Network of European Research Infrastructures for Earthquake Risk Assessment and Mitigation

Report

Strategy document on the Euro Array concept

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Seventh Framework Programme

1 - Summary

The majority of European nations support national seismic equipment facilities. Each facility is responsible for providing seismic instrumentation, technical assistance and data management support. These facilities are used by academics and national networks for scientific and hazard-related studies both within and outside Europe. Although of significant size in certain cases, none of these facilities is large enough to support a European-scale experiment without close collaboration with other facilities.

The hardware, software, manpower and level of support varies significantly between national facilities. For any large-scale multi-national European broadband seismic project to succeed, for example at the Euro Array scale, synchronisation of all participating facilities is imperative. This integration must be achieved at all levels, from field methods and data quality standards to data archiving and accessibility. This requirement was recognised within the NERA proposal and this paper presents guidelines for optimising this integration. Although data acquisition can readily be achieved with a diverse set of instrumentation and techniques, a consensus must be achieved on data quality, products and access for end-users.

The integration of seismic facilities and datasets is essential if European Earth Scientists want to maintain a high degree of competitiveness worldwide. Similar undertakings are already ongoing elsewhere with large continental-scale projects such as Earthscope or Sino Probe. The European plate still presents a large number of scientific questions which can only be addressed by increased resolution and scale of study. The concept presented here of integrating experiments, instrumentation and data products, by means of a series of coordinated mobile network deployments complementing the permanent monitoring networks, appears as the most effective tool to address these questions.

2 - Introduction

This document presents the recommendations of NA2 within NERA, establishing technical protocols and standards for participating facilities to ensure the highest quality data are obtained with the optimal experimental procedure, maximising outputs from large-scale collaborative projects within Europe. This document is aimed at outlining best practise to all collaborative projects, not only to those involving NERA participants. Although some of the recommendations presented here may seem overly prescriptive, the diversity of the European facilities can only be mitigated by significant synchronisation of methodology and end-products. This document is being written with a broadband Euro Array scale experiment in mind but the application of these recommendations to all collaborative projects within Europe, at whatever scale, should significantly improve efficiency and data outcomes. For example, a Euro Array scale experiment could readily involve the integration of both large-aperture broadband deployments and more focussed localised studies.

We have split standards in to **compulsory**, **best practise** and **recommended**.

- **Compulsory** items will lead to the highest standard of data quality and returns and must be vigorously adhered to by all participants.
- **Best practise** items will lead to the highest standard of data quality and returns but may sometimes be inappropriate or unfeasible.
- **Recommended** items will in general not affect data quality but should assist participants to optimise procedures where currently multiple options exist.

3 – Recommended standards and methods

We address in turn all aspects of broadband seismic data acquisition and data management such that every step of the experiment cycle can be agreed and synchronized prior to the commencement of any experiment.

3.1 - Station equipment and settings

The European seismic equipment facilities house a diverse set of instrumentation. A database is maintained by ORFEUS WG3 allowing groups to identify available instrumentation. Although the sensors and dataloggers available across Europe differ significantly in their origin and functionality, prescriptive methodology and data product management does not preclude utilisation of equipment from a range of facilities in a single experiment.

In order to ensure a minimum standard of data quality is achieved and to optimise data usage the following standards must be achieved:

Compulsory

1. Sensor must be broadband (flat response from at least 20Hz - 30s).*
2. Digitiser must be >130dB (24bit technology). *
3. Datalogger must have rapid data recovery and a minimum storage capacity of 6 months.
4. Known dataless Seed response for full system.
5. GPS timing.

** **Compulsory** for broadband experiments only: Not always appropriate, e.g. local seismicity studies where these standards can be regarded as **Best practise.***

Recommended

1. A recording rate of 100sps ensures the broadest potential use of data.
2. 1sps data should also be recorded (or transmitted) to improve QC analysis.
3. System compatibility with real-time GPRS communications (not always implemented).
4. Local datalogger storage in mseed or other accepted standard with available and tested tools to convert to mseed.

3.2 - Vault types and site selection

The design of temporary seismic stations is highly dependent on local conditions and the availability of materials. We do not prescribe a compulsory pit design, but assign desirable noise performance criteria instead.

Compulsory

1. Installation: all deployments must be supervised by experienced persons (not necessarily facility staff).

Best Practise

1. Agreed site-noise levels:
    a. *basin / soft soil site:* lower than Peterson (1993) high noise model up to 100s.
    b. *rock / rural site:* 20dB lower than the high noise model up to 100s, (excluding the microseism).

Recommended

1. Before installation, tests using a broadband sensor for >1day must show the station is better than the agreed noise level for that period
   a. If this is not possible, analysis of data within 1 month required and the station must be moved if not meeting criteria.
2. Acceptable vault types:
   a. The vault design will not be dictated but requires that the specified noise model be met: In general this will require avoiding inhabited buildings; buildings >1 story; and if using an existing structure, always install the sensor in the basement.
   b. Site autonomy. Sites without mains power will require solar panels with battery backup. A minimum of 60 days autonomy without charge is suggested, e.g. battery capacity of 240Ah for a 2W system (potentially >100 days autonomy required in the high-Alps or high-latitudes where access is likely to be restricted during winter)
3. Sensor orientation using standard method: Standard methods for sensor orientation are prone to significant error, even at permanent installations [Ekstrom, 2008]. We therefore recommend that wherever possible tools be acquired at the start of any large-scale project to minimize sensor orientation errors (e.g. gyroscopic compass).
4. For security reasons, where possible private land should be used for deployment with agreement of the land-owner. Any site-rental rates must be agreed between participants prior to commencement of the experiment and normalised across the array to prevent disagreements at a later stage.

3.3 - Communications and maintenance schedule

Although real-time data transmission is optimal for data recovery and quality control it is clearly not always feasible due to power and signal requirements, and typically high communications costs. Mobile communications would be the preferred realtime communications solution as in general, mobile phone signal will be available at the majority of sites in Europe except in extremely remote regions. Where mains power is available real-time data transmission through the mobile phone network becomes highly desirable. Where mains power is not available, real-time communication through the mobile network will result in significant power overheads which may make this prohibitive. Real-time transmission should be considered on a site-by-site basis but the following factors must be taken in to consideration:

1. Financial costs:
   a. In the majority of European countries, **real-time data transmission** can be achieved for around €20 per month with a hardware start-up cost of around €1,000 per station. There is an associated cost with data centre manpower for array monitoring and data QC, dependent on array size: 2 man-days per month for 50 stations is realistic, ***equivalent to 24 man-days per year per 50 stations***.
   b. **Offline stations** result in major hidden costs: Assuming a field-servicing and data download rate of 3 stations per day with 2 extra days for conversion and QC of 50 stations, a service interval of 3 months requires around 18 days per 50 stations, ***equivalent to 70 man-days per year per 50 stations***. Additionally, the hidden cost of significant increase in % of lost data (see section below) must also be taken into account.

    c. Hardware and software for real-time data retrieval need not differ from that required for offline data processing and so is regarded as cost neutral.
    d. Repairs of offline stations will be carried out during servicing and therefore are at no extra cost. However, real-time station repairs will require extra site visits and must therefore be considered on top of these figures, especially if the array is not maintained by in-country staff. On the other hand, if realtime stations continue to deliver data without problems, routine visits are not required. Realtime stations also will include on-site recording, so even if it is clear communications have failed for some reason, data will still be recorded locally if possible.
2. Data recovery rates:
    a. A realistic expected data loss for offline seismic stations is around **10-20%**, usually a result of vandalism, instrument failure or power supply issues.
    b. Real-time data transmission allows station issues to be identified within hours or days of manifestation. Where issues cannot be resolved remotely site visits can be scheduled to ensure recovery in a timely manner. Data loss rates for real-time networks can be as low as **1%**.

3.4 - Data recovery and security

EIDA has been recognised as the optimal data exchange package for European collaborative experiments. Eight EIDA nodes currently exist (e.g., GFZ, INGV, IPGP, ODC, RESIF, SED/ETHZ + 2 outside NERA). It has been recognised within NERA NA2 that a number of developments of the EIDA software and its management are required. This is currently being addressed and should result in a viable and sustainable package for expansion to all European data centres. Therefore, the following recommendations which directly relate to EIDA are subject to successful implementation of these improvements.

In general, conversion to archive format (miniseed) and data QC will be carried out in the normal way by the PI or supporting instrument facility. However, the archive format data on the community portal will be hosted at a single nominated EIDA node for each experiment, typically in the experiment's host country, if an EIDA node exists.

Compulsory

1. Data must be in the final format within 1 month of the site visit.
2. Data must be available to project partners on the community portal within 2 months of site visit (at nominated EIDA node).
3. Permanent data backups must be maintained by the PI or supporting facility.

Best practise

1. Minimum visit and data download every 3 months for duration of deployment (offline stations).

Recommended

1. Archive-ready data from each station goes to the nominated data center dependent on station location (e.g. miniseed data from UK hardware operating in Switzerland are sent to the Swiss EIDA node for archiving).
2. If an experiment does not have a national EIDA node then arrangements must be made between participating groups or ODC prior to commencement of any experiment.

3. Real-time data are quality controlled with at minimum a weekly assessment of all available sites.

3.5 - Data formats and access

Compulsory

1. FDSN network codes must be assigned for each temporary deployment.
2. All waveforms will be archived in miniseed format. Metadata will be in dataless SEED.
3. Dataless seed creation is the responsibility of the facility.
4. Miniseed format: big-endian, 4096byte record size; Steim 1 or 2 compression.
5. Huddle test and state of health data to be archived.
6. Data archiving must be in the same style: SDS structure preferred unless other structure is already in use that is compatible with EIDA distribution.

3.6 - Data openness

Data openness has recently become a significant issue for national funding agencies, and it is these agencies who will generally dictate any data-access restriction periods. There is increasing recognition that public data-access following a proprietary protection period for initial publication, usually 2 or 3 years, is beneficial. Within the seismological community, data openness following publication is generally accepted as being of significant benefit to all parties and has been undertaken for a number of years. Such openness is certainly compatible with the seismological community where publicly available software processing packages (database maintained by ORFEUS) and open processing environments, such as ObsPy, are commonplace. Prior to the period of data release, data sharing agreements are required between all participating groups and Memoranda of Understanding should be implemented prior to the commencement of any experiments.

In order to maximize benefit to the wider seismological community, a ***special event scenario*** is being strongly encouraged, facilitated by the implementation of EIDA nodes. In case of M5+ events inside or adjacent to the network, all data should be made publicly available for the day of the event, as soon as possible.

3.7 - Centralised data coordination

We recommend distributed data but centralised quality control, following the EIDA model:

1. Archives distributed using EIDA
2. Standard quality control – for stations noise, station uptime, SOH monitoring, PQLX
3. If possible for international projects including multiple agencies, project management should be done centrally with a project website, including station quality reports, station information (including standardised deployment and servicing sheets), instrumentation availability etc
    a. Instrument inventory optimisation can then be done using this web hub by project scientists.

4 - OBS data

OBS (Ocean Bottom Seismometer) data have not been addressed here directly. However, all our proposals allow OBS stations to be integrated into this project without significant effort. The integration of onshore and offshore facilities within Europe is currently underway and synchronization of data products is seen as an essential product of this. Details are outlined in the attached White Paper which resulted from a workshop targeted at the integration of onshore and offshore instrumentation facilities within Europe (Annex 2).

5 - Evaluation of the EuroArray concept

Attempts to build a single, European-scale facility or to launch a continental scale experiment have not succeeded in the past. However, the recent IberArray undertaking in Spain [Diaz, 2010], has been augmented by for example the concurrent PYROPE array in southwestern France, and demonstrated that collaboration between national facilities can lead to significantly enhanced coverage and improved data sets. Similarly, the WILAS project [Dias et al, 2011] involving over 40 temporary stations in Portugal extended the IberArray experiment to achieve full broadband coverage of the Iberian Peninsula. Likewise, the PASSEQ Experiment (Wilde-Piorko et al, 2009) involved 17 institutions from Europe and the USA, with a 400km line running from Germany through the Czech Republic and Poland to Lithuania.

This appetite amongst the European Earth Sciences community for a large-scale European experiment has recently led to an initiative to undertake coordinated broadband seismic experiments across the European Alps, under the umbrella project of "Alp Array". A kick-off meeting was held in October 2011 where interested scientists and facility representatives met to discuss the scientific questions to be addressed and also tackle the infrastructure integration problem. This document is presented in the context of this initiative where a practical manifestation of the facility integration could be addressed directly. The outcome of this meeting was a consensus on potential scientific targets in the greater Alpine region as well as evaluation of the integration of European seismic facilities.

6 – Discussion and Conclusions

We present here an outline plan for the integration of European seismic instrumentation facilities. Each facility retains its own national identity and operating structures but application of the guidelines presented here allow a number of facilities to undertake collaborative large-scale projects without any detrimental effect on data quality or scientific outcomes.

We have addressed the key components of a seismic experiment:

- Station equipment and settings
- Vault types and site selection
- Communications and maintenance schedule
- Data recovery and security
- Data formats and access
- Data openness
- Centralised data coordination

By agreeing to this set of standards and protocols prior to the initiation of an experiment, collaborating national facilities can mitigate against the problems associated with the diverse instrumentation and operational protocols. One significant barrier to collaboration within the European Scientific Community, i.e. discrete national funding of instrumentation facilities rather than a centralised European seismic facility, is therefore overcome without any intervention by the project's scientific participants. The Euro Array concept is therefore significantly more realistic with this model than when previously proposed, where it was dependent on the construction of a centralised European pool of mobile seismometers, directly based on European funds.

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Annex 1 – List of Activity Meetings

January 2011 – Work Package coordination meeting, de Bilt, Netherlands

April 2011 – Task 2.2 coordination meeting, Vienna, Austria

May 2011 – Workshop: Integrating seafloor and land-based seismographic observations

October 2011 – Alp Array project kick-off meeting, Zurich, Switzerland

Annex 2 - Integrating Mobile European Plate Observing Systems

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Introduction

Mobile networks of seismometers are required to answer fundamental questions about the formation, structure and dynamics of the European plate and to evaluate important risks and resources. With the European plate surrounded on 3 sides by water and containing major seas, marine seismometers must be an integral part of this network. The efficient use of these instruments depends not only on their existence, but also on the ease of their access by the seismological community.

We propose actions to make marine seismographs more accessible to the seismological community. A major action is the standardization of methods for requesting these instruments and for providing the data. We also propose a framework for better communication between European parks, which should ease standardization and improve the quality and availability of instruments. This initiative falls within the EPOS (European Plate Observatory System) framework, complementing the EMSO (European Multidisciplinary Seafloor Observatory) initiative in the same way that land-based mobile instrument parks complement permanent stations.

Motivation

The last two decades have seen an explosion in the availability and quality of mobile seismological systems. Whereas, 20 years ago, a "detailed" regional study might consist of deploying 10, mostly short-period, seismometers for a few months, the same region can now be studied using hundreds of smaller, easier to use and more sensitive systems. Also, collaboration between countries and their instrument parks allow more instruments to be applied to one problem. These advances allow seismologists to image sections of the European plate with unprecedented resolution. A recent example is the IBERARRAY-PYROPE experiment, in which Spanish and French seismometer parks combined forces to study the structure beneath the Iberian Peninsula and Pyrenees mountain chain.

Marine seismograph stations, commonly known as OBS for "ocean-bottom seismometer", have similarly advanced. Whereas, 20 years ago, there were no more than 100 academic OBSs in the world, almost all of them short-period, there are now about 1000 such instruments, many of them large- or wide-band.

Many studies aimed at studying seismic hazard, mapping the potential for natural resources, or addressing fundamental geodynamic questions should use a combination of land-based and marine seismometers. This is particularly true for Europe, which is surrounded on three sides by seas and which contains great inland seas. Europe's greatest seismic hazards are centered close to these seas and its most important energy resources are on continental margins. Even many land-based regions, such as the Alpine mountain range, are close enough to seas that a complete seismological coverage can only be obtained by including marine stations.

However, very few experiments use both land-based and marine stations, much less than should be expected. The land and marine seismological communities have developed somewhat independently, leading to different means of requesting each type of instrument in most countries. In addition, marine data is rarely made available on public seismological data archives, making it more difficult for this data to be used beyond the objectives of the initial projects, or for the data quality to be evaluated.

Marine parks are generally smaller than their land counterparts, and the costs per deployment higher, mostly due to the high price of ships for the deployments but also due to the cost of batteries for long-term deployments. The additional challenge of obtaining ships can also discourage scientists from trying to use marine instruments. Finally, marine measurements have a different (and generally stronger) background noise spectrum than well-installed land stations.

Our goal is to allow scientists to develop seismological experiments with the optimum geometry, scale and sensitivity for the problem, with a unified access to both marine and land instrumental pools and, ideally, ship time (or at least support in obtaining suitable ships for deployment).

Action Plan

Unifying marine and land-based seismological systems on a European level is currently unlikely for a number of reasons, including differing funding structures, diverse national priorities and heterogeneous hardware. As long as the instruments remain under national control, the best approach to assimilation is the clarification and synchronization of the means and cost of requesting instruments in each country. The key to successful integration is of course improved cooperation between facility managers.

We propose a series of actions to take in order to integrate marine and land-based seismological systems. The majority of actions are on the side of the marine parks, as the land-based parks have become relatively well organized over the past 10 years.

1. Maintenance of a common website outlining hardware and services of the different parks and the local instrument request procedures.
2. Organize yearly organizational meetings between the marine parks, to discuss and, if possible, standardize the request procedure and cost structure for use of the instruments.
3. Organize yearly technical meetings between the marine parks, to discuss technological advances and problems. These meetings could enable a future generation of instruments with a common interface.
4. Help the marine parks to transform their data into a seismological standard format, which is then put on a publicly available server with tools to evaluate data quality. Well-established formats are miniSEED for the continuous data and dataless SEED for

instrument positions and responses; OBS-specific information about, for example, timing corrections should be investigated. We strongly recommend adopting policies that enforce opening the data fully after a reasonable embargo period comparable to the practice in land experiments. This stipulation is rapidly becoming the norm for national funding agencies anyway, e.g. NSF, NERC.

5. Evaluate the data success rate of each experiment on a European level in order to identify common problems that must be corrected or avoided.

6. Coordinate funding developments and test experiments to improve the reliability, data quality, longevity and cost of marine deployments.

7. Clarify rules for obtaining ship time and the costs of the ships and work towards a framework where a request for ship time and access to the ocean bottom pool is unified (associated with the Eurofleets initiative?). In some cases, the use of chartered ships might be more economical than using ships from the national research fleets, but the organization of these charters should be done in a unified way, and not have to be up to the individual PI.

8. Establish a limited pool of equipment and mechanisms for obtaining ship time for “rapid response” experiments, both in response to natural events of major societal significance (e.g. aftershock studies of damaging events) or major scientific interest (e.g. volcanic crisis at mid-ocean ridge).

At the same time, integration on a national level of land and ocean instrumentation, making instrument requests and payment structure compatible, is a priority. Some national parks have already united land and ocean facilities under a similar umbrella (e.g. amphibious DEPAS pool in Germany and NERC Geophysical Equipment Facility (GEF) in the UK).

We recognize that in spite of encouraging unification and simplification of the rules of access, each national pool must remain free to set their own rules. For example, pools in countries with high seismic hazard might always want to retain a number of instruments for response to national emergencies. But these rules must be clear in order for European-level coordination to advance.

Although some bilateral agreements between the major OBS-parks already exist, true Pan-European coordination between OBS parks will bring additional benefits by simplifying the logistics of exchanging OBS capability and providing access to scientists from European countries which do not have their own national pool. European coordination will also provide benefits on a national level: it will allow local experiments to be more ambitious (using the ideal geometry instead of the one imposed by their local park), it will allow parks to function and prosper even in years where there is a dip in their national demands, and it will help parks to improve their instruments.

Links to European Initiatives

A short section expanding on links to EPOS/EMSO – why is money needed outside EPOS etc

Future directions

Instrumentation. It is at the current stage also not advisable to request a standard instrument to be developed, as different types of instruments provide important differences. For example, marine instruments need to store their own power, so there will always be a tradeoff between the size of an instrument, the type of sensor, and the maximum deployment length. We do recommend, however, that instruments move toward at least wideband sensors (60s or longer), as the broader band is necessary for many seismological studies and new low-power sensors are nearly as compact as short-period sensors and have power consumptions (150 mW) comparable to or lower than the rest of the instrument electronics. Broadband sensors will be necessary for some experiments, but their higher power consumption (700-1000mW) significantly reduce their possible deployment time and their larger size can limit the number of instruments that can be transported by a research vessel.

Technological innovation. Although OBSs are already a useful part of scientific experiments, further advances can be made to make them better. We list a few below, some of which are already being developed in one or more of the parks. Coordination of these efforts would allow these problems to be attacked more efficiently:

- Reduction of seafloor current noise: Seafloor currents create a much higher noise signal on the horizontal channels than exists at land stations. Although this noise can be removed by burying the sensors, lower cost methods can also be developed, such as reducing the sensitivity of seafloor sensors to currents and independently measuring tilt in order to correct for the current noise. The UK's OBS park is working on the first problem, but future European help could be crucial to making advances that can be applied to all instruments. Studies of tilt and rotation funded by Europe could also lead to rotation being used as a seismological measurement in its own right, whose potential is currently being evaluated in land experiments.

- Orientation of seismometer components: Currently, OBS seismometers are almost never oriented, as compasses near enough to the sensor to be attached are too affected by the sensor's EM field, and other means, e.g. the use of gyros must be explored.

- New power sources: The development of batteries using seafloor conditions (biotic, seawater, currents) would greatly extend the time that OBSs could stay at the seafloor, greatly reducing ship costs.

- Data shuttles: A means to send data capsules to the surface on command, would allow the verification of instrument/data quality from a small ship without having to recover an instrument and perhaps perturb its favorable emplacement.

- Multiparameter measurements: Each OBS deployment provides a measurement structure (power, data storage) in an isolated, hard to reach region. Numerous other important parameters (currents, magnetic field, temperature…) could also be measured at the same time.

- High sampling rates: These would allow studies of other phenomena, such as marine mammal migrations, other near biological activity and hydrothermal vent flow variations.

Common Website. A common website would allow potential users to see all of the instruments available in Europe, give information on how to contact/request instruments, and allow the parks to organize their developments. There could be public and private pages. Public pages would include an Introduction, a List of Parks with their instruments, websites and contacs, and a description of the Deontology (guidelines for making the parks accessible: instrument requests, data format, data distribution, quality analysis…). Private pages would include Active Projects (developments currently underway at each park), Future Projects (needed/desired developments), and Lessons Learned (information on common problems and how to avoid/repair them).