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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Summary

Fluid injection into the subsurface can generate earthquakes called micorseismicity. 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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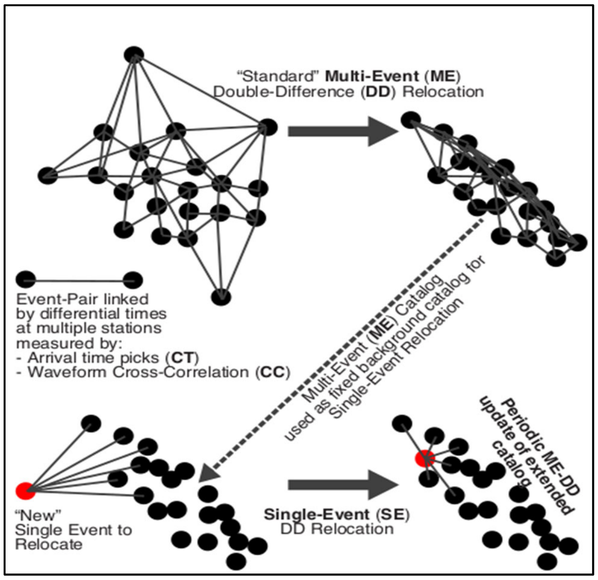

Figure 1: Schematic illustration showing the RT-DD method proposed by Waldhauser (2009). In this approach each new single event is located with respect to DD background catalogue.

SCRTDD Module: Real-Time Double-Difference Monitoring Embedded in SeisComP3 Framework

The scrtdd 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. scrtdd 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.

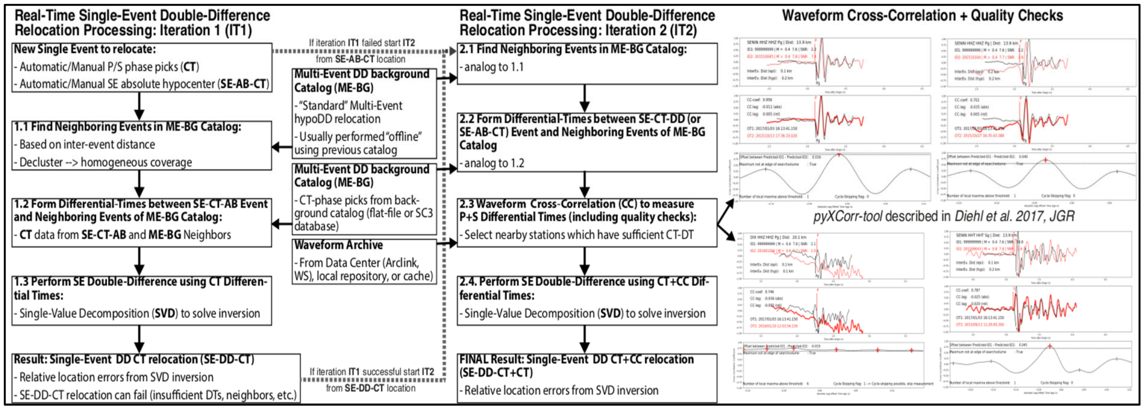

Figure 2: Workflow summarizing the real-time double-difference (RT-DD) processing implemented in the newly developed module.

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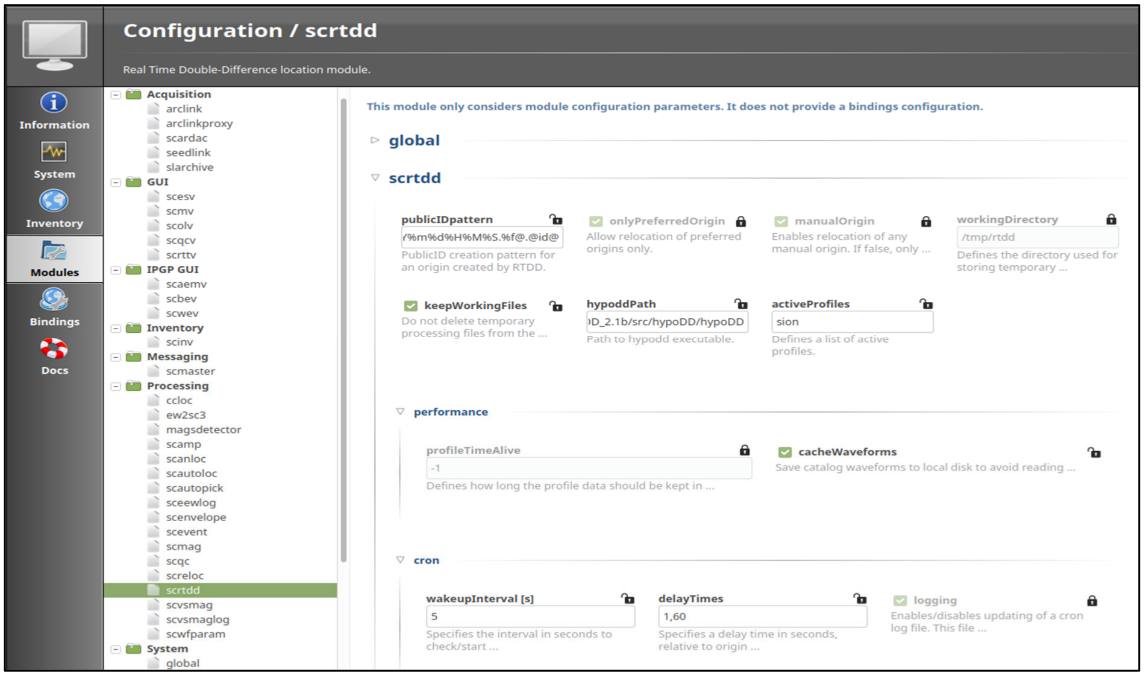
The use of enhanced workflows to improve the relative and absolute location of earth-quakes, as well as estimate their size is possible with existing relative location algorithms, such as hypoDD. Currently, the hypoDD algorithm (Waldhauser and Ellsworth, 2000) is called as an external routine. This has 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 scconfig tool (see Figures 3-7).

Figure 3 displays a screenshot of the scrtt 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 scrtdd 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.



Configuration / scrtdd

Real Time Double-Difference location module.

This module only considers module configuration parameters. It does not provide a bindings configuration.

global

scrtdd

publicIDpattern /%m%d%H%M%S.%f@.@id@
PublicID creation pattern for an origin created by RTDD.

☑ **onlyPreferredOrigin**
Allow relocation of preferred origins only.

☑ **manualOrigin**
Enables relocation of any manual origin. If false, only ...

workingDirectory /tmp/rtdd
Defines the directory used for storing temporary ...

☑ **keepWorkingFiles**
Do not delete temporary processing files from the ...

hypoddPath)D_2.1b/src/hypoDD/hypoDD
Path to hypodd executable.

activeProfiles sion
Defines a list of active profiles.

performance

profileTimeAlive -1
Defines how long the profile data should be kept in ...

☑ **cacheWaveforms**
Save catalog waveforms to local disk to avoid reading ...

cron

wakeupInterval [s] 5
Specifies the interval in seconds to check/start ...

delayTimes 1,60
Specifies a delay time in seconds, relative to origin ...

☑ **logging**
Enables/disables updating of a cron log file. This file ...

Figure 3: scrtdd configuration window implemented in SeisComP3 software.

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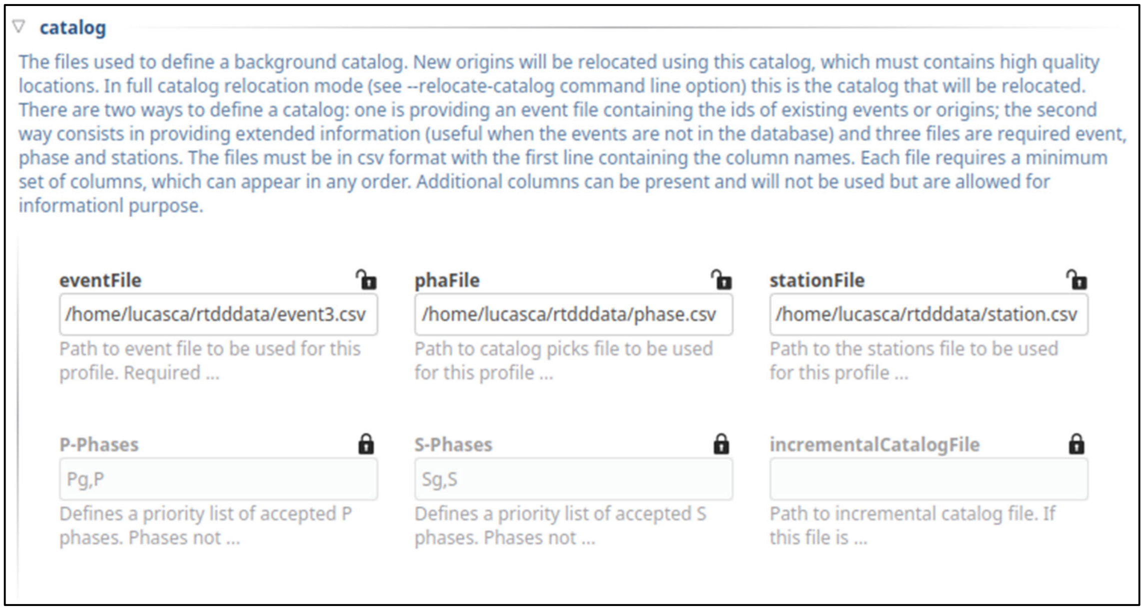


catalog

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 informationl purpose.

eventFile: /home/lucasca/rtdddata/event3.csv
Path to event file to be used for this profile. Required ...

phaFile: /home/lucasca/rtdddata/phase.csv
Path to catalog picks file to be used for this profile ...

stationFile: /home/lucasca/rtdddata/station.csv
Path to the stations file to be used for this profile ...

P-Phases: Pg,P
Defines a priority list of accepted P phases. Phases not ...

S-Phases: Sg,S
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.

dtct

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

Parameter	Value	Description
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

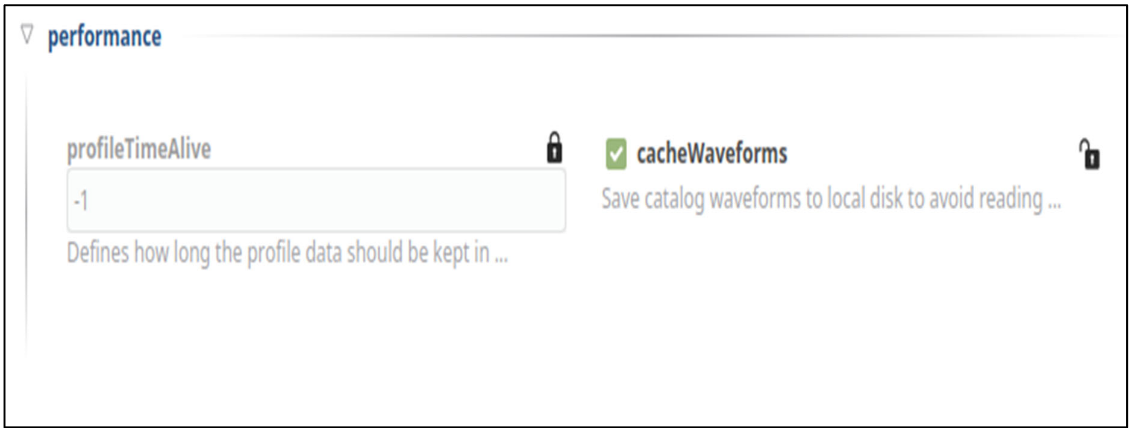
Those options control the creation of differential travel times from cross correlation for pairs of earthquakes (dt.cc file in HypoDD terminology).

Parameter	Value	Description
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

Parameter	Value	Description
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

Parameter	Value	Description
profileTimeAlive	-1	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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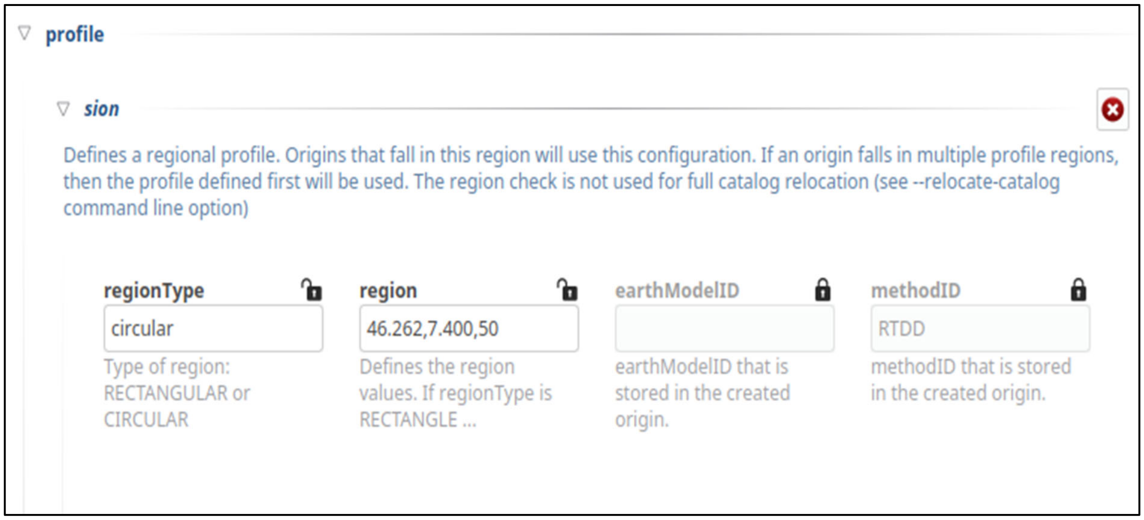

profile

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	region	earthModelID	methodID
circular	46.262,7.400,50		RTDD
Type of region: RECTANGULAR or CIRCULAR	Defines the region values. If regionType is RECTANGLE ...	earthModelID that is stored in the created origin.	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. SeisComP3 is a widely used software suite for data acquisition, processing, archiving and visualization of seismic data at global and regional scales More recently, SeisComP3 is also used for microseismic monitoring operations (Grigoli et al. 2018). SeiscomP3 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 SeiscomP3 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.

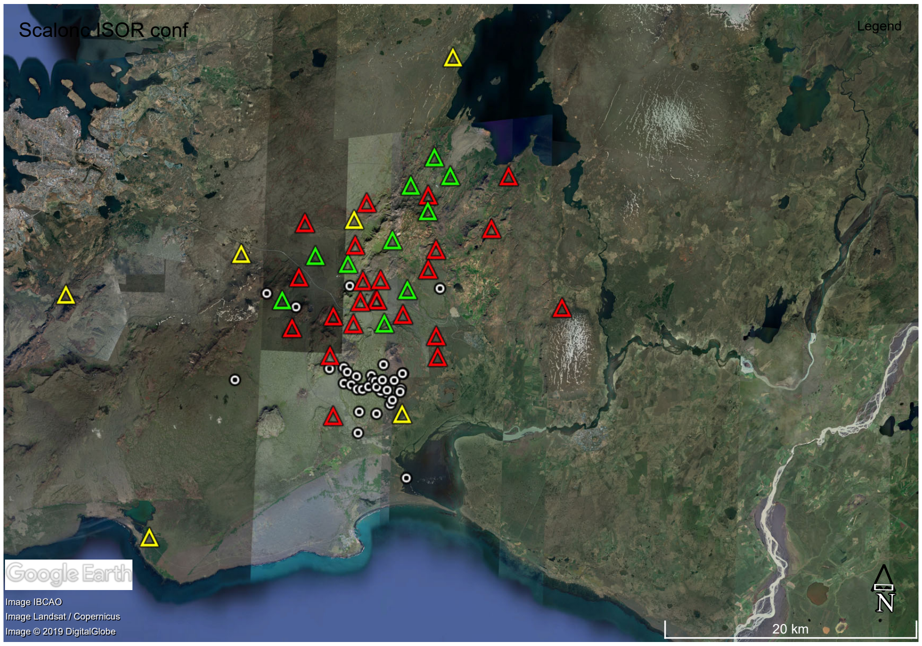

Figure 8: Seismic events (black and white dots) detected and located using the base configuration of Scanloc. COSEISMIQ, ISOR and IMO stations are denoted by red, green and yellow triangles respectively

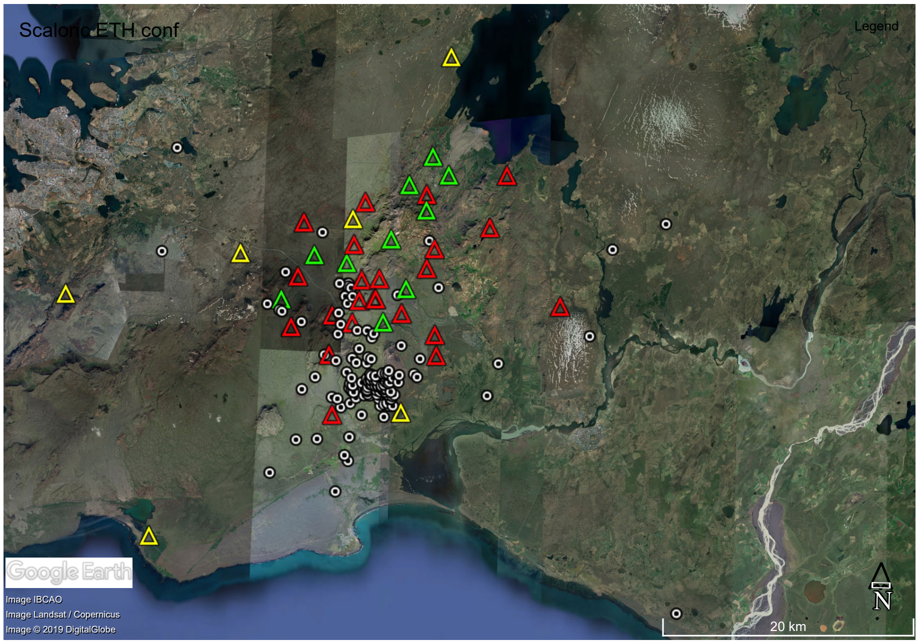

Figure 9: Seismic events (black and white dots) detected and located using the optimized configuration of Scanloc. COSEISMIQ, ISOR and IMO stations are denoted by red, green and yellow triangles respectively

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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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