An improved earthquake catalogue in the Marmara sea region, Turkey using massive template matching

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EGU2016 - 12992

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1. Introduction

After the 1999 Izmit earthquake, the Main Marmara Fault (MMF) represents a 150 km unruptured segment of the North Anatolian Fault located below the Marmara Sea. One of the principal issue for seismic hazard assessment in the region is to know if the MMF is totally or partially locked and where the nucleation of the major forthcoming event is going to take place.

The area is actually one of the best-instrumented fault systems in Europe. Since 2007, various seismic networks comprising both broadband, short period and OBS stations were deployed in order to monitor continuously the seismicity along the MMF and the related fault systems for a total of 124 seismic stations (Figure 1).

A recent analysis of the seismicity recorded during the 2007-2012 period has provided new insights on the recent evolution of this important regional seismic gap. This analysis was based on events detected with STA/LTA procedure and manually picked P and S wave arrivals times (Schmittbuhl et al., 2015).
The seismicity is strongly varying along strike and depth (Figure 2). In particular, the central basin shows significant seismicity located below the shallow locking depth, 3 km (GPS measurements). Its b value is low and the the average seismic slip is high. These observations are consistent with a deep creep on this segment. On the contrary the Kumburgaz basin at the center of the fault shows sparse seismicity with the hallmarks of a locked segment. In the eastern Marmara Sea, the seismicity distribution along the Princess Island segment in the Cinarcik basin, is consistent with the geodetic locking depth of 10 km and a low contribution to the regional seismic energy release.
The assessment of the locked segment areas provide an estimate of the magnitude of the main forthcoming event to be about 7.3 assuming that the rupture will not enter significantly within creeping domains.

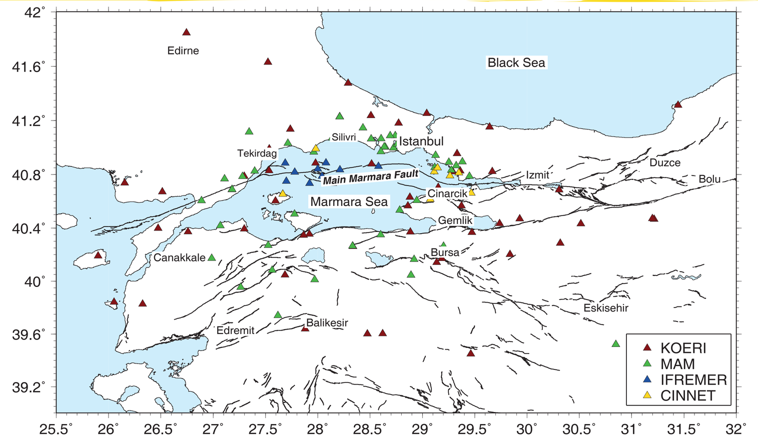


Figure 1 Map of seismic stations: KOERI and MAM (permanet networks); IFREMER and CINNET (temporary networks).

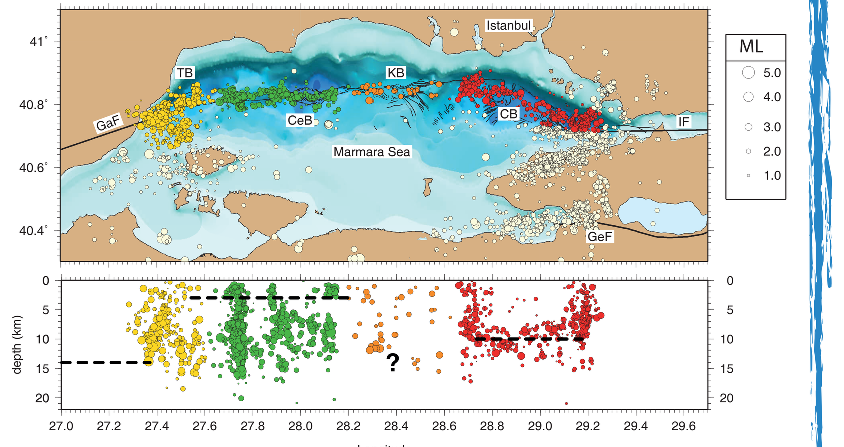


Figure 2 Relocated recent seismicity (2007-2012). Tekirdag basin (TB) in yellow. Central Basin (CeB) in green. Kumburgaz basin (KB) in orange. Cinarcik basin (CB) in red. The regional seismicity in white. Batymetry and faults are also indicated

2. Objective

In order to extend the level of details and to fully take advantage of the dense seismic network and to improve the seismic catalog, we implement an automatic earthquake detection technique based on a template matching approach (Lengliné et al., 2016). This approach uses known earthquake seismic signals in order to detect newer events similar to the tested one from waveform cross-correlation. To set-up the methodology and verify the accuracy and the robustness of the results, we initially focused in the eastern part of the Marmara Sea (Cinarcik basin, Figure 3) and compared new detection with those manually identified.

3. Catalog

The analysed data set consist in earthquakes recorded in the eastern part of Marmara Sea (Cinarcik basin) from 28 three component broadband stations (50Hz) operated by KOERI and TUBITAK and 6 three component short period CINNET stations (100Hz) supported by ANR (the French National Reseach Agency).

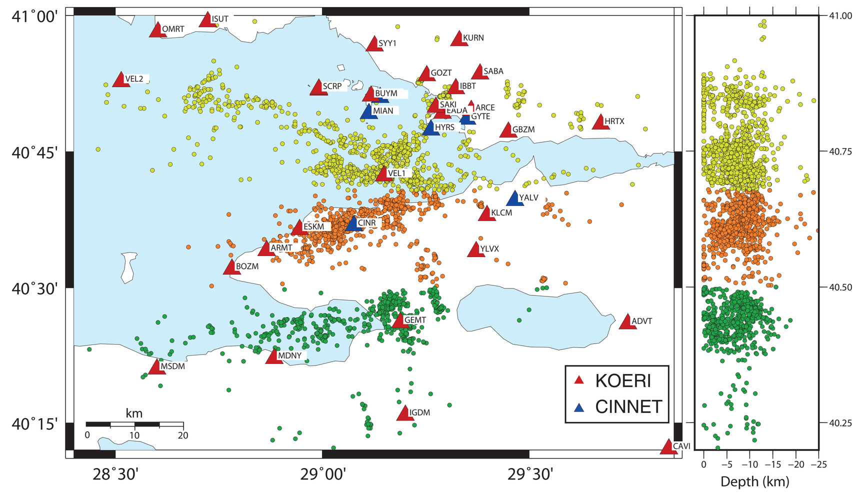


Figure 3 Analysed catalog. With different colours we indicate the considered selections of events. Blue triangles indicate the CINNET stations, the red triangles the KOERI stations

The considered data set consist in more 3000 events recorded in the period 2008-2011 .
It covers six orders of magnitude of seismic moment Mo (10^10 – 10^16 Nm), in a range of hypocentral distance 0-200km (figure 4).
In order to better recover the whole seismic catalog, we choosed to divide the data in 3 groups of events, with different geographical features.

Preliminary results on the Northern group are presented.

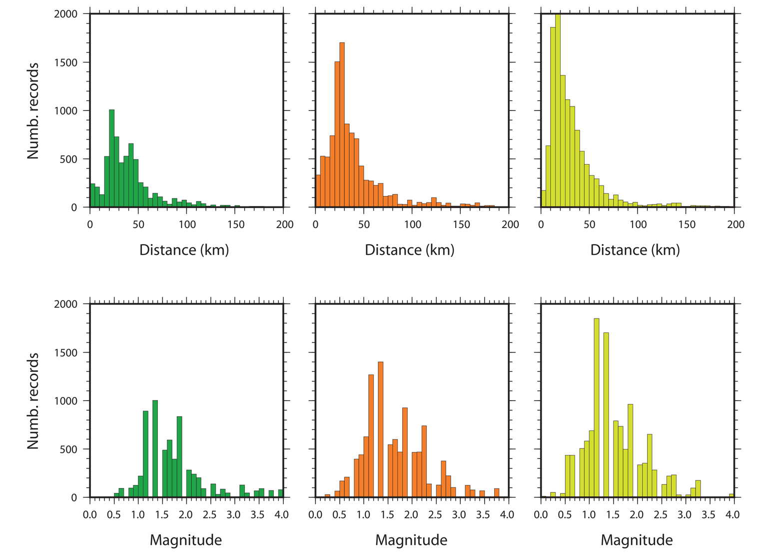
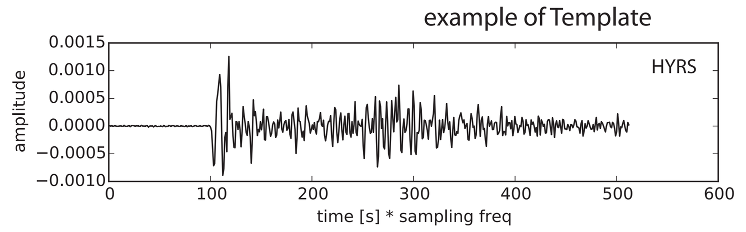
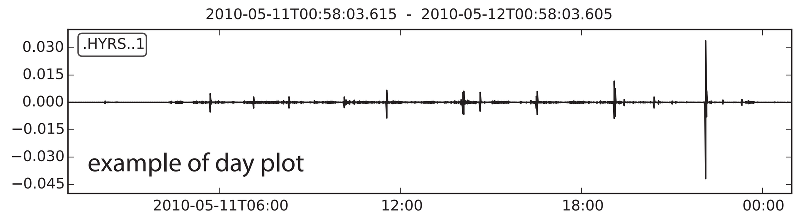


Figure 4 Histogram of number of recordings (considering the vertical component) in function of hypocentral distance (top) and local magnitude (bottom) for different groups.

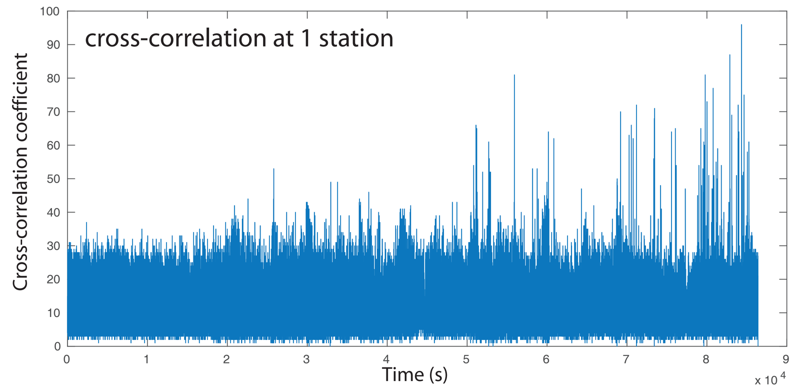
4. Method



we extract 5.12s windows starting 1s before P-wave pick at all stations on all the components



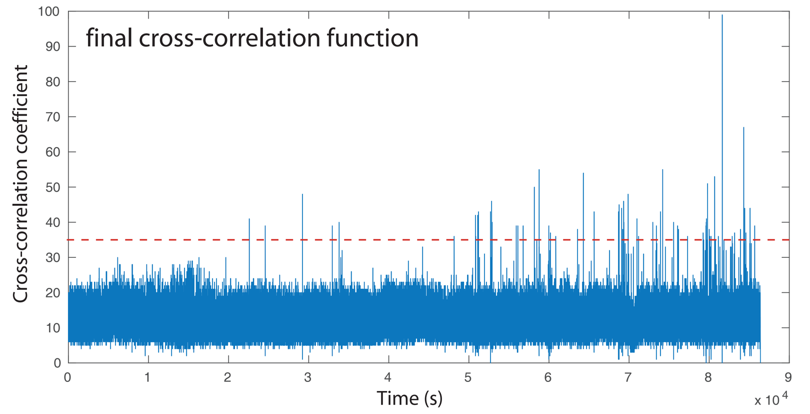
Template and continuous signals are filtered in the same frequency range [5-20 Hz], determined by comparison of noise and signal spectra.



Cross correlation coefficent is computed at each time step (0.01 s) between the template waveform and the current windowed continuous signal.

This procedure is performed on the vertical component of the 3 stations.

We apply a maximum filter over a duration of +/- 0.1s to the correlation signal. We then stack the obtained correlation coefficients from all the different stations after the application of the corresponding travel time correction.



The maximum filter allows coherent stacking even in the case where a small travel times between the template and detected events is considered (for example two events are not exactly collocated).
A threshold of 35% is considered.
In case of multiple templates are associated with a common detection, we simply consider the one with the highest tcorrelation coefficient.

5. Threshold and templates selection setting

We consider a particular day (2010-05-11) with a seismic swarm of 49 co-located events (star in Figure 7) to define the detection threshold and templates selection.

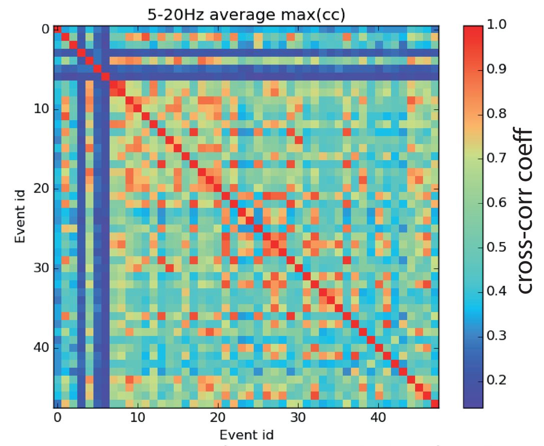


Figure 6. Matrix of cross-correlation for all the couples of events is computed considering an average value for the stations HYRS, MIAN, SEDF (most important number of P-picking)

Clustering analysis is performed considering different threshold of similarity (basing on cross-correlation coefficient)
For each "family" we choose the best event in terms of:
- maximum magnitude
- number of arrival times

Similarity	Templates
65%	5
70%	6
80%	9
85%	13

Table 1 Number of selected templates based on similarity (2010-05-11)

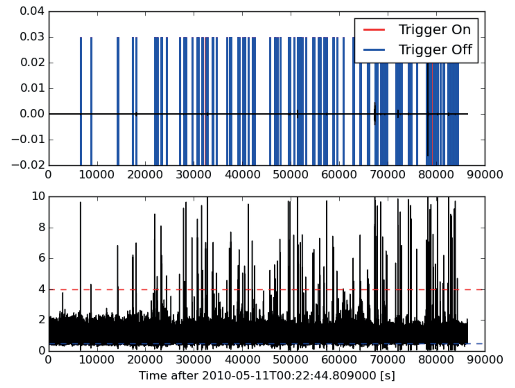
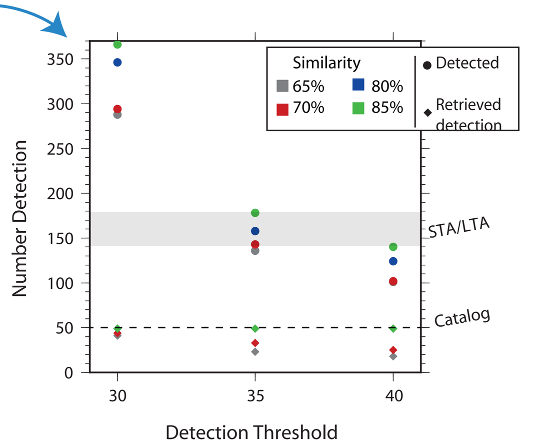


Figure 5. Example of STA/LTA at MIAN.Z
ST-window : 1s and LT-window : 10s

Detection with several parameters in order to retrieve the STA/LTA and catalog number of events



We finally chose to select the events based on 80% of similarity and to set at 35% the Detection Threshold

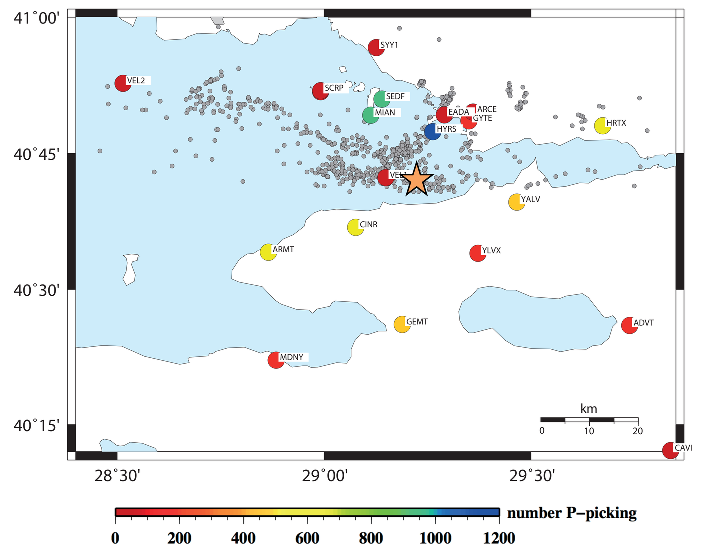


Figure 7. Map of 766 selected templates for the Nothern group. The star represent the location of the seismic crises of 11/05/2010. The station color is proportional to number of P-wave arrival time (on the whole dataset)

For the whole Northern group we performed the same analysis starting from 1096 events with minimum 3 stations recording.

766 template are selected considering a threshold of 80% with the clustering analysis.

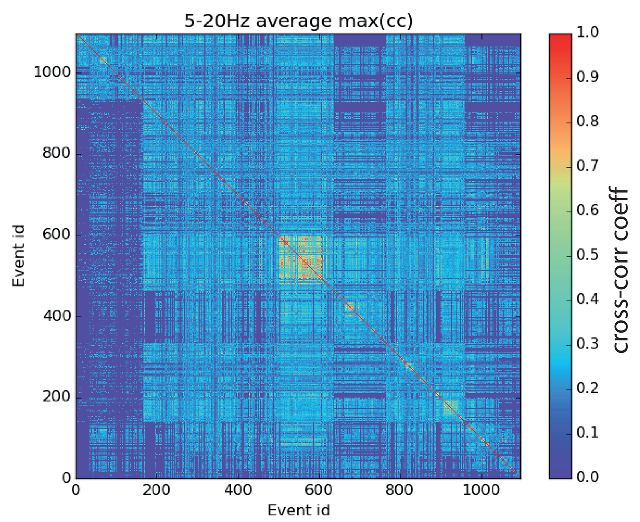


Figure 8. Matrix of cross-correlation for all the couples of events for the Nothern group

6. Application and results on 11-12 may 2010

The results of the automatic detection procedure on 11 and 12 may 2010 are presented. For each newly detected event we extract the waveforms (5.12 s long) associated to this detection at all possible stations based on the supposed P-wave arrival given by the template travel times + detection time.
The strong waveform similarity leading to large values of cross correlation and the same difference in Ts-Tp arrival times at each station suggest that the detected events and templates events are very similar in location.

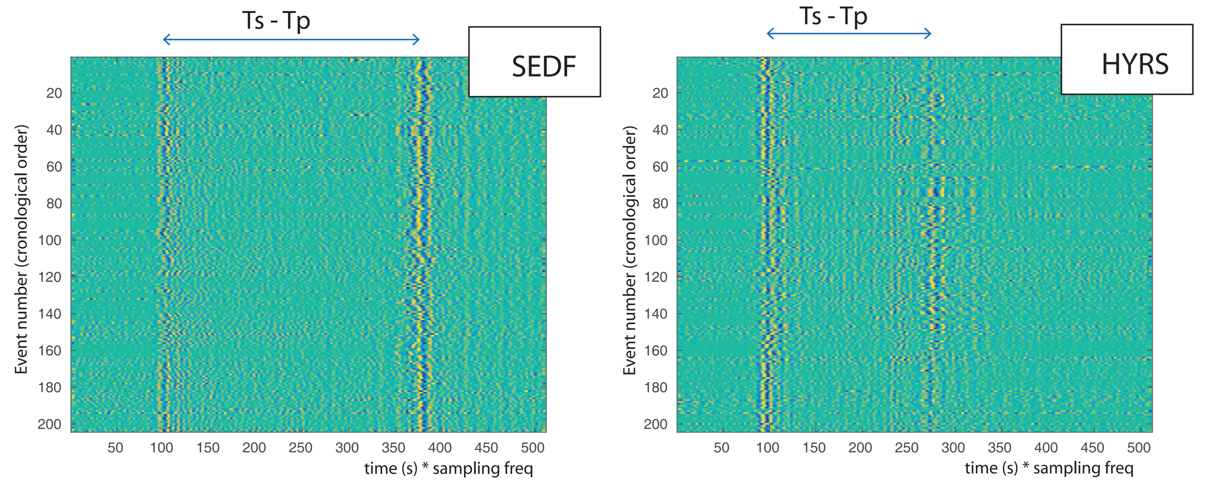
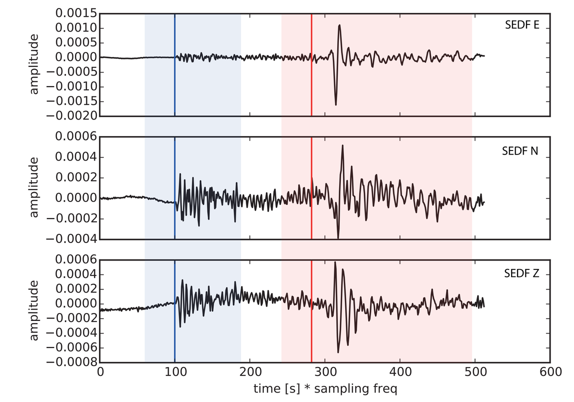


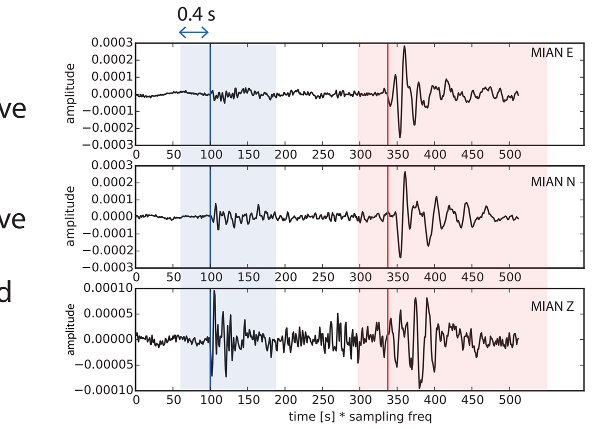
Figure 9 Waveforms recorded at SEDF and HYRS (vertical component) for all the detected events (11 - 12 may 2010). All signals are filtered between 5 and 20 Hz and normalized by their maximum amplitude. Events are sequentially ordered .

Far all pairs of events we compute travel time delays from cross-correlation by extraction the P-wave and S-wave windows on the vertical and two horizontal signals.



1,28 s long windows for P-wave (deduced from template)

2,56 s long windows for S-wave (theoretical arrival time, considering Vp/Vs = 1.74 and Vp=5.5 km/s)



All computed time-delays associated with a correlaiton coefficient higher than 60% are selected.

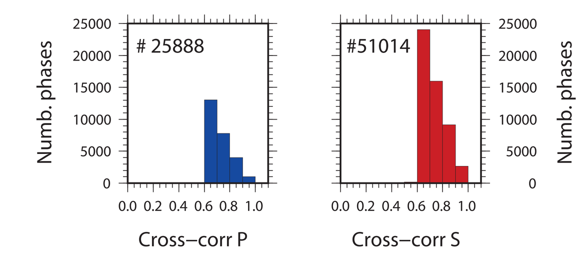


Figure 10 Histograms of computed P and S time-delays .

The application of our methods leads to the relocation of 198 events in 11 and 12 may 2010, compared with the initial number of 60 events

Travel time delays are then used to invert for the double-difference relative locations with HYPODD software (Waldhauser and Ellsworth, 2000) considering a 1-D velocity model

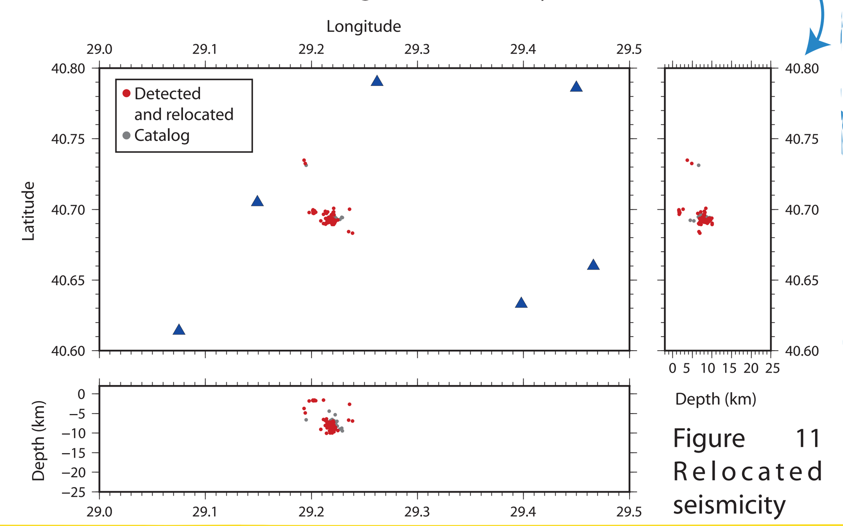


Figure 11 Relocated seismicity

7. Preliminary results on three months of data

Preliminary analysis scanning the continuous data on the months of march, avril and may 2010 with the waveforms of 766 selected templates are presented.

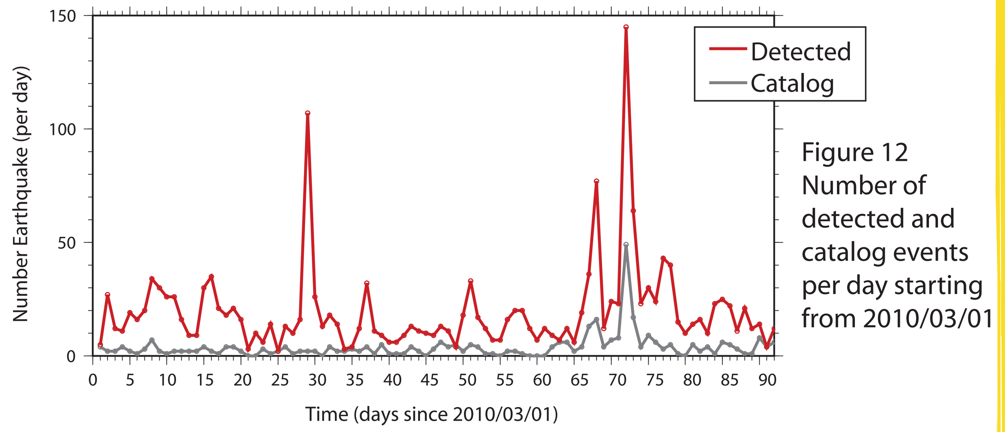


Figure 12 Number of detected and catalog events per day starting from 2010/03/01

A total of 1781 events are detected. It means we detect around 5 times more events than in the catalog (about 300 events).
Based on these new detections we obtain a preliminary relative location from time delays computations based on waveform correlation of 1595 events. The obtained image of the seismicity takes up the mean features of what observed from catalog (figure 3, yellow)

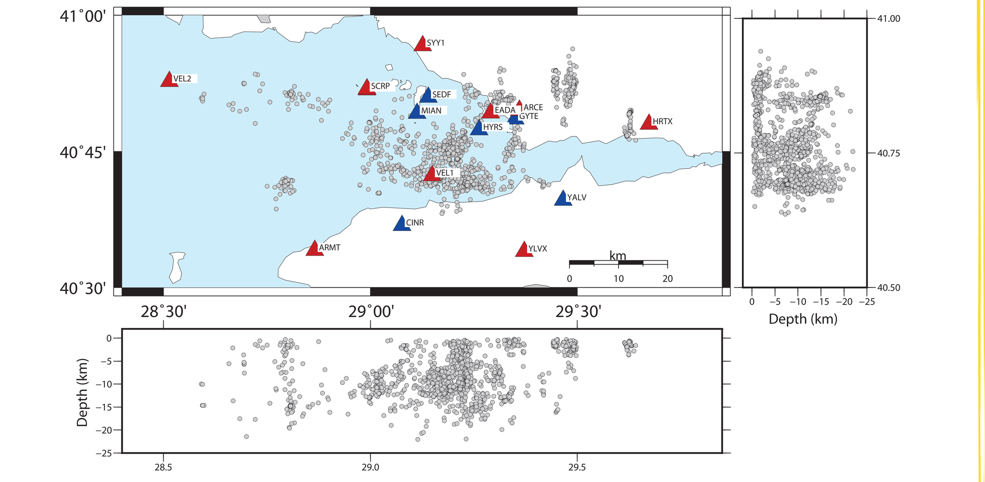


Figure 13 Relocated seismicity for the months of march, avril and may 2010

8. Future perspectives

Through the massive analysis of cross-correlation based on the template scanning of the continuous recordings, we will construct a refined catalog of earthquakes for the Marmara Sea in 2007-2014 period.
Our improved earthquake catalog will provide an effective tool to improve the catalog completeness, to monitor and study the fine details of the time-space distribution of events, to characterize the repeating earthquake source processes and to understand the mechanical state of the active fault systems in this area.

References

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