Near Fault Observatories in Europe: the road of integration. Why do we need NFOs?

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The seismic hazard generated by faults slipping in large earthquakes and the need to mitigate the risk for nearby exposed populations and infrastructures requires scientists to seek a better understanding of the physics of faulting and the near-surface response to earthquake shaking.

However crustal faults are complex natural systems whose mechanical properties evolve over time. Thus, the understanding of the multi-scale, physical/chemical processes responsible for earthquakes and faulting requires considering phenomena that intersect different research fields (the road of integration). Near Fault Observatories (NFOs) are innovative research infrastructures based on dense, state of the art networks of multi-parametric sensors that continuously monitor the underlying earth instability processes over a broad time interval. An example of a multi-disciplinary sensor at a typical NFO site in Vrancea, Romania, is shown in Figure 1.

NFOs not only complement the existing regional geophysical monitoring networks generally characterised by relatively large station spacing (in the order of tens of kilometres); they can be considered as true on-site laboratories that focus on recording the
The broadest possible range of signals related to the physical/chemical processes that occur along and around active fault zones, down to very small scales. NFOs are targeted to track the evolution of fault systems, for example through accurate location and characterization of micro-seismicity, the mapping of the aseismic forcing mechanisms such as creeping that may influence further rupture development, and the definition of the diffusive processes associated to fluid migration and fluid-rock interaction. Due to the long time scales involved, it is challenging to observe a full single seismic cycle for a large (e.g. tens of kilometres long) fault. NFOs, can monitor with high resolution deformation episodes occurring along minor faults that pertain to the major system, and so the more frequently occurring small events (such as M 3) can be considered as local mainshocks, considerably shortening the seismic cycle. This provides scientists the opportunity to test models and hypotheses on a more robust statistical basis but also to follow the pre-, co- and post-seismic phase of an active fault, even if small (e.g. from hundreds of meters to a few kilometres), with all the related scaling problems. At the same time, the collected information on the geometry and deformation style of the major faults can be used to develop ground shaking scenarios that account for diverse slip distributions and rupture directivity models.

The NFO community in EPOS
The NFO-TCS in EPOS consists of seven NFOs, operating on different tectonic regimes and different areas of Europe (Figure 2), all at sites of elevated seismic hazard. They include plate boundary systems at South Iceland Seismic Zone, the Marmara Sea and the Corinth rift. In mountain settings, NFOs monitor the Alto Tiberina and Irpinia faults in the Appennine mountain range, the Valais region in the Alps, and the Vrancea fault in the Carpathian Mountains. They monitor diverse faulting mechanisms (strike-slip, normal and thrust), high to low angle faults, shallow and deep faults, as well as regions with fast and slow strain rate accumulation. Each fault zone can generate large earthquakes (M>6) that pose substantial to great earthquake hazard. Two of the zones, Marmara Sea and Corinth, include off-shore seismic sources that pose an additional tsunami hazard while steep slopes and sediment-filled valleys in the Valais give rise to hazards from landslides and liquefaction. The active volcanoes flanking the South Iceland Seismic zone bring the added dimension of volcano-tectonic interaction and natural geothermal activity. The focus of the observatories varies, ranging from small- to large-scale seismicity and includes the role of different parameters, such as fluids, playing in fault initiation, the internal structure of fault systems, site effects and derived processes such as earthquake generated landslides and tsunamis. In response to their specific objectives, the NFO’s operate a diverse set of monitoring instrumentation to monitor the surface and sub-surface using seismic, deformation, strain, geochemical and electromagnetic equipment.

What does EPOS gain from the NFOs?
NFOs represent a great scientific opportunity for major advancements in understanding fault systems. For EPOS, they constitute an ideal testbed for generating expertise on multidisciplinary data integration, creating tools for the next generation of multidisciplinary research, routine data analysis and data visualization. Due to their small size and focus, NFOs can drive innovation and development of cross-disciplinary services, standards and products that are important for other EPOS TCS. The NFO community also facilitates knowledge transfer through sharing technological (best practice) and scientific know-how (transnational access), both within the NFOs themselves and across other TCS.

**Data Access:** NFOs will contribute seismic and GNSS datasets through existing EPOS TCS services, and will provide new access services to specific datasets and high-level scientific products currently not within EPOS.

**Visualisation and Processing:** Development of next-generation of multidisciplinary tools through the Virtual Laboratory service will help in providing improved models of transient processes in/around fault zones, and for building advanced database and catalogues of such processes.

**Testing Facility:** A testing facility built on real-time and offline high-resolution data will foster the development of next generation methodologies and software for real-time monitoring of faulting processes. In EPOS-IP, the focus will be on operating and benchmarking various existing Earthquake Early Warning (EEW) methodologies already operated by some of the NFOs at the Irpinia NFO.

In summary, we expect the NFOs will provide many opportunities for scientific and technical training as well as public outreach, at different levels: general education of the public on natural hazards and seismo-tectonic processes, higher education (summer schools, masters and postgraduate research) on advanced instrumentation techniques, multi-parameter analysis of crustal processes. Bringing together multidisciplinary data and expertise at a single site to be processed and integrated, will put important pieces in the puzzle of earthquake mechanics. Finally, besides the monitoring of the faults before the occurrence of main events, NFO dense networks can also improve operational actions conducted in the aftermath of a large earthquake, such as EEW and detailed, fast ground shaking and damage characterization during the on-going rupture on the fault.