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# IS-EPOS: A DIGITAL RESEARCH SPACE TO FACILITATE INTEGRATED APPROACH TO ANTHROPOGENIC SEISMIC HAZARDS

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## *Abstract*

The problem of hazards induced by exploration and exploitation of georesources focuses growing interest of science, industry, public administration, NGO-s and general public. Anthropogenic seismicity, i.e. the undesired dynamic rockmass response to georesources exploitation, is one of the examples of unwanted by-products of technological occupation of humans. It becomes a real problem in areas previously known as aseismic and in association with quite diverse technological processes. The socio-economic impact of the induced seismicity is very significant. Induced earthquakes can cause material loss, injuries and even fatalities.

The anthropogenic seismic hazards are undoubtedly linked to particular inducing technologies. However, the rockmass reactions to inducing factors of the same physical kind have much in common. The research focused on common features of these reactions and transverse to inducing technologies seems to be the way to accelerate recognition of the problem. This can be accomplished only on through integration of research based on the most advanced ICT solutions. We present here IS-EPOS IT-platform, which is an open virtual access point for researchers studying anthropogenic seismicity and related hazards. The relevant seismic and non-seismic data are gathered in the so-called episodes of induced seismicity. The episode is a comprehensive data description of a seismic process, induced or triggered by human technological activity, which under certain circumstances can become hazardous for people, infrastructure and the environment. The episode consists of a time-correlated collectio n of seismic data representing the seismic process, technological data representing the technological activity, which is the cause of this process and all other relevant geodata describing the environment, in which the technological activity and its result or by-product, the seismic process take place. The IS-EPOS platform integrates presently six episodes of anthropogenic seismicity respectively linked to underground hard rock and coal mining in Poland, hydro energy production in Poland and Vietnam and geothermal energy production experiment in Germany. The researcher accessing the platform can make use of low level software services for data browsing, selecting and visualizing and a number of high level services for advanced data processing out of which the probabilistic seismic analysis service group is particularly rich. The IS-EPOS platform is a prototype of TCS Anthropogenic Hazards belonging to pan-European multidisciplinary research platform created within European P late Observing System long-term plan for the integration of national and transnational research infrastructures for solid Earth science in Europe.

This work was done in the framework of IS-EPOS: Digital Research Space of Induced Seismicity for EPOS Purposes project, funded by the National Centre for Research and Development in the Operational Program Innovative Economy in the years 2013-2015 and EPOS Implementation Phase project funded from Horizon 2020 - Research and Innovation Framework Programme, call H2020-INFRADEV-1-2015-1 in the years 2015-2019.

*Keywords: Anthropogenic Hazards; Induced Seismicity; web-platform; Research Infrastructure for Georesources; EPOS*

## 1. Introduction

The phenomenon that industrial operations can cause anthropogenic seismicity was firstly observed in underground mining during the 18th century. Since the last decades, it has been well established that production and technological processes may promote or inhibit the time-to-failure in pre-existing active faults mainly driven by tectonic processes (triggered seismicity). Also important is the fact that particular anthropogenic activities may totally control the nucleation process, resulting to earthquakes that would not occur otherwise (induced seismicity). According to [1] approach, the general term of "stimulated" seismicity is proposed to describe both cases of triggered and induced seismicity. These stimulated events can in turn trigger or induce additional seismic activity which considerably increases the seismic risk in areas that have previously been aseismic and consequently, they are not properly prepared to overcome such threats (e.g. [2]).

With rising demands for energy and minerals, the problem of hazards induced by exploration and exploitation of georesources focuses growing interest of science, industry, public administration, NGO's and general public. Anthropogenic seismicity is one of the examples of unwanted by-products of technological occupation of humans and becomes a real problem in areas previously characterized by low or even no seismic activity and in association with quite diverse technological processes. The keen interest for induced seismicity research has led to an increased amount of scientific works published during the last few years in relation with various technological-production processes all over the world. These processes refer to underground and open-pit mining operations and mass shifts (e.g. [3-8]), both conventional as well as unconventional (e.g. shale gas) hydrocarbon exploitation (e.g. [9-12]), surface reservoir impoundment (e.g. [13-15]), geothermal energy production (e.g. [16-19]), underground fluid and gas storage (e.g. [20, 22]), experimental drilling/injection operations (e.g. [23]) and any other technological processes that perturb the boundary conditions in the affected rockmass. Although relatively small but felt earthquakes may be annoying for the citizens, the actual socio-economic impact of induced earthquakes relies on their potential to cause reduction or halting of production, material loss, infrastructure damage or collapse and, most importantly, injuries and even fatalities.

It is therefore clear that the anthropogenic seismic hazards are undoubtedly linked to particular and apparently diverse inducing technologies (see the review study by [24] and references therein). However, the rockmass reaction to inducing factors of the same physical kind have much in common. The research focused on common features of these reactions and transverse to inducing technologies seems to be the way to accelerate recognition of the problem. This can be accomplished only through integration of research based on the most advanced ICT solutions. IS-EPOS platform is a recently constructed and operating digital research space, for providing a permanent and reliable access to advanced Research Infrastructures (RI) to the Induced Seismicity Community (Fig. 1, https://tcs.ah-epos.eu ). It is a result of "IS-EPOS Digital Research Space of Induced Seismicity for EPOS Purposes" Polish national project funded from structural funds in the years 2013-2015, run by the consortium led by Institute of Geophysics Polish Academy of Sciences (IGF PAS) and partnered by Academic Computer Center "Cyfronet" AGH (ACK CYFRONET), Central Mining Institute (CMI) and an industrial partner – Coal Company. This objective offers access to various datasets related to selected anthropogenic seismicity cases, specialized software for advanced data analysis and document repository. The relevant seismic and non-seismic data are gathered in the so-called episodes of induced seismicity. The episode is a comprehensive data description of a seismic process, induced or triggered by human technological activity which under certain circumstances can become hazardous for people, infrastructure and the environment.

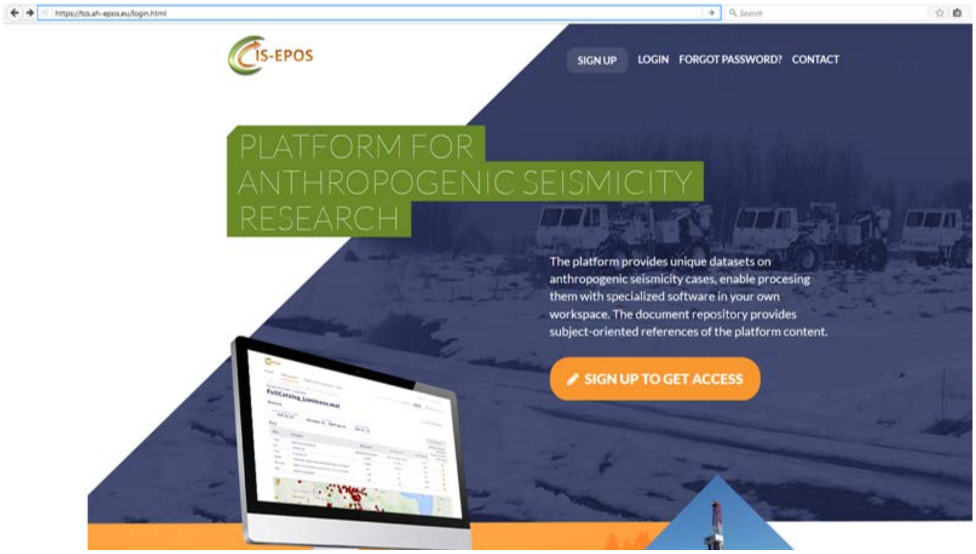

Fig. 1 - The homepage of IS-EPOS web-platform

## 2. IS-EPOS Platform overview

Research in the field of anthropogenic seismicity requires not only seismicity data but also data regarding the progress of the technological/production activities, as it is the origin of the undesired induced seismic events. Such data are typically restricted and proprietary, and, therefore, usually not available for independent researchers who wish to develop and verify innovative methods and approaches. IS-EPOS e-platform promotes new opportunities to study and comprehend the dynamic and complex solid-Earth System by integrating use of data, data products, analysis models, and on-line facilities. The integration of the national and transnational Research Infrastructure (RI), both existing and new, will increase the access and use of multidisciplinary data recorded by the solid Earth observing systems, acquired in laboratory experiments and/or produced by computational simulations.

The IS-EPOS platform has been designed to serve as one of the main pillars of the Thematic Core Service Anthropogenic Hazards (TCS AH) belonging to pan-European multidisciplinary research platform created within European Plate Observing System (EPOS) program. IS-EPOS platform is open for research community and general public according to its rules of access. Presently, TCS AH is developed by 14 European research institutions in the framework of the work package WP14 of EPOS IP infrastructural project (H2020-EU.1.4.1.1. in the years 2016-2019), and will be integrated with other thematic core services by EPOS Integrated Core Service (ICS).

IS-EPOS platform is a complex and innovative solution. Its main innovative element is the uniqueness of the integrated RI which comprises two main deliverables: (1) Exceptional datasets, called "episodes" - sets of encapsulated data, which comprehensively describe geophysical processes induced or triggered by human technological activity in the field of exploration and exploitation of georesources, posing hazard for populations, infrastructure and the environment activity. An episode consists of a time-correlated collection of geophysical data representing the geophysical process, technological data related to the technological activity which is the cause of this process and all other relevant geodata describing the environment, in which the technological activity and its result, the geophysical process, take place; (2) Problem-oriented, bespoke services uniquely designed for the discrimination and analysis of correlations between technology, geophysical response and resulting hazard. Many diverse elements intertwine in the IS-EPOS undertaking - from online operating measuring equipment, through harmonization and standardization of collected data, archiving and sharing procedures, to IT solutions which facilitate conducting virtual experiments on collected data and with the help of implemented software services. The architecture of IS-EPOS platform envisages its further development, including appearance of new European entities integrating data on platform. At the same time, IS-EPOS will be further developed within TCS AH and included in EPOS structure, which means it will have to be interoperable both with EPOS main components: Integrated Core Services and other TCSes. The architecture of IS-EPOS Platform is presented on the Figure below (Fig. 2).

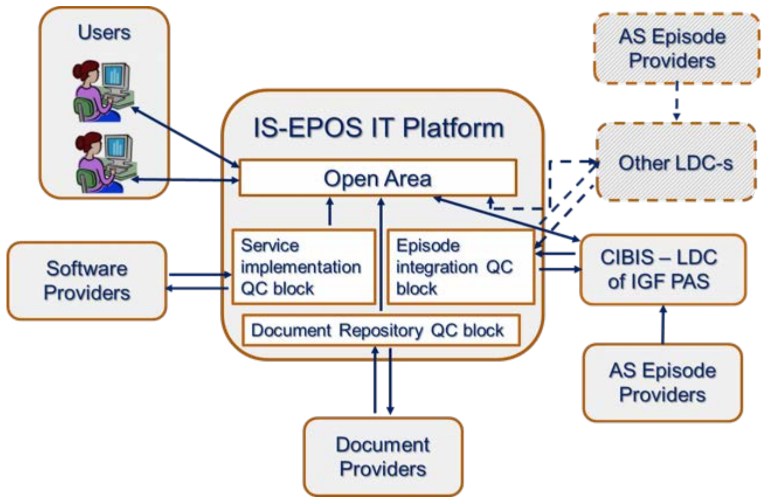


Fig. 2 – Topology of IS-EPOS platform. LDC – Local Data Center, QC block – Quality Control block, AS Episode – Anthropogenic Seismicity Episode, CIBIS – Center for Research Infrastructure of Induced Seismicity, one of LDC.

The gateway to the IS-EPOS platform is located on the IT structure of ACK Cyfronet AGH. Through it, the platform users can register and log into the portal it provides. After logging into the portal, the user gains access to three blocks of functionality: integrated episodes of anthropogenic hazards, implemented software – services and documents entered into the repository. Each of these blocks is managed by adequate quality control groups. The software and documents are stored in their dedicated repositories, from which they can be accessed through the IS-EPOS portal, while the episodes are located in Local Data Center (LDC) cooperating online with the portal. Within the IS-EPOS project, one LDC – Center for Research Infrastructure of Induced Seismicity, CIBIS, was built in the Institute of Geophysics, Polish Academy of Sciences. Local Data Centers provide metadata describing in detail the data resources stored there to the IS-EPOS platform. Thanks to that, at request of a user interested in specific data, the suitable episode package is copied from local center and made accessible to the user for further processing.

Local Data Centers gather data, either online from measuring equipment installed at site or delivered through a dedicated interface, e.g. by industrial partners. An important functionality of LDC, fully realized in CIBIS, is harmonization and adjustment of upcoming data to required standards and preparation of metadata for the data to be integrated. An episode of anthropogenic hazards, formed in LDC and designed for integration into IS-EPOS is subject to a thorough quality control in the quality control block of episode integration. After positive verification, information about it is published into IS-EPOS platform to be accessible to users.

## 2.1 Science – Industry Partnership

Relationships between the impact of georesources exploration and exploitation of the Earth, and the Earth's response are complex. Therefore, they require a holistic approach with a special attention devoted to problems that are faced, on daily basis, by industry, people and the environment exposed to hazards induced by the industrial activities. An insight into these relationships can result only from cross-disciplinary studies of technology-nature couplings. It is obvious that a serious analysis of the Earth's response, that is the result, cannot be done without a simultaneous analysis of conditions of the technological activity, that is the cause. To achieve these goals, science – industry contacts should be enhanced to reach a trustful level of synergy. It has to be acknowledged that, although all IS-EPOS stakeholders with science background are important and highly appreciated, the industry exploiting georesources has a distinguished position because its knowledge on the technological stimulation leading to hazardous Earth's responses is high and can be very useful in investigations of the hazards. In the framework of science-industry partnership, an Industry Partner makes a part of its infrastructures, either hard (instruments, monitoring networks) or soft (data, including relevant operational), available to IS-EPOS and research. It is worth to note that research does not need the most recent data, which can be sensitive for the Industry Partner. The comprehensiveness of the studied case description with data is what is really essential. IS-EPOS, from its side, implements the mechanisms, which prevent violation of rights of the particular Industry Partners, including intentional or unintentional abuse of information that can be related to the Partner. Furthermore, Industry Partners provide advice on the potential usefulness and practical applicability of the solutions meant to be used in practice. In return, Industry Partners obtain possibility to convey to EPOS wider problems of their interest, and EPOS, through its internal communication lines, encourages researchers to focus their attention on these problems. Industry Partner has priority in the implementation of services developed in IS-EPOS. Tests of these services in operational conditions will positively influence their further development.

## 2.2 AH-Episodes

An AH-Episode comprises all data describing comprehensively a separate and precisely defined anthropogenic seismicity case associated with the field of exploration and exploitation of georesources. These technological and production activities may therefore, under certain circumstances, become hazardous for people, infrastructure and the environment. An AH-Episode data infrastructure includes at least seismic and production data, supplemented with any other geo-data available (geological, geophysical, tectonic, geomechanical, geodetic) that could be relative to the problem. In IS-EPOS, the LDC collects data of six episodes of anthropogenic seismicity linked to underground hard rock and coal mining in Poland, hydroelectric energy production in Poland and Vietnam, as well as the geothermal energy production experiment in Germany and provides them, on user's request, to IS-EPOS platform. Some AH episodes include seismic data recorded continuously by download interfaces, others are processed in the form of triggered signals and seismic catalogs. Network and sensor data do not necessarily refer to specific seismic networks, but may also contain any other sensors used in the industry to monitor the technological processes, for example pressure sensors, thermometers and strainmeters. Production data associated with the specified Research Infrastructures include injection rates, production rates, amount of ore exploited, advance of the mining front, level of water reservoirs, well pressure, panel geometry etc. All analog data provided are converted into a relevant digital format, required by IS-EPOS. Metadata are produced from the received data, stored and provided by LDC to the IS-EPOS platform. In addition to the six episodes already implemented during the IS-EPOS project, at least 20 new episodes related to conventional hydrocarbon extraction, reservoir treatment, underground mining and geothermal energy production are being integrated into the e-environment of the TCS AH. The heterogeneous multi-disciplinary data (seismic, displacement, geomechanical data, production data etc.) are transformed to unified structures developed within IS-EPOS project, to form integrated and validated datasets. Dedicated visualization tools for multidisciplinary data that constitute an episode are also implemented. These tools are capable to aggregate and combine different data types and facilitating specific visualization possibilities (e.g. combining seismic and technological information).

## 2.3 Services

IS-EPOS provides access to software dealing with specified scientific problems, designed in the area of anthropogenic hazards. For this purpose, the platform enables studies within selected, grouped services. All of these services consist of software packages and visualization services, both applied to selected data subsets that a user has pre-defined and uploaded to the personal workspace. The users have therefore the possibility to proceed to either episode-oriented research (application of various methodologies focusing on a particular episode), or method-oriented research (perform a certain methodology at several datasets in order to compare results with each other and test the efficiency of selected approaches).

The available services in IS-EPOS are grouped into high-level and low-level services, each of them containing several applications. High-level services sustain advanced methodologies for AH data analysis categorized into specified groups which concern source parameters estimation, collective properties of seismicity, probabilistic seismic hazard analysis (either stationary of time dependent) and stress field modeling. In particular, the services currently implemented in the platform are briefly introduced below.

### 2.3.1 Stationary Seismic Hazard

This Service implements several functions for estimating the probability density function and cumulative distribution function of magnitude. Four magnitude distribution estimation methods are supported: maximum likelihood using the unbounded Gutenberg-Richter relation based model, maximum likelihood using the upper-bounded Gutenberg-Richter relation based model, unbounded non-parametric kernel estimation and upper-bounded non-parametric kernel estimation. The upper limit of magnitude distribution is evaluated using the generic formula by [25]. Additional parameters such as the activity rates, the Gutenberg-Richter b-value or Kernel smoothing factors, are also calculated, with respect to the selected approach. These parameters can be further utilized for probabilistic seismic hazard analysis, i.e. for estimating exceedance probability, maximum credible magnitude and mean return period.

### 2.3.2 Time-Dependent Seismic Hazard (in mining front surroundings)

This service comprises functions which are dedicated to episodes associated with mining induced seismicity. Its purpose is to evaluate seismic hazard parameters in connection with the evolution of mining operations and therefore to detect a causative relationship between seismic events and front advance. Hazard parameters estimated are the activity rate, the Gutenberg-Richter b-value, the return period and the exceedance probability of a prescribed magnitude for selected seismically time windows related with the advance of the mining front. Three options are available for creating these time windows: constant time period (duration of dataset), constant event number (dataset size) and constant front advance size (material mass moved). The spatial constraints are also set in terms of the distance perpendicular and normal to the mining front at each time point (beginning and ending of time windows). Four magnitude distribution estimation methods are supported, just as in stationary hazard service (see section 2.3.1). Hazard parameters are calculated and plotted for each one of the time windows for which sufficient data are available.

### 2.3.3 Time-Dependent Seismic Hazard (in mining a selected area)

This service is a generalization of time-dependent seismic hazard, which can be performed for all episodes. Its purpose is to evaluate the temporal evolution of the seismic hazard parameters and therefore to detect a causative relationship between seismic events and production/technology activity. Hazard parameters estimated are the activity rate, the Gutenberg-Richter b-value, the return period and the exceedance probability of a prescribed magnitude for selected seismically time windows. Two options are available for creating these time windows: constant time period and constant event number. The spatial constraints are set by defining a specify circular, rectangular or polygonal area. Four magnitude distribution estimation methods are supported, just as in stationary hazard service (see section 2.3.1). Hazard parameters are calculated and plotted for each one of the time windows for which sufficient data are available.

### 2.3.4 Completeness Magnitude Estimation

The completeness magnitude of a given catalog, Mc, defined as the lowest magnitude at which all seismic events in a selected space-time volume are recorded by a network, is calculated by this service. Mc is an essential prerequisite for many seismicity analyses and its estimation is achieved by the application of 4 different approaches based upon [26]. The maximum curvature method, the 90% and 95% goodness of fit test and the modified by [27] goodness of fit test are performed for evaluating the magnitude of completeness. All methods are based upon the assumption of the validity of the Gutenberg-Richter law (exponential distribution of magnitudes). Additional parameters and graphs, such as b-values and their uncertainties and residuals from Gutenberg-Richter law, are also provided as a function of minimum magnitude.

### 2.3.5 Spectral Analysis

This service determines seismic source parameters based on spectral analysis of the P and S waves. Two independent spectral parameters, i.e. low frequency spectral level and corner frequency, are estimated with Snoke's fitting algorithm [28]. Assuming source model by [29] and spectral parameters, the service is able to calculate seismic moment and moment magnitude, seismic energy, source radius, stress drop, apparent stress and slip on the fault. The spectrum with the best Snoke fitting is also plotted (Fig. 4).

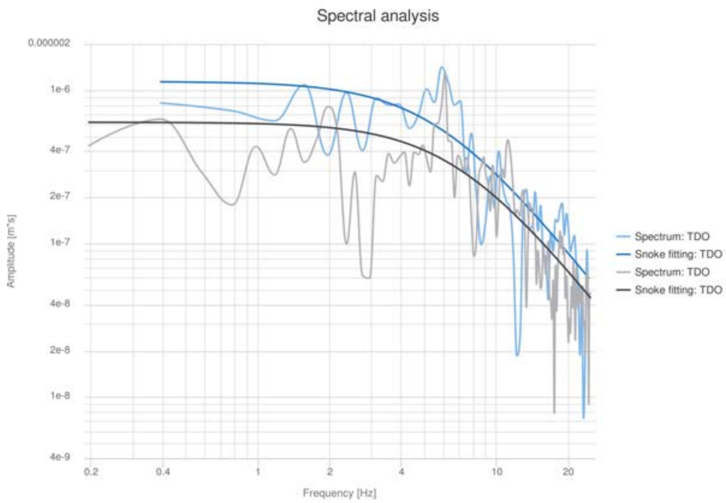


Fig. 4 – Power Spectra, from S-waves picked from two horizontal components in the same station.

### 2.3.6 Moment Tensor Inversion

Moment tensor inversion is performed by this service, executing 'focimt' program [30], which is a standard description of earthquake kinematic source processes in the whole range of magnitudes. Seismic moment tensor inversion allows to estimate the fault plane parameters and the balance between volumetric and non- volumetric strain in the seismic source [31]. This application makes use the P-wave first arrivals from the waveforms recorded by the seismic stations and  resolves seismic moment tensors using various decomposition schemes. Three moment tensors are calculated: unconstrained (full) moment tensor solution, deviatoric moment tensor solution (no volumetric change in the source), and double-couple moment tensor solution (no volumetric change in the source, no linear dipole). In addition to the moment tensor components various source parameters are calculated as well (fault plane solutions, P/T/B axes orientation, scalar seismic moment etc). The program provides option to perform quality assessment of the moment tensor by the means of station Jacknife test (http://www.induced.pl/focimt/).

### 2.3.7 Source Localization

This service implements TRMLOC localization/relocalization software [32, 33] which performs efficiently the inversion of seismic (acoustic) first arrival time onsets for hypocenter location using the probabilistic inverse theory approach. The application provides the maximum likelihood hypocenter location, enables other hypocenter location estimators to be calculated and what is most important, it allows an advanced analysis of location (inversion) uncertainties. This advanced performance is possible due to the numerical algorithm implemented in TRMLOC. Being based on general concepts of the modern probabilistic inverse theory, the algorithm exhibits the same level of generality as any other, more traditional Bayesian location algorithms. However, unlike the classical probabilistic approaches, it performs implicit sampling simultaneously with the forward modeling. Various results, uncertainty analysis and meta-characteristics of the data and solutions are estimated by the program.

### 2.3.8 Stress Inversion

This service implements the software package MSATSI [34] which allows performing stress inversion using earthquake focal mechanisms. The purpose of this service is to determine the stress axes orientation and relative stress magnitude by inverting earthquake focal mechanisms. To evaluate stress axis orientation (σ1, σ2, σ3 axis orientation as well as P and T axes orientation) and relative stress magnitude (R value) earthquake focal mechanisms are inverted. Stress state can be defined for a point (0D case), profile or time change (1D case), map (2D). The framework of calculating the deviatoric stress tensor together with its uncertainties using bootstrap resampling method is also provided along with a variety of plots. MSATSI is based on the C library SATSI created by [35].Various numerical results and plots are produced by the program (http://www.induced.pl/msatsi).

### 2.3.9 Low-Level services

Low-Level services contain tools for data transformation and handling, which, in particular, include: coordinate system transformation, seed response calculation, seismogram picking tool (Fig. 5), Signal download tool, Catalog filtering and Magnitude to magnitude conversions.

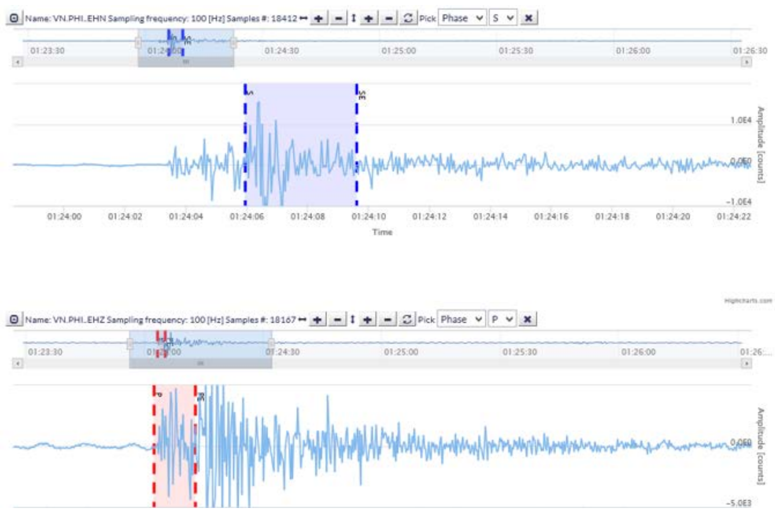

Fig. 5 – Picking tool demonstration, P-wave phase (bottom) and S-wave phase (top)

### 2.3.10 Visualization Services

Visualization services include several generic tools implemented in the platform. The tools can be used to illustrate, e.g. the evolution of seismic activity together with the production/technological processes related to each episode. Various plotting options are provided, allowing the users to identify potential patterns and links between seismicity-technology. Depending on the inducing technology of the episode and the available data, the following additional visualization tools are offered: (i) visualization of mining front advance; (ii) seismic activity with water level, water volume, injection rate or wellhead pressure; (iii) injection rate and wellhead pressure histograms; (iv) focal mechanisms demonstration; (v) integrated episode data and 3D visualization.

## 2.4 Document Repository

The IS-EPOS platform integrates various kinds of documents such as publications in international scientific journals, peer reviewed and unreviewed reports, expert opinions, user manuals, books, recommendations, instrument technical specifications, images etc. Those documents are freely available for all user classes. Electronic materials may be provided as stand-alone and available or attached to the specific Research Infrastructure data or software. The classification of the documents inside the repository takes into consideration multiple aspects and provides to the user an opportunity to search for a specific document according to various criteria. These criteria include Authors' names, date released and title but also classification according to certain episode, methodology and/or technology will be available. Additionally, a Platform User Guide is available in the Document Repository in order to give to the platform users and visitors a brief but comprehensive description of the portal functions and services together with instructions for how to navigate into the portal. The user guide is divided into thematic categories for specific and easier access concerning different functions available in platform, demonstrated by examples described step-by-step. A quick-start guide providing an overview of the platform and the basic navigation procedures is available and recommended for new users.

## 3. System Architecture

The IS-EPOS platform was created as a Science Gateway – a Web-based platform offering to researchers means for accessing all available data related to seismic episodes and performing advanced operations on these data. The processing and presentation provided by the platform relies on one hand on Data and Metadata Repositories, which are filled and managed with the services of Data Acquisition and Integration, and, on the other on the Computing Infrastructure that enables performing calculations on the relevant data. The relations between the IS-EPOS platform and other components are shown in Fig. 6. All parts of the system are bound and managed by Scientific and Technical Coordination.

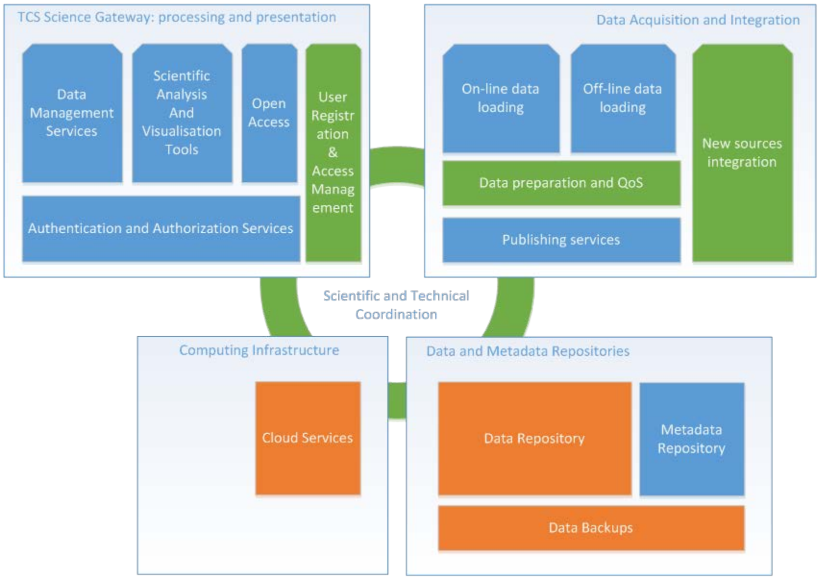


Fig. 6 –IS-EPOS platform with its relations to other components. Blue color is used for IT solutions built within the project; green color marks verification processes that are performed by appointed individuals; orange color is used for external infrastructure components used by other services.

The IS-EPOS platform itself comprises the following components:

- Data Management Services – the services expose all data and metadata prepared and provided by the Data Acquisition and Integration component (constituted by multiple by LDCs), allowing advanced searches, filtering and usage of these data. This includes, e.g. browsing seismic episode information, searching for episode data, visualization of seismic catalogs, bulletins and other seismic and non-seismic data, filtering and conversion of the data. It also allows for management and metadata annotation of the files provided by the user.
- Scientific Analysis and Visualization Tools provide means to execute either predefined or user-provided (with respect to the user's access level) applications and organize them in larger experiments that can include also advanced result analysis or visualization. The component includes also standalone analysis and visualization services.
- Open Access to basic services available to users who are not registered within the platform.
- Authentication and Authorization Services – services and tools allowing for authorization to the platform and access control.
- User Registration & Access Management – all the processes performed by appointed individuals to decide on allowing or denying access to the platform to a given user.

The gateway to the IS-EPOS platform is the IS-EPOS portal, which also integrates all the aforementioned services and provides a comprehensive on-line workspace environment to the IS-EPOS users. The implementation of IS-EPOS portal is based on the InSilicoLab framework [36], which provides core components that implement the workspace environment and realize the integration with advanced distributed computing infrastructures. Thanks to this integration, the platform applications can be executed on any infrastructure –

cloud services, HPC clusters or even single servers or personal computers. A schema of the platform services implementation based on the framework is shown in Fig. 7. The InSilicoLab processing model relies on a set of so-called workers, which perform the computations and return the results to the gateway facing the user. The InSilicoLab core services are able to manage many simultaneous computations with different granularity (from tasks computed in seconds or minutes, to calculations taking hours or days). The applications can also be run in a pipeline, in which case, the results of previous applications are used as input to subsequent ones.

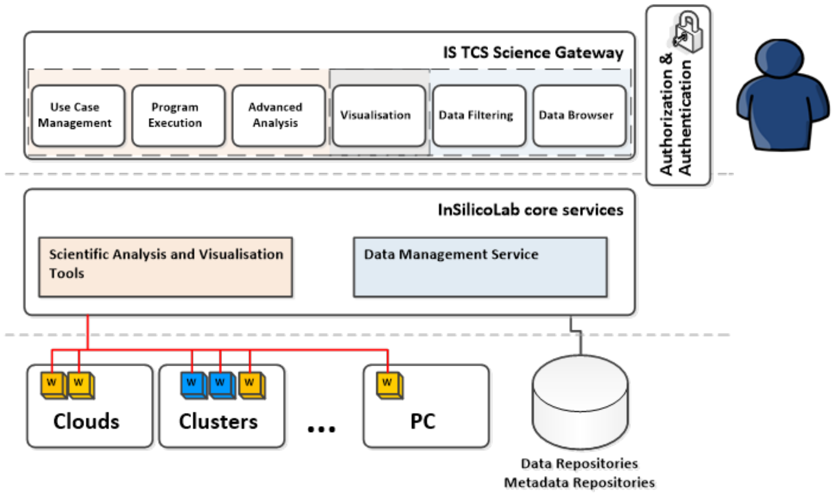


Fig. 7 - IS-EPOS platform services implementation based on the InSilicoLab framework.

## 4. Conclusions

IS-EPOS is the main pillar of the Thematic Core Services "Anthropogenic Hazards", developed presently within EPOS IP project, which integrates data describing comprehensive anthropogenic hazard cases of time correlated seismic and technological data, the so called AH-episodes. Software packages and interactive visualization services, together with browsing and selection tools are also provided within the e-platform. The main goal is to construct a digital research space for AH, providing to the scientific community permanent and safe access to advanced research infrastructure, conducting modern research by suggesting innovative solutions, and encourage effective cooperation with international scientific IT networks. This pilot TCS is operating as since January 2016 and is open for research groups from institutes and universities, industrial partners and residents. IS-EPOS is currently operating with fully functional services whereas data from 6 seismic episodes is already being implemented (https://tcs.ah-epos.eu/).

## 5. Acknowledgements

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## 6. References

References must be cited in the text in square brackets [1, 2], numbered according to the order in which they appear in the text, and listed at the end of the manuscript in a section called References, in the following format:

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