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Optimization of PRESTo Early Warning System for South-Eastern Korea

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PRESTo software

PRESTo (http://prestoews.org) is a free and open source software platform for Earthquake Early Warning (EEW) that integrates recent algorithms for real-time, rapid earthquake location, magnitude estimation and damage assessment.
The software is mainly targeted at who are interested in characterizing within seconds the damaging potential of an occurring earthquake, with the possibility to provide personalized alarm messages to any number of end-users.
PRESTo in fact continually processes the real-time streams of ground motion recorded by the seismic stations for P-waves arrival detection. However, PRESTo can also work in a simulation mode whereby waveforms of past events can be played back into the system. In both cases, the software promptly performs event detection and provides location and magnitude estimates as well as shaking predictions at target sites.
The earthquake location is obtained by an evolutionary, real-time probabilistic approach based on an equal differential time formulation.
At each time step, the algorithm uses information from both triggered and not-yet-triggered stations.
The main parameters affecting the software behaviour are related to the event detection algorithm, i.e. the so called Binder: “Binder station for coincidence” (B.St) and “Binder secs for coincidence” (B.Time). The first variable represents the minimum number of triggered stations in the coincidence time windows to declare an event. The second variable represents the duration of the coincidence time windows expressed in seconds.
Magnitude estimation exploits empirical relationships that correlate this parameter to the filtered peak displacement (Pd) measured over the first seconds of P- and S-waves signal.

(1) $$LOG_{10}(Pd) = a + b \cdot M + c \cdot LOG_{10}\left(\frac{R_{HYP}}{10}\right)$$

where Pd could be measured on P or S signal using a time window of 2 or 4 seconds; M represents the magnitude and R_{HYP} the hypocentral distance in km.

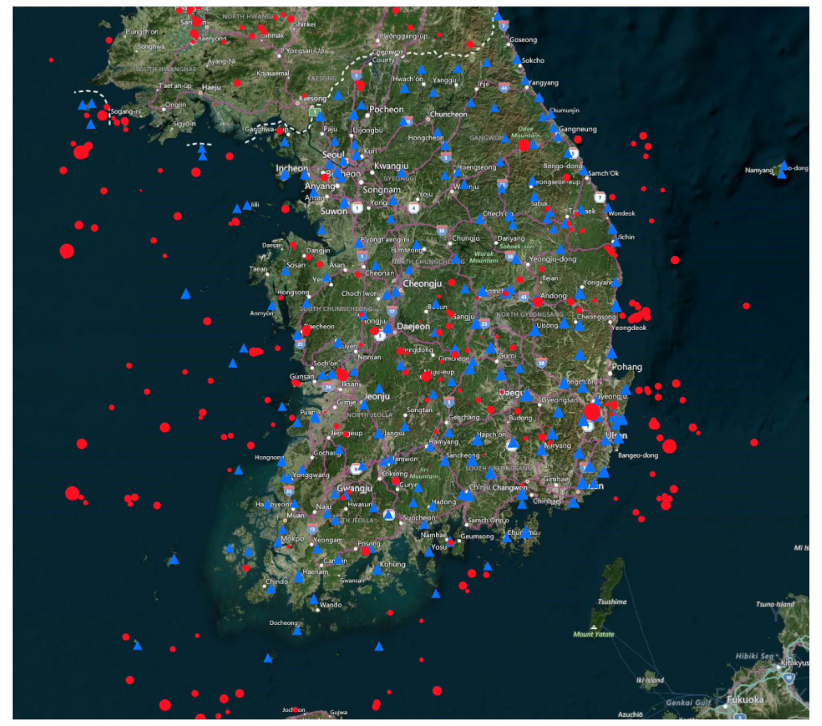

Fig.1 - South Korea: Red points represent earthquakes (the size is proportional to the magnitude); Blue triangles represent seismic stations.

Target area: South-Eastern Korea

In September 2016 and again in November 2017, Korea witnessed some of the largest magnitude earthquakes occurred in-land in its recent history. They were located in the South-Eastern part of the peninsula, near the cities of Gyeongju and Pohang, with magnitude ML 5.8 and 5.4 respectively (Fig.2). These earthquakes require a new calibration and tuning phase, to be correctly characterized by PRESTo, and suggest the application of a new and refined EW algorithms as shown below.

In this work the PRESTo algorithm parameters and regression laws were optimized and calibrated for the region of South Korea around the Gyeongju earthquake, specifically for a sub-network with a side of about 200 km (Fig.3).

Fig.2 - South Korea, Gyeongju region. In red the largest earthquake epicenter recorded in the area; in blue the seismic stations.

Fig.3 - South Korea: the green square overlay represents the selected target area; in red the earthquakes epicenters; in bluethe seismic stations.

Seismic Data-Base

The Korean seismic network is composed of hundreds of accelerometric stations well distributed over the entire country.
As mentioned previously, in September 2016 and in November 2017 two largest earthquakes occurred nearby of the cities of Gyeongju (Magnitude 5.8) and Pohang (Magnitude 5.4), located in the South-Eastern part of the peninsula (Fig. 2).
Following these large events, separated by 35 km, a new calibration and tuning of EW software has been performed to improve the seismicity characterization, reduce the lead time and better the accuracy of the expected impact for felt to damaging earthquakes in Korea.
The target region is characterized by 99 earthquakes with a magnitude range of 2÷5.8. The area was covered by about 41 stations with a total number of 15681 waveforms in the period 2007-2017. The distribution of data in terms of magnitude is reported in Fig. 4.

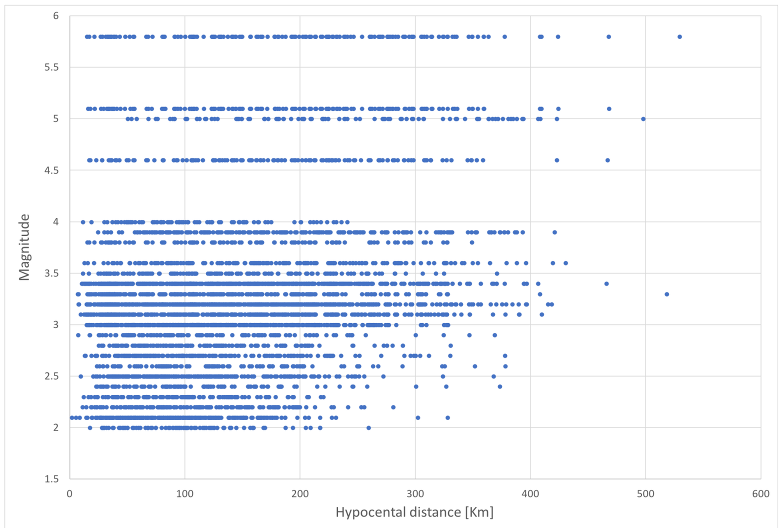

Fig.4 - Distribution of magnitude as a function of hypocentral distance for the target area.

Regression laws

The peak displacement (3-component modulus) were measured (Pd) in time windows of 2 and 4 seconds from the P-wave arrival and for 2 seconds of S-wave signal (Fig. 5). A set of three empirical laws for magnitude using peak displacement have been developed. In order to obtain a stable and reliable Pd, the double integrated acceleration was filtered using a two-pole Butterworth band pass filter between 1 and 10 Hz. Given the dominance in the seismic database of low magnitude events and noisy data, this setting provides the best results for the regression laws, especially in terms of final uncertainty. The obtained regression coefficients values and uncertainties are reported in Tab.1. In Fig. 6 an example of how the equation fits the data for a magnitude 3.0 is reported.

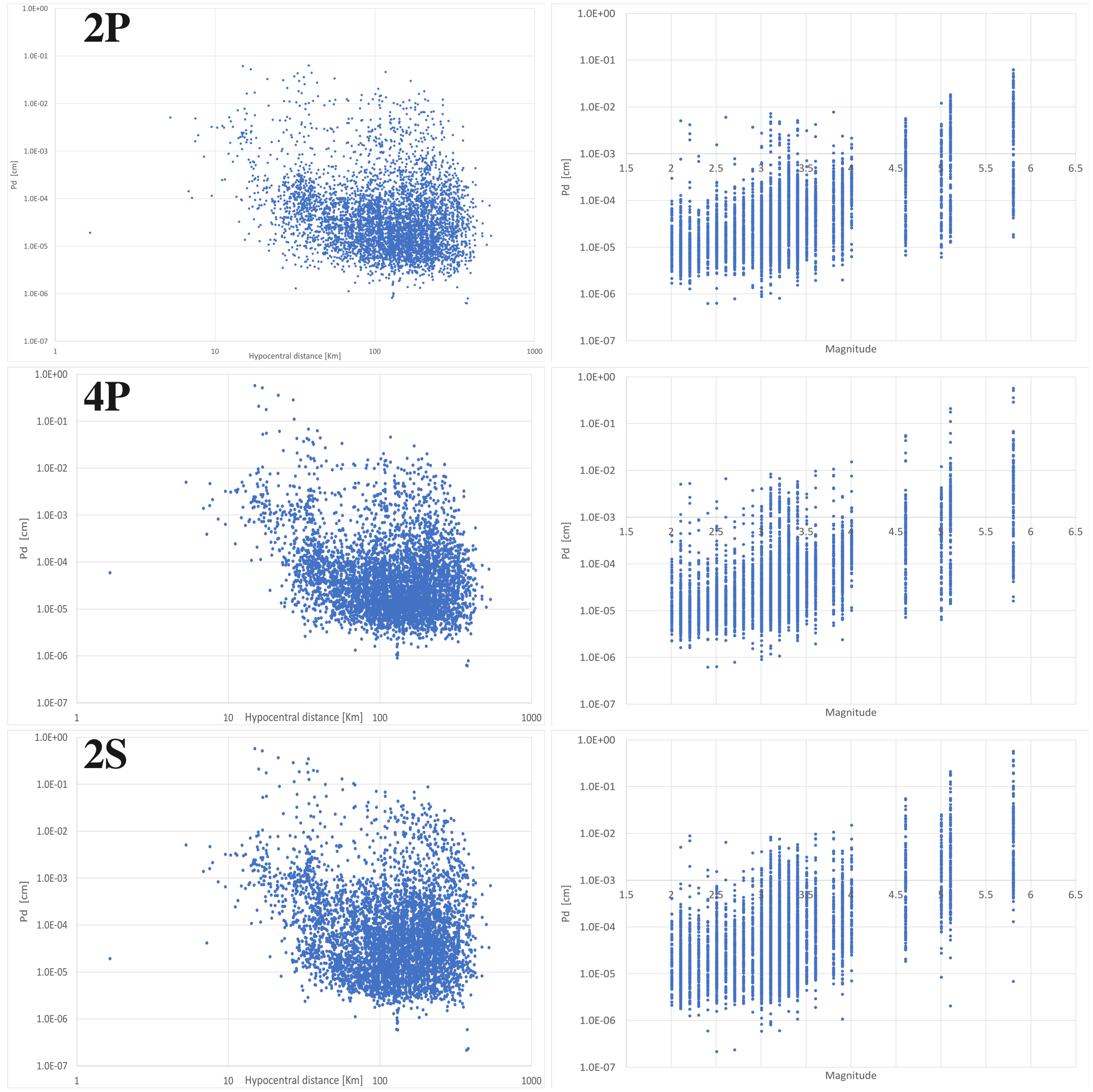

Fig.5 - The distribution of Pd versus hypocentral distance (Left) and magnitude (Right) for P-wave time windows of 2 (Top) and 4 seconds (Center) and for a 2 second time windows for S-wave signal (Bottom).

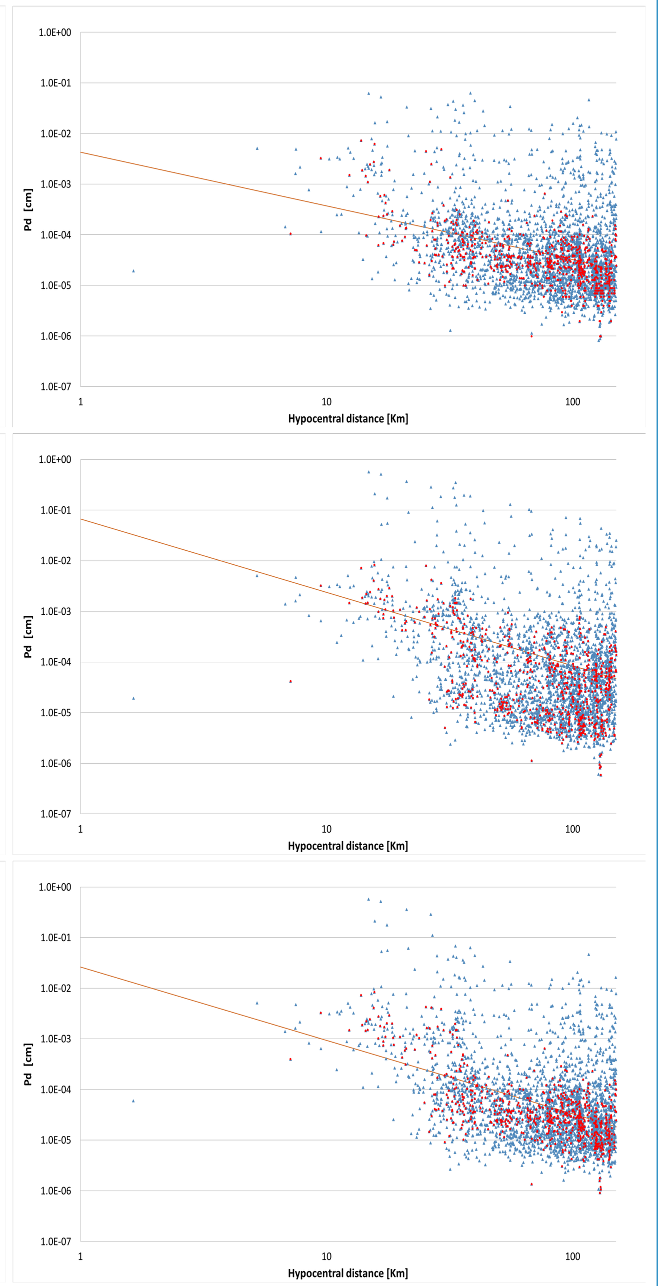

Fig.6 - Distribution of Pd versus hypocentral distance (blue triangles); red points represent the Pd values in the magnitude range of 2.9÷3.1; the red line represents the Eq. 1 evaluated using the values from Tab. 1 for 2P (top); 4P (middle); 2S (Bottom).

	a	σ_a	b	σ_b	c	σ_c	RMS
P2	-5.94	±0.34	0.835	±0.09	-1.08	±0.02	0.34
P4	-5.57	±0.33	0.846	±0.09	-1.47	±0.02	0.39
S2	-5.18	±0.33	0.846	±0.09	-1.47	±0.02	0.39

Tab.1 - Estimated values and uncertainties for coefficients of Eq. 1.

PRESTo calibration

An offline optimization of PRESTo has been performed once the setup operation was completed.
Several playback runs have been conducted by changing the available PRESTo parameters each time and comparing the outcomes. The results are reported in terms of B.st and BTime variable values and missed events (Tab.2).

Tab.2 - PRESTo playback test configuration and results.

Test number	B.St	B.Time	Missed Events
1	8	8	35
2	5	9	12
3	5	8	12

The configuration number 3 in Tab. 4 has been selected as the best configuration due to the minimum number of missed events and the lower value of B.Time. The majority of missed events are located off-shore, where the seismic network azimuthal coverage is weaker. The playback results have been futrther analyzed in terms of magnitude residuals (bulletin magnitude - final PRESTo estimation) distribution (Fig.7) and histogram (Fig.8).

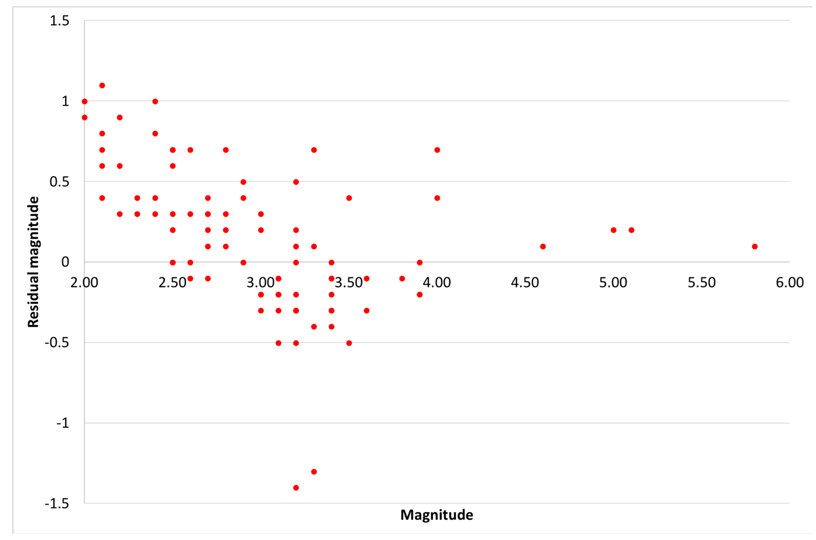

Fig.7 - Distribution of magnitude residuals as a function of bulletin magnitude.

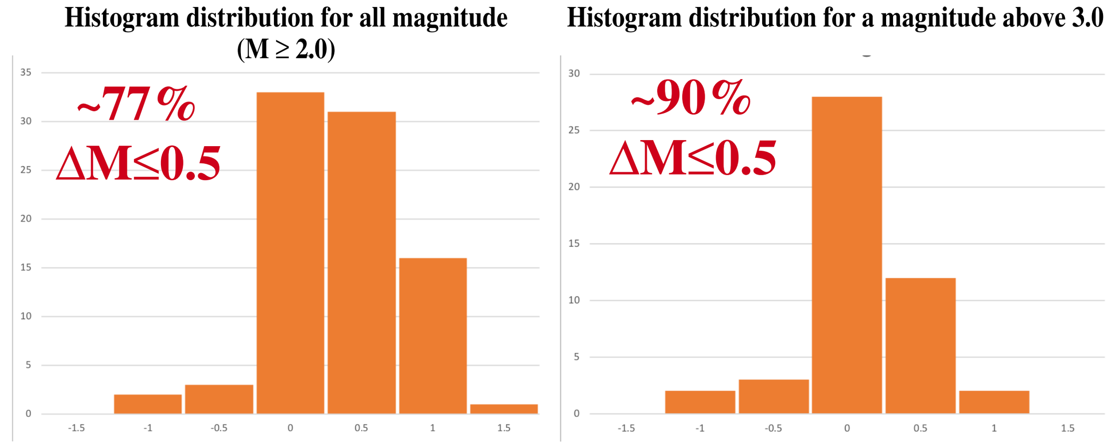

Fig.8 - Histogram distribution of magnitude residual for all magnitudes (left); Histogram distribution of magnitude for events with magnitude equal or higher than 3.0 (right).

About 77% (63/87 events) of the triggered events produced a final magnitude estimation within ±0.5 magnitude points from the bulletin one. The results gains even more relevance when considering that 34 events (39%) were external to the seismic network perimeter. The percentage rises to 90% (43/47 events) considering earthquakes with magnitude 3.0 and above.
Finally, the rapidness of the PRESTo system to declare an event has been tested. Figure 9 and 10 show the time needed to provide a first alert after the P-waves have reached the first station.

The parameters used represent a good trade-off between providing a prompt alert and the need to reduce false alerts due to noisy or glitchy data.
The new PRESTo calibration and tuning provides very good results at all magnitudes. Moreover, a better reliability is observed for magnitudes above 3.0.

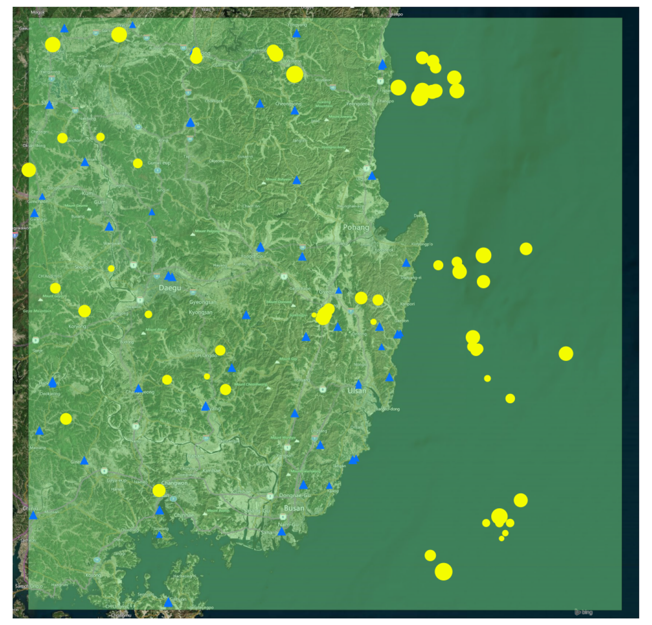

Fig.9 - Map of the delavy as a function of the earthquake location, where the yellow circle size is proportional to the delay; Blue triangles represent the stations; The green square overlay represents the selected target area.

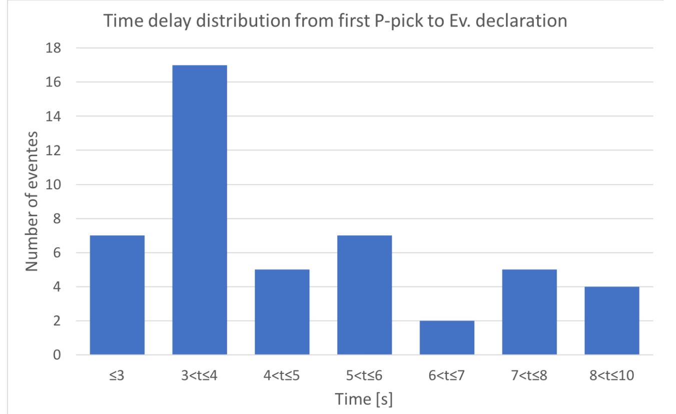

Fig.10 - Histogram distribution of the delay between 1st pick and 1st alert (all events)

Pohang earthquake, 15-11-2017, M5.4

In November 2017, Korea witnessed some of the largest magnitude earthquakes occurred in-land in its recent history. One of them was located in the South-Eastern part of the peninsula, near the city of Pohang, with magnitude ML 5.4. This earthquake was not used to calibrate the new attenuation law (Eq.1). So, it represent the perfect test case for this study. The first station reached by P-wave signal is PHA2, located in Pohang district. After 5.74 seconds PRESTo declares an earthquake with a preliminary magnitude of 5.6 (really close to the bulletin one) . The final magnitude estimation is available about 8 seconds after the first one with a residual equal to zero: PRESTo estimated the correct magnitude. Also the final epicentre location is in very good agrrement with the bulletin one (ΔR < 10 Km).

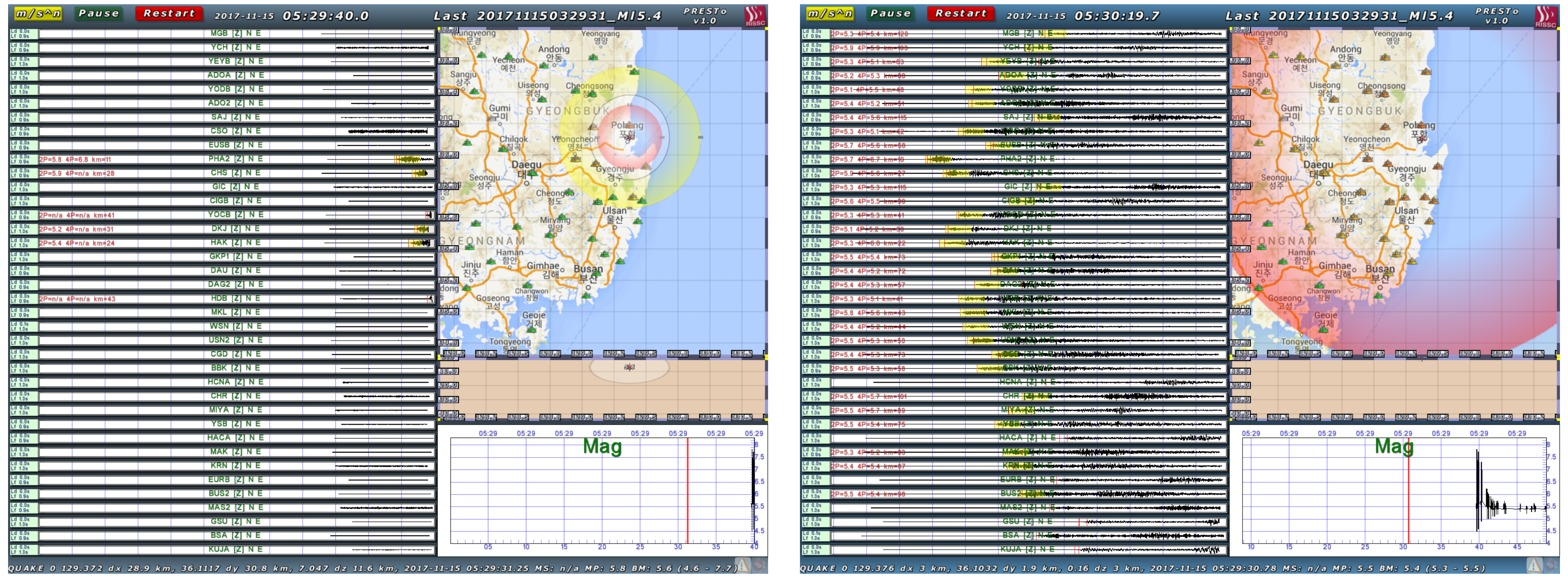

Fig.11 - PRESTo playback screenshot for the Pohang event. First event declaration (left); Final event declaration (right)

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