Technical strategy for the mobile seismological components of AlpArray

Recommendations of the AlpArray Working Group 1 Procedures and data management

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1. Summary

AlpArray is an initiative to study the greater Alpine area with interdisciplinary research in an international context. A major component is a series of large-scale broadband seismological network deployments[1]: a main AlpArray Seismic Network ("backbone") and a number of dense, targeted networks known as AlpArray Complementary Experiments. The interested parties (currently 64 institutes in 17 countries) plan to combine their existing infrastructures into a transnational effort that includes data acquisition, processing, imaging and interpretation. The main experiment will encompass the greater Alpine area, from the Main River and the Bohemian Massif in the north to the Northern Apennines in the south and from the Pannonian Basin in the east to the French Massif Central in the west. We aim to cover this region with high-quality broadband seismometers by combining the ca. 220 existing permanent stations with an additional 500+ instruments from existing mobile pools and from specific national infrastructural efforts. The project will include both a uniformly dense backbone network (ca. 350 temporary broadband stations required) providing homogenous and high-resolution coverage, and a set of more dense targeted networks with broadband and short-period sensors along key parts of the Alpine chain (ca. 200 temporary stations). The current document describes standards that should be adhered to for temporary broadband stations in the backbone, and should be aimed at in the targeted networks. These land-based efforts will be combined with deployments of ocean bottom seismometers in the Mediterranean Sea; the standards for these OBS stations fall outside the scope of this document.

This report is prepared by the AlpArray Working Group 1 "Procedures and Data Management". AlpArray is organised into a number of different working groups, as seen in the overall AlpArray organisation structure in Figure 1. These recommendations will be acted upon by WG2 "Deployment".

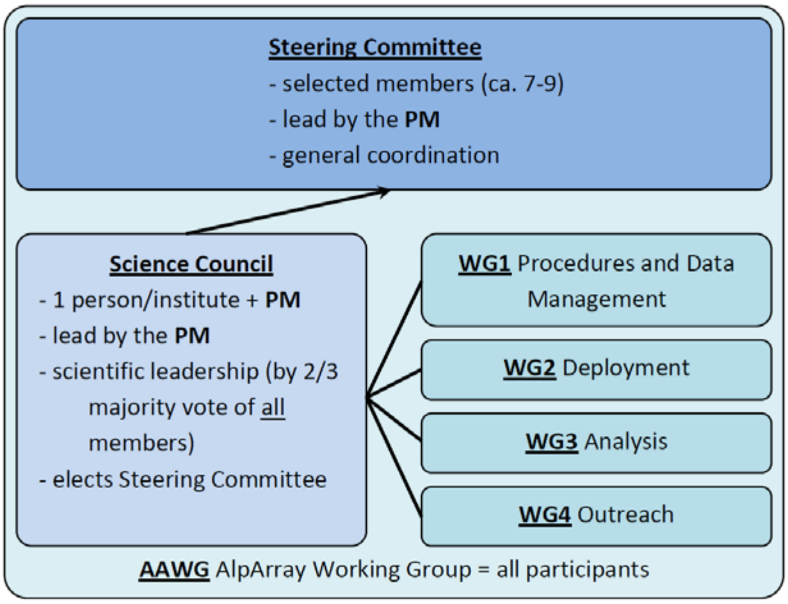

Figure 1: Organizational structure of the AlpArray project (see the Science Plan for more details)

[1] More information about AlpArray is at www.seismo.ethz.ch/alparray – including documents (as they become available) outlining the scientific goals and the proposed legal structure with the Working Groups.

Instrumentation for the AlpArray seismological experiments will be provided by participating nations from a combination of instruments from existing equipment facilities and from as yet unsecured funding opportunities. The hardware, software, manpower and level of support vary significantly between national facilities. Each facility or research group which deploys instruments is however responsible for providing the seismic instrumentation, technical assistance and support for data management. Although of significant size in certain cases, none of the national facilities are large enough to support such large-scale experiments without close collaboration with other facilities. Integration must be achieved at all levels, from field methods and data quality standards to data archiving and accessibility. This requirement was recognised at the early stages of the AlpArray initiative 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.

Responsibility for station operation (including stations permitting, station planning, station installation, station service, data recovery, data transfer, consumables, etc.) is in the hands of the group which deploys the instruments and the relevant PIs in the country in which the instruments are located (if different). The "Deployment" Working Group (WG2 – see Fig. 1) comprises representatives from each country participating with instrumentation or hosting stations.

It is expected within the data deployment phase that an AlpArray data management full-time employee (FTE) will be available to (1) ensure all AlpArray data is being retrieved in timely manner; (2) ensure metadata for stations is correct; and (3) coordinate quality control (QC) efforts, informing partners and management of problems with sites and equipment.

AlpArray will be founded on cross-community coordination spanning many nations and disciplines within seismology, and the adherence to standards. The concurrent EPOS[2] Preparatory Phase FP7 project attempts to build these ties and standards for the broader European solid earth community, and so AlpArray can be considered a flagship project demonstrating the viability of the EPOS concept.

[2] http://www.epos-eu.org/; The European Plate Observing System (EPOS) is the integrated solid Earth Sciences research infrastructure approved by the European Strategy Forum on Research Infrastructures (ESFRI) and included in the ESFRI Roadmap. EPOS is a long-term integration plan of national existing RIs.

2. Introduction

This document presents the recommendations of WG1 "Procedures and Data Management". The aim is to establish technical protocols and standards for participating institutions that will ensure the highest quality data. Although some of the recommendations presented here may seem overly prescriptive, challenges arising from the diversity of the participating facilities in this large-scale collaborative project can only be mitigated by significant synchronisation of experimental deployments and data gathering. Adherence to these protocols should significantly improve (1) efficiency in the deployment phase and (2) the final data quality. The ultimate goal is the capability to readily integrate data from permanent stations, 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.

We recommend that WG1 remains active, updated in composition and involved for the duration of the AlpArray initiative to enable assimilation and implementation of any future improvements to the recommendations presented here.

The strategy for data archival and dissemination will be to use the infrastructures defined and created by EIDA[3] (the European Integrated waveform Data Archives), the continually developing standard already operational within the permanent seismological network community. EIDA is currently built on ArcLink software distributed within SeisComP3, and includes documented standards for data archival, as well as access to the waveforms via a web portal or command line scripting.

Indeed throughout this document, we apply standards regularly adhered to by permanent broadband networks – the goal being that by encouraging best practice, the AlpArray project will gather data of the highest possible quality, that will be managed and offered to community in the most effective and cost-efficient manner possible. A major component of this effort is a highly recommended suggestion to centralise data quality control and metadata evaluation for the project. It is envisaged one of the national funding applications includes the salary to an AlpArray staff comprising at least 1 technician (FTE), who, in addition to undertaking the QC, can also maintain a web presence and take responsibility for ensuring the operability and visibility of the AlpArray data services (i.e., managing project sensor inventory; providing an overview of the incoming data managed and archived by the regional partners; NOT to manage the entire dataset).

[3] See http://www.orfeus-eu.org/eida

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

Participating seismic equipment facilities house a diverse set of instrumentation. A seismic station consists of a sensor and a datalogger / digitiser (typically the digitiser and the datalogger are a single unit), with associated hardware for communications, power etc. 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 and to optimise data usage the following standards must be achieved:

Compulsory

1. Sensor must be 3 component and broadband: flat velocity-response in the frequency domain from at least 0.03 Hz (30 sec) to 20 Hz, preferable down to 0.008 Hz (120 sec).[4]
2. Digitiser must be >130 dB (24-bit technology) between 0.1 Hz and 10 Hz.
3. Known dataless SEED response for full system (both for sensor and datalogger) (http://www.iris.edu/manuals).
4. The digitizer must have GPS timing. GPS timing quality must be known and stored in SOH log file or be otherwise available for QC. Timing accuracy of at least 10 msecs during normal operation is required. GPS must be continuously on.
5. The digitiser must be set to record at 100 sps or higher sampling rate in order to ensure the data collected has the broadest possible scientific usage.
6. Datalogger must have rapid data-recovery for field maintenance, and a minimum storage capacity for the 100 sps continuous streams of 6 months.
7. Datalogger will locally store continuous waveforms in any format that is then converted to miniSEED by openly available, well-test tools to miniSEED format in an error-free manner prior to be sent to the data centre. Note that each data contributor will have to provide data to EIDA node in miniSEED format, and it is the task of the network running the station to ensure high quality miniSEED data acceptable to an EIDA node is made available.
8. All sensor / datalogger systems must be tested alongside another sensor of known response before deployment (huddle test) to ensure all components work and system meets the nominal calibration values.

Recommended

1. 1 sps data should also be locally recorded (or transmitted) to improve QC analysis.
2. Datalogger should be able to support real-time GPRS (mobile phone) communications (though this will not always be implemented).

[4] **Compulsory** for broadband experiments only: Not always appropriate, e.g., local seismicity studies where these standards can be regarded as **Best practise**. 30 s bandpass is sufficient for the local seismicity studies.

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 noise performance criteria instead. It is noted that at some sites, e.g., on sediments in deep Alpine valleys or in the sedimentary foreland basins and grabens, these noise criteria cannot be met without relocating the station by 10's of km, so common sense must prevail.

The individual agencies and institutions planning and deploying the stations need to strike a balance between ease of finding and permitting locations that will meet the noise requirements, and complexity of the installation (e.g., sites near settlements will be noisy, but will likely have mains power, security, communications and be easy to service; autonomous sites with low noise will be easier to find but more difficult to operate, and it may be too complex and costly to setup an appropriate vault with security and appropriate power, especially in the high Alps).

Examples for vault construction (including proper insulation, pressure tight housing, etc.) can be found in Appendix B.

As the AlpArray project progresses towards field installations, an AlpArray station installation and check sheet will be prepared and added as an appendix to the current document.

Compulsory *(mostly hard rock / rural sites)*

1. Installation: all deployments must be supervised by experienced persons (but not necessarily facility staff). An experience person is someone familiar with (1) preparation of high quality seismic vaults; (2) operation and configuration of sensor and digitizer (and communications equipment if this will be used); (3) field data analysis and data recovery, including analysis of state of health (SOH) data. This is typically **NOT** a student.
2. Site-noise levels, for all 3 components (*rock / rural site)*: 20dB lower than the high noise model up to 100s (excluding the microseism) (this can and should also be met by 30s sensors).
3. Tests using a broadband sensor for >1day must demonstrate the modal noise level for the station meets the agreed noise levels for that period. This should be done within 2 months (compulsory), better within 4 weeks (strongly recommended), even better before installation and within 10 m of the candidate site (best practice). If the agreed noise levels do not meet the criteria the station must be moved (compulsory).
4. When determining the orientation of station, the method of orientation should be recorded at each site, including degrees of declination if true North is used.
5. Due to security, access or power issues it is not always possible to locate stations exactly where required for optimal array coverage. For the backbone, we recommend that if the final site falls within 3 km of the planned site it is acceptable without further agreement. If the final site falls between 3 km and 6 km then the deployment team must check with the national coordinator. If the site lies >6 km from the planned location then this must be referred to the main AlpArray WG2 (Deployment) team. For the targeted networks, this criterion may need to be even stricter, depending on the purpose and station spacing, and will be decided on a case by case basis with WG2.
6. The method used to calculate the geographical coordinates, altitude and depth from free surface for the sensor (not the position of the GPS attached to the datalogger!) must be

recorded and made available (e.g., handheld GPS, Google Earth). Coordinate precision of 4 decimal places (~1 m is required). Coordinates must be measured in WGS84, elevation is above the ellipsoid. This might seem trivial with new stations with GPS but still ambiguities (ellipsoid vs. geoid) and coordinates read from old maps exist.

Recommended

1. Site-noise levels, for all 3 components (*basin / soft soil site*): lower than Peterson (1993) high noise model up to 100 s (this can and should also be met by 30s sensors).
2. Due to the diversity of site geology and local conditions a single specific vault design is inappropriate, therefore:
   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. Further, in order to minimise local structure-related site amplifications, buildings >1 story should be avoided, and if the deployment will be in an existing structure, the sensor must be installed 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 240 Ah for a 2 W system (potentially >100 days autonomy required in the high-Alps or high-latitudes where access is likely to be severely restricted during winter).
3. Standard methods for sensor orientation are prone to significant error, even at permanent installations (Ekström & Busby, 2008). We therefore recommend that wherever possible tools are acquired at the start of any large-scale project to minimize sensor orientation errors (e.g., gyroscopic compass). Potentially a handful of these systems would serve the entire AlpArray community for the duration of the initiative.
4. For security reasons, where possible private land should be used for deployment with agreement of the land-owner.

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 real-time communications solution as in general, a mobile phone signal will be available at the majority of sites in the Alpine region 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, although SOH transmission would still be feasible. Real-time transmission should be considered on a site-by-site basis but the following factors must be taken in to consideration. For off-line stations, a maintenance schedule which includes site visits every 3 months should be implemented. In the high Alps, site visits in the winter months will only be possible if the stations are located in the immediate vicinity of inhabited or otherwise supported areas.

1. Financial costs:
    a. In the majority of Alpine-region countries, **real-time data transmission** can be achieved for around €20 per month (up to €35 for reliable connections) with a hardware start-up cost of around €1,000 per station (though many mobile pools already have the required hardware). There is an associated cost with data centre manpower for array monitoring and data QC, dependent on array size: 4 man-days per month for 50 stations is realistic, ***equivalent to 40 man-days per year per 50 stations***. Additionally, network monitoring tools need to be setup so that communication dropouts, or other station problems that are indicated by monitoring the SOH data, can be tracked and appropriate automated notifications distributed.
    b. **Offline stations** result in major hidden costs: Consider for example a plan to provide periodic maintenance for an off-line mobile network comprising 50 stations - having a service interval of 3 months for each station. If we assume 2 stations can be serviced (including data download and minor repairs) per day, with 2 extra office days added for conversion and data QC, this requires ***120 man-days per year per 50 stations***. Additionally, the hidden cost of a significant increase in the proportion of lost data (see section below) must also be taken into account.
    c. Excluding the already-mentioned communications equipment, 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. If sufficient spare parts are available, repairs of offline stations can generally be carried out during servicing and therefore are at no extra cost.
    e. Real-time station repairs would require additional site visits and must therefore be considered on top of these figures, especially if the array is not maintained by in-country staff. A contingency budget for such circumstances should therefore be considered. If real-time stations continue to deliver data without problems routine visits are not required. Real-time stations will also include a minimum of 6 months on-site recording, so if there are communications failures data will still be recorded locally. The manner of data archival in case of gaps in the transmission is to be dealt with the station operating networks; if a network does not already have a solution, the final archive should be the locally recorded and manually retrieved data.
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 well maintained real-time networks can be lower than **1%**.

3.4. Data recovery and security

EIDA is now recognised as the standard data exchange solution for European collaborative experiments. Eight EIDA nodes currently exist, a number of which are already AlpArray participants (e.g., GFZ, INGV, IPGP, ODC, RESIF, SED/ETHZ). The concepts behind EIDA or ArcLink, the underlying software, are followed for the archival and dissemination of all waveform data at numerous large seismological observatories (GFZ, SED/ETHZ, RESIF, INGV). EIDA is also used to distribute restricted datasets from mobile experiments. It is recognised that in order to be suitable for AlpArray, the EIDA software requires additional technical development and the community management structure needs to be formalised. These issues are currently being addressed and the resultant EIDA should be a viable and sustainable package that can be used at all European data centres. The following recommendations that directly relate to EIDA are subject to successful implementation of these improvements.

The general archival policy for AlpArray is that data collected within a particular country will be archived at the relevant EIDA node in that country, if existing. If no local EIDA node exists, the data will be archived at an EIDA node agreeable to both the PI's institute and the host country. In general, conversion to the final archive format (miniSEED) and associated data QC will be carried out by the PI, supporting instrument facility or responsible EIDA node data centre.

Compulsory

1. If native format is not miniSEED, data must be converted to archive-ready miniSEED format at the host institute within 1 month of the site visit. Host institute must work with relevant EIDA node to agree on what is "archive-ready" (typically quality controlled day-long miniSEED files).
2. Data must be at the nominated EIDA node and made available to project partners on the community portal within 2 months of site visit. Quality control *(see note below)* of all data is completed within this 2 month period and prior to sending the data to the nominated EIDA node.
3. Permanent data backups must be maintained by the PI or supporting facility.

Best practise

1. For off-line stations, site visits and data download should be made every 3 months for the duration of the deployment.

Recommended

1. Archive-ready miniSEED data from each station goes to the nominated data centre 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 delivered in real-time to relevant EIDA node. Real-time data are quality controlled *(see note below)* with at minimum a weekly assessment of all available sites.

NOTE: Quality control standards and procedures will follow those of EIDA nodes. However, currently no standards yet exist across EIDA nodes. These should be developed before AlpArray is recovering data, but as there is no clear funding, it cannot be guaranteed it will happen. In case of delays, representatives of AlpArray WG1 and WG2 will convene in due time to set the standards (data availability, completeness and gaps, latency, PSD/PQLX plots, polarity reversal, component exchange, time stability, etc). Following the QC rules will be compulsory.

3.5. Data formats and access

Compulsory

1. FDSN network codes must be assigned to temporary stations with one code per deploying institution or mobile pool.
2. The virtual network _ALPARRAY_ will be attached to all projects. All data associated with AlpArray, including temporary and permanent stations, will be accessible using this mask.
3. All waveforms will be archived in miniSEED format. Standard SEED naming conventions must be followed. Metadata will be in dataless SEED or FDSN stationXML. Station naming will be AAxxx for temporary backbone stations, with "xxx" being numbers assigned by WG2 (a range of numbers can be given to an institution / a pool to allow flexibility), and all stations must be registered under ISC station registry. Examples:

Station name	Type	Network code	Equipment	EIDA node	Virtual mask
ZUR	permanent	CH	Swiss	Switzerland	_ALPARRAY_
AA101	temporary	XA	Swiss	Switzerland	_ALPARRAY_
AA201	temporary	XB	SEIS-UK	Switzerland	_ALPARRAY_
BUD	permanent	HU	Hungarian	ODC	_ALPARRAY_
AA202	temporary	XB	SEIS-UK	ODC	_ALPARRAY_

4. Metadata creation and QC is the responsibility of the facility or the EIDA node, as agreed before each project begins.
5. MiniSEED format can be either Steim 1 or 2 compression.
6. Huddle test and state of health data will be archived locally, and must be made available on request. Example of huddle testing can find at PASSCAL website: http://www.passcal.nmt.edu/content/huddle-testing-feedback-sensors-and-dataloggers.
7. Data archiving must be in a standard style: standard SeisComP3 SDS structure preferred unless other structure is already in use that is compatible with EIDA distribution. Reference as of October 2013: http://www.seiscomp3.org/wiki/doc/applications/slarchive/SDS

Best practise

1. A huddle test is required before the experiment. When freighting the instruments (potentially causing damage to them) an additional brief (>12h) huddle test is recommended in the country of installation. This also helps the local PI and project members to learn about the operation and functionalities of the equipment.

3.6. Data openness

Data will be openly available to all project partners within 2 months of data collection in the field. It is encouraged that data will be fully openly available immediately, but in recognition that this is not always possible (i.e., Ph.D. studies), a maximum delay of 3 years after data collection for the backbone (determined by the Steering Committee) or a targeted deployment ends, will be mandatory (see "Memorandum of Collaboration").

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 must be implemented prior to the commencement of any experiments. Though EIDA primarily follows an open access data policy, the distribution tools already supports restricting access of datasets to specific users.

In order to maximize benefit to the wider seismological community, a ***special event scenario*** is mandatory, facilitated by the implementation of EIDA nodes. In case of M5+ events inside or adjacent to the network, a 24 hour window (1h before event time to 23h after) of all data should be made publicly available as soon as possible.

Compulsory

1. Data is made available via EIDA to all partners within 2 months of data collection.
2. Data is made publically available via EIDA within 3 years of end of experiment, as determined by the Steering Committee.
3. For M>5 events inside or adjacent to the network all data from -1hr to +23hr from origin time is made publically available via EIDA as soon as possible.

Best practise

1. Data is made available publically via EIDA as soon as it is available.

3.7. Centralised data coordination

We recommend distributed data archiving but centralised quality control:

1. The archives are distributed across Europe, with centralised access services using EIDA.
2. Standard quality control applied locally, but coordinated centrally – for station noise (including PQLX), station uptime / gaps, SOH monitoring. See above for QC features.
3. Project management for the archives will be done centrally with a project website (maintained by the 1 FTE at the nominated data centre), 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.

Items 2 and 3 above require a significant amount of work across the duration of the AlpArray initiative, and as such we propose there is an "AlpArray data hub" which would be staffed by at minimum 1 FTE, to be funded through one national project, working at the corresponding institute with an ORFEUS Data Centre affiliation.

4. OBS data

OBS (Ocean Bottom Seismometer) data have not been addressed here directly. However, our proposals are consistent with a future integration of OBS data 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 outcome 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 (Appendix A).

5. Discussion and Conclusions

We present here an outline plan for how the large-scale, international, seismological AlpArray experiment can technically be realized through integration of the individual European seismic facilities. Each participating facility retains its own national identity and operating structures but application of the guidelines presented here allow any number of these facilities to undertake this collaborative large-scale projects without any detrimental effect on data quality or scientific outcomes. A key component of the plan is the responsibility of the specific AlpArray working groups (backbone, targeted networks) for the station operation.

We have addressed the key components of the seismic experiment within the AlpArray project:

- 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 the project, collaborating national facilities can mitigate against the problems associated with the diverse instrumentation and operational protocols. One significant barrier to collaboration on such large-scale experiments 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. AlpArray is an ambitious concept yet is realistic in addressing the European environment, and by pooling the resources of the community, we can leverage a significant pool of mobile seismometers to do serious science without having to construct a centralised European mobile pool.

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Appendix A – Integrating Mobile European Plate Observing Systems: Seismology

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Wayne Crawford, Frederik Tilmann, Alex M. Brisbourne and the Committee for the Harmonization of European OBS Parks (CHEOPS)[5]

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 centred 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,

[5] Mechita Schmidt-Aursch, Valenti Sallares, Antonio Pazos, Giorgio Mangano, Tim Henstock and Wayne Crawford.

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).

Good Practices

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 of the costs and harmonisation of the means of requesting instruments in each country. The key to successful integration is of course improved cooperation between facility managers.

The following is a list of "good practices" that should be implemented by marine parks to integrate marine and land-based seismological systems.

1. Organize yearly organizational or technical meetings between the parks.
2. Archive data in a European or national seismological data centre that can provide data over the web in a seismological standard format.
3. Develop and distribute tools for standard OBS data pre-processing (e.g., component orientation, clock correction verification and noise removal).
4. Encourage openness about data collection success rates and problems. Create tools to evaluate these parameters.
5. Lobby for a single (or at least coherent) process for funding and ship time.
6. Encourage rapid response / ship time mechanisms in countries with OBS parks.

Priority should also be given to integrating land and ocean instrumentation on a national level, making instrument requests and payment structures compatible. Some national parks have already united land and ocean facilities under a similar umbrella (e.g., the amphibious DEPAS pool in Germany and the NERC Geophysical Equipment Facility (GEF) in the UK).

Each national pool is 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. And they must clearly state if they do not follow the "good practice" guidelines.

Data will be provided to the data archives in "raw" format (corrected for measured clock drifts, but not verified using cross-correlation, re-oriented using correlation or earthquakes, or noise reduced). These methods require resources beyond those of the individual parks and can moreover introduce supplementary errors if not correctly applied.

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.

Action Plan

Implementing the above good practices requires means beyond those existing in the individual OBS parks. European-level support is needed to support coordination between the parks, increased visibility of the parks and clarify the use of their instruments. An infrastructure is also needed for developers that can transform the routines for data conversion and pre-processing already developed at some of the parks into tools that can be applied to all of the parks in two steps: (1) tools to convert data from each park into a standard seismological format and (2) tools to apply OBS-specific data pre-processing to these standardized data.

A Committee for the Harmonization of European OBS Parks (CHEOPs) has been formed to realize this goal. The principal tasks of this committee are (1) to educate the seismological community about the availability and capabilities of OBSs experiments and the resources needed to collect high-quality data; (2) to identify the need for OBSs in important scientific targets and make sure that the OBS parks can respond to these needs; (3) to better integrate OBS parks into national and European geoscience initiatives and structures; (4) to create a European-level infrastructure dedicated to improving and harmonizing European OBS parks (data quality, data access, usage requests).

Active seismic experiments

This paper focuses on passive seismological measurements because they are the most closely related to land seismological experiments. However, active seismic experiments are a major component of ocean-bottom seismology and have several links to integrating land- and ocean-seismology.

First, active seismic experiments can provide constraints on structure, fault geometry and properties of sediments, crust and upper mantle that can be crucial for understanding regional geodynamics and for better locating earthquakes and putting them into context. Indeed, there have been several land-sea active seismological experiments.

Second, even active seismic experiments that are not focused on issues of direct interest to passive seismologists may provide unique data in otherwise unexplored regions. Continuous data from these experiments should, if possible, be saved in standard seismological databases. This practice could also help the OBS parks, who usually provide shot-based data to their clients and must re-extract them if the clients recalculate the shot positions or times. If the continuous data are stored in a standard format, a standard tool could be developed for extracting shot-based data, and data validation methods developed for passive seismology could also be applied to these data.

Finally, OBSs used for active seismic experiments would also benefit from a greater collaboration on the European level, to improve their instruments and to have access to instruments from other parks for very large experiments.

Links to European Initiatives

OBS parks need to better coordinate with existing European and national seismology initiatives. Better integration is one of the major goals of the Earth Plate Observing System (EPOS) initiative, and we should take advantage of this infrastructure, if possible, to initiate the most pressing actions, such as the first technical meetings and possibly methods for requesting an OBS-specific infrastructure. OBSs have also played an important role in the European Multidisciplinary Seafloor Observatory (EMSO) and our developments can have a direct effect on the quality of their stations. Finally, ORFEUS strongly supports this initiative. Their ability to provide logistical/financial support is uncertain, but should be discussed.

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 trade-off 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 reduces 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.
- 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 favourable emplacement. Potentially, expendable instruments could release shuttles at regular intervals.
- Multiparameter measurements: Each OBS deployment provides a measurement structure (power, data storage) in an isolated, hard to reach region. Numerous other important parameters (tilt, 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.

Appendix B – Vault types

PASSCAL seismic vaults

Introduction link:
http://www.passcal.nmt.edu/content/instrumentation/field-procedures/seismic-vaults

Broadband vault construction link:
http://www.passcal.nmt.edu/content/instrumentation/field-procedures/seismic-vaults/broadband-vault-construction

A possible solution based on the CIFALPS experiment

Characteristics:

- fast, easy and discrete installation;
- reasonable cost (<200€);
- can be constructed either inside or outside buildings.

Requirements:

- good thermal insulation of the sensor (for low noise at long periods data on the vertical component);
- a horizontal slab.

Approximate costs:

Equipment	**Typical cost €**
A pipe (polyvinyl chloride or HDPE) with a screwed / lockable cap, watertight if outside. (Diameter up to 45 cm and at least 10 cm wider than sensor diameter; height between 40 and 100 cm.)	100
A pre-fabricated (wood) formwork for building a slab (about 50 cm x 50 cm x 20 cm)	10
Fast dry mortar / cement (50 kg or 25 kg) to construct the slab	25-50
1 panel of mineral wool insulation	5
1 panel of hemp insulation	10
Aluminium insulation	10
Rubber seal to protect incoming cabling	10
TOTAL	**170-195**

Examples:

		
HDPE pipe with a rubber seal	Polyvinyl chloride pipe with a rubber seal	Wood formwork

Pipe size:

- Broadband sensor STS-2 or T120PA: $\emptyset ext = 400mm$
- Wide band sensor CMG-40T: $\emptyset ext = 315mm$

For outside, soft soil sites (note: hard rock sites preferred for AlpArray):

- dig a hole (about 1m deep) and fully burry the vault (note: site must be above the water-level);
- drain the slab (drain pipe);
- build a 50 kg slab (25 kg is enough for inside sites).

Construction steps:

1. Construction of the slab with pipe inserted in the wet mortar	2. Internal thermal insulation (hemp wool + mineral wool) all around the sensor.	
		

3. External insulation	
	

Final result	
	
Outside	Inside