *Nij* is the noise cross-correlation between sensors *i* and *j* . For an array with M sensors, theoretical gain becomes $G^2 = M$. Therefore six short period element BRTR array (Figure 1) should have (√6) gain for perfectly correlated signal and uncoherent noise. We have used couple of teleseismic events with epicentral distaces between 30 – 50 degree for SNR correlation calculations. There are 15 combinations of sensor pairs for 6 element BRTR array. The Interstation distances are shown on Table 1 below.

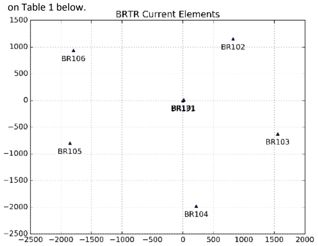


Figure 1: BRTR Array current site configuration

Table 1: Interstation distances between station pairs.

PAIRS	DIST(KM)
101 – 102	1,41
101 – 103	1,66
101 – 104	1,99
101 – 105	2,03
101 – 106	2,04
102 – 103	1,91
102 – 104	3,19
102 – 105	3,32
102 – 106	2,64
103 – 104	1,91
103 – 105	3,42
103 – 106	3,7
104 – 105	2,38
104 – 106	3,54
105 – 106	1,75

1.1 Data processing

Performed processing steps are as follows;

- 30 seconds of noise data and 10 seconds of P-wave signal are selected.
- Time series are bandpass filtered with center frequencies 1, 1.25, 1.5, 2, 3, 6 Hz.
- P wave signals are shifted (aligned) according to the signal slowness before correlation. Noise data are not shifted.
- Cross-correlation values are computed for all combinations of sensor pairs.
- All of the signal and noise correlation values are combined in a diagram for each particular frequencies.

We have used GEOTOOL (PTS) software for data analysis. F-K analysis was performed in order to align the waveforms according to slowness (velocity and back azimuth). An example analysis is given Figure 2 and Table 2. Kyrgyzstan event (26.06.2016 11:17, M: 6.4) is one of the teleseismic events that were recorded clearly by BRTR array. P-wave signal is correlated very well between array sensors. The signal and noise correlation values are decreasing with increasing frequency.

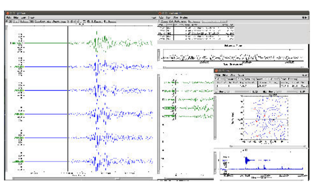
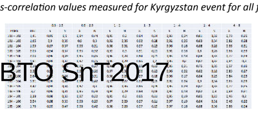


Figure 2: Example of cross-correlation calculation for an event (26.06.2016 – 11:17 Kyrgyzstan M: 6.4) using Geotool software. This figure show and include the waveform, F-k analysis and correlation calculation steps.

Table 2: Cross-correlation values measured for Kyrgyzstan event for all frequencies



CTBTO SnT2017

1.2 Results of the Gain Analysis

Figure 3 shows us the average results of the correlation analysis for 1.5 Hz data. The signal correlation is around 0.9 which is expected, while we have noise correlation values around 0.3. There is no big differences regarding correlations between intersensor distances for current array configuration. Finally, putting the signal and noise correlation values into the array gain formula we obtain the BRTR gain for teleseismic data with different frequencies (Figure 4). Our correlation gain analysis shows that for 1.5 Hz frequency our array gain is very close to theoretical gain calculated by *log10(√6).*

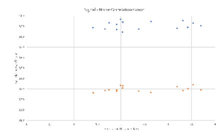


Figure 3: Plot of average signal and noise correlation values for 1.5 Hz. Blue symbols represents signal and orange ones denote noise data.

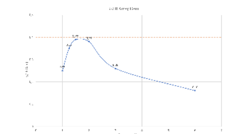


Figure 4 : BRTR Array gain for teleseismic distances. This gain plot indicates that BRTR array achieves maximum gain around frequencies 1.5 -2.0 Hz. Orange dashed line shows the theoretical gain value log(√6) *= 0.39.*

2 – ARRAY RESPONSES

2.1 New Inner Ring Design (9 Elements)

We have looked at the BRTR array response functions in slowness space. It is evident that there are big side lobes which are located near the main lobe. This might cause an offset in azimuth resolution of the array. Figure 5 shows us the difference between current BRTR geometry and additional 3 elements as inner ring. BR10A, BR10B, and BR10C codes denote the new possible sites to be installed. On the right, we show the vertical section of the array response parallel to the kx component of the slowness vector. It is easier to notice the response improvement just by looking at this graph. With 3 new sites, big side lobes lose energy and the main lobe radius stays almost the same as the current configuration. Therefore the minimum resolvable wavenumber that BRTR can detect remains unchanged. Theoretical array gain with the new elements is expected to increase ~0.07 magnitude units.

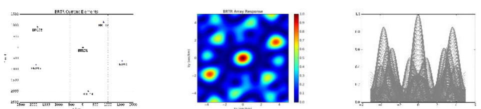


***Figure 5a**: BRTR current configuration and corresponding response(middle) with cross-section of the response (right).*

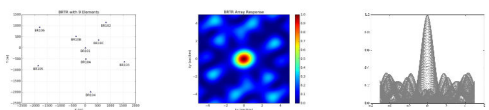


***Figure 5b**: BRTR with new 3 elements inner ring configuration and corresponding array response.*

2.2 New Inner and Outer Ring Design (17 Elements)

The main difference between 9 elements and 17 elements is the radius of the main lobe. Installing an outer ring results in larger array aperture and hence better resolution for teleseismic event detection. We compare the 3 different arrays with similar circular geometry in Figure 3. TORD and BRTR look very similar to each other. BRTR has narrower main lobe than TORD but on the contrary TORD has smaller side lobes which is due to array geometry and aperture size. TORD has about 6 km aperture while new BRTR configuration has 7.5 km. Larger distances between array elements are the main cause for the number of side lobes. Consisting of 25 elements, 3 km small aperture ARCES array gives very good azimuthal resolution due to its geometry. However due to large main lobe, this array can't easily distinguish between waves with small wavenumber differences.

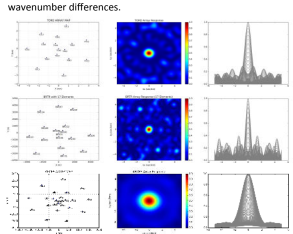


***Figure 6:** Top figure(a) shows the TORD array configuration and response graph while in the middle (b) BRTR with 17 elements geometry. Bottom row (c) is the geometry and the response of the ARCES array.*

Conclusion

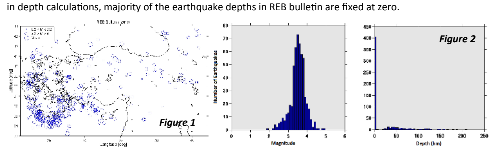
Since our primary goal is to both satisfy the IMS criteria and increasing the teleseismic capabilities of the BRTR, we have looked at the various configurations of BRTR array using theoretical array gain calculations and response function analysis. It is clear from the results that;

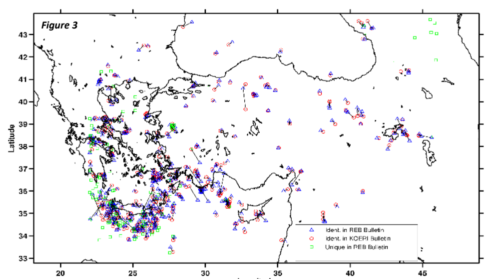
- BRTR array will be improved in terms of azimuth resolution and array gain just by adding 3 additional elements as inner ring. SNR gain would be increased about 1.2 times. This configuration will be similar to ZALV array. However due to small aperture, BRTR array will be considered as "Regional" array.
- Adding more elements as outer ring will enhance the resolution of measuring apparent velocities, consequently increasing the teleseismic detection capability due to bigger aperture size.
- We need to install temporary seismometers for at least 6 months to the planned locations in order to assess the site conditions. Our results are only theoretical and some of the locations we have chosen may not be suitable for seismic station installation.
- Since the cost of a project of this caliber will be quite substantial, we could start by installing 3 new array elements as inner ring and then later add the outer ring stations when the budget is available.

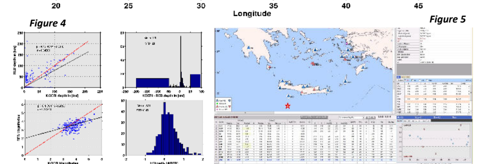
Comparison of CTBTO/IDC and KOERI/RETMC Earthquake Bulletins

Kandilli Observatory and Earthquake Research Institute (KOERI) is currently operating a local seismic network in Turkey consisting of 225 permanent stations.15343 events were located spanning the January-December 2016 time frame. The enhanced station coverage having an average station spacing of ~40 km, lead to a minimum magnitude (M_L) calculation of 0.5. Overall, M_L magnitudes vary between 0.5 and 5.5 Vertical and horizontal location uncertainties do not exceed 2km and 3km, respectively. Vast majority of the earthquakes occurred below 30 km depth mostly in the upper crust, whereas the relatively deeper earthquakes were distributed along both the Hellenic and Cyprian arcs that form the plate boundary between the Anatolian and northward subducting African plates.

Our primary goal is to investigate and assess the location accuracy of the Reviewed Event Bulletin (REB). Together with all the primary and auxiliary seismic stations around the globe operated by the International Monitoring System (IMS), REB solutions also include data from a certified primary seismic array (PS43-BRTR) located in Ankara, the capital city of Turkey. In this regard, our starting point is to compare the locations of both REB and KOERI bulletins. Within the same time period of six months, IDC reported 542 earthquakes with magnitudes varying within the 2.2-4.9 range as indicated in Figures 1 and 2. Due to high uncertainties in depth calculations, majority of the earthquake depths in REB bulletin are fixed at zero.







Comparison of KOERI/RETMC & IDC catalogues

Figure 3 demonstrates the dislocation vectors of the common 445 events out of the 542 events reported in REB bulletin. These events were retained based on a maximum epicentral distance difference of 150 km and a maximum origin time difference of two minutes. The length of most of the dislocation vectors do not exceed ~30 km with some exceptions beneath the Hellenic arc where the deeper earthquakes are reported in both catalogues. This might be related to the less dense station coverage of KOERI in that region. Most of the REB solutions are reported with mislocation errors smaller than 40 km. Furthermore, comparisons of magnitude and depth calculations of both catalogues are shown in Figure 4.

Vast majority of the unique events in REB are mostly located along the Hellenic arc and seven events were found to be beneath Georgia and its vicinity. One duplicate event beneath Greece was detected in REB (not identified in other international bulletins such as EMSC) which requires further investigation.

Conclusions

The comparison of both catalogues can be summarized as follows:

- Minimum calculated magnitude in REB is 2.2, whereas KOERI catalogue can detect magnitudes as low as 0.5 considering the dense station coverage. Magnitude estimations tend to demonstrate considerable scattering with no systematic differences in M_L (Figure 4).
- Striking differences in depth values were observed due to weak depth resolution in REB hypocenter solutions (the fixed depths at zero seen in Figure 4). On the other hand, depth calculations for the deeper earthquakes are in good agreement in both catalogues with only a few exceptions. Vast majority of the unique events in REB are mostly located along the Hellenic arc and five events were found to be beneath Georgia and its vicinity.
- Surprisingly, we identified a significant number of events present in REB but not reported by KOERI bulletin along the African-Anatolian Subduction system (green squares in Figure 3). Most of the earthquakes that occurred along this subduction system were not reported in the KOERI bulletin due to insufficient station coverage with a high azimuthal gap value exceeding 270°, the discrepancies between "Seismic Detection Network Threshold" and "Earthquake Catalog Completeness Threshold" maps and their implications. In addition, some of the events were not automatically detected by the SeisComp3 software which makes it harder for the observer to pick them up in a limited period of time. In addition, five unique events in REB Bulletin located beneath Turkey mainland (in the vicinity of İzmir-Manisa cities) are most likely caused by quary blasts that were not included in KOERI Bulletins.
- Out of 97 unique events in REB, we also detected 8 events that were not included in the EMSC bulletin as well. An example solution is provided in Figure 5 for an M: 2.9 earthquake at a depth of 23km that occurred close to the Hellenic trench, the south of Crete Island. The calculated azimuthal gap value is 260°.

Analysis of DPRK Events

Turkish NDC provides national authorities a preliminary but comprehensive analysis of any nuclear test conducted and detected by the IMS within 6h after start of business hours. An example on 9 September 2016 DPRK test is presented below.