

National EPOS initiatives and participation to the EPOS integration plan

Kuvvet Atakan^{*1}, Massimo Cocco², Beata Orlecka-Sikora³, Ronald Pijnenburg⁴, Jan Michalek¹, Christian Rønnevik¹, Dorota Olszewska³, Beata Górk-Kostrubiec³, Martyn R. Drury⁴

⁽¹⁾ Department of Earth Science, University of Bergen, Allég.41, 5007 Bergen, Norway www.uib.no/geo;
e-mail: Kuvvet.Atakan@uib.no

⁽²⁾ Istituto Nazionale di Geofisica e Vulcanologia, Roma, Italy www.ingv.it; e-mail: Massimo.cocco@ingv.it

⁽³⁾ Institute of Geophysics, Polish Academy of Sciences, Warsaw, Poland www.igf.edu.pl; e-mail: orlecka@igf.edu.pl

⁽⁴⁾ Department of Earth Sciences, Utrecht University, Netherlands www.uu.nl/en/research/departement-of-earth-sciences;
e-mail: r.p.j.pijnenburg@uu.nl

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Abstract

European Plate Observing System (EPOS) is designed on a three-level architecture. The national research infrastructures (NRIs) constitute the backbone of the EPOS delivery framework, where data are generated, processed, analyzed and archived. These data are then integrated by thematic core services (TCS) and distributed through the centralized integrated core services (ICS). In this architecture, data provision from the NRIs is an essential element for the sustainable operation of the EPOS research infrastructure (RI). National EPOS initiatives in various countries in Europe are developed thanks to the increased awareness of the importance of FAIR (Findable, Accessible, Interoperable and Reusable) data management in science. As such, out of the 14 countries (13 members and one observer) that constitute the EPOS European Research Infrastructure Consortium (EPOS-ERIC), 11 have dedicated EPOS consortia established and included in the national roadmaps for research infrastructures. Moreover, there are in total 24 countries involved in the EPOS delivery framework where 10 are not yet members of EPOS-ERIC. However, the diversity of regulations and procedures adopted in different countries, hampers the development of dedicated EPOS consortia contributing to sustainability. In this paper, the national EPOS initiatives are discussed in order to emphasize synergies achieved and the shared efforts to build the EPOS RI during its life-cycle (the design, preparation, implementation, and pilot operational phases), tackling the challenge of sustainable operation.

Keywords: European Plate Observing System (EPOS); Research Infrastructure (RI); Earth Science; Solid Earth Science

1. Introduction

The architecture of the European Plate Observing System (EPOS) relies on a federated approach to govern data integration. Since its conception phase, EPOS is tackling the challenge of making openly accessible the enormous wealth of available solid Earth science data generated and collected by national and international research infrastructures. EPOS is established as one of the European Research Infrastructure Consortia (ERIC) in 2018 with its headquarters in Rome, Italy [EPOS-ERIC, 2021]. Currently, 14 countries are involved in EPOS-ERIC (13 of which are formal members, and one is an observer). Furthermore, in total 24 countries are involved in EPOS, most of which are committed to provide data, data products, software, and services (DDSS) to be integrated by 10 thematic subdisciplines of solid Earth science.

EPOS entered the ESFRI Roadmap in 2010 after a careful evaluation undertaken by international experts. At that time, 13 countries were participating the EPOS RI, with a further five more countries that joined during the European Strategic Forum for Research Infrastructures (ESFRI) evaluation and negotiation process (Greece, Turkey, Romania, Norway, Poland). The European Commission funded the EPOS Preparatory Phase project [EPOS PP, 2010-2014] aimed at the design of the EPOS architecture and governance model. EPOS PP was coordinated by INGV (Italy), and it included 20 partners from 18 countries and 2 international research organizations. It was decided in EPOS PP to include only one research organization for each participating country and to start the further engagement of other national research organizations. The EPOS Implementation Phase was then started in 2015 when the European Commission funded the EPOS IP project that lasted four years (2015-2019) and involved 47 partners and four international organizations. During the EPOS-IP project the Thematic Core Services (TCS) were created, and the implementation of the EPOS functional architecture was achieved.

EPOS represents a collaborative framework aimed at joining efforts and resources, sharing existing experiences and skills of domain scientists and e-scientists to develop a federated approach for integrating research data and scientific products ensuring data management and interoperability through e-science innovation [see Bailo et al., 2022, this volume]. This federated approach relies on the construction of the Thematic Core Services (TCS), where data and metadata are further quality-controlled and standardized, as well as of the Integrated Core Services (ICS) where data, metadata and services are integrated to make them usable fostering cross- and multi-disciplinary science. The EPOS Delivery Framework is composed of the data integration system represented by the TCS and the ICS and it is governed by EPOS ERIC [see Cocco et al., 2022, this volume].

The EPOS architecture is founded on the data provided by National Research Infrastructures (NRIs) integrated into a centralized system “Integrated Core Services (ICS)” organized through 10 thematic communities and their services (Thematic Core Services – TCS). This architecture (Figure 1) relies not only on the services provided by the thematic communities but also to a large extent to the underlying data provision by the national research infrastructures. This provision is ensured by the engagement of national research organizations belonging to the 24 countries involved in EPOS. Nearly 140 research organizations are engaged in the EPOS RI. Among them, 65 research organizations and 4 international organizations are formally engaged in the TCS consortia, belonging to 21 countries out of the 24 involved in EPOS. The data and service provision are currently ensured by 35 Service Providers, which are making available nearly 198 validated data, data-products, software and services (DDSS elements) provided through 239 services. The long-term sustainability of the entire EPOS delivery framework is therefore dependent on the entire supply chain of data provision starting from the national level (NRIs) to the service provision by the thematic communities (TCS) and finally to the fully integrated data, data products, software, and services (DDSS) at the centralized European level (ICS). The sustainable operation of the EPOS RI requires that the data and the services are intact, reliable, and robust at any given time [see Saleh-Contell et al., 2022, this volume].

In this study, we look deeper into the data supply chain and focus on the integration of data provision from the NRIs or other national level initiatives, which constitute the foundation of the EPOS architecture. A summary of status for the various national EPOS initiatives is given together with a few selected examples that are described in more detail to highlight both the challenges that are faced, as well as the success stories, where national initiatives are coordinated in a well-organized structure combining a variety of observational data from continuously monitoring, highly distributed, permanent sensor networks, data collected through temporary installations and campaign based measurements, as well as advanced data products stored, archived and curated at various national institutions.

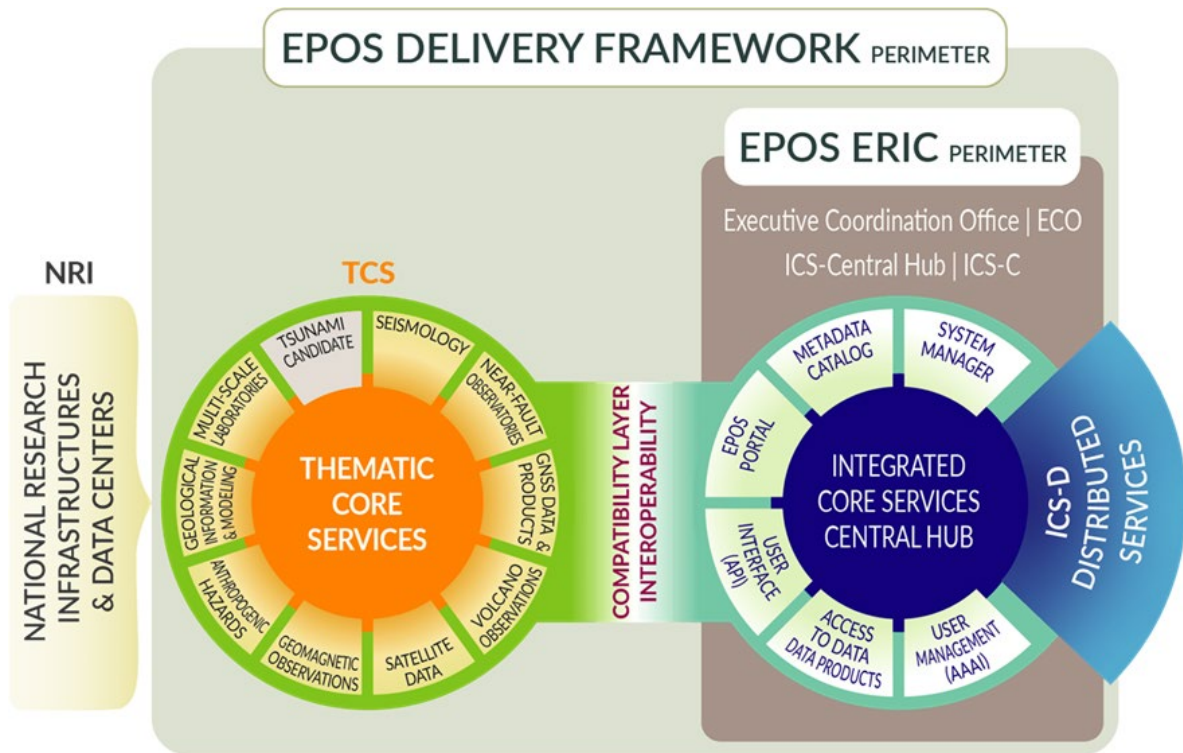


Figure 1. EPOS architecture showing the three layers of the data supply chain, starting at the bottom (left) National Research Infrastructures (NRIs), in the middle Thematic Core Services (TCS) and Integrated Core Services (ICS) at the top (right).

2. Overview of national EPOS initiatives

The status of EPOS related national initiatives was investigated during the EPOS Implementation Phase (EPOS-IP Project) (see Table A1 in appendix). According to this analysis, 24 countries were monitored for the status of national initiatives. Among them, four countries had established EPOS consortia and successfully awarded support from national funding agencies through dedicated contracts. These countries are Finland, Italy, Norway and Poland. In 13 countries EPOS consortia (or joint research units) were established, however no dedicated contracts were yet signed with the national funding agencies. In addition, seven countries had no EPOS related consortia established and there was no support from the national funding agencies.

In 2021, within the framework of the EPOS Sustainability Phase (EPOS-SP) project, updated information was collected both from the EPOS ERIC member countries, as well as other countries that are involved in the data provision to the EPOS delivery framework but not yet included as members of EPOS-ERIC. A summary of this is given in Table 1. In total, 24 countries were included, among which 14 (13 full members and 1 observer) were members of EPOS-ERIC. Out of the 14 member countries, 11 have EPOS included in their national roadmap for research infrastructures. For the remaining 10 countries that are not yet members in EPOS-ERIC, only one country (Finland) has EPOS included in its national roadmap for infrastructures. In another case (Germany), EPOS is only mentioned in a note to the national roadmap for research infrastructures. Since 2017 there is a significant improvement in the success of the national EPOS initiatives, with an increase from four in 2017 to 11 in 2021. Obviously, formal establishment of EPOS-ERIC may have played a role here.

In the following, four example cases from Italy, Norway, the Netherlands, and Poland are presented in more detail.

Country	Involvement Status	Involvement Details	EPOS Presence in National Roadmaps
Belgium	EPOS ERIC Member	1) EPOS is included in the national RI roadmap; 2) There is national funding foreseen to modernize existing services to be integrated in EPOS, but the services themselves are not included in a national priority list.	NA Belgian roadmap under preparation
Denmark	EPOS ERIC Member	1) EPOS is included in the national RI roadmap.	YES Danish Roadmap for Research Infrastructures 2015
France	EPOS ERIC Member	1) EPOS is included in the national RI roadmap. There is an ongoing update to the 2016 version; 2) There is a cluster of French contributions to ES-FRI in Earth Sciences and Environment (Data Terra); 3) Ongoing actions to secure funding of EPOS services are: funding proposals, requests for more permanent IT staff.	YES French National Strategy on Research Infrastructure 2016 Edition
Greece	EPOS ERIC Member	1) EPOS is included in the national RI roadmap; 2) Ongoing actions to secure funding of EPOS services are: requests for national funds.	NA Roadmap updated in 2014
Iceland	EPOS ERIC Member	1) EPOS is included in the national RI roadmap (EPOS Ísland was accepted as one of 6 projects on the Iceland RI roadmap in January 2021); 2) EPOS services are prioritised through of the inclusion on the RI roadmap; 3) Ongoing actions to secure funding of EPOS services are: a proposal for funding the first year of build-up of e-infrastructures (submitted April 2021 to national RI roadmap funds).	NA No roadmap available
Italy	EPOS ERIC Member	1) EPOS is included in the national RI roadmap; 2) EPOS Italia is organised in a Joint Research Unit (2017); 3) Ongoing actions to secure funding of EPOS services are: community proposals to EU programs; alignment of EPOS-ERIC and national objectives.	YES Programma Nazionale per le Infrastrutture di Ricerca (PNIR). Roadmap updated in 2017
The Netherlands	EPOS ERIC Member	1) EPOS is included in the national RI roadmap; 2) EPOS-NL in place and recognised in the RI roadmap; 3) Identification of more interested parties to increase contributions in kind, participation in new proposals.	YES National Roadmap for Large-Scale Scientific Infrastructure. Roadmap updated in 2016
Norway	EPOS ERIC Member	1) EPOS is included in the national RI roadmap; 2) EPOS-Norway (EPOS-N) consortium is established in 2009; 3) EPOS-N RI is now in its operational phase providing services, and an application for an expansion in Phase-II is under evaluation.	YES Norwegian Roadmap for Research Infrastructure. Roadmap updated in 2016

Country	Involvement Status	Involvement Details	EPOS Presence in National Roadmaps
Poland	EPOS ERIC Member	1) EPOS is included in the national RI roadmap; 2) Services are linked to research priorities in the country; 3) Ongoing actions to secure funding of EPOS services are: request of increased support at ministerial level.	YES Polish Roadmap for Research Infrastructures. Roadmap updated in 2020
Portugal	EPOS ERIC Member	1) EPOS is included in the national RI roadmap; 2) C4G (https://www.c4g-pt.eu/) is the Portuguese node of EPOS; 3) Ongoing actions to secure funding of EPOS services are: outcomes of request of renewal of C4G project.	YES Portuguese Roadmap of Research Infrastructures. Roadmap updated in 2020
Romania	EPOS ERIC Member	1) EPOS is included in the national RI roadmap.	YES Romanian Roadmap of Research Infrastructures (2017). Roadmap update is in preparation
Slovenia	EPOS ERIC Member	No reply to WP8 survey (not sure who was invited, if any)	NA Slovenian Roadmap of Research Infrastructures. Roadmap updated in 2016
United Kingdom	EPOS ERIC Member	1) No information on existence/presence of national RI roadmap.	NA UKRI/BGS is the representing entity for EPOS in UK and contributes as one of the hosting organizations of EPOS ICS.
Switzerland	EPOS ERIC Observer	1) EPOS is included in the national RI roadmap 2019.	YES Swiss Roadmap for Research Infrastructures 2021-2024
Bulgaria	NACB Member	NA	YES Bulgaria National Roadmap for Research Infrastructure 2017-2023
Finland	NACB Member	1) EPOS is included in the national RI roadmap.	YES Finland's Strategy and Roadmap for Research Infrastructures 2014-2020
Germany	NACB Member	1) EPOS is present in a note of the National Roadmap for RIs.	NA Report of the science-based evaluation of large research infrastructure projects for a National Roadmap, updated in 2019

Country	Involvement Status	Involvement Details	EPOS Presence in National Roadmaps
Ireland	NACB Member	NA	NA National Roadmap for Research Infrastructures 2007
Slovak Republic	NACB Member	NA	NA No roadmap available
Spain	NACB Member	NA	NA National Roadmap for Research Infrastructure 2013
Austria	NACB Observer	NA	NA Austrian Research Infrastructure Action Plan 2014
Hungary	NACB Observer	NA	YES National Research Infrastructure Roadmap 2018
Czech Republic	NACB Observer	NA	NA Roadmap of Large Research Infrastructures of the Czech Republic for the years 2016-2022
Turkey	NACB Observer	NA	NA National Roadmap for Research Infrastructures under preparation

Table 1. Summary of the status on national EPOS initiatives in 2021. Among the 24 countries involved in EPOS, there are 13 countries that are members of the EPOS ERIC and an additional one as observer. More information on status of the national roadmaps for infrastructure can be found at: <https://www.esfri.eu/national-roadmaps>. EPOS ERIC: European Plate Observing System, European Research Infrastructure Consortium; NACB: National Agencies Coordination Board; NA: Not available.

3. Selected examples of national EPOS initiatives

3.1 EPOS-Italy

The Italian participation to EPOS started in 2007 when the Italian Ministry decided to submit to the European Forum on Research Infrastructures (ESFRI) the proposal to include the European Plate Observing System (EPOS) in the ESFRI Roadmap. The Italian proposal assigned to the Istituto Nazionale di Geofisica e Vulcanologia (INGV) the role of coordinating the European initiative, which at that time included 6 other countries (France, United Kingdom, Switzerland, Germany, The Netherlands, and Denmark). This first step is relevant because it is an action promoted by the Italian Ministry for University and Research (MUR) that involved INGV as the coordinating Research Organization.

EPOS entered in the Italian Roadmap for Research Infrastructures in 2011 with INGV as the coordinating institution. The Italian solid Earth science community was invited to participate to the working groups established

in EPOS PP to design the thematic services for the different scientific domains included in the designed EPOS architecture. This national participation was promoted by INGV as EPOS coordinator, and it essentially concerned national research infrastructures and facilities (observatories and laboratories) to be involved in the data and service provision. The engagement process of Italian research organizations in EPOS followed a bottom-up approach driven by the choice to prioritize the engagement of data providers and IT experts, according to the EPOS strategic plan, and was supported by dedicated communication initiatives. It is important to emphasize that the relationships with the Italian Ministry and the national scientific community started following the EPOS preparatory phase. During the Preparatory Phase INGV and the Italian Ministry submitted the bid to host the EPOS ERIC legal seat in Rome, at the INGV Headquarter, which was subsequently selected by the EPOS Board of Governmental Representatives.

In parallel with the EPOS IP project, where six Italian research organizations were formally engaged in the project activities, the Italian community started to design and build a Joint Research Unit (JRU) to foster and facilitate the participation to the EPOS activities. The conceptual design of the JRU was accompanied by dedicated communication activities to share the EPOS vision and mission, to inform about the EPOS implementation strategies and achievements, as well as to make the Italian solid Earth science community aware of the potential benefits of the EPOS data integration plan. The discussions to establish the JRU concerned national research organizations, universities, foundations dealing with seismic risk and e-science, as well as the Italian geological survey. Since the beginning, EPOS has been presented to the Italian solid Earth science community with the ambition to clarify the different ways to participate in the initiative: as contributors by hosting service providers and national hubs, as data providers by sharing data and services to support open science, and as users accessing to the EPOS multidisciplinary data and services. In 2017 the Joint Research Unit EPOS-Italy was signed for the first time. Since then, 10 scientific organizations have joined the JRU: 4 research organizations (INGV, Centro Nazionale delle Ricerche – CNR, Osservatorio Geofisico Sperimentale OGS Trieste, Istituto Superiore per la Protezione e la Ricerca Ambientale ISPRA), 4 universities (University of Naples Federico II, University of Rome Tre, University of Genoa and University of Trieste), and 2 foundations (EUCENTRE Pavia for seismic risk, and CINECA Bologna for super-computing and e-science). The JRU EPOS-Italy has been acknowledged by the Italian Ministry in 2018.

The scope of the JRU EPOS Italy is to coordinate and support the Italian participation to the EPOS delivery framework governed by EPOS ERIC. The Italian team participates to the TCS activities and the research organizations participating to the JRU have signed consortium agreements to be engaged in the TCS boards and scientific committees. The JRU EPOS-Italy has developed its own Annual Activity Plan, which is organized into three main objectives: support to the national nodes (service providers) identified by TCS, support the further implementation of data provision and service providers not yet validated by EPOS ERIC, support international cooperation and global scientific initiatives. The Italian Ministry provides funding to both EPOS ERIC and the JRU EPOS-Italy. The funds for EPOS ERIC concern the annual membership fee and the contribution to host the legal seat of EPOS ERIC (host premium). According to the selected bid to host the legal seat in Rome, INGV is providing further in-kind contributions (and also human resources) to EPOS ERIC, as reported in the financial statements. The funds provided to the JRU are managed by INGV and redistributed to the other participants to support the activities declared in the annual activity plan. These resources can be declared in EPOS ERIC as a further in-kind contribution provided by Italy to support the TCS service provision. The research organizations committed to host national nodes (service providers) further provide in-kind resources necessary to operate the involved national research infrastructures and facilities. The in-kind contributions provided by the JRU, and the in-kind resources provided by the committed research organizations are mapped in the TCS Cost Book and contribute to increase the sustainability of the EPOS delivery framework. Thanks to the collaboration with CINECA, EPOS participated in several EC projects dealing with e-science [EUDAT, 2012-2018; VERCE, 2011-2015; EGI Engage, 2015-2018; EOSC Pilot, 2017-2019; EOSC Hub, 2018-2021; CHEESE, 2018-2022; among several others].

The Italian participation to the EPOS integration plan of data and services for solid Earth science is effectively harmonized with the EPOS ERIC architecture and governance model. Several Italian research organizations have taken commitments to host service providers and/or coordinate the TCS on behalf of the thematic community, therefore supporting the EPOS federated approach to data and service integration. The interactions among the policy maker (i.e., the Ministry), the Representing Entity nominated in the EPOS ERIC Statutes, and the Italian team engaged in EPOS activities are structured and organized in an effective way fostering design and planning. The Italian Civil Protection Agency is also informed about EPOS activities and engaged as a stakeholder for devel-

oping scientific products for geo-hazards and risk. This might represent a good practice for harmonizing national priorities and strategies with pan-European initiatives and efforts to operate a distributed research infrastructure.

3.2 EPOS-Norway (EPOS-N): Norwegian node of EPOS

Parallel with the EPOS Preparatory Phase project, in 2009 seven Norwegian Institutions, University of Bergen (UiB), Christian Michelsen Research (CMR), University of Oslo (UiO), NORSAR, National Mapping Authority (NMA), Geological Survey of Norway (NGU) and Norwegian Geotechnical Institute (NGI), representing the key research organizations dealing with data provision in Earth sciences, jointly established a Norwegian National EPOS Consortium (NNEC). The main goal of NNEC was to build the Norwegian node of EPOS, through a coordinated effort with contributions from the distributed monitoring sensor networks in seismology (Norwegian National Seismic Network and Norwegian Array stations) operated by UiB and NORSAR, and geodesy (National GNSS permanent network) operated by NMA, as well as the geological and geophysical databases provided by NGU.

In 2016, the six members of the NNEC, UiB, NORCE (Former CMR), NORSAR, NGU, NMA and UiO, have jointly been awarded with a grant from the Research Council of Norway to establish the Norwegian node of EPOS, EPOS-Norway [EPOS-N, 2021]. During the period 2016-2021, these six institutions have focused on three main activities: (i) improving the monitoring capacity in the Arctic through new installations of seismic and geodetic (GNSS) stations, (ii) developing a national e-infrastructure integrating all solid Earth relevant data, data products, software and services in Norway, and (iii) establishing a solid Earth science forum to engage the user communities and for getting feedback on the development of an integrated data portal (EPOS-N Portal). Since 2018, EPOS is included in the National Roadmap for Research Infrastructures in Norway and through the establishment of the Norwegian node of EPOS, EPOS-N, Norway has entered the EPOS-ERIC as one of founding members.

During the period 2016-2021, EPOS-Norway has successfully accomplished installation of 23 new stations in the Arctic region, in Norland area in Northern Norway and the Arctic islands of Jan Mayen, Bear Island and Svalbard (Figure 2). In addition to continuous seismological and GNSS data from these stations, ocean bottom seismographs were used in several campaign-based data collections which provided new insights to the critical offshore regions

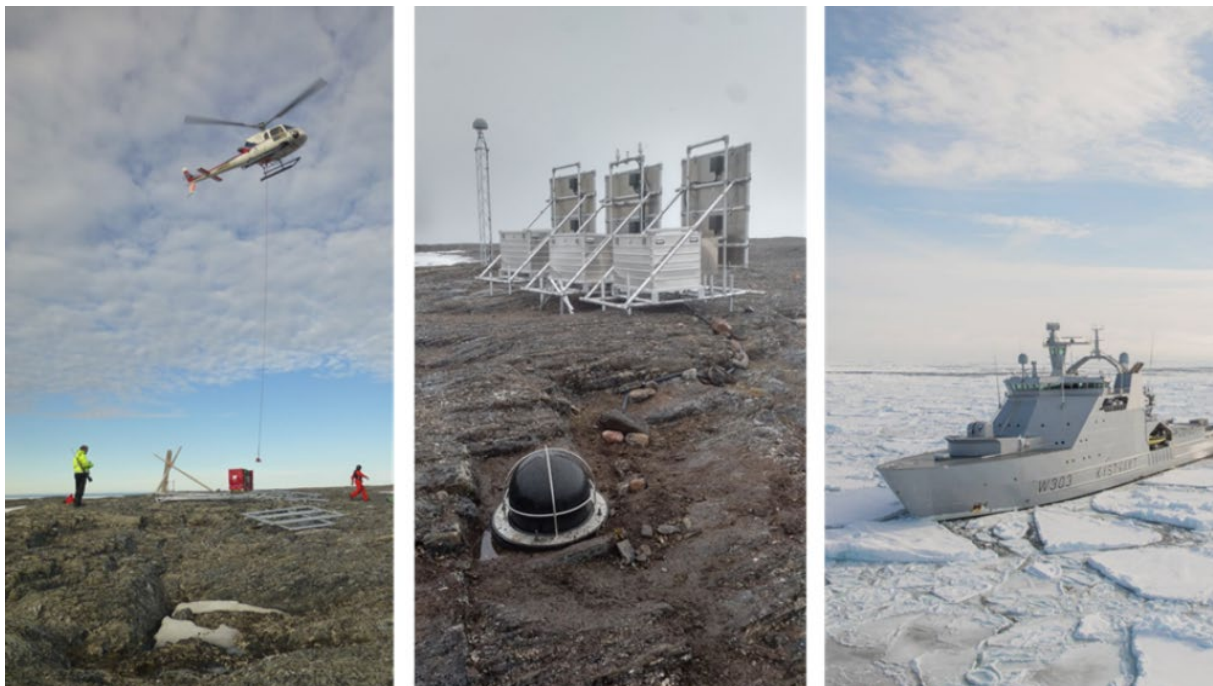


Figure 2. Seismological and GNSS station installations at Svalbard as part of EPOS-Norway Arctic monitoring RI (Photo: Felix Halpaap). Picture in the middle shows the installations at Verlegenuken, northernmost part of Spitsbergen. Photographs on the left and right give snapshots of the logistic support for transport of equipment to the site provided by a helicopter and the Royal Norwegian Navy Vessel – K/V Svalbard, respectively.

in the Arctic, including the Mohns and Knipovich Ridges and the offshore area south of Spitsbergen in Storfjorden, where the source region of the continuous earthquake activity which started with the M=6.1, 2008 earthquake was monitored. In a dedicated survey new high-resolution aeromagnetic data were collected mapping the entire Knipovich Ridge shedding light to the complex mid-oceanic ridge opening history in the Northern Atlantic Ocean. Seismological data collected through, both the already existing stations of the Norwegian National Seismic Network (NNSN) and NORSAR arrays, as well as the newly installed stations within the framework of EPOS-N, are now integrated into the Norwegian EIDA node, which provide data from the Arctic regions to EPOS.

The second major achievement of EPOS-N is the development of a national data portal in solid Earth science in Norway, which is now completed, and the EPOS-N Portal provides now open access to more than 300 different data sets that are integrated (Table 2a and 2b). EPOS-N Portal [EPOS-N Data Portal, 2021] (Figure 3) provides open access to a wide-range of data sets from several sub-disciplines of Earth sciences and offers advanced search and visualization services to the scientific community. Furthermore, the advanced visualization services are now being integrated into a European level service and a prototype of an ICS-D (Integrated Core Services – Distributed).

Partner institutions	Research Infrastructures (RIs) integrated in EPOS-Norway in Phase-I and new RIs to be integrated in Phase-II
GEO-UiB	Norwegian National Seismic Network (NNSN)
GEO-UiB	Norwegian National Ocean OBS Pool* to be established by EPOS-N Phase-II consortium
NORSAR	Norwegian Seismic and infrasound Arrays and 3C Stations and the infrasound and seismic array in Finnmark* to be established by the Phase-II consortium
NORSAR	National Broad-Band Seismometer Pool
NORSAR	National Short Period Seismometer Pool* to be established by the Phase-II consortium
NMA	Norwegian Geodetic (GNSS) Networks
RPL-UiT	Norwegian Rock Physics Laboratories* (RPL-UiT)
TGO-UiT	Norwegian Geomagnetic stations* (TGO-UiT)
NGU	Paleomagnetic Laboratory*
NGU	Norwegian Geological and Geophysical Databases
NGU	National Transient Electromagnetic (TEM) measurement capacity*
NGU, NORCE, NMA	Detailed surface deformation (InSAR) data for Norway*
NGI	Tsunami modelling capacity*
NORCE, GEO-UiB	EPOS-Norway Portal (national e-Infrastructure) providing access to solid Earth science data in Norway, with advanced data visualization techniques

Table 2a. Research Infrastructures (RIs) already integrated in EPOS-Norway in Phase-I and new RIs planned to be integrated in Phase-II (marked with *). GEO-UiB: Department of Earth Science, University of Bergen; NORSAR: Norwegian Seismic Array; NMA: National Mapping Authority; RPL- UiT: Rock Physics Laboratories, The Arctic University of Norway, Tromsø; TGO-UiT; Tromsø Geophysical Observatory, UiT; NGU: Geological Survey of Norway; NGI: Norwegian Geotechnical Institute; NORCE: Norwegian Research Centre.

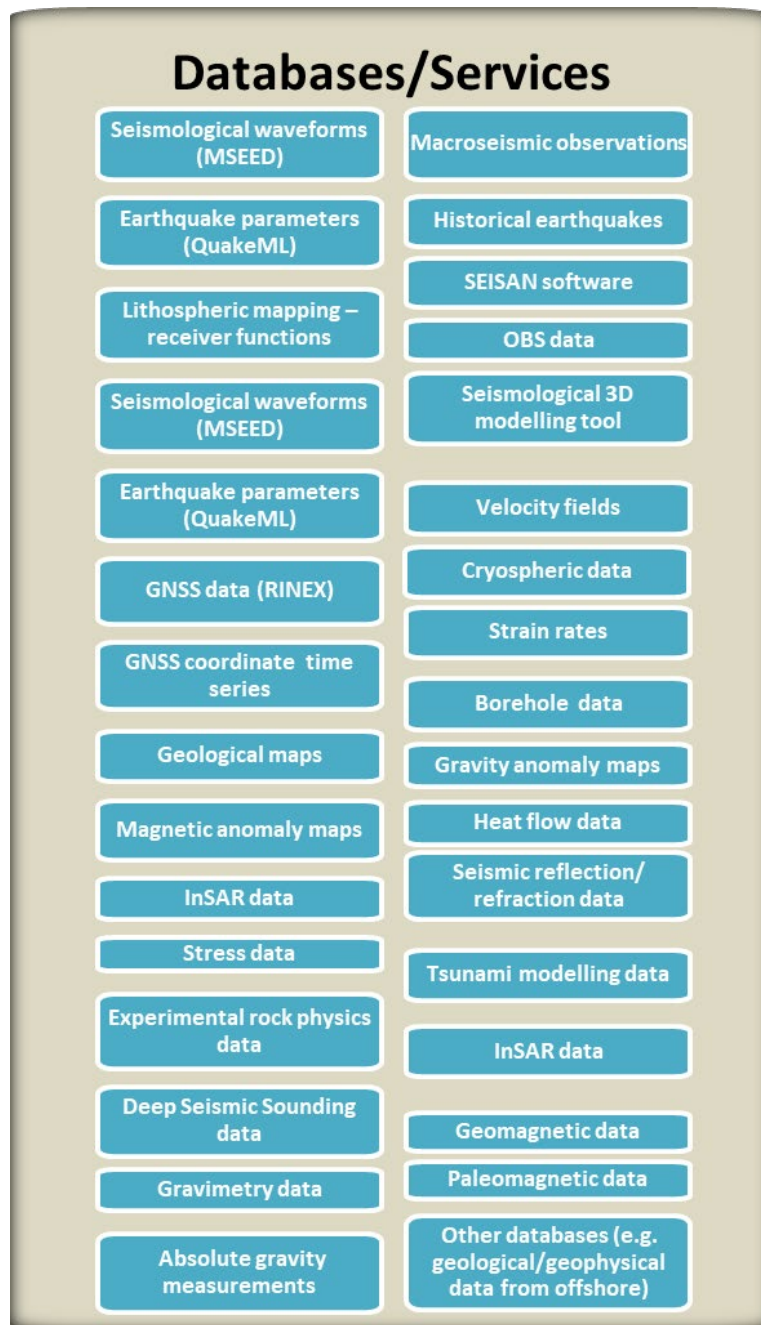


Table 2b. Various integrated data, data products, software and services (DDSS), accessible through the EPOS-Norway (EPOS-N) Portal, including also a number of new data planned to be integrated during the Phase-II of EPOS-Norway.

A new proposal for a Phase-II of EPOS-Norway was submitted to the Research Council of Norway in 2021, that included enhanced data integration as well as new physical installations (Table 2a and 2b). Despite the outstanding score (7 out of 7) achieved in the evaluation process, the project was not funded. This illustrates the sustainability challenges as a consequence of changing national priorities. The EPOS-N Phase-II proposal will be re-submitted in 2023.

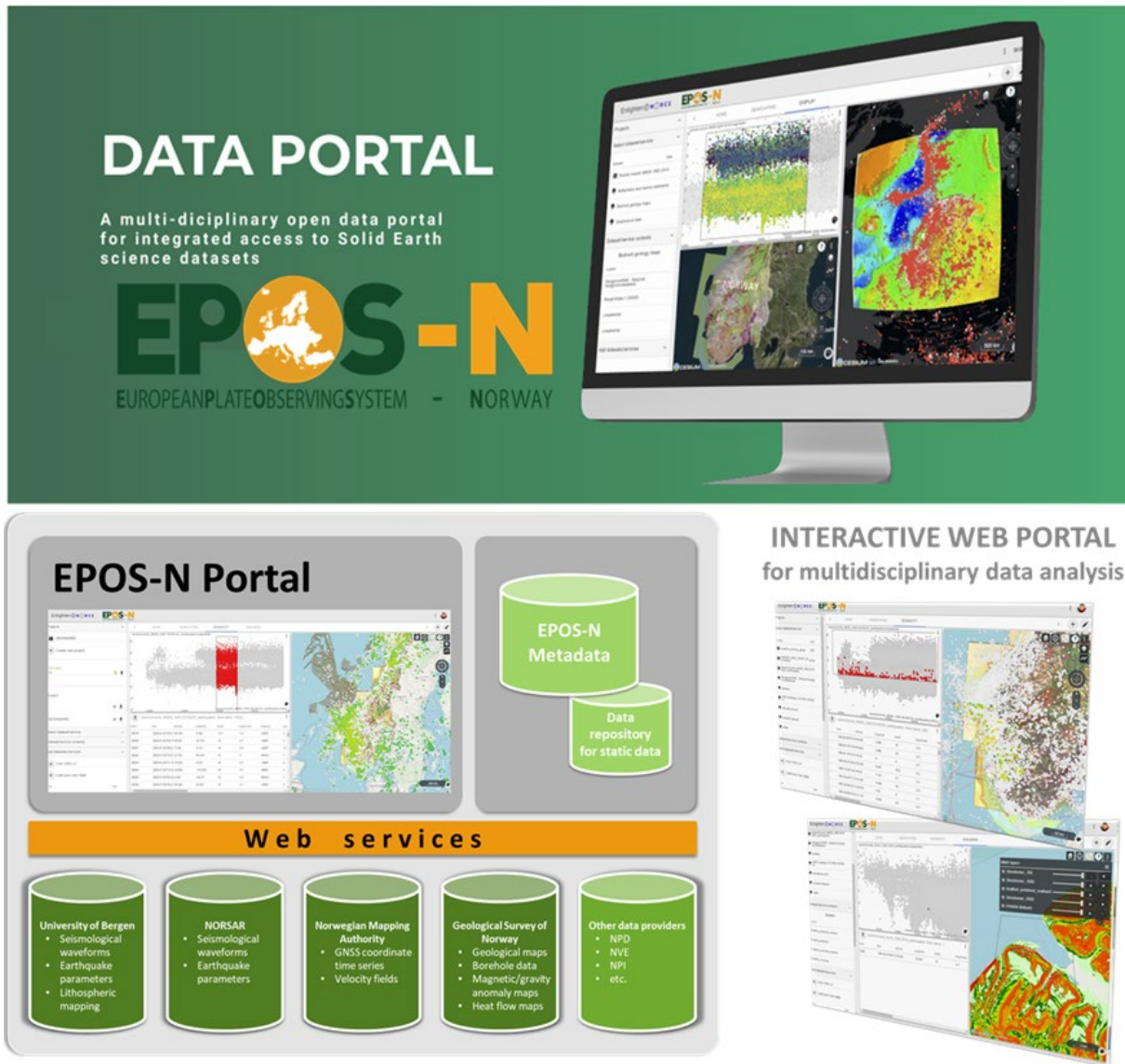


Figure 3. EPOS-Norway (EPOS-N) Portal integrates and provides open access to more than 300 data sets and offers advanced search and visualization capacities. EPOS-N Portal is accessible at <https://epos-no.uib.no/eposn-data-portal/>.

3.3 EPOS Netherlands (EPOS-NL): Access to Dutch research facilities and data

Dutch universities and knowledge institutions have a long history of operating advanced laboratory facilities and producing and maintaining unique laboratory data, pertaining to research on georesources and geohazards. However, these facilities and data are often less than optimally accessible for external users. EPOS-NL (European Plate Observing System- Netherlands) was formed to overcome this limited accessibility and to further develop the Dutch research infrastructure for solid Earth sciences [EPOS-NL, 2021]. EPOS-NL is a partnership between Utrecht University, Delft University of Technology and the Royal Netherlands Meteorological Institute and is financed through the national Roadmap program for large-scale research infrastructure of the Dutch research council (NWO).

EPOS-NL provides free of charge (trans-)national access (TNA) to a unique cluster of large-scale, geophysical facilities at Utrecht University (UU) and Delft University of Technology (TU Delft). Access can be requested by any Earth scientist, whether in the Netherlands, or anywhere else in the world, by applying to one of our biannual calls [see EPOS-NL, 2021]. EPOS-NL facilities that can be accessed include two facilities. The first one of these is the Earth Simulation Laboratory at UU and the Petrophysics laboratory at TU Delft, where, research can be performed

to investigate: (i) the deformation and transport behavior of (fault) rock, through experiments at stresses and temperatures simulating crustal or upper lithosphere conditions at depths <40 km, and (ii) the fundamental processes related to the km-scale, tectonic deformation of the crust and lithosphere of the Earth, through state-of-the-art analogue models. The second one is the Multi-scale Imaging and Tomography (MINT) facilities, distributed over UU and TU Delft. MINT allows imaging and microchemistry mapping of Earth materials in 2D and 3D, at an unprecedented range in scales, from decimeters down to nanometers (Figure 4).

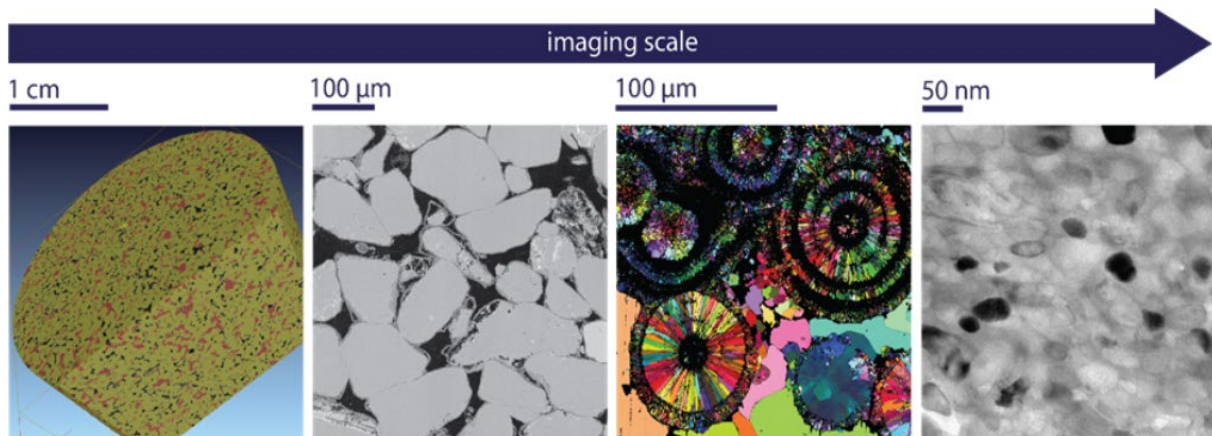


Figure 4. 2D and 3D imaging in the EPOS-NL Multi-scale Imaging and Tomography (MINT) facility, distributed across Utrecht University and Delft University of Technology.

Submitted applications to get access to these facilities are reviewed by an external committee based on excellence and have a high chance of being awarded. In 2021, during which access was largely provided remotely (send-in-sample analysis) due to COVID-19 restrictions, 80% of the proposals received were awarded. EPOS-NL has committed to providing access in this way up to 2025 but strives actively to provide TNA even beyond 2025.

EPOS-NL helps to further develop the above research facilities to which it provides access. Moreover, it provides a key contribution to developing the DAP geothermal well, which in the coming years will be installed on the Delft University of Technology campus. This 2.2 km deep well will serve as a heat source for the university and surroundings, and simultaneously as a large-scale research facility to study the effects of geothermal energy production. Understanding the response of the subsurface to human activities such as these is key in our search for alternative geo-energy resources.

EPOS-NL further contributes actively to the data infrastructure provided by EPOS, and to two TCS specifically. The first one is the EPOS Multi-Scale Labs (MSL) community, where Earth scientific laboratory data stored in Europe are made centrally discoverable. EPOS-NL contributes data to MSL and largely finances the current coordination and IT development needed to further improve MSL data discoverability, through the MSL data catalogue EPOS TCS-MSL, [2021]. This catalogue is currently being developed and is aimed at becoming the top access point for solid Earth scientific lab data in Europe, in 2023. The second TCS where EPOS-NL contributes is the EPOS Seismology community. The ORFEUS Data Centre [ORFEUS, 2021] at the Royal Netherlands Meteorological Institute (KNMI) is a highly mature provider of seismological data in Europe, and one of the main pillars on which the EPOS Seismology data services are based.

3.4 EPOS-Poland (EPOS-PL)

In 2012, Polish research centers in solid Earth sciences and ICT: Institute of Geophysics, Polish Academy of Sciences (IGPAS), Institute of Geodesy and Cartography (IGC), Institute of Geological Sciences, Polish Academy of Sciences (IGSPAS), Central Mining Institute (CMI), Wrocław University of Environmental and Life Sciences (WUELS), The Jarosław Dąbrowski Military University of Technology (MUT), The Polish Geological Institute – National Research Institute (PIG-NRI, agreement terminated in 2016), Academic Computer Center Cyfronet of the AGH Uni-

versity of Science and Technology (ACC Cyfronet AGH), and representatives of the private sector dealing with exploitation of geo-resources: Polska Grupa Górnicza sp. z o.o. (PGG, former name Kompania Węglowa SA – Coal Company SA, KWSA), signed the Letter of Intent in 2012, transformed into the Consortium Agreement in 2015, and formed EPOS-PL. In 2019 the following three institutions joined EPOS-PL: Space Research Centre, Polish Academy of Sciences (SRCPAS), Warsaw University of Technology, Faculty of Geodesy and Cartography (FGC WUT), and the Institute of Environmental Engineering, Polish Academy of Sciences (IEEPAS). The main goal of EPOS-PL was to enhance the innovation potential of solid Earth sciences in Poland and Europe based on modern IT technologies, develop the advanced integrated research infrastructure of the solid Earth sciences, and integrate the research and development community in the field of solid Earth sciences. Responding to the needs of the Polish research community and following a recommendation by ESFRI concerning national RI roadmaps, the Ministry of Science and Higher Education initiated in September 2009 a selection procedure of projects for the Polish RI Roadmap. During this process, EPOS was recognized as a very ambitious undertaking of great socio-economic significance and has been included in the Polish Roadmap for Research Infrastructure since 2011, with the updates of the document in 2015 and 2020. Since 2012, the Ministry has taken part in the works being undertaken at the international level. The Ministry launched the funding mechanisms for the projects included in the RI Roadmap. Under the present funding scheme, the Ministry supports Polish participation in European and international research infrastructures by covering annual membership fee – directly to EPOS ERIC and the national contribution – to the Polish EPOS-PL Consortium. Additional sources of financing include (1) call for proposals dedicated to the research infrastructures included in the Polish Roadmap from European structural funds, (2) call for proposals for new equipment launched by the Ministry every year. Apart from integrating research infrastructure available at Polish academic and research institutions and large investment projects financed with structural funds, Polish participation in the EPOS project focused on building a European center for studies of triggered and induced seismicity associated with geo-resources exploitation. Since 2018 Thematic Core Service Anthropogenic Hazards (TCSAH) [Lasocki et al., 2022, this issue] has become operating in EPOS-ERIC. Consequently, in 2013 IGPAS, with three other Polish partners in the EPOS WG10 “Infrastructures for Georesources”: ACK Cyfronet, CMI and Coal Company, applied for funding the project “IS-EPOS: Digital Research Space for EPOS Purposes”. The project was accepted for co-financing by the European Regional Development Fund (ERDF) as part of the Operational Program Innovative Economy, 2013 – 2015, with a budget of 4 M€. Within this project, the prototype of the EPISODES research platform (former name IS-EPOS), integrating research infrastructure in the field of the anthropogenic geo-hazards associated with exploitation of georesources, was built with the e-data node (Figure 5), both presently being the primary services of TCS AH. In 2016, Polish consortium applied for the project EPOS-PL: EPOS – European Plate Observing System, 2016-2022, with a budget of 15 M€, [EPOS-PL, 2021]. The main results of this undertaking are the innovative services that contribute to minimizing the environmental impacts and risks of the raw materials extractive industry, which will help secure continuity and sustainability of exploitation and help minimize the undesirable impacts of mining-induced deformation on surface infrastructure.

This includes: (1) Multi-parameter monitoring polygons for the integrated observation of geodynamic processes in two areas of georesources exploitation in Poland – the interdisciplinary MUSE episodes (Multidisciplinary Upper Silesia Episodes) are integrated and accessible through the EPISODES platform of TCS AH; (2) Six Research Infrastructure Centers (RIC) – Lithospheric RIC, Analytical Laboratories – Paleomagnetic and Environmental Magnetism, GNSS Data RIC, Geomagnetic and Magnetotelluric Observations RIC, Gravimetric Observations RIC; (3) RIC system software to organize, integrate and manage the data and their metadata; (4) e-research platform of TCS AH [see Lasocki et al. 2022, this issue]; (5) on-line visualization in Gis3D, with reference maps, numerical models of topology and 3D buildings; (6) SWIP-5 software for seismogram analyses; (7) Service for monitoring tropospheric refractivity and zenith path delays in near real time and in real time; (8) IGIK-TVGMF: a MATLAB package for computing and analyzing temporal variations of gravity/mass functionals from GRACE satellite based global geopotential models [Godah, 2019]; (9) System FOSREM Fibre-Optic System for Rotational Events & Phenomena Monitoring; (10) SOS-Stress in-situ strain and stress measurement tool for boreholes using its overcome system, incorporated into geotechnical investigations and tested through SOS-Stress 16 network in the Ruda-Bielszowice coal mine during EPOS-PL project, with the patent application submitted; (11) Structural monitoring system – a system for measuring the opening and changes of fractures on the buildings, tested on Miroszewski Palace in Będzin; (12) Service for modelling of de-stressing blasting in mines and a laboratory for testing materials at high strain rates.

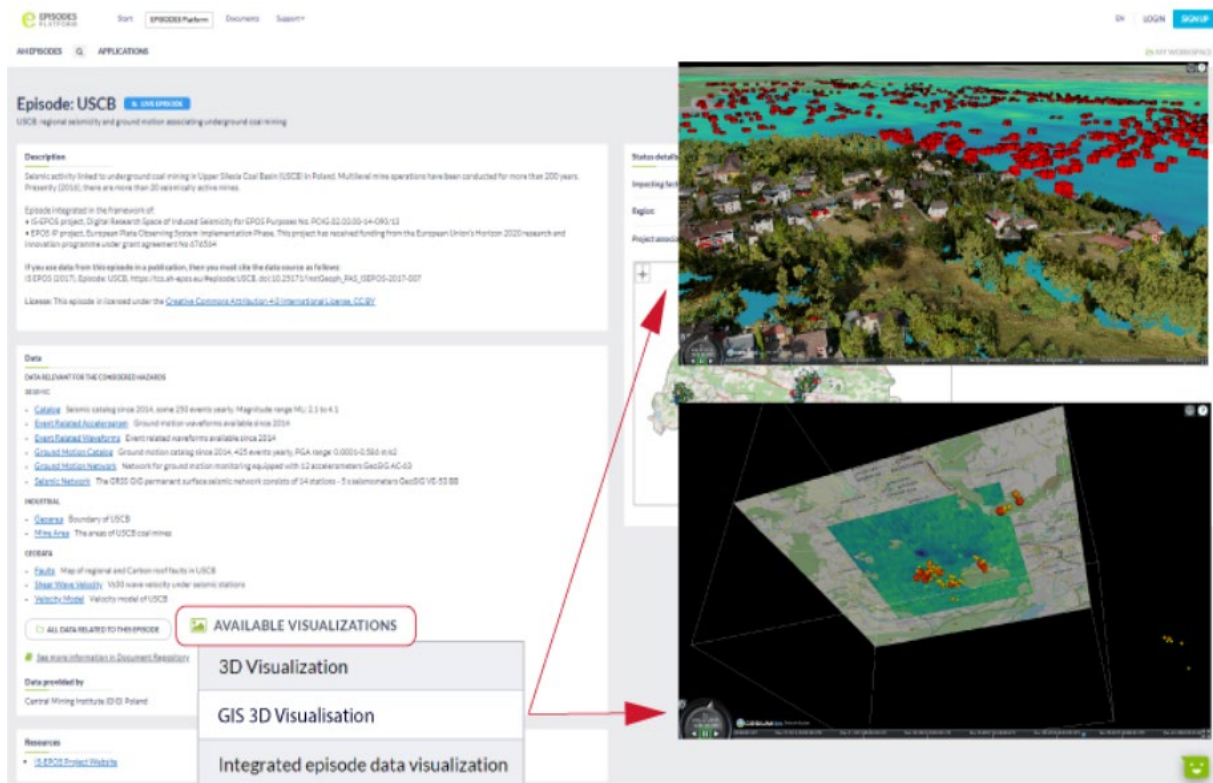


Figure 5. An example of various visualizations from an episode from the EPOS-PL Episodes Platform. Episodes Portal is accessible at <https://tcs.ah-epos.eu/#episodes:>.

In 2019 the EPOS-PL consortium proposed EPOS-PL+ project for creating the Satellite Data RIC in Poland, the geophysical safety system for mine support pillars and EPOS-AI Platform – a new functionality of e-research platform of TCS AH, utilizing an artificial intelligence service. For these goals, the consortium was awarded by the EPOS-PL+ project with a budget of 12.5 M€ and the project will finish in 2023.

4. Discussion and Conclusions

EPOS by its nature is a highly distributed research infrastructure (RI) covering the entire European tectonic plate. Data, data products, software and services are collected by nearly 140 research organizations in 24 countries in Europe. National research infrastructures constitute therefore the backbone of EPOS delivery framework and are essential elements for the sustainability of EPOS. Over the last decade the involvement of a large group of organizations during the design, preparation and implementation phases of EPOS, have helped raising awareness on the importance of the national EPOS initiatives. A significant increase in the number of established national EPOS consortia with dedicated funding achieved from national funding agencies, from four in 2017 to 11 in 2021, is a manifestation of this. In this development, the national roadmaps for research infrastructures that are established by the national agencies (various funding agencies, research councils, ministries, etc.), had an important role. Out of the 32 countries in the European Strategic Forum for Research Infrastructures (ESFRI) list [ESFRI, 2021], 24 have established roadmaps for research infrastructures, which are updated in different time frames. The remaining eight countries in the ESFRI list have not yet established a roadmap for RIs, among which three are in the process of developing. Even if EPOS has succeeded in the inclusion in 11 national roadmaps for RIs, there is still a significant challenge to be tackled.

The process of inclusion of any research infrastructure (as EPOS) in a national roadmap differs from country to country. In some cases, approval of inclusion in the roadmap is subject to the specific national consortium succeeding in a competitive infrastructure call open for all fields of science for funding. This was the case of Norway for example, where the Norwegian National EPOS Consortium (NNEC) was established in 2009, however, EPOS was

not included in the roadmap until 2016. Only after succeeding in the competitive call for research infrastructure support from the national research council in 2016, was EPOS considered eligible to be included in the national roadmap. In other cases, inclusion in the national roadmap is a pre-requisite for funding such as in Czech Republic and Sweden.

Participation in EPOS is not only through the establishment of a national EPOS consortium. In some cases, participation is primarily coordinated by a single organization such as CNRS in France, GFZ in Germany and UKRI-BGS in UK. In Italy, on the other hand, a Joint Research Unit (JRU) is established for EPOS, with INGV coordinating the participation of further nine organizations in EPOS. In some rare cases, participation is granted through ministerial initiatives, such as the case in Greece.

It is also important to note the various synergy effects in participating in EPOS. One of the immediate effects is the development of national observational capacity and its geographical coverage. Examples of such new investments done within the context of the national consortia for enhanced observational capacity exists (e.g., improved Arctic monitoring achieved in EPOS-N). Other synergies are also seen in the interactions between the national initiatives and some of the EPOS thematic core services (TCS). A striking example here is the developments within the national EPOS initiative in Poland which have had important synergies in developing and building the TCS Anthropogenic Hazards (TCS-AH) community. Other examples of synergies exist as well, such as raised awareness in national consortia for their data provision in various TCS due to the effect of participating in EPOS.

Another important synergy was achieved by the engagement of geological surveys in EPOS. This involvement has significantly contributed to the integration of geological and geophysical datasets and have helped bringing the two communities closer. Furthermore, the three geological surveys in France, UK and Denmark (BRGM, UKRI/BGS and GEUS, respectively), with a coordinated and joint effort have now the responsibility of hosting the Integrated Core Services Central Hub (ICS-C). BRGM and UKRI/BGS provide hosting of the ICS-C system installed both in France and UK, securing safety and redundancy, and supported by GEUS providing the monitoring system.

A further synergy effect promoted by the development of national initiatives is certainly the community building and the user engagement. Out of the nearly 140 research organizations involved in EPOS, 65 organizations are formally participating to TCS by signing the consortium agreement. The remaining organizations are engaged in national initiatives or are following the construction of the EPOS RI. They ensure and prove the existence of an involved community capable of promoting an informed use of the infrastructure as well as of strengthening the data and service provision in the near future. In this context, the financial support to national initiatives, provided coherently to the architecture and the EPOS ERIC strategic planning, enables EPOS to tackle the challenge of long-term sustainability including the further development of the EPOS delivery framework. For this to happen, national initiatives need to be harmonized with the EPOS architecture and strategic planning including financial planning. This is a key aspect of financial sustainability as the EPOS financial model is based on the provision of host premium and in-kind contributions from EPOS ERIC members [see Kauzar-Contell et al., 2022 this issue]. The support at the national level makes it possible to increase the provision of in-kind contributions to TCS to be included in the TCS Cost Book.

In addition to the national contributions to EPOS coordinated through dedicated consortia or through individual institutions and associated research infrastructures, there are also other national initiatives that are developed independently within the same scientific domain. One such example is the DataTerra [2021] initiative in France. Such initiatives can be found also in few other countries. These developments can on one side be complementary to EPOS if coordinated well but may also be in competition with EPOS or replicating EPOS at a national scale if not coordinated. There is a high potential for positive synergies between these independent national initiatives and the national EPOS activities. Another example of positive synergies comes from regional collaborations including several countries in a specific region. Current collaboration established among the Nordic countries (Finland, Norway, Denmark, Sweden and Iceland) through a dedicated project Nordic-EPOS [2021] supported by the Nordic Ministries is a good example in this regard. After its first year there are already significant synergies appearing in the form of harmonization and standardization of data provision and FAIR (Findable, Accessible, Interoperable and Reusable) data management.

Further to the fact that NRIs are the backbone of the EPOS delivery framework, another important consideration where NRIs can play a role, is the funding resources for the membership fees for individual countries' participation in EPOS-ERIC. Even if individual country's membership to EPOS ERIC is secured by the relevant ministries in each country, membership fees are not necessarily directly provided by the same national authorities. In many cases, payment of the membership fee is delegated to either the national consortia or to individual institutions

that are mandated to participate in EPOS as a representative entity on behalf of the relevant ministries. This is unfortunately not a sustainable solution, as many organizations and consortia have already pointed out the difficulties in prioritizing the EPOS ERIC membership fee among an ever-increasing number of other research priorities. With reduced budgets experienced in many of these public organizations during the last years, the sustainability of the EPOS ERIC membership over time may become challenging. It is therefore extremely important that national funding agencies carefully consider a sustainable solution to this issue, which is common for all ERIC's.

The evolution of the landscape for national participation in EPOS and contribution of data, products, and services from NRIs creates a complexity, which is challenging for the sustainability of the data provision in the wider EPOS delivery framework. It is obvious that it is not possible to have a unified approach for addressing this issue. More efforts are needed in finding appropriate mechanisms for participation in EPOS, taking into account the existing landscape with various regulations and procedures in different countries. Despite this evolving landscape, there is one common element in participating in EPOS, which is the engagement of the research communities in each country. Without this engagement and dedication of scientists both as individuals and as research groups, it would be difficult to build a complex research infrastructure as EPOS. The current engagement through 10 existing thematic communities included in EPOS, and especially the interest shown by new thematic communities in joining EPOS, are promising signs that this engagement was achieved and is continuing.

Data sharing and resources. This paper is focused on the processes of data provision from the national research infrastructures and therefore no data is used in this paper.

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***CORRESPONDING AUTHOR: Kuvvet ATAKAN,**
Department of Earth Science, University of Bergen,
Bergen, Norway,
e-mail: Kuvvet.Atakan@uib.no, www.uib.no/geo