



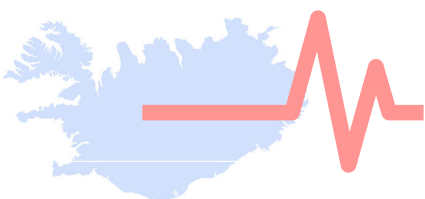
Control SEISmicity and Manage Induced earthQuakes (COSEISMIQ)

Deliverable 1

Deliverable 1 (Month 12): Implementation of advanced micro-seismicity monitoring tools in SeisComp3 modules and workflows optimized for geothermal plays

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Deliverable 1 (Month 12): Implementation of advanced micro-seismicity monitoring tools in SeisComP3 modules and workflows optimized for geothermal plays

Summary

Fluid injection into the subsurface can generate earthquakes called microseismicity. In order to mitigate the risk associated with these events an Advanced Traffic Light Systems (ATLS), a decision support tool, is being developed. Input information for ATLS requires a knowledge of where induced microseismic events evolve in space and time, in the subsurface.

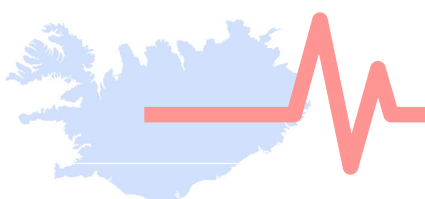
In this deliverable we describe an advanced microseismic monitoring tool developed at the Swiss Seismological Service (SED) that allows the determination of high precision microseismicity locations in a real-time manner.

Real-Time Double-Difference Hypocentre Relocation

In induced seismicity studies accurate hypocenter locations are needed in order to estimate the seismogenic volume affected by stimulation procedures. Precise hypocenter locations are also essential to estimate geometries of potentially reactivated faults. On the other hand, the spatio-temporal evolution of seismicity can be indicative for fluid-flow processes. It allows first-order estimates on hydraulic properties as well as the existence of possible hydraulic connections. Information on spatial extent, geometries and the spatio-temporal evolution of seismogenic structures can therefore help to improve the seismic hazard assessment of induced seismicity in near-real-time. This requires relative relocations computed in near real-time. A strategy for such near real-time relative relocation procedure has been developed by the Swiss Seismological Service (SED) and implemented as a software module called *scrtdd*. *scrtdd* can run alongside SeisComP3, a software package for seismological data acquisition, earthquake monitoring and real-time data exchange. SeisComP3 is the main software used for seismic monitoring in the COSEISMIQ project, as well as in many geoenergy-related industrial projects.

The procedure proposed by the SED follows the strategy implemented in Waldhauser (2009) and it uses waveform cross-correlation and double-difference methods to rapidly relocate new seismic events with high precision relative to past events with accurately known locations (background catalogue). The background catalogue was derived by a standard, multi-event double difference relative relocation procedure. The principle is schematically shown in Figure 1.

The method combines differential times derived from automatic as well as manual picks. In addition, the waveforms of new events are automatically cross-correlated with those archived for nearby past events to measure accurate differential phase arrival times. The differential-time data are subsequently inverted to compute the relative location of a new event with respect to the double-difference background catalogue. Details on the implemented algorithms are shown in the flow-chart in Figure 2



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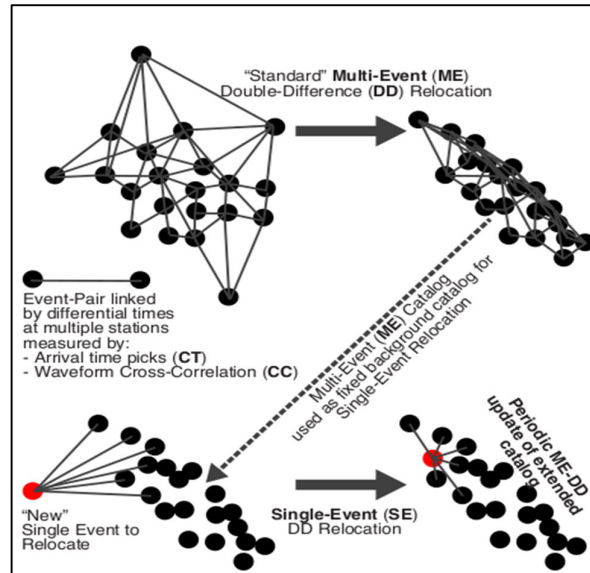


Figure 1: Schematic illustration showing the RT-DD method proposed by Waldhauser (2009). In this approach each new single event is located with respect to DD background catalogue.

SCRDDD Module: Real-Time Double-Difference Monitoring Embedded in SeisCompP3 Framework

The `scrddd` module is designed as a secondary locator similar to `screloc` module, which receives origins from real-time locators such as `scautoloc`/`scanloc` and relocates them with a configurable locator such as `NonLinLoc`. `scrddd` listens to new automatic and manual origins submitted to the messaging system by other locator modules (`scanloc`, `screloc`) and relocates them. The module has been written in C++ programming language in order to achieve high processing speed. Details are shown in the flow-chart in Figure 2.

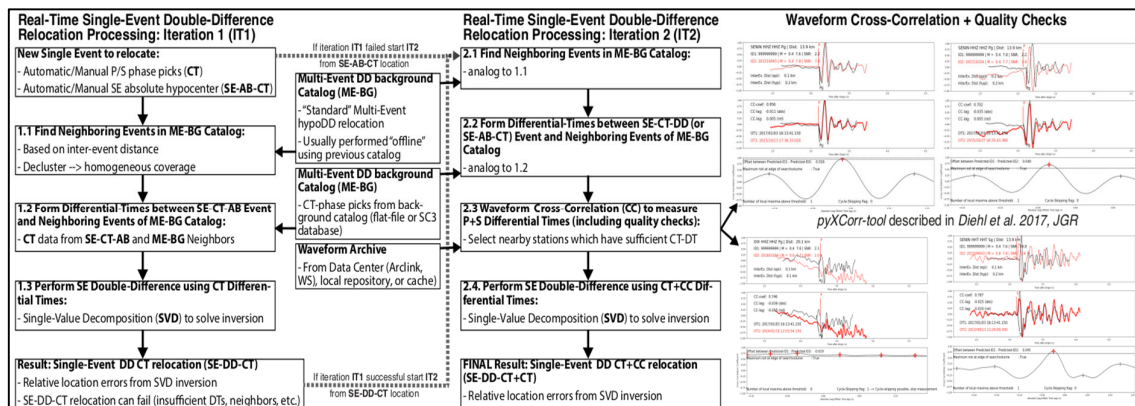
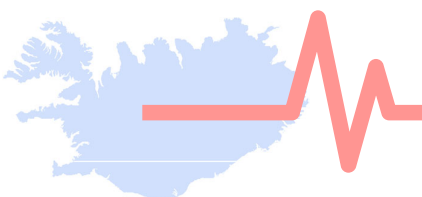


Figure 2: Workflow summarizing the real-time double-difference (RT-DD) processing implemented in the newly developed module.



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The use of enhanced workflows to improve the relative and absolute location of earth-quakes, as well as estimate their size is possible with existing relative location algorithms, such as hypoDD. Currently, the hypoDD algorithm (Waldhauser and Ellsworth, 2000) is called as an external routine. This has the advantage of lowering the learning threshold for those users, who are already familiar with hypoDD software and want to quickly move towards a SeisComP3 integrated implementation.

The module processes all origins or only the preferred origin of a new event. In real-time applications, initial processing and subsequent updates can be scheduled similar to configurations in the scwfparam module. In this module, configurations allow to specify when the processing is started after the arrival of a new event and when and how many times it should be retried in the case of a processing failure. Parameters can be adjusted in the sconfig tool (see Figures 3-7).

Figure 3 displays a screenshot of the scrtd configuration window implemented in SeisComP3 software.

New origins are relocated in real time relative to a background catalogue of high-quality locations (i.e. an existing double-difference catalogue). Those high-quality events that form the background catalogue can already be presented in SeisComP3 database if desired. In the latter case, the background catalogue has to be generated. For this reason, the scrtd module can perform multiple-event (non-real-time, useful to generate a background catalogue) and single-event (real-time) double-difference relocations. Figure 4 illustrates how to search for the location information in an existing base catalogue.

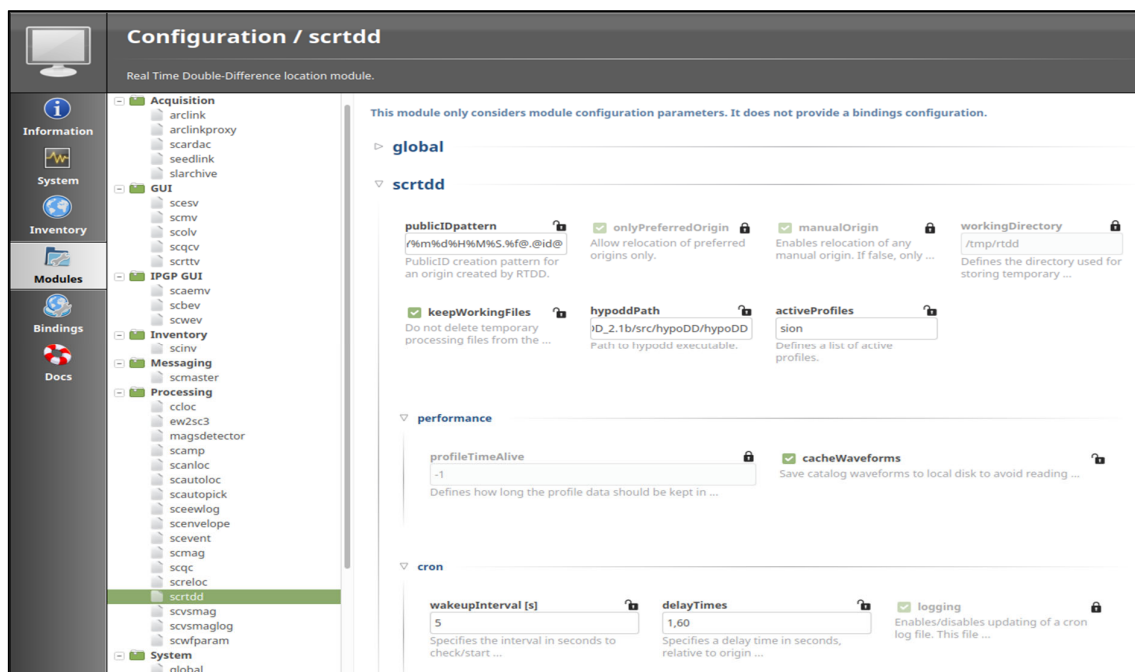
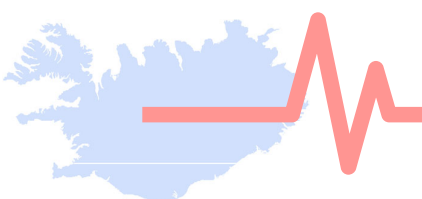


Figure 3: scrtd configuration window implemented in SeisComP3 software.



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catalog

The files used to define a background catalog. New origins will be relocated using this catalog, which must contains high quality locations. In full catalog relocation mode (see --relocate-catalog command line option) this is the catalog that will be relocated. There are two ways to define a catalog: one is providing an event file containing the ids of existing events or origins; the second way consists in providing extended information (useful when the events are not in the database) and three files are required event, phase and stations. The files must be in csv format with the first line containing the column names. Each file requires a minimum set of columns, which can appear in any order. Additional columns can be present and will not be used but are allowed for informational purpose.

eventFile

Path to event file to be used for this profile. Required ...

phaFile

Path to catalog picks file to be used for this profile ...

stationFile

Path to the stations file to be used for this profile ...

P-Phases

Defines a priority list of accepted P phases. Phases not ...

S-Phases

Defines a priority list of accepted S phases. Phases not ...

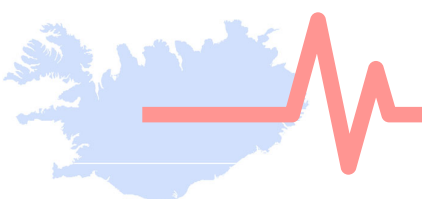
incrementalCatalogFile

Path to incremental catalog file. If this file is ...

Figure 4: Location information to search in an existing base catalogue (i.e. background catalogue) for the best-suited reference events in the neighbourhood of the new event.

Real-time relocation is performed in two steps (Figure 2). Step 1 is used to achieve a first rough but quick location refinement: a preliminary relocation of the origin is performed using only catalogue absolute travel time entries (dt.ct in HypoDD terminology). In step 2, the refined location is used to perform a more precise but slower relocation using both catalogue absolute travel times (ct-data) and differential travel times computed by means of cross correlation (cc-data). Figure 5 displays the configuration parameters required to create differential travel-time measurements using catalogue phase data and waveform cross-correlation data.

Waveform data is loaded via standard SeisComP3 interfaces (FDSN, WS, SDSArchive etc.) and can be cached both in memory for faster processing (several seconds to minutes per event) and on disk, to avoid reloading the same data again via a network. Figure 6 displays the graphical user interface, showing that the waveform data is stored both in memory and on disk. Different profiles can be defined by geographic boxes (similar to screloc). This allows project or cluster-specific hypoDD configurations (including velocity models etc.) for various regions. An example of a prototype system that implements the DD-RT process currently running on a seismic sequence in Sion Switzerland can be seen on Figure 7.



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dtct

These options control the creation of catalog absolute travel time entries for pairs of earthquakes (dt.ct file in HypoDD terminology).

minWeight

Min phase weight required. Phases not satisfying this ...

minESdist

Min distance (km) between event pair and station ...

maxESdist

80

Max distance (km) between event pair and station ...

minEStoIeratio

20

Min ratio between event-station distance and pair ...

maxIEDist

Max distance (km) between events in a pair allowed. ...

minDTperEvt

8

Min number of differential travel times (Including P+S) ...

minNumNeigh

6

Min number of neighboring events required. Events not ...

maxNumNeigh

31

Max number of neighbors used. Further events are ...

dtcc

Those options control the creation of differential travel times from cross correlation for pairs of earthquakes (dt.cc file in HypoDD terminology).

minWeight

Min phase weight required. Phases not satisfying this ...

minESdist

Min distance (km) between event pair and station ...

maxESdist

50

Max distance (km) between event pair and station ...

minEStoIeratio

20

Min ratio between event-station distance and pair ...

maxIEDist

Max distance (km) between events in a pair allowed. ...

minDTperEvt

8

Min number of differential travel times (Including P+S) ...

minNumNeigh

6

Min number of neighboring events required. Events not ...

maxNumNeigh

29

Max number of neighbors used. Further events are ...

crosscorrelation

minCCCoef

0.70

Min crosscorrelation coefficient accepted to use a ...

start

-0.5

Start of data window to cross correlate with respect to ...

end

0.50

End of data window to cross correlate with respect to ...

maxDelay

0.2

Maximum data window delay accepted (secs)

Figure 5: Configuration parameters required to create differential travel-time measurements using (top) catalogue phase data and (bottom) waveform cross-correlation data.

performance

profileTimeAlive

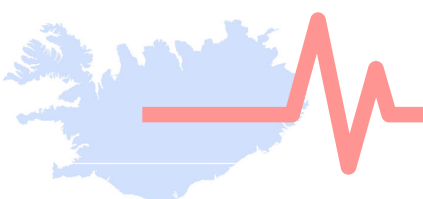
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Defines how long the profile data should be kept in ...

cacheWaveforms

Save catalog waveforms to local disk to avoid reading ...

Figure 6: Graphical user interface showing that waveform data is cached both in memory and on disk.



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profile

sion

Defines a regional profile. Origins that fall in this region will use this configuration. If an origin falls in multiple profile regions, then the profile defined first will be used. The region check is not used for full catalog relocation (see --relocate-catalog command line option)

regionType

circular

Type of region: RECTANGULAR or CIRCULAR

region

46.262,7.400,50

Defines the region values. If regionType is RECTANGLE ...

earthModelID

earthModelID that is stored in the created origin.

methodID

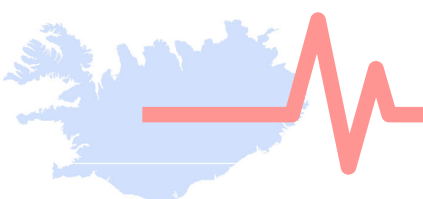
RTDD

methodID that is stored in the created origin.

Figure 7: A prototype system that implements the DD-RT processes currently running on a seismic sequence in Sion, Switzerland.

Optimizing Seiscomp3 Configuration for Induced Seismicity monitoring in Iceland

In order to analyse induced seismicity recorded at the Hengill site in Iceland, we installed and optimally configured a Seiscomp3 system. SeisCompP3 is a widely used software suite for data acquisition, processing, archiving and visualization of seismic data at global and regional scales. More recently, SeisCompP3 is also used for microseismic monitoring operations (Grigoli et al. 2018). SeiscompP3 has been used for real-time earthquake monitoring at the Swiss Seismological Service (SED) since 2012. Earthquake detection is performed using the *scanloc* module, a sophisticated event detector based on clustering techniques and specifically designed for local and microseismic monitoring operations. This module was already applied to induced seismicity analysis (Grigoli et al. 2018), however before each monitoring operation it is necessary to configure the detection parameters carefully. Within COSEISMIQ we setup and optimized a SeiscompP3 machine and related modules for the analysis of the induced seismicity in the Hengill area. To configure the detector (*scanloc* module), we used 24h continuous data, which included an Ml 4.5 natural earthquake occurred in the Hengill area on 2018 December 30th. Figure 8 shows the detection and location results obtained using the initial configuration of the Seiscomp3 machine, the same used at ISOR for routine seismicity monitoring operations. With this configuration, we were able to successfully detect approximately 35 events. Figure 9 shows the results with an optimized configuration of the Seiscomp3 machine that allowed to detect and locate about 137 events.



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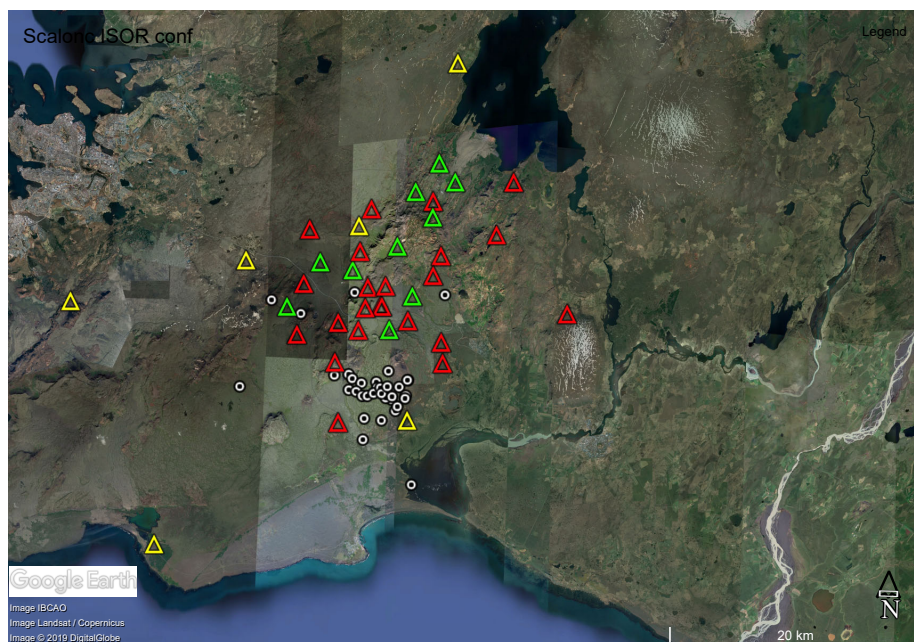


Figure 8: Seismic events (black and white dots) detected and located using the base configuration of Scanloc. COSEISMIQ, ISOR and IMO stations are denoted by red, green and yellow triangles respectively

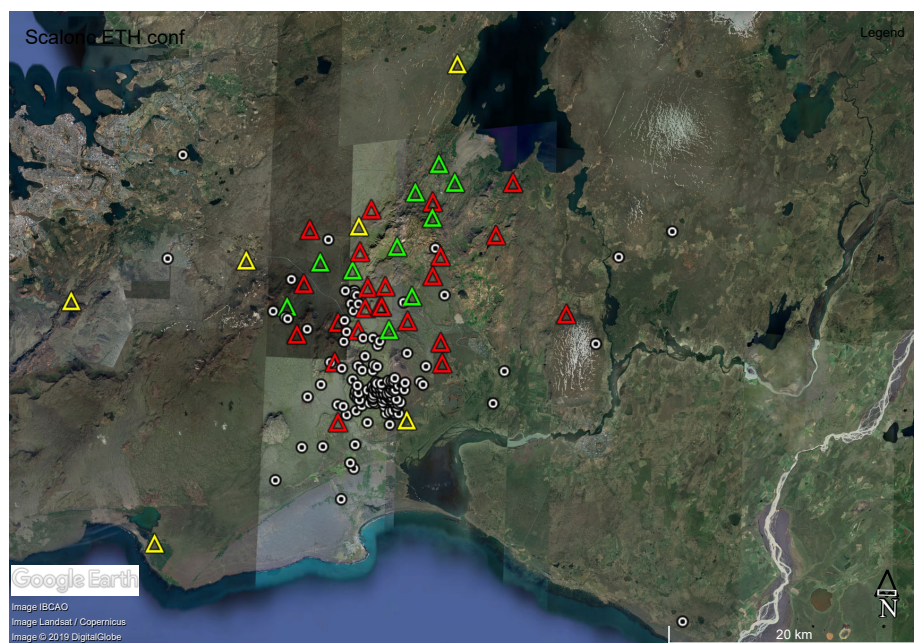
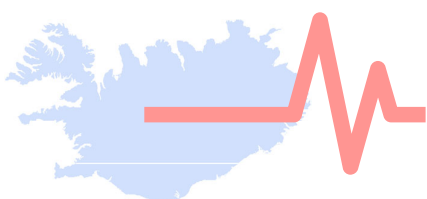


Figure 9: Seismic events (black and white dots) detected and located using the optimized configuration of Scanloc. COSEISMIQ, ISOR and IMO stations are denoted by red, green and yellow triangles respectively



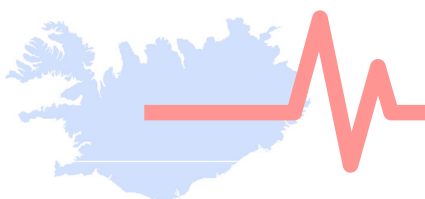
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Conclusions

In this deliverable, we introduced a new Seiscomp3 module for advanced seismological analysis, which has been developed by the Swiss Seismological Service (SED) at ETH. This module allows us to obtain high precision relative earthquake locations in real-time, which is fundamental to analyse the spatio-temporal evolution of induced seismic sequences. It also feeds the Advanced Traffic Light System (ATLS) that will be tested within the COSEISMIQ project. Finally, we optimally configured the Seiscomp3 system for induced seismicity monitoring in the Hengill area, which is now fully operational.

References

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