NERA

Network of European Research Infrastructures for Earthquake Risk Assessment and Mitigation

Report

Absolute and relative high-resolution relative locations

Activity:	*JRA2: Tools for real time seismology, acquisition and mining*
Activity number:	*D12.3*
Deliverable:	*Toolbox 1: Absolute and relative high-resolution relative earthquake locations*
Deliverable number:	*D12.3*
Responsible activity leader:	*Alberto Michelini*
Responsible participant:	*INGV*
Author:	*Alberto Michelini*

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Summary

This report addresses the work done within the WP12 for what concerns the development and the enablement of software for the absolute and relative high resolution earthquake locations. The activity carried out by the work package partners spans methodologies to be used at different scale-lengths (i.e., from local/regional events to teleseismic distances). The toolbox software includes the following procedures

1. **Virtual Seismologist** (ETHZ – SED) - Earthquake Early Warning methodology. Software embedded within SeisComP3 (SC3). VS(SC3) integrates with SeisComP3 modules for event detection, association and location.

2. **WaveLoc** (CNRS/INGV) - Software for earthquake location using waveforms and direct search through migration at local/regional scale.

3. **Early-Est** (INGV/AL Software) - very rapid earthquake location using migration of several body wave phases at global scale obtained through real-time seedlink connections (note that Early Est has been also presented in deliverable D12.2 since the software performs both location and earthquake size determinations).

4. **Relative Relocation Toolbox** (ULiv) –Modular toolbox for calculating effectively and easily *relative arrival times* using *cross-correlation*:

With the exception of the **Relative Relocation Toolbox** which is basically a set of scripts that wrap the well known and widely used double difference software HypoDD (http://www.ldeo.columbia.edu/~felixw/hypoDD.html) for relative earthquake location which is at a more prototypal level of development, the other software has been used and implemented in several institutions and observatories.

For all software, there has been made available a short description and the corresponding references on the NERA project web-site (http://www.nera-eu.org).

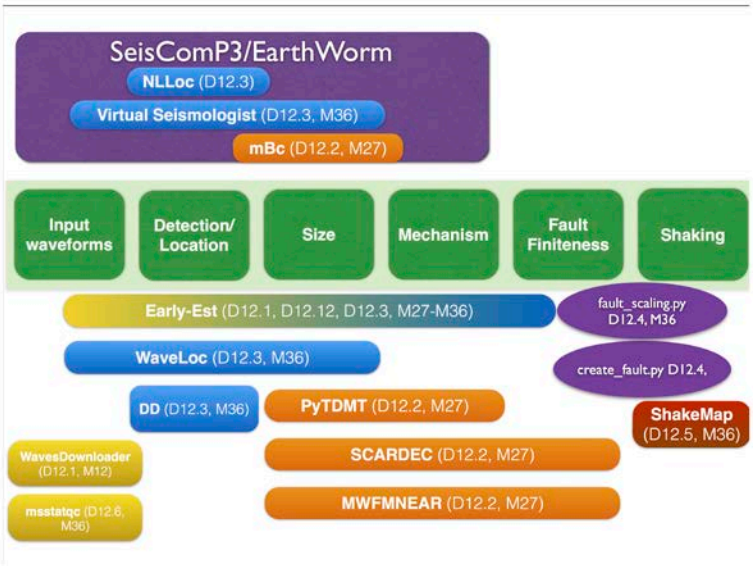

Figure 1. Simplified diagram showing the software implemented in JRA2 and the associated deliverable. The D12.3 software packages are shown in blue.

Preamble

This deliverable makes ample reference to the software procedures published on correspondent software web sites. To this regard and to provide the “glue” between the developed software and the contents of the deliverable, it has been prepared a work package web portal on the NERA, JRA2 work package page (http://www.nera-eu.org) on which the individual software is both described concisely and made accessible. It follows that this deliverable is to be assessed in conjunction with the material made available on the corresponding web pages.

Absolute and relative high-resolution relative earthquake locations

Earthquake location is a very fundamental analysis of seismology. In JRA2 there have been tested both absolute and relative methodologies for earthquake location.

For absolute location, the Virtual Seismologists (VS) earthquake early warning development has been inserted into the SeisComP3 software package whereas the two methodologies WaveLoc and Early-Est (EE) are not included in ant standard software package and share some common features. In fact, they both skip the so called “phase association” stage and they continuously test the model grid to identify the most the earthquake origin in space and time that best migrates the origin times. In principle they are both based on stacking observed preprocessed waveforms (waveloc) and arrival picks (EE).

EE is now the global earthquake location and magnitude software used by INGV in the context of its candidacy to become Tsunami Watch Provider (cTWP) of tne NEAMTWS. EE is also implemented at NOA (National Observatory of Athens), KNMI/ORFEUS and will be soon implemented by NIEP (Rumania).

Virtual Seismologist (ETHZ-SED)

This software is an Earthquake Early Warning methodology embedded within SeisComP3 (SC3). VS(SC3) integrates with SeisComP3 modules for event detection, association and location. 3 new modules are built to 1) produce continuous estimate of waveform enveliopes 2) combine current origin information with amplitude information to provide VS magnitudes and 3) log and dissemination solutions.

SeisComP3 requires a licence from GFZ Potsdam. The SED modules follow GPL, with a minor amendment, and can be found at
http://www.seismo.ethz.ch/static/seiscomp_contrib/license.txt

The SeisComP3 software suite is openly available at

http://www.seiscomp3.org

The current latest version of the documentation is at

http://www.seiscomp3.org/doc/jakarta/current/apps/vs.html

Any user of SC3 can run VS(SC3) with a minor additional configuration.

In Europe, VS(SC3) is being tested at: SED (Switzerland), NIEP (Romania), NOA (Greece), U. Patras (Greece), U. Thessaloniki (Greece), KOERI (Turkey), IMO (Iceland).

VS(SC3) is alsobeing installed and monitored at GNS, New Zealand.

WaveLoc (CNRS/INGV)

This software has been developed by Alessia Maggi and is available at https://github.com/amaggi/waveloc. The software uses python (http://www.python.org) and the obspy seismological software library (https://github.com/obspy/obspy/wiki).

The instructions with examples for the installation and a tutorial are available at http://amaggi.github.io/waveloc/. Recently, the methodology has been published (Langet, N., Maggi, A., Michelini, A., & Brenguier, F. (2014). Continuous Kurtosis-Based Migration for Seismic Event Detection and Location, with Application to Piton de la Fournaise Volcano, La Reunion. *Bulletin of the Seismological Society of America*, *104*(1), 229–246. doi:10.1785/0120130107)

Early-Est (INGV/AL Software)

Early-Est (http://www.nera-eu.org/content/mm_files/do_916/Early-Est.pdf) is a system for rapid, real-time earthquake monitoring, including phase picking, phase association and event detection, location, magnitude determination, first-motion mechanism determination, discriminants for earthquake tsunami potential, and tabular, graphical and web output. More specifically, the earthquake size estimation is implemented through the calculation of several magnitudes (mb, Mwp, Mwpd), the source-time duration and the mechanism by calculation the fault plane solutions using the software HASH. The methodology is part of the real-time seismic monitoring activities of the INGV seismic center (http://early-est.rm.ingv.it) and it is implemented in experimental mode also at the National Observatory of Athens (http://icp.gein.noa.gr/early-rtm/warning.html) and at KNMI/ORFEUS (http://145.23.252.222/early-est/global/warning.html)

Relative Relocation Toolbox (Uliv)

The software implementation is basically for the relative relocation of large amounts of data as those recorded in aftershock sequences. To provide an idea, data set of ~1TB of mseed data; ~40.000 events automatically detected and located; 120 seismic stations including BB and SP with various sampling rates. The computation involves approximately 10M cross-correlation times and parallelization is essential to test different frequency bands. Events relocated with hypoDD (currently in 1D velocity model, but working on 3D model).

Basic components of the workflow are the modules

cut_correlate (works directly on mseed data to cut out ASCII waveforms, Pre-filtering to achieve best signal to noise ratio, Can work with different sampling rates, Uses event information and reported arrival times for time window selection, Can predict cross-correlation time windows based on origin time and 1D velocity model (especially useful for automated S-wave processing), Builds up a database of station based waveforms) and

x_correlate (time domain cross-correlation optimized for performance, sub-sample accuracy achieved by parabola fit to the cross-correlation function, “update” mode available that only last row of the cross-correlation matrix is calculated, Maximum event separation for computation can be freely selected, Output can be easily filtered and manipulated using awk-scripts).

The software is available upon request t to prof. Andreas Rietbrock (a.rietbrock@liverpool.ac.uk).

Conclusions

The earthquake location package toolbox has provided both the implementation of a state-of-the-art earthquake early warning very rapid location methodology (VS) and the development of innovative, direct search methodologies for earthquake location at both local/regional and at global scale.

In the DoW of the project it had been listed the software NonLinLoc by Anthony Lomax for implementation in the Earthworm and SeisComp3 packages. NonLinLoc, was, however, implemented independently in both packages right after the start of this project and for this reason it would had been inappropriate to spend resources on replicating the same activity. Instead, efforts have been made toward the development and testing of the more modern software Waveloc and Early-Est and toward wrapping the relative location code HypoDD aiming at the analysis if large data volumes.