**Network of European Research Infrastructures for Earthquake Risk Assessment and Mitigation**

# Report

## Near Fault Observation Systems, Networking and Communication Protocols

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|---|---|
| Activity: | *Networking Near-Fault Observatories* |
| Activity number: | *NA5, Task 5.2* |
| Deliverable: | *Near fault observation systems networking and communication protocols* |
| Deliverable number: | *D5.2* |
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# Summary

This report summarizes the networking and communication established during the NERA project between the six near-fault observatories participating in WP5: Networking of near fault observatories. The participating observatories are: The South Iceland seismic zone (SISZ) in Iceland, the North Anatolian fault zone (NAFZ) in Turkey, the Alto Tiberina fault (ATF) and Irpinia fault (IF) in Italy, the Corinth rift laboratory (CRL) in Greece and the Valais area (VA) in Switzerland, all operating different multidisciplinary systems to monitor and research seismic hazard in the observatories. Description of the observations systems, as indicated by the title of this deliverable, is not included here, as such descriptions were already included in deliverable D5.1 "*Inventory of Operational Near-Fault Observatory Networks and Data"*.

Here we describe the human networking established through sharing of scientific know-how, software and technologies, in workshops and meetings during the project and in the distribution and sharing of analysis software and data-access services among the participating NFO's. The ultimate goal of this sharing and networking is to develop and implement standards and quality control procedures for the multidisciplinary data collected in NFO's and enable access to their data.

# Contents

# 1. Introduction

The technical descriptions of the near fault observatories' (NFO) networks and stations, as well as their analysis systems were thoroughly described in D5.1 "*Inventory of Operational Near-Fault Observatory Networks and Data"*. Therefore the description of observation systems can be considered already dealt with, making the subject of this deliverable the human networking. This networking is established through sharing of scientific know-how and technologies in workshops and meetings scheduled throughout the project, and through the distribution and sharing of analysis software and data-access services among the participating NFO's. The ultimate goal of this networking is to propagate knowledge between the observatories and develop and implement common standards and quality control methods for the multidisciplinary data collected in NFO's.

The fault zones represented by the six observatories to be networked (Figure 1) are in different tectonic regimes, including:

i) plate boundaries with strike-slip faulting, such as the South Iceland Seismic Zone (SISZ) in Iceland, and the Marmara Sea in Turkey (NAFZ), and plate boundaries with normal faulting like the Corinth Rift (CRL);
ii) low- and medium-angle normal faults like the Alto Tiberina (ATF) and Irpinia (IF) faults;
iii) a region characterized by both strike-slip and normal faulting like in the Valais region (VA) in the Swiss alps.

The fault structures range from well-developed long faults, such as in the Marmara Sea, to more complex networks of smaller, book-shelf faults such as in the SISZ. Earthquakes of M≥6 can occur in all the fault zones. Two of them, NAFZ and CRL, located under the ocean can generate tsunamis, and the steep slopes in the Swiss Alps can become unstable during earthquakes in the Valais and lead to landslides. Geothermal drilling and re-injection in the SISZ and the Valais has induced considerable seismicity and volcano-tectonic interaction between the SISZ and near-by Hekla volcano repeatedly occurs.

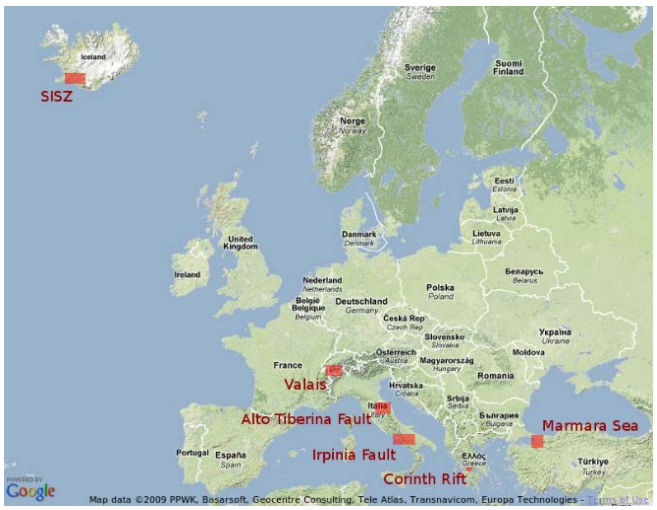


**Figure 1** Location of the NERA near-fault observatories to be networked

To support and propagate technological and scientific development in observatory operations and research, the NFOs have established collaboration and exchange of technological and scientific know-how through structured workshops with specific themes. Lines of communication and collaboration between observatories have been established by these workshops, whose aims have been to review the main systems in operation at the NFOs, as well as their technologies and data products and reach a consensus on which systems will be networked. The workshops have been held in collaboration with work package 2 of the REAKT project.

# 2. Observation Systems at the Observatories

The infrastructures, as well as the automatic and interactive processing and analysis systems at the six near-fault observatories were already described in detail in the deliverable report D5.1. For a general overview and to emphasize the multidisciplinary nature of the data archived at the NFOs, the network types are listed below in Table 1. This variety of observations also complicates the problem of establishing data standards and commonly defined quality control procedures. The infrastructure at each observatory is also under continuous development, with new systems and networks being added. In addition, not all the systems in the NFOs are under the control of the NERA partner, which may cause complications in guaranteeing data access.

| Types of data | SISZ | NAFZ | ATF | CRL | IF | VA |
|---|---|---|---|---|---|---|
| Seismic SP/BB | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Accelerometer | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| OBS | | ✓ | | | | |
| Tide gauge | | | | ✓ | | |
| GPS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Strain | ✓ | | | ✓ | | |
| Borehole, water level | ✓ | | ✓ | ✓ | | |
| Chemical | ✓ | | | ✓ | | ✓ |
| Magnetic | | ✓ | | ✓ | | ✓ |

**Table 1.** Types of systems in each near-fault observatory to be networked in NERA.

# 3. Networking and Communication between observatories

The multidisciplinary nature of the NFOs and the lack of standards for all but the seismic and GPS data makes the establishment of communication protocols premature at this stage. Instead, the procedures that have emerged during the project do not involve strict protocols, but rather:

i. interaction and sharing of know-how, both technical and scientific, through common meetings and structured workshops, as well as
ii. collaboration and communication between individual partners to facilitate the transport and propagation of common methods and analysis software between the observatories.

As these common procedures become better established, adjustment and adherence to the emerging standards will lead to more homogeneous, and better quality data sets and will also make maintenance and upgrades much easier, safer and less time-consuming

## 3.1 Meetings and workshops

Meetings were scheduled to coincide with project meetings, at months 1, 12, and 24, as well as two short meetings at EGU in Vienna in 2011 and 2013 and one meeting in Erice at month 34, during the EPOS (European Plate Observing System) workshop: *A Roadmap for Earth Science in Europe: The next generation of Geophysical Research infrastructures*. In the first meeting the work plan for the duration of the project was laid out, while the other three meetings focussed on:

i. planning workshops at selected observatories and deciding on topics to focus on
ii. discussing possible ways for providing access to the NFO data and
iii. preparing a white paper to petition to EPOS to be included as a subgroup of working group 5 Other geoscience data.

The meeting in Erice was an important step for the NFOs towards reaching working group status in EPOS.

Three workshops were held, the first two were two-day, while the third was 3 days. The first workshop, held in Naples in March 2012 (month 16) was attended by 21 researchers from all NFO's; the second in Zürich in March 2013 (month 28) attended by 30 scientists from all NFO's. The third and last workshop was held in Reykjavík in January 2014 (month 40). The workshop was a three-day event and attended by 19 scientists. All workshops were coordinated and shared with WP2 of the REAKT project, which is focussed on physics of short term seismic changes and its use for large earthquakes predictability.

***Workshops:***

### 3.1.1 Naples workshop 6-7 March 2012

*Location:*
Universitario monte S. Angelo, Naples; host of the Irpinia fault NFO and data center.

*Focus:*
Introduction to the tectonics and focus of each NFO. Presentation of the networks and systems at each observatory described in the inventory report (D5.1). Discussions on networking of operations, processing and data. Visit to the Irpinia Fault data processing center.

| List of registered participants | |
|---|---|
| **Name** | **Institution** |
| A. Criscuolo | AMRA |
| H. Lyon-Caen | ENS |
| S. Lambotte | EOST |
| J. Burianek | ETH |
| D.Fah | ETH |
| C. Cauzzi | ETH |
| K.Vogfjiord | IMO |
| G.B. Gudmundsson | IMO |
| E. Kjartansson | IMO |
| L. Chiaraluce | INGV |
| W. Marzocchi | INGV |
| A. Nercessian | IPG |
| P. Dublanchet | IPG |
| P. Bernard | IPG |
| D. Marsan | ISTerre |
| M. Bouchon | IsTerre |
| H. Karabulut | KOERI |
| C. Zulfikar | KOERI |
| D. Kalafat | KOERI |
| Papadimitriou | NKUA |
| N. Voulgaris | UNIATH |


**Figure 2.** Workshop participants

*Day 1*
Introduction of Observatories and discussions: Overview of networks and equipment, analysis software, data base, maintenance and quality control of data base and access:

- Irpinia Fault Observatory
- Alto Tiberina Observatory
- Irpinia data centre
- Valais Observatory overview
- Corinth Observatory overview
- Marmara Observatory overview
- SISZ Observatory overview

*Day 2*
1a) Short introduction of the Istanbul seismological supersite proposal MARsite
1b) Operational aspects of interest for networking. Topics for discussion:

- How interaction and collaboration between the observatories will be initiated and maintained
- Technology, philosophy, software – analysis and monitoring that could be of interest to the other NFOs
- How products and procedures of interest would be transferred

2a) Networking of data. Topics for discussion:

- Which data to be networked (metadata, raw data, bulletins, parameter data)
- Where the data will be archived (locally or centrally; virtual or actual repository)
- Who will archive SP, SM and event-based seismic data, OBS-, GPS-, strain- and other types of data
- Should the NFOs be included as a subgroup of WG1 in the European Plate Observing System, EPOS

2b) Data bases, data formats and quality controls. Topics for discussion:

- Status of the observatories' data bases; access from web; QC issues

3) Planning for deliverable D5.2.

The workshop schedule, minutes of the discussions and presentations can be found on the NERA internal web-site under WP5.

### 3.1.2 Zürich workshop, 19-20 March 2013

*Location*:
The Swiss Seismological Service (SED), ETH Zürich, host of the data center for the Valais area observatory.

*Focus*:
Networking near-fault observatories in Europe to establish collaboration and exchange of technological and scientific know-how, to foster synergies and to support technological development in observatory operations and monitoring. The workshop was intended for developers, computer scientists and seismologists, particularly those working in seismological network operations.
Additional topics were addressed in two parallel working group sessions, A and B.

Working group A revisited some of the topics discussed in the Naples workshop:

- Seismological databases, common tools, and quality control, real-time and almost real-time seismological products

Working group B focussed on new topics:

- Earthquake source parameters, earthquake swarm analysis and repeaters.

A visit was made to the electronic laboratory of SED, presenting processing software and instrument pool.

| No. | Name | | Institution |
|---|---|---|---|
| 1 | Aktar | Mustafa | KOERI |
| 2 | Behr | Yannik | ETH/SED |
| 3 | Bernard | Pascal | IPGP |
| 4 | Burjanek | Jan | ETH/SED |
| 5 | Cauzzi | Carlo | ETH/SED |
| 6 | Chiaraluce | Lauro | INGV |
| 7 | Clinton | John | ETH/SED |
| 8 | D'Alema | Ezio | INGV |
| 9 | Deschamps | Anne | Geoazur |
| 10 | Diehl | Tobias | ETH/SED |
| 11 | Di Stefano | Raffaele | INGV |
| 12 | Edwards | Ben | ETH/SED |
| 13 | Elia | Luca | Uni Napoli/Amra |
| 14 | Fäh | Donat | ETH/SED |
| 15 | Festa | Gaetano | Uni Napoli/Amra |
| 16 | Aochi | Hideo | BRGM |
| 17 | Kalafat | Dogan | KOERI |
| 18 | Kästli | Philipp | SED |
| 19 | Kjartanssor | Einar | IMO |
| 20 | Lyon-Caen | Hélène | ENS |
| 21 | Marzorati | Simone | INGV |
| 22 | Matrullo | Emanuela | ENS-CNRS |
| 23 | Mohsen | Ayman | An Najah |
| 24 | Pinar | Ali | KOERI |
| 25 | Plicka | Vladimir | CUNI |
| 26 | Sverrisson | Sverrir | IMO |
| 27 | Tunc | Suleyman | BOUN |
| 28 | Tunc | Berna | KOLI |
| 29 | Vogfjörd | Kristin | IMO |
| 30 | Zahradnik | Jiri | CUNI |

Figure 3. Participants of VA workshop in Zurich, March 2013.

*Day 1*
1) Presentations on standard practices at near-fault observatories

- Valais region, SED/ETHZ Switzerland
- Gulf of Corinth (GC), CNRS, Paris, France; NKUA, Greece
- Irpinia (IF) faults, AMRA, Naples, Italy
- Alto Tiberina (ATF) faults INGV, Roma, Italy
- North Anatolian Fault (NAF) in the Marmara Sea, KOERI, Istanbul, Turkey
- South Iceland Seismic Zone (SISZ), IMO, Reykjavik, Iceland

2a) Presentations and discussions of specific topics in working group A

- Multi Parameters stations in the Dead Sea Area
- Data Set Merging for the Seismic Navigating Station in the Dead Sea Area
- Coordination of geophysical observations in and around western Corinth Gulf: towards best quality of raw and processed data and the information dissemination
- Construction of a seismological data base interfacing with the present *SIL* automatic and manual analysis system
- Nearly real-time modular system of analysis for *TABOO* seismological data flow
- Nearly real-time monitoring system *TABOO* seismic network activity
- Real-time digital filtering of earthquake waveform recordings, with applications in event detection and ground motion determination.
- *Scwfparam*: a tool for Rapid Parameterisation of Ground Motions and Input to *ShakeMap* in *SeisComP3*
- The *Virtual Seismologist* Earthquake Early Warning Algorithm in *SeisComp3*
- Seismic processing at the Irpinia Seismic Network / *PRESTo* Early Warning System
- Expansion of the Istanbul Early Warning and Rapid Response System
- Test cases of near-real-time fault mapping with automatic relative relocation of micro-earthquakes

2b) Presentations and discussions of specific topics in working group B

- Routine Source Parameter Estimation on the Swiss National Networks
- Source parameters of the aftershock of October 23, 2011 Van Earthquake (Mw=7.2)
- Multiple-point source models, case study of Van earthquake
- Detailed analysis of the 2004 multiplet sequence at CRL
- Scaling relationship for source parameters of the seismicity of the Corinth Rift (Greece)
- Repeating earthquakes identification and analysis applied to the Irpinia fault zone
- Analysis of Seismicity Clusters in Marmara Sea
- Towards real-time double-difference earthquake location in Switzerland
- Full waveform inversion of 1D velocity models in Corinth Gulf
- Influence of Super-Shear Earthquake Rupture models on Simulated Near-Source Ground Motion from 1999 Izmit Turkey Earthquake

*Day 2*

3a) Continued presentations and discussions of specific topics of working group A

3b) Continued presentations and discussions of specific topics of working group B

4) Summary overview of group A and B discussions and general discussion

5) EPOS overview
   - Final discussion revisiting a topic from the Naples workshop, concerning the possibility of the NFOs being recognized as EU research infrastructures within the EPOS community. It was decided to explore the options.
   - Plans discussed for a third possible workshop in Turkey in September 2013 (month 35) and a fourth in Iceland in January 2014 (month 38).

The workshop schedule and summary of session discussions, as well as the presentations can be found on the NERA internal web-site under WP5 and at (http://mercalli.ethz.ch/~faeh/NERA_WP5/). Summaries of the topics in working groups A and B are reproduced in the Appendix.

### 3.1.3 Reykjavík workshop, 13-15 January 2014

*Location*:
Icelandic Meteorological Office (IMO), Reykjavík, host of the data center for the SISZ observatory.

Focus:
Multidisciplinary data and their use in the NFO's, seismic analysis and Earthquake Early warning processes in use at the NFO's,
New instrument developments in the NFO's,
How will NFO's meet the commitment to sustainable access to data.
Definition of thematic services, TCS for WG5b, Near-fault observatories in EPOS.
Introduction to interaction between the SISZ and adjacent Western Volcanic Zone
A visit was made to IMO's natural hazards monitoring hall, where seismic, volcanic, hydrologic, meteorologic and show avalanche hazard monitoring is coordinated

| | Name | Partner |
|---|---|---|
| 1 | Donat Fäh | ETHZ |
| 2 | Philipp Kästli | ETHZ |
| 3 | Jan Burjanek | ETHZ |
| 4 | Lauro Chiraluce | INGV |
| 5 | Marco Cattaneo | INGV |
| 6 | Pascal Bernard | IPGP |
| 7 | Gaetano Festa | UNINA |
| 8 | Kristín Vogfjörð | IMO |
| 9 | Benedikt Ófeigsson | IMO |
| 10 | Kristín Jónsdóttir | IMO |
| 11 | Gunnar Guðmundsson | IMO |
| 12 | Einar Kjartansson | IMO |
| 13 | Sigurlaug Hjaltadóttir | IMO |
| 14 | Francesco Panzera | IMO |
| 15 | Þóra Árnadóttir | IES |
| 16 | Benedikt Halldórsson | EERC |

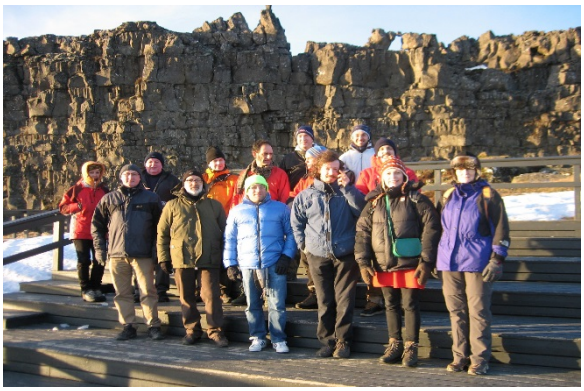

Figure 2. Participants of the workshop in the SISZ, January 2014

*Day 1.*
Multidisciplinary data and their use in the NFO's

- Integration of data from seismic, magnetic, and geochemical sensors of the Valais Near-Fault Observatory.
- TABOO's new multi-sensor stations.
- Technical lessons and scientific outcome from strain meter instrumentation in CRL.
- Icelandic Continuous GPS network IS-CGPS and strain network: operational procedures and processing.

Seismic analysis and Earthquake Early warning processes in use at the NFO's

- Earthquake early warning in NFO's: Irpinia and Turkey.
- Estimate relative corner frequencies within a seismic sequence.
- Joint-analysis of relative earthquake locations and focal mechanisms to map faults and slip directions on faults in the SISZ.
- Seismic bulletin preparation for Operation Earthquake Forecasting.
- Use of S-waves in automatic locations in Iceland.
- Real-time monitoring processes in operation in the SISZ.

Definition of thematic services for WG5c in EPOS
- Near fault observatories towards ...EPOS.
- Discussions

*Day 2.*
Strong-motion observations and analysis in the NFO's
- Real time Strong Motion Processing, and potential for motion based alerting, at SED
- The use of strong motion data for NFO analysis and monitoring.
- Strong Motion research in Iceland.

New instrument developments in the NFO's
- Innovative instrumentation with laser technology: information of the present developments and achievements of project LINES, for long (plurikilometric) fiber laser seismometers and tilt meters (application for borehole and offshore).
- Instruments under development in Futurevolc:
- New ice-seismometers: low power, stable clock, "unlimited" tilt – possible use in NFO's.
- Instruments for chemical monitoring in rivers– possible applications in boreholes in the SISZ.

Tectonic processes and interaction between the SISZ and adjacent W. Volcanic Zone
- Tectonics and crustal deformation in Southwest Iceland.
- Faulting in the SISZ and WVZ and Volcano-tectonic interaction at the western margin of the SISZ.
- Induced seismicity by waste water injection at Húsmúli, near the intersection of the WVZ and the SISZ.
- Interaction between the SISZ and the Eastern Volcanic Zone.

How will NFO's meet the commitment to sustainable access to data?
- Policy of CRL for the data distribution.
- Implementation of GSAC data service to allow access to GPS data.
- Data services to be implemented in Futurevolc.
- Deliverables and milestone from Task 5.3.

*Day 3.*
Definition of thematic services for WG5b, Near-fault Observatories in EPOS

Bus trip to Thingvellir and the intersection of the South Iceland Seismic Zone with the Western Volcanic Zone

The workshop schedule and presentations can be found on the NERA internal web-site under WP5.

## 3.2 Distribution/sharing of software between the NFO's

The titles of the presentations given in the workshops demonstrate the partners' introduction of best practices at each NFO regarding (i) station installation and operation (ii) implementation and developments of new instrumentation; (iii) development of analysis techniques, like real-time processing, earthquake-early warning and statistical earthquake forecasting. Two of the observatories, in particular, have significant developments in analysis techniques:

- The Irpinia observatory, where development of Earthquake-Early Warning (EEW) methods, like *PRESTo* has been emphasised.
- The SED/ETH Valais observatory, where a module has been developed, implementing the EEW *Virtual Seismologist* algorithm in the *SeisComP3* seismic analysis software package; and where, at the EU testing center for CSEP (Collaboratory for the Study of Earthquake Predictability), the *MapSeis* software package has been developed to enable statistical earthquake forecasting.

These advanced software packages were transferred from the developing NFO to the other observatories. These transfers include:

***PRESTo:*** The PRobabilistic and Evolutionary early warning SysTem, *PRESTo* (Satriano et al., 2011), developed at the Irpinia observatory was implemented for EEW of large earthquakes in the NAFZ observatory. The software integrates recent algorithms for real-time, rapid earthquake location, magnitude estimation and damage assessment. The algorithm returns magnitudes estimates within seconds and can give early warnings of imminent shaking, before the large damaging shear waves arrive.

***Virtual Seismologist:*** The earthquake early warning algorithm *Virtual Seismologist* (*VS*) (Cua, 2005, 2007; Cua et al., 2009) was implemented in the NAFZ and in the SISZ. VS can determine magnitude within seconds and estimates of ground shaking before the shear waves arrive. The implementations, which use a *SeisComP3* module developed at the Swiss Seismological Service (SED/ETH) (Behr et al, 2012) are still under testing and adjustment as alert times are still on the order of 20-30 seconds. Fully tested and adjusted, the algorithm has strong potential to enable EEW for Istanbul and the NAFZ area. However, the short distances from the SISZ to inhabited areas, critical infrastructures and the capital limits *VS's* use as an early warning tool to enable pre-emptive, mitigating actions to be taken in large earthquakes, but it will still be able to give critical information about shaking immediately after the event.

***MapSeis:*** This *MatLab* based code developed at ETH by Eberhard (2014) was implemented in the SISZ to set up short-term earthquake forecasts with the ETAS model (Okada, 1988, 1999, 2011; Jordan 2006). This test implementation of statistical earthquake forecasts in the SISZ marks the first step towards Operational Earthquake Forecasting in Iceland.

Finally, some of these and other techniques implemented at the observatories utilize community software, like the *SeisComp3* (www.seiscomp3.org) seismic analysis software developed at GFZ, Potsdam (Hanka et al., 2010). For example this is already the operative seismic analysis system at the Swiss Seismological Network (SED/ETH) and it is being implemented in the SISZ observatory in Iceland to maintain the seismic data base, where its associated web service, ArcLink will also be used to enable access to seismic data. Initial steps were taken by the SED/ETH group to form a *SeisComP3* working group within NERA WP5 and REAKT WP2.

Another open-source, community software package to give web-service access to a GPS repository is the *GSAC* (Geodetic Seamless Archive Centers) software system distributed by UNAVCO (www.unavco.org/software/data-management/gsac/gsac.html). This system is being implemented at many European GPS data centers through the COOPEUS project, as

a collaboration between EPOS and UNAVCO. For example it has been implemented at the SISZ observatory to enable access to GPS data.

# 4. Conclusions

Networking efforts between the NFO partners of NERA WP5 were focussed on sharing and transfer of scientific and technological knowledge. This was achieved in the three workshops that were held as well as through the distribution of software developed at two of the observatories to the other partners.

Interaction and internal education during the NFO workshops included introduction and discussion of the main scientific questions addressed at each observatory. Most of the discussions focussed on seismic data and analysis, where significant attention was paid to data bases and structures, as well as seismic real-time analysis techniques, although other types of data were also discussed. Collaboration and sharing of expertise included the propagation of earthquake early warning and forecasting methodologies between the partners.

While the multidisciplinary nature of the data archived at the NFOs has prevented the establishment of data standards and quality controls to be defined and implemented (except for seismic and GPS data where they already exist), the ground work has been laid for such work in the EPOS project and will be continued there in that project's implementation phase. Furthermore, the NFO workshops provided the perfect environment to initiate the required preparatory work for the inclusion of NFOs as a working group in EPOS.

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# Appendix

# Summaries of working groups in Zürich workshop

**Working group A: Seismological databases, common tools, quality control, real-time and almost real-time products**

The deployment of multi-parameter sensors, including seismic and meteorological sensors, around the Dead Sea was briefly discussed. Since this project is at an early stage, topics such as data retrieval and processing were not discussed in detail. Most of the presentations and the discussions were focused on the different processing schemes, the corresponding software and the final network and research products that are developed and produced at the different observatories. A particular focus regarding products was on generating near real-time ShakeMaps and earthquake catalogues for research purposes which are generated continuously but not in near real-time.

General outcomes of the discussions were:

1. The use of commercial software does not appear to be an option for any of the participating observatories;
2. There are generally two approaches regarding processing software: in-house, custom tailored software and community solutions such as *SeisComp3* or *Earthworm*. The advantages and disadvantages of either approach are summarized in the following table:

| | Pros | Cons |
|---|---|---|
| In-house software | Software and products are optimized for local seismicity | No community support, high maintenance efforts, less future proof |
| Community software | Exchange platform and long term support; debugging help by others | Compromises have to be made on architecture and general system layout |

3. The decision on which approach to take largely depends on available software and resources (funding, manpower) at the time of the system design. The fact that most observatories are run by researchers who have to regularly produce scientific publications hampers the adoption of community standards since they are perceived as an additional burden.
4. Cross-evaluation of research focused on real-time earthquake catalogues using statistical methods appears to be a promising strategy to assess their performance and reliability.

Another topic that was extensively discussed was the strategy for data storage particularly with regard to continuity, reliability and flexibility of data archives. The conclusions from this discussion were:

1. Only few institutions are still using file-based structures for archiving data;
2. Different types of databases (relational vs. other types) were discussed; the general direction here is to use community tested solutions.

The main topic of day 2 was the different types of Earthquake Early Warning (EEW) algorithms that are run at participating observatories. The algorithms can be divided into two different strategies:

1. Single-station onsite approaches which issue alerts based on the exceedance of thresholds for parameters such as cumulative velocity, peak displacement or predominant period.
2. Regional/network approaches that compute earthquake epicenters from P-wave arrivals and use empirical relationships to estimate the corresponding magnitude from P- and S-wave amplitudes. The advantages and disadvantages of either approach are again summarized in the following table:

| | Pros | Cons |
|---|---|---|
| Single-station approach | Very fast | No, or no precise epicenter location; less reliable magnitude estimate than regional approach. |
| Regional approach | Slower than Single-station approach (both presented algorithms require at least 6 P-wave arrivals to declare an event) | More reliable estimates of magnitude and epicenter than single-station approach. |

3. In Istanbul a single-station approach is operational and regional approaches (PRESTo, Virtual Seismologist) are currently tested. In Switzerland the Virtual Seismologist is in testing phase and at the Irpinia seismic network PRESTOplus, a combination of single-station and regional approach, is in testing phase.

Another presentation showed results from the Gulf of Corinth near fault observatory with a focus on data processing and difficulties with earthquake catalogue inconsistencies between the three institutions involved: the universities of Athens and Patras and CNRS/CRL.

The final topic, discussed jointly by working group A and B, was double-difference type relocations. Some preliminary results from the double-difference base catalogue for the Valais Switzerland region were shown and discussed. Finally results from the near real-time implementation for the South Iceland Seismic Zone were presented with the performance during several swarms and demonstrating how automatic locations improve by relative location techniques.

**Working group B: Earthquake source parameters, earthquake swarm analysis and repeaters**

Working group B was focused on the issues of earthquake source parameters and earthquake swarm analysis and repeaters. On the topic of earthquake source parameters they overviewed the current practice at seismological observatories, as well as in smaller projects, and discussed merits of different approaches. The issue of inadequate noise estimation due to transient signals contaminating analysis windows was discussed. Although no solution was proposed (apart from visual inspection), SED practice of conservatism by increasing the noise estimate (with respect to the measured value) would go some way to reduce the impact of this in automatic analysis. Most discussion was centered on S-wave analysis (or multiples thereof). It was suggested to extend these spectral analyses to P-wave at limited extra effort and cost. There was no consensus on the window duration for spectral analysis: windows ranged from milliseconds to tens of seconds. Theoretically equations applied are applicable to the direct phase, so short time-windows are suitable. However, this may lead to underestimation of seismic moment. The influence of site amplification was discussed related to Mw determination. Significant site-to-site variability was noted in Mw estimates, which could be accounted for by including site amplification in the analysis. An extension of an existing method for multiple point-source models was shown to be useful in finite-fault modelling using local and regional seismograms. It was shown that detail of the faulting process could be extracted and uncertainties accounted for.

In terms of cluster and repeater analysis, good results were shown from cross-correlation approaches. Such approaches were shown to increase detection/classification by up to an order of magnitude, with improved results from a recursive approach. The exact approach for cross-correlation was discussed, with arguments for and against the use of single phase, or whole waveform correlation and the relation to velocity model uncertainties. Migration of seismicity was observed at up to 50 m/day, while spectral analysis of the multiplets showed low stress drop, increasing with Mw, based on spectral ratio analysis. Very different Gutenberg–Richter earthquake recurrence statistics were shown for different clusters in the same region: it was suggested that this would be interesting to compare with stress measures (differential or stress-drop) in order to test the relation between the two. The final discussion of the group was related to the practical application of source parameters in terms of engineering applications (i.e., seismic hazard). It was shown that two kinematic models of the Izmit 1999 earthquake could produce surprisingly different PGV distributions, whilst still fitting individual stations. The main reason for this was the lack of absolute timing information on the seismograms used for the derivation of the kinematic models. This highlighted the fact that source parameters play an important role in earthquake simulation and ground-motion analysis. Authors of such models should be careful to specify the limitations of their models and should make it clear how they were derived.