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DEVELOPMENT OF AN EARTHQUAKE EARLY WARNING SYSTEM BASED ON EARTHWORM. APPLICATION TO SW IBERIA

Núria ROMEU PETIT[1], Xavier GOULA SURIÑACH[2], José Antonio JARA SALVADOR[3], Yolanda COLOM PUYANÉ[4] and Teresa SUSAGNA VIDAL[5]

ALERT-ES (*Sistema de Alerta Sísmica Temprana*) project had the purpose of studying the feasibility of an Earthquake Early Warning System (EEWS) for the potentially damaging earthquakes that occur in the zone San Vicente Cape-Gulf of Cadiz (southwest Iberia). This area is characterized by the occurrence of large and damaging earthquakes, such as the 1755 Lisbon (I_{max}=X) or 1969 San Vicente Cape (M_s=8.1) events.

This study shows the process to develop, in Institut Cartogràfic i Geològic de Catalunya (ICGC), a prototype based on Earthworm USGS (2005) and the first results after a 6 month working period. The following requirements were taken into account: an efficient reception of waveforms from seismic stations on the area of study; an optimization of the picking, event declaration and location procedures to minimize the warning time for an acceptable location; and, finally, a quick computation of the proxies needed to estimate the magnitude.

The first step in the project was the selection of the *Earthworm* modules' structure. In this respect the processing modules were restricted to *pick_ew*, *binder_ew* and *eqproc*:

1. The main Earthworm module to automatically pick arrival times of the P waves, *pick_ew*, was modified in order to compute the P_d and τ_c parameters, for the estimation of the magnitude of an earthquake, in a window τ_0 whose length will depend on the epicentral distance of the channel being processed.

2. The *binder_ew* module originally has the purpose of automatically declaring events from the association of certain pickings of the P waves. It supplies a rough and quick hypocentral location of the event, which is updated for every new arrival-time received. However, this rough location was considered good enough to replace a proper locator in the ALERT-ES prototype.

3. Finally, the last processing module, *eqproc*, continuously gathers information from *pick_ew* and *binder_ew*, to assemble all parameters related to a new event and to publish the complete and updated location and magnitude. This module was deeply modified to estimate the event moment magnitude (M_w) from a weighted average of the magnitudes related to all P_d and τ_c stored parameters for each location received (Carranza et al., 2013).

The second step in the project has been fine-tuning the settings of the prototype to adapt its parameters to the area of study. The configuration of the automatic picking module, *pick_ew*, has been done for a total of 18 Broadband stations of three different networks: IM (Istituto de Meteorologia, Portugal), IGN (Instituto Geográfico Nacional, Spain) and WM (Real Observatorio de la Armada / Universidad Complutense de Madrid, Spain). The configuration of the event declaration and location was setup through 6 simulations of recent earthquakes. The results of the analysis proved that a 6-station configured system represented the best compromise between precision and elapsed time for the

[1] Engineer, Institut Cartogràfic i Geològic de Catalunya (ICGC), Barcelona, nuria.romeu@icgc.cat
[2] Head of Seismology, Institut Cartogràfic i Geològic de Catalunya (ICGC), Barcelona, xavier.goula@icgc.cat
[3] Engineer, Institut Cartogràfic i Geològic de Catalunya (ICGC), Barcelona, joseantonio.jara@icgc.cat
[4] Geologist, Institut Cartogràfic i Geològic de Catalunya (ICGC), Barcelona, yolandacolom@gmail.com
[5] Seismologist, Institut Cartogràfic i Geològic de Catalunya (ICGC), Barcelona, teresa.susagna@icgc.cat

actual available stations deployed in the area (Pazos et al., 2014). Besides, the simulations of recent earthquakes made possible to check the quality of the hypocenter estimation referred to the Instituto Geográfico Nacional (IGN) catalogue: the average of the distance between those hypocenters was 47km for San Vicente Cape area and 22km for San Vicente Cape area; and origin time average error was 6.3s and -0.2s, respectively for each earthquake area.

The last step was putting the prototype to work for a stable period of 6 months starting on July 23, 2013. A first successful result was that only regional events were detected, no noises, no teleseisms. A total of 44 regional earthquakes and in particular 9 from San Vicente Cape area and 17 from Gulf of Cadiz area were detected, as it can be seen in Figure 1. If we compare differences between actual hypocentral parameters determined by IGN and detected ones, the mean values are of the same order of those previously obtained in simulations (Pazos et al., 2014). Same coherent results are also obtained for average warning times for San Vicente Cape area (54s) and Gulf of Cadiz area (44s) and Lead Times at some towns as, Cadiz (50s and 0s respectively for each earthquake area), Seville (60s and 15s) or Lisbon (25s and 40s). Concerning estimations of the magnitude of the earthquakes, only 1 earthquake, from the 26 detected in the area of study, gave a probable M_w value. This particular event was the one with largest magnitude, M_w=4.4. After an analysis of the displacement records of all those events, only that event has a signal/noise ratio (SNR) high enough to estimate the M_w.

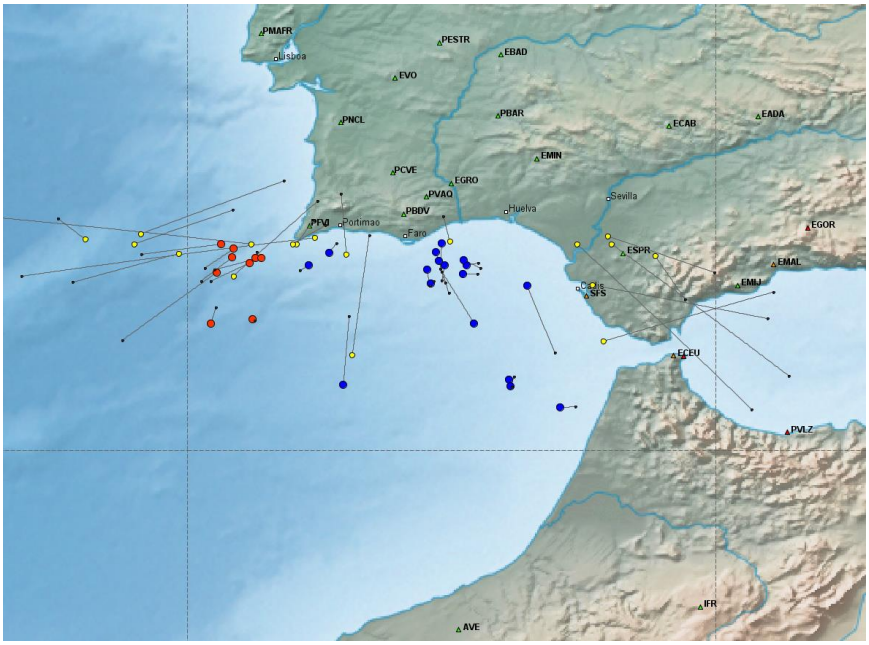

Figure 1. Results for the 6 months period analysed: reference epicentres are represented in small grey dots. Their corresponding automatic epicentres are also shown in dots of different colours depending on its area of origin (blue for Gulf of Cadiz, orange for San Vicente Cape and yellow for other regionals). Stations of the seismic network are depicted as triangles. Most populated cities are also shown.

Summarizing, an EEWS Earthworm based prototype has been developed, installed and under test during a 6 month period. The main conclusions are the following:

i) detections are reliable, because no false events have been detected,

ii) hypocenter location, warning times and lead times observed on some towns are useful and coherent with estimations previously done with simulations.

iii) a longer test period with a SNR threshold over displacement signal will improve the confidence in magnitude estimations in desired earthquakes.

In consequence, an Earthquake Early Warning System based on Earthworm is feasible for southwest Iberia.

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