REPORT
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Harmonizing Solid Earth Resources and Workflows: The HOMEROS Implementation of Open Science Data Management

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Abstract Seismological and geodetic research increasingly relies on large volumes of observational data, making their systematic management, documentation, and efficient reuse a core challenge. Within the broader framework of Open Science, open data stewardship promotes data accessibility, transparency, and reproducibility across the research lifecycle. This work presents the approach adopted in the HOMEROS (Harmonizing Observations from Multi-hazard Environments in Research for Open Science) project, focusing on the organization and harmonization of seismological and geodetic datasets in specific areas of Greece. The paper describes the infrastructures, standards, and workflows used to manage seismic waveform data, earthquake catalogues, GNSS data and products, and seismic hazard assessment outputs, with particular emphasis on metadata consistency, provenance, and reproducibility. By integrating national resources with European research infrastructures such as European Plate Observing System (EPOS), European Integrated Data Archive (EIDA), GNSS Data and Product Services, and the European Open Science Cloud (EOSC), HOMEROS supports the transition from fragmented datasets to interoperable and well-documented digital research objects. The results demonstrate that coordinated data stewardship practices can improve data quality, facilitate multi-hazard analysis, and enhance the visibility and reuse of solid Earth observations, strengthening the role of Greek infrastructures within the European research ecosystem.

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Non-technical summary Seismological and geodetic observations help scientists understand earthquakes, ground deformation, and seismic hazards. These observations generate large amounts of data that need to be carefully organized, documented, and shared so they can be reliably accessed and reused. The HOMEROS (Harmonizing Observations from Multi-hazard Environments in Research for Open Science) project addresses this challenge by improving the organization and accessibility of seismological and geodetic datasets from selected areas of Greece. These include ground motion recordings, earthquake catalogues, satellite-based measurements of ground movement, and information used in seismic hazard assessment. By applying consistent methods for describing, managing, and sharing these datasets, HOMEROS makes them easier to find, understand, verify, and reuse. The project also connects Greek data resources with European research infrastructures, including EPOS, EIDA, and the European Open Science Cloud (EOSC), helping researchers share information and collaborate more effectively. These efforts support more transparent and reproducible scientific work and make it easier to combine different observations when studying earthquakes and related hazards. Ultimately, HOMEROS contributes to more accessible and reusable Earth science data while strengthening the connection between Greek and European research infrastructures.

1 Introduction

The rapid expansion of observational capabilities in the solid Earth sciences has generated a vast volume of seismological and geodetic resources, ranging from dense seismic and high-rate GNSS networks recording and providing vast amount of data to continuous satellite-based deformation products. These include raw data, metadata and derived scientific products. However, their diversity in formats, acquisition strategies, temporal resolution, and metadata depth introduces significant interoperability challenges often hindering their effective integration and reusability (Bailo et al., 2020). As observational datasets continue to expand in both

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volume and complexity, the gap between data availability and data usability has become a key limitation for reproducible and data-intensive research. Without harmonized metadata, persistent identifiers, and well documented provenance, even openly accessible data remain difficult to use, integrate, and reuse at scale.

To address these issues, the Earth-science community is increasingly embracing Open Science practices and data stewardship frameworks aimed at improving transparency, accessibility, and reproducibility across the research lifecycle, including the FAIR (Findable, Accessible, Interoperable, Reusable) Guiding Principles (Wilkinson et al., 2016) and best practices emerging from large research infrastructures (RIs) and international initiatives such as Global Earth Observation System of Systems (GEOSS) and the EOSC (European Commission and Directorate-General for Research and Innovation, 2019). These approaches promote transparent data usage, machine-actionable metadata, persistent identifiers, standardized access protocols, and community-aligned data standards to enable interoperability across heterogeneous observational domains.

Building on these challenges, the HOMEROS (Harmonizing Observations from Multi-hazard Environments in Research for Open Science) project focuses on the practical application of Open Science practices to solid earth resources for selected areas in Greece, ensuring their integration into the broader European Open Science ecosystem. The project addresses the management of seismological (e.g., waveforms, parametric earthquake catalogues) and geodetic (e.g., GNSS measurements) data, metadata, and derived products, with emphasis on interoperability, provenance, quality control, persistent identification, and sustainable dissemination. Its main objectives are to:

I. consolidate and upgrade the management of seismological and GNSS resources within the Greek infrastructure landscape.

II. implement interoperable metadata and quality-control procedures compatible with European standards (e.g., FDSN StationXML, EIDA, and EPOS GNSS guidelines).

III. enhance transparency, citation, and licensing practices for Greek observational datasets.

IV. support long-term stewardship through repository services, persistent identification, and documented processing workflows.

HOMEROS applies two complementary frameworks for research-data stewardship, namely the FAIR and TRUST (Transparency, Responsibility, User Focus, Sustainability, Technology) principles. Within the Open Science framework, the FAIR principles support the discoverability and reuse of digital research objects (Jacobsen et al., 2020), whereas the TRUST principles address the reliability and long-term governance of the repositories that manage and preserve these objects (Lin et al., 2020). These complementary approaches help turn the overarching ideals of Open Science into actionable guidance for effective data stewardship (Figure 1).

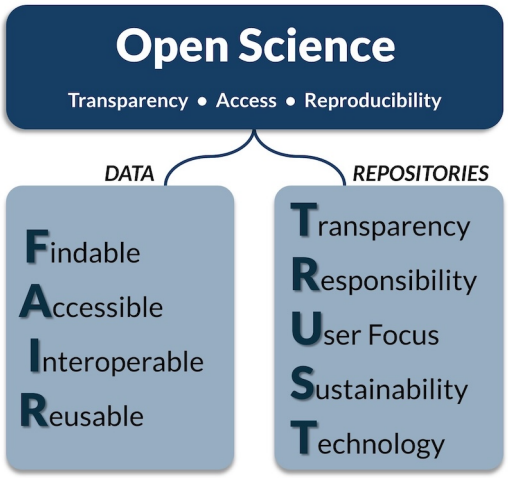


Figure 1 Conceptual relationship between Open Science framework, the FAIR principles (Findable, Accessible, Interoperable, Reusable), and the TRUST principles (Transparency, Responsibility, User Focus, Sustainability, Technology).

Within this broader framework, European and international research infrastructures, such as EPOS, GEOSS, ORFEUS/EIDA, and EOSC provide important services and standards for the discovery, access, and reuse of solid Earth data (Cocco et al., 2022). However, applying these principles across heterogeneous seismological and geodetic resources remains challenging because of legacy formats, differences in metadata practices, and discipline-specific processing approaches. Community standards such as StationXML, QuakeML, MiniSEED, and SINEX provide an important basis for interoperability and cross-disciplinary workflows (Bailo et al., 2022).

At the same time, the long-term scientific value of seismological and geodetic observations depends not only on the FAIRness of the data but also on the trustworthiness and sustainability of the repositories that curate them. Waveform and GNSS archives must remain functional and reliable for decades. TRUST principles provide a structured approach for evaluating whether repositories can meet these expectations by emphasizing governance clarity, transparent curation policies, technological resilience, and long-term sustainability planning. Recent evidence from the seismological community underscores the practical impact of these principles. In this context, practices such as persistent identification, open licensing, and standardized citation contribute to the visibility, traceability, and reuse of research data (Pedersen et al., 2025). Open Science principles, underpinned by FAIR and TRUST, provide a framework for effective and sustainable stewardship for solid Earth data (Table 1).

The present report focuses on selected HOMEROS pilot implementations through which these principles were applied to seismological and geodetic resources. Particular attention is given to waveform and earthquake-catalogue products, GNSS time series and metadata, Interferometric Synthetic Aperture

	Purpose	Target	Relevance to Solid Earth resources
Open Science	Promote transparency, accessibility, reproducibility, and participation across the research lifecycle	Entire research ecosystem	Encourages sharing waveform and GNSS data, open analysis tools, reproducible workflows
FAIR principles	Improve discovery, access, interoperability, and reuse of digital objects	Data, metadata, services	Standardized metadata (StationXML, QuakeML), DOIs, provenance, QC
TRUST principles	Ensure long-term reliability and governance of repositories	Data repositories, archives, infrastructures	Reliable waveform archives (EIDA), GNSS repositories

Table 1 Summary comparison of the Open Science framework and the FAIR and TRUST principles and their complementary roles in supporting solid Earth science data stewardship.

Radar (InSAR) derived deformation products, quality-control procedures, provenance documentation, and repository-based dissemination. The manuscript distinguishes between practices implemented or tested within the project and activities that remain under development or depend on broader institutional and European integration. The aim is therefore not to claim comprehensive harmonization of the wider Greek research-data landscape, but to document the workflows, data-management practices, and pilot resources developed within HOMEROS and assess their potential contribution to more interoperable, traceable, and reusable solid Earth research.

2 HOMEROS Project Overview and Study Areas

HOMEROS aims at Harmonising Observations from Multi-hazard Environments for Research in Open Science (https://oscars-project.eu/projects/homeros-harmonising-observations-multi-hazard-environments-research-open-science), under the Open Science Clusters Action for Research & Society (OSCARS; https://oscars-project.eu) framework. The project investigates the challenges of standardizing geoscience research workflows when integrating diverse data sources and services that support key geohazard variables in Seismology, Geodesy, and Geology. The project leverages data, tools, and services from Research Infrastructures, local resources (both institutional and national), and resources from the EOSC nodes and federation whenever and wherever possible. Through the integration of diverse datasets, including external data and service providers such as Copernicus (European Parliament and Council of the European Union, 2021), diverse aspects of Earth observation and hazard assessment are investigated.

More specific, HOMEROS in a streamlined manner, followed by an in-depth description of the enhanced seismological and geodetic workflows, metadata, and documentation—with direct machine-actionable references to their accessible repositories (such as the HOMEROS Zenodo community). Building on the project's pilot implementations, special emphasis is placed on how HOMEROS leverages the EOSC EU Node to bridge institutional computing disparities. Specifically, while machine-learning-assisted seismic analyses are driven by interactive notebooks, demanding geodetic workflows utilize Virtual Machines to process 24-hour GNSS RINEX datasets into Integrated Water Vapour measurements for atmospheric and hydrological monitoring. The use of VM snapshots ensures full reproducibility, standardized environments, and potential continuous processing. Finally, to demonstrate its role in setting new standards for the Greek seismological and geodetic community, the paper details how these robust results and open outputs are actively adopted and integrated by other national academic and institutional stakeholders, such as through collaborative hazard assessment frameworks and training initiatives.

Therefore, HOMEROS project brings together a multidisciplinary consortium of Greek Universities with longstanding expertise in Seismology, Geodesy, Geology, and research-infrastructure development. The core Greek partners include the Aristotle University of Thessaloniki (AUTh) and the National and Kapodistrian University of Athens (NKUA), both operating key national seismological and GNSS monitoring facilities and contributing data to EPOS, ORFEUS/EIDA, and other European research infrastructures. These partners were supported by the University of Lund, which contributes expertise in interoperable metadata models, data-lifecycle management, and e-infrastructure integration. Collectively, the consortium covers the full research workflow from data acquisition and quality control to open dissemination and long-term stewardship.

Beyond institutional coordination, the HOMEROS implementation explicitly recognizes that the scientific value of observational infrastructures depends on data precision, quality control, temporal continuity, spatial coverage, reproducibility, and provenance. These characteristics are not merely technical details but core scientific attributes that determine whether observations can be reliably exploited for scientific applications including statistical analysis and the physical interpretation of underlying geodynamic processes. HOMEROS therefore treats data characteristics and research methodology as integral elements of its implementation strategy, embedding quality assurance and documentation across all workflows described below. Within the project timeframe, these elements were addressed primarily through pilot implementations and demonstrator workflows applied to selected datasets and study areas, rather than through full-scale operational harmonization of all national resources.

The scientific activities of HOMEROS focus on selected areas in Greece, each of which encompasses a relatively homogeneous fault population and active deformation regime, thus constituting natural laboratories for multi-hazard assessment and for testing advanced seismological and geodetic data workflows. The central Ionian Islands, along with the western Gulf of Corinth, accommodate the highest seismicity in the eastern Mediterranean, exhibiting high deformation rates and frequent occurrences of strong (M > 5.0) earthquakes. The area of the central Ionian Islands (Figure 2) comprises the Kefalonia Transform Fault Zone (KTFZ), the most prominent strike-slip structure in the eastern Mediterranean, an active boundary between the Hellenic Subduction Zone and continental collision between the Eurasian lithospheric plate and Adriatic microplate. The area is marked by persistently high seismicity rates, hosting several $M_w \geq 6.0$ earthquakes over the past decades as well as in the historical era (Papadimitriou, 2002; Karakostas et al., 2015; Papadimitriou et al., 2017; Kourouklas et al., 2023). Moderate magnitude mainshocks (5.0 < M < 6.0) also generate their own notable seismic sequences, as illustrated by recent examples such as the 2019 M_w 5.4 offshore north Lefkada seismic swarm (Kostoglou et al., 2020), the 2022 M_w 5.5 off-shore Kefalonia sequence (Bonatis et al., 2025) and the 2024 swarm–like activity on the northern part of Kefalonia island (Anagnostou et al., 2025). The western Gulf of Corinth (wGoC; Figure 2) constitutes one of the most rapidly extending continental rift systems, with extension rates reaching 10–15 mm/yr (Briole et al., 2021), also hosting both moderate and large ($M_w \geq 6.0$) earthquakes as well as swarm-like seismicity (Bountzis et al., 2025; Kaviris et al., 2021; Serpetsidaki et al., 2023). Recent seismic hazard studies, including a logic-tree–based probabilistic seismic hazard assessment for the central Ionian Islands (Kaviris et al., 2024) and a combined probabilistic and scenario-based seismic hazard assessment for the western Gulf of Corinth (Kaviris et al., 2022) have demonstrated the necessity of enhancing and expanding relevant actions.

Complementing the seismological observations, geodetic datasets concerning the above areas include long-term GNSS analyses (e.g., 2001–2016; Bitharis et al., 2023), while combined seismological and geodetic investigations in the Ionian Islands (2014–2018) have documented intricate co-seismic and interseismic deformation patterns (Sakkas et al., 2022). Such geodetic products are central to HOMEROS, as they highlight the need for interoperable, reproducible processing pipelines and harmonized metadata to support cross-disciplinary solid Earth research.

The remarkable 2025 Santorini – Amorgos seismic crisis, associated with the Santorini volcano unrest, challenged HOMEROS to expand its initial selection of study areas, by incorporating seismological data of significant size and quality, along with high quality geodetic observations. The Santorini volcano is well known for its explosive eruptive history, persistent microseismicity, and sensitivity to magmatic and hydrothermal processes, all of which produce measurable deformation signals across the Santorini caldera. In early 2025, Santorini volcano exhibited intense and complex unrest, as documented by high-precision relocated seismicity (Karakostas et al., 2025; Lomax et al., 2025). This earthquake catalogue encompasses high precision earthquake locations that were achieved using the NLL-SSST-coherence relocation method (Lomax and Henry, 2023; Lomax and Savvaidis, 2022). Phase arrival data were sourced from the bulletins of the Geophysics Department of the Aristotle University of Thessaloniki (1981) and the National Observatory of Athens (1975). A substantial portion of microseismicity in the study area was analyzed within the framework of the project by its members. The rapid compilation of this relocated catalogue, published on 31 March 2025 through the established workflows of the HOMEROS project, significantly advanced our understanding of the physical processes responsible for this extraordinary seismicity. The seismological observations reveal a marked reactivation of shallow magmatic processes, including migrating seismicity along pre-existing structural pathways, indicative of magma or fluid movement at shallow depth (Lomax et al., 2025). These seismic patterns were accompanied by a rapid inflationary trend and abrupt changes in deformation rates (Sakkas et al., 2025). High-resolution GNSS and InSAR data subsequently confirmed a deformation pattern consistent with a rebounding shallow dike intrusion beneath the Anydros basin (Lomax et al., 2025). Together, these observations indicate that the 2025 unrest episode constitutes the most significant geodynamic perturbations documented at the Santorini seismovolcanic center to date, providing a valuable dataset for evaluating the HOMEROS framework. The episode underscores the importance of harmonized, interoperable, and provenance-rich seismological and geodetic data, as accurate modeling of volcanic unrest requires the coordinated use of broadband waveforms, and dense microseismic catalogues along with continuous GNSS time series and InSAR deformation fields.

3 HOMEROS Project Implementation: Applying Open Science Principles to the Greek solid earth resources

3.1 Harmonizing Seismological Resources

HOMEROS treats seismological resources as first-class digital objects whose scientific value depends critically on consistent formats, comprehensive metadata, documented provenance, and sustainable publication pathways. The project's seismological workflow therefore focused on (i) creating harmonized and machine-actionable data products (waveform archives, relocated earthquake catalogues, and seismic hazard assessment datasets), (ii) implementing reproducible processing pipelines that capture provenance, and (iii) ensuring that the resulting digital objects are aligned with Open Science principles.

Through the project's community repository on Zenodo (https://zenodo.org/communities/homeros/records?q=&l=list&p=1&s=10&sort=newest), HOMEROS presents seismological datasets constructed in ad-

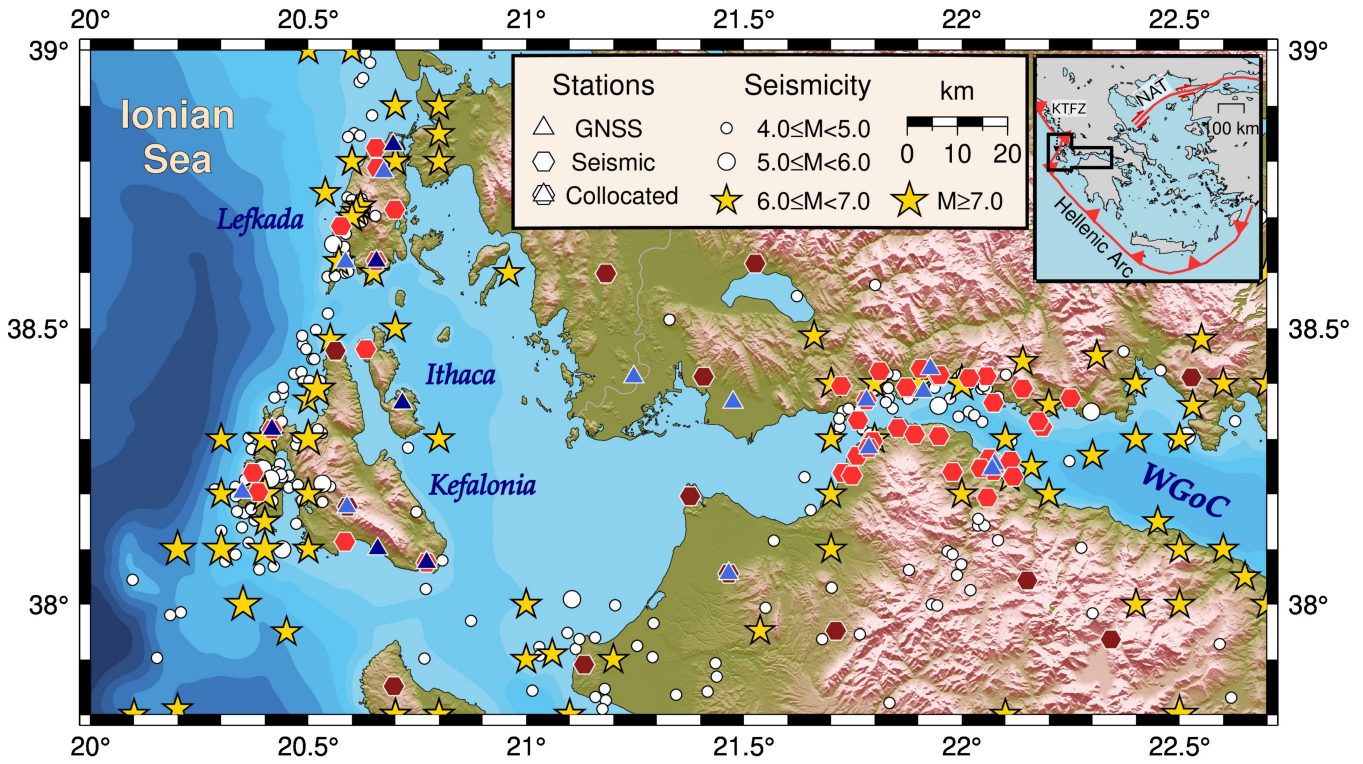


Figure 2 The central Ionian Islands and western Gulf of Corinth area. White circles denote the epicentres of instrumental earthquakes with M > 4.0 since 2011, while yellow starts indicate all known historical earthquakes with M $\geq$ 6.0. The earthquake data presented were compiled from the earthquake catalogue maintained by the Geophysics Department of the Aristotle University of Thessaloniki (AUTh; https://seismo.auth.gr/en/seismicity-catalogs/). Dark red hexagons illustrate seismic stations operated by the Seismological Station of the Geophysics Department of AUTh (AUTh; https://seismo.auth.gr/) and the Section of Geophysics-Geothermics of the Department of Geology and Geoenvironment of the National and Kapodistrian University of Athens (NKUA; http://www.geophysics.geol.uoa.gr/), whereas red hexagons indicate stations whose recordings are available online through the European Integrated Data Archive (EIDA) node hosted by the Institute of Geodynamics of the National Observatory of Athens (GEIN-NOA) (https://eida.gein.noa.gr/). Dark-blue triangles indicate GNSS stations included in the HOMEROS project framework and maintained by either HermesNet of AUTh or GL-NKUA, whereas light-colored triangles depict other operational GNSS stations in the study area. Superimposed triangle and hexagon symbols indicate collocated GNSS and seismic stations. The inset map shows the territory of Greece, with the study area enclosed by the black polygon, together with the main regional seismotectonic features, including the Kefalonia Transform Fault Zone (KTFZ), the North Aegean Trough (NAT), and the Hellenic Arc.

herence to Open Science data publication practices agreed by the scientific community. Relocated earthquake catalogues and seismic hazard datasets are provided in formats that are widely used in their respective scientific communities, with accompanying descriptions of their content, provenance, and intended use. More detailed information on data-management and methodological aspects is provided through the Data Management Plans (DMPs) developed within the Hellenic academic and the seismological communities, through close collaboration with the Hellenic Academic Libraries Link (HEAL-LINK; https://www.heal-link.gr) and using the OpenCDMP platform (https://dmp.heal-link.gr/explore-descriptions). The HOMEROS project acknowledges existing limitations in data production and publication workflows that can restrict alignment with Open Science principles and best practices. Within HOMEROS, such challenges are addressed through the application of workflows that progressively improve metadata completeness, quality-control tests and the persistent identification and publication of datasets. Specific examples include the validation and structuring of seismological waveform metadata and the documentation of processing parameters and uncertainties for GNSS products. These practices provide a more consistent basis for data discovery, interpretation, and reuse.

Additionally, HOMEROS improves the statistical robustness of downstream analyses by providing manually picked earthquake catalogues for the enforced standardized quality-control procedures, include validation of station metadata and instrument responses against the StationXML records of the contributing networks, per-station noise characterization used to define the operational station set, quality based weighting in the manual picking stage aided by the NonLinLoc software (Lomax et al., 2000) and HYPOINVERSE (Klein, 2002). This reproducible pipeline is, described in the DMPs that accompany the compiled catalogues (https://dmp.heal-link.gr/explore-plans/overview/public/37692484-26aa-42fb-9bcf-3582dac0ca3c).

Among the data products made publicly avail-

able by the HOMEROS project, is a manually picked earthquake catalogue for the central Ionian Islands area, for one year period in 2024 (https://doi.org/10.5281/zenodo.17910322 and its accompanying description in the HOMEROS seismology DMP (https://dmp.heal-link.gr/explore-plans/overview/public/6866f02b-edd6-42b1-a0a9-5544c095b87b). An intense earthquake swarm took place in the offshore area north of Kefalonia Island during the first months of 2024. The earthquake catalogue prepared and curated by the HOMEROS project includes approximately 5400 earthquakes for the first 4 months of the year, significantly exceeding the number of earthquakes located through routine analysis (~290 events for the same 4 month period when the swarm was most active). Figure 3 presents a comparison of Root Mean Square Error (RMSE) values for matched earthquakes between the HOMEROS catalogue, and the routine analysis catalogue provided by the Greek Seismological Institutions. For 895 matched earthquakes throughout 2024, using a 3 second time tolerance, the HOMEROS catalogue exhibits a clear skew toward lower RMSE values, indicating an improvement in statistical quality metrics achieved by careful manual picking and consistent timing accuracy, quality-based weighting of the picked phases and uniform noise characterization criteria, a workflow described in the "2024 Central Ionian Islands earthquake dataset" description of the HOMEROS seismology DMP. The published catalogue is also compiled using a velocity model dedicated for the study area by Haslinger et al. (1999), in contrast to the published routine catalogues that utilize a generalized velocity model for the Greek territory. The resulting catalogue is substantially more complete than previously published catalogues for the same area and period, contributing to a better understanding of the seismicity of the central Ionian Islands.

Explicit documentation of processing parameters and uncertainties in the DMP descriptions of each published catalogue as well as in the catalogue repository descriptions, allows these factors to be systematically propagated into subsequent analyses, including earthquake relocation, seismicity rate estimation, seismic hazard assessment, and physical interpretation of source processes. In this way, data quality and methodological transparency are essential for improving the reliability of statistical inference and enabling the detection of even subtle geophysical phenomena.

HOMEROS actively participates in testing and evaluating cutting-edge services and products that promote FAIR principles, such as the EOSC EU Node services (https://open-science-cloud.ec.europa.eu/) and NAAVRE services (Zhao et al., 2022, https://naavre.net/). Within this context, a demonstrator was developed that integrates machine-learning seismological workflows with a unified data harmonization pipeline (https://doi.org/10.5281/zenodo.22745993). The workflow processes raw seismic waveform data into validated, documented, and openly accessible seismological products through reproducible interactive environments implemented in Jupyter Notebooks. Figure 4 illustrates the complete end-to-end pipeline: waveform ingestion, automated

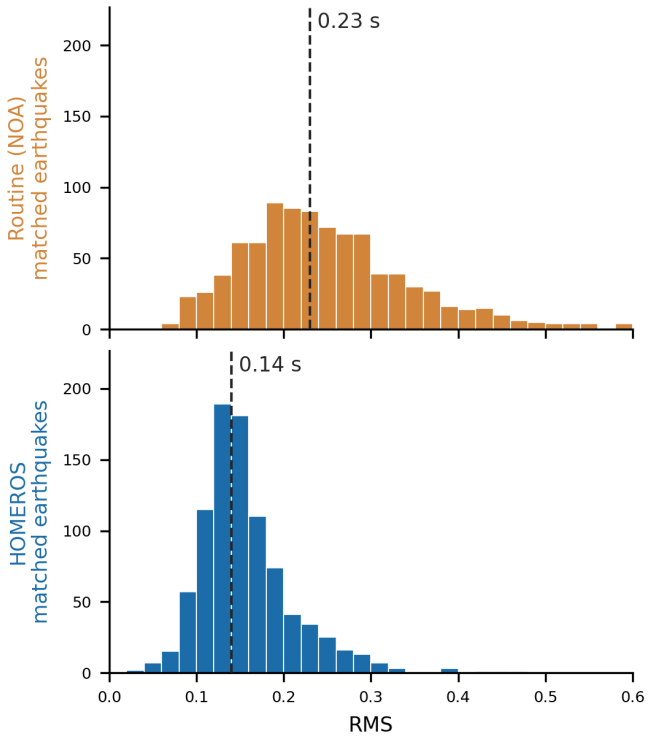


Figure 3 RMS error comparison between the HOMEROS catalog (bottom panel) and the routine catalog published by the Greek seismological institutes (upper panel) for 895 matched earthquakes and for the central Ionian Islands area during 2024. Earthquakes were matched within a 3 second tolerance window.

quality control, metadata validation, format conversion, provenance tracking, and catalogue compilation, accompanied by simple visualization products (e.g., maps) and phase file outputs, ready to be fed to classical epicenter relocation software packages (e.g., HypoDD). This notebook was developed as part of the continuing evolution of the EOSC EU Node platform and was utilized during the infoshare webinar of the platform services by the Special Interest Group on Research Engagement Development (SIG-RED) (https://events.geant.org/event/2130/) alongside a second use case of the virtual machines service of the EU Node and its application in the reproducible processing of geodetic data. A virtual laboratory based on this demonstrator is also available through the NAAVRE services, a user-centric platform built to allow the creation of customizable Virtual Labs that support the whole research lifecycle and is already being used by postgraduate students of the Geophysics Department of AUTh as a learning tool for ML applications in Seismology (https://beta.naavre.net/vreapp/vl/homeros-seismology).

A core element of the HOMEROS project is to offer a simple yet effective pathway for making geohazard datasets accessible. A key application of this objective is seismic hazard assessment, which relies on simulations to estimate ground–shaking intensity measures, such as Peak Ground Acceleration (PGA) and Peak Ground Velocity (PGV). These outputs are often presented only as maps within publications, rendering

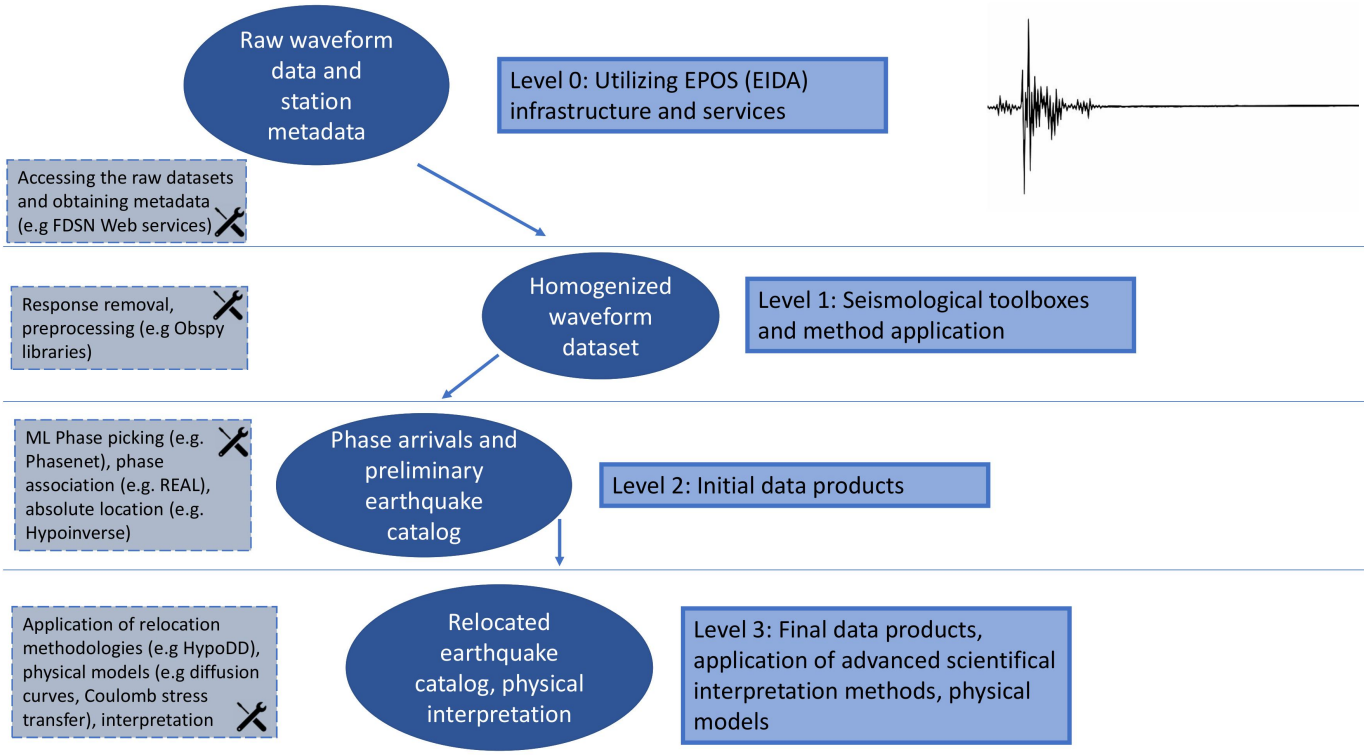


Figure 4 Seismological data pipeline, from raw waveforms to catalogue creation and physical interpretation using Machine-Learning Pickers.

their integration in other processes (e.g., multi-hazard assessment) extremely difficult if not impossible. In HOMEROS, we provide seismic hazard simulations for various areas as examples of openly available, machine-actionable data sources. For this reason, we follow specific principles in simulating and exposing the results (Figure 5). As the core computational block of our workflow, we use the OpenQuake engine (Pagani et al., 2014), an open-source Python-centric project aiming to facilitate seismic hazard studies. Probabilistic Seismic Hazard Assessment (PSHA) utilizes two fundamental elements for simulations, i.e., seismotectonic models and Ground Motion Models (GMMs). We utilize openly available seismotectonic models provided by the European Facilities for Earthquake Hazard and Risk (EFEHR; www.efehr.org). Specifically, we used the European Seismic Hazard Model (ESHM) of 2013 (ESHM13) and 2020 (ESHM20), which provide the spatial extent and characteristics of seismic zones across Europe (Woessner et al., 2015; Danciu et al., 2021). These models are provided in standardized formats (shapefiles), able to be ingested by various solutions.

While the seismotectonic models are openly available, we used a hazard-oriented earthquake catalogue, extended from an existing catalogue, to better characterize the seismicity patterns across Greece (Makropoulos et al., 2012). The latter catalogue was built on earlier works from Makropoullos and Burton (1981) and Makropoulos et al. (1989), extending the catalogue with earthquakes up to 2009 (Makropoulos et al., 2012). We updated the catalogue through 2023 using the same methods as the 2012 study. We retrieved new earthquake data from the ISC Bulletin (International Seismological Centre, 2026) and converted body-wave magnitudes (m_b) to surface magnitude (M_S) and, then, M_w. Unlike the original publication, our update also includes the raw post-2009 ISC m_b values, for reproducibility purposes. The dataset includes all earthquakes with $M_w \geq 4.1$ across all focal depths, allowing users to isolate crustal or intermediate-depth seismicity for their specific applications. This new catalogue for Greece was made available in the context of HOMEROS, with the proper documentation detailing the extension process, under the CC-BY-4.0 license (Zymvragakis et al., 2026a). Specifically, the parameters a and b of the earthquake magnitude distribution described by the Gutenberg-Richter (GR) law (Gutenberg and Richter, 1944) were computed using the maximum likelihood method (Aki, 1965; Wiemer and Wyss, 2000). In the context of the broader PSHA workflow, we demonstrate this method in an openly available Jupyter Notebook (Spingos et al., 2026) (accessible at https://doi.org/10.5281/zenodo.20734480 and https://github.com/homeros-oscars-project/homeros-

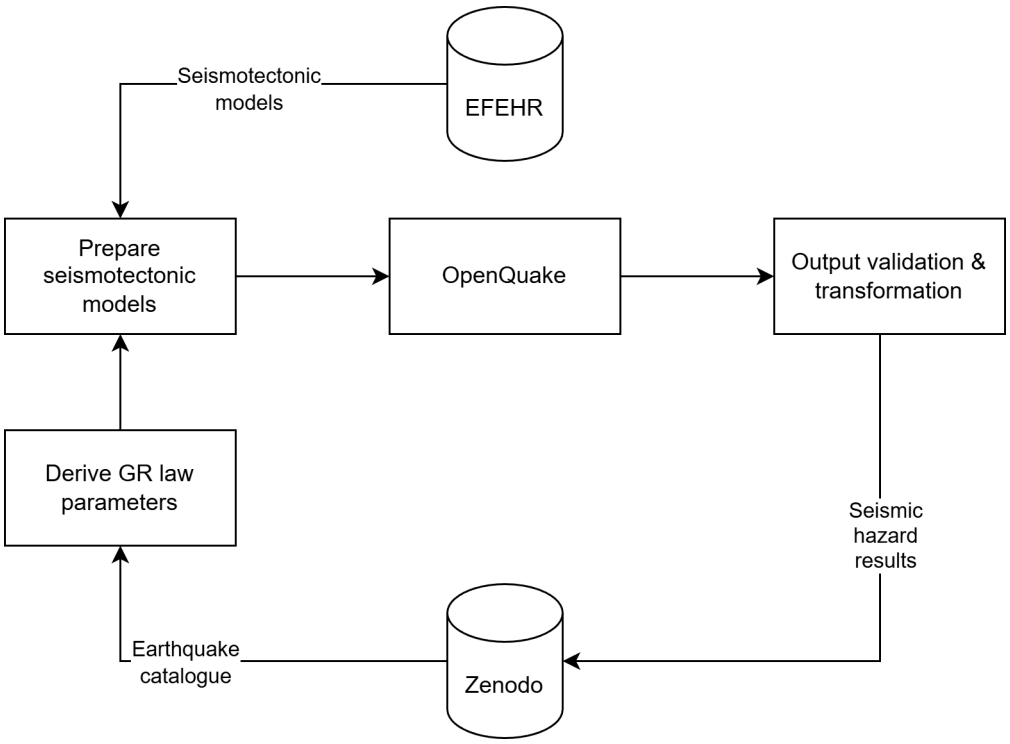


Figure 5 Simplified data flow for probabilistic seismic hazard assessment in HOMEROS. The seismotectonic models are obtained from the open EFEHR web-services, while the SL-NKUA Seismic Hazard Earthquake Catalogue is retrieved from Zenodo.

psha-notebooks).

The OpenQuake outputs of the simulations are provided in a new simplified CSV format. Within HOMEROS, we propose a simple, yet hopefully effective, data model to share PSHA simulations with researchers across hazard and risk domains, which may not be proficient in OpenQuake or XML handling, and who, possibly, use tools that are not inherently compliant with OpenQuake formats. The file format aims to provide structured data, which is easily parsable by both humans and machines (any programming language, whether backend- or frontend-oriented). We define the following attribute groups. Fields with the "node_" suffix describe the grid node. In the first version of the model, these refer to the identification ("node_id") and geographical coordinates ("node_longitude_deg" and "node_latitude_deg") in decimal degrees (in the WGS84 coordinate system). Then, the "hazard_" logical grouping aims to include the base information concerning the hazard outputs. For instance, "hazard_im_type" defines the intensity measure type of each record (e.g., PGA, PGV), while "hazard_value" holds the actual simulated value at that grid point. Moreover, by adopting this approach, a single file can contain multiple simulation results for different parameterizations (e.g., different intensity measures at different return periods). Finally, the "meta_" group of fields is used to assign various metadata concerning the dataset, such as "meta_source_models" for source models used and "meta_site" for characterizing the site effects of the node (as integrated in the calculations). For traceability reasons, the publication DOI associated with the values can be assigned at "meta_publication_doi", whereas the dataset's DOI can be provided under "meta_dataset_doi". A full description of the fields is provided in Appendix A. It is noted that the proposed model is applicable to seismic hazard map outputs, uniform hazard spectra and hazard curves.

Limitations of the CSV format include the absence of real entity relations. For example, to assign a specific DOI to a node (e.g., study source) for traceability, it would require greatly enlarging the file size. Moreover, the CSV format is highly compressible but is not inherently compressed. For small grids, sizing considerations might be negligible, but these characteristics introduce limitations to scalability. In any case, the last step before publishing the dataset to an open repository (e.g., Zenodo), accompanied by the necessary documentation to indicate their source and description, was to validate manually the OpenQuake output (through inspection of seismic hazard maps and histogram, to ensure the absence of artifacts) and transform it to the HOMEROS data model.

To date, we have released two datasets in the seismic-hazard-oriented approach of the HOMEROS framework, concerning the Aigio-Lykoporia zone (Zymvragakis et al., 2026c) and Foinikas Basin (Zymvragakis et al., 2026d). The latter has been integrated in a multi-hazard study in the area (Kaviris et al., 2026). Moreover, we have released a seismic hazard dataset compiled from two previous studies (Kaviris et al., 2022, 2024). Although the simulation methodology follows the same logic as that adopted in HOMEROS, the simulations themselves were developed independently; their data are therefore provided using the same format and structure as the newly generated simulations (Zymvra-

gakis et al., 2026b).

3.2 Harmonizing Geodetic Resources

Geodetic resources within HOMEROS encompass continuous GNSS time series, campaign measurements, derived displacement products, and multi-sensor auxiliary datasets such as InSAR deformation fields. Harmonizing these resources is essential because Greek GNSS infrastructures have historically operated with heterogeneous metadata schemas, diverse processing strategies, and non-uniform dissemination practices. HOMEROS addresses these inconsistencies by developing standardized workflows and interoperable data models in agreement with the broader Open Science and data stewardship principles. Metadata fields – covering antenna/receiver models, monumentation characteristics, calibration data, operational history, and data-quality indicators – are aligned with the EPOS GNSS Metadata Guidelines and mapped to machine-readable schemas such as GeodesyML and SINEX. This mapping provides a structured basis for documenting station characteristics, processing information, and data-quality attributes, and for assessing their compatibility with established European data-management practices. The workflow governing GNSS data registration, FAIR repository ingestion, metadata exposure through the forthcoming M^{3}G service, and subsequent processing is illustrated in (Figure 6).

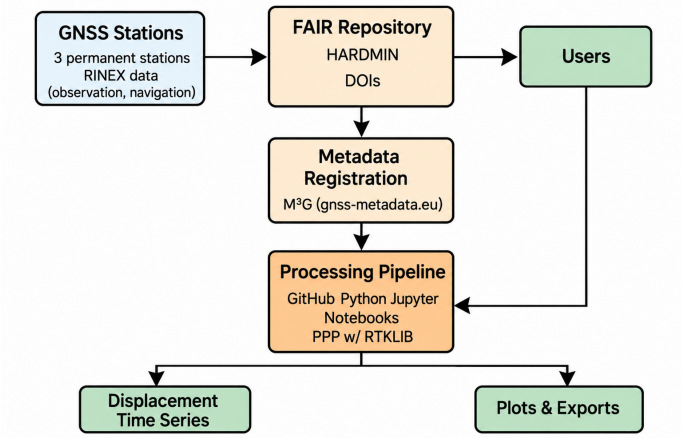


Figure 6 HOMEROS GNSS workflow: acquisition, metadata registration, processing pipeline, and publication of displacement time series.

The strategic installation of three high-precision, permanent GNSS stations, collocated with existing seismological stations, on Lefkada and Kefalonia Islands, represents a significant milestone for the HOMEROS project in its effort to harmonize multi-hazard observations across the central Ionian Islands area. By reducing azimuthal gaps along the KTFZ , these stations substantially enhance the spatial resolution and improve deformation monitoring in a region characterized by complex strike-slip and transpressional style of faulting. This infrastructure (3 new stations) provides high-frequency, continuous geospatial streams with millimetric precision, specifically designed to capture near-field deformation of $M_w > 5.0$ earthquakes and improve strain-rate estimations across fault segments with heterogeneous slip behaviors.

Beyond tracking steady-state interseismic and coseismic velocities, the stations offer the temporal resolution necessary to detect transient signals such as coseismic offsets, post-seismic relaxation, and slow-slip or swarm-related earthquakes. The GNSS time series from the permanent RATZ station, located in Ratzakli village in southern Kefalonia, provide an indicative example of this example (Figure 7). The time series reveals a period of relative stability, followed by a distinct geodetic offset observed in March 2026. Prior to a short data gap, the North and East components exhibit only minor fluctuations, while the vertical component remains stable around 136.470 m. However, post-gap observations suggest an abrupt displacement, consistent with a co-seismic or transient deformation signal. Such offsets are characteristic of localized tectonic activity frequently observed in the area of central Ionian Islands and highlight the importance of continuous, high-resolution GNSS monitoring. Data gaps, represented by linear segments in the time series, reflect periods of missing observations due to external factors and underline the necessity of robust data acquisition and quality-control procedures. These data streams are not merely raw coordinates; they serve as critical inputs for multi-hazard modeling, enabling deeper research into earthquake precursors, sea-level changes, and the geodynamic evolution of the Hellenic Arc.

In alignment with the OSCARS initiative, the data are managed under Open Science principles, with implementation guided by FAIR principles. These datasets will be openly available to the global scientific community through the project's integrated portal (like https://oscars-project.eu/projects/homeros-harmonising-observations-multi-hazard-environments-research-open-science) and Open Science repositories like Zenodo or EGI and Heal Link FTP access. The datasets will be made available through these dissemination pathways as they are finalized and published; the GNSS dataset for the Lefkada station is already available through the HARDMIN repository (https://hardmin.heal-link.gr/dataset/79c13cef-bb0b-496e-98ca-ea024d6e2a12; https://hardmin.heal-link.gr/dataset/7e497c83-1b13-47cb-8bc9-a7ac732cc68e; https://hardmin.heal-link.gr/dataset/eygiros-gnss-rinex-data-2026). Data are primarily served in RINEX (Receiver Independent Exchange Format) whereas further developments are planned to provide web-based map interfaces and dedicated APIs, facilitating interactive exploration and machine-to-machine access. This supports a range of downstream geodetic analyses, including static and Real-Time Kinematic (RTK) positioning, as well as the estimation of Tropospheric Zenith Total Delay (ZTD), thereby bridging geodetic observations with meteorological applications for extreme weather monitoring. In our case, to meet the HOMEROS objectives, the GNSS stations are collocated with broadband seismological sensors, enabling the seamless integration of GNSS time series with seismic and Synthetic Aperture Radar (SAR) datasets to provide



Figure 7 GNSS time series (North; Lat, East; Lon, Up, H) for station RATZ (Kefalonia), showing a co-seismic or transient deformation signal in March 2026.

a comprehensive, multi-observational view of regional environmental and tectonic processes.

The emphasis on metadata completeness and structural consistency directly addresses the need to assess dataset suitability for scientific use. Within HOMEROS, a geodetic dataset is considered scientifically usable only when its positional precision, temporal continuity, processing strategy, and uncertainty characterization would be explicitly documented. These criteria enable users to evaluate whether a given GNSS time series is suitable for applications spanning from long-term tectonic velocity estimation to the detection of transient deformation signals associated with seismic or volcanic activity. By encoding such information directly in interoperable metadata records, HOMEROS ensures that data quality and limitations are not implicit assumptions but provide explicit documentation of relevant data-quality and processing attributes for the published resources.

HOMEROS does not replace institutional processing pipelines; instead, it harmonizes their outputs by defining a unified publication structure that includes machine-actionable time-series formats (CSV or TimeSeriesML), SINEX solution files, and associated metadata capturing processing strategies, applied corrections, and uncertainty parameters. These harmonized outputs form the backbone of cross-institutional analyses ensuring that displacement time series are transparent, reproducible and directly comparable across institutions. This harmonization also enhances the statistical robustness of geodetic analyses by minimizing inconsistencies in displacement estimates derived from different sources. Explicit documentation of reference frames, applied corrections, filtering strategies, and uncertainty models enables downstream users to propagate uncertainties consistently and integrate multiple datasets into regional- or national-scale deformation models. Such consistency is essential for robust statistical characterization of strain accumulation, co-seismic offsets, and post-seismic transients.

For Open Science dissemination and preservation, selected HOMEROS GNSS datasets are published

through HARDMIN, the Hellenic Academic Research Data Management and Preservation Infrastructure. The published records include the GNSS datasets from the newly installed stations in Lefkada and Kefalonia Islands, along with the associated metadata and documentation, where available. HARDMIN provides repository-based access to these resources, including persistent identification and versioning. By publishing GNSS time series, SINEX files, and InSAR-derived deformation products in HARDMIN, HOMEROS keeps its geodetic resources persistently accessible, citable, and curated, integrated with national Open Science services and complementing their dissemination via Zenodo.

The GNNS stations installed in the framework of HOMEROS project in Lefkada and Kefalonia Islands, are collocated with seismological stations, thus providing direct value for multi-hazard assessment through improved constraints on interseismic strain accumulation, refining estimations of locking-depth, enabling better calibration of probabilistic seismic hazard models, and supporting the validation of co-seismic rupture models. In addition, the 2025 unrest episode at Santorini demonstrated the critical importance of harmonized GNSS datasets for detecting rapid inflation episodes, dike – Intrusion signals, and transient deformation preceding major seismic bursts. The Ionian infrastructure now offers a comparable level of readiness for the early detection of deformation anomalies in this highly tectonically active area. Furthermore, high-rate GNSS supports landslide and coastal instability monitoring through the detection of slow slope instabilities, the monitoring of coastal uplift and subsidence, and the assessment of earthquake-triggered ground failures. Finally, integrating GNSS deformation fields, seismicity patterns, and InSAR displacement maps enables cross-validation of geophysical signals, reduces the likelihood of false positives, and improves the statistical detection of transient deformation, while providing stronger constraints for physics-based modeling.

The HOMEROS project also integrates satellite radar data into its geodetic workflows. InSAR observations derived from Sentinel-1 imagery are processed externally, yielding multi-temporal deformation maps and Persistent Scatterer Interferometry (PSI) products. The HOMEROS-specific contribution lies not in introducing a novel processing methodology, but in embedding this processing within a harmonized and reproducible data workflow. Metadata are generated systematically and capture acquisition geometry, temporal coverage, processing configuration, software versions, quality indicators, and other information required for reuse and interpretation. In parallel, processing steps, parameter settings, and execution environments are recorded to provide provenance traceability from the original Sentinel-1 acquisitions to the final deformation products. To guarantee harmonization, HOMEROS structures the processing and dissemination of these data around a four-level workflow, extending from open SAR acquisitions and their processing using SNAPPING (Foumelis et al., 2022), for the primary PSI results, to standardized PSI results, their associated metadata and their long-term archiving. As a subsequent processing step, ascending and descending Line of Sight (LOS) measurements are decomposed into East–West and vertical components. This process is illustrated in Figure 8 and provides a consistent pathway for integrating InSAR-derived deformation with GNSS displacement fields. A practical implementation of this workflow is provided for the Central Ionian Islands dataset archived on Zenodo (Foumelis et al., 2025), which is versioned under a persistent DOI and scheduled for six-monthly updates as new Sentinel-1 observations become available.

Quality Control (QC) is integral to the overall harmonization process. QC routines are applied systematically to GNSS and InSAR data to identify outliers, discontinuities related to equipment changes, atmospheric artifacts, and periods of reduced measurement precision. GNSS station jumps, multipath noise, and seasonal signals are detected through automated algorithms, while InSAR products undergo LOS-consistency checks, coherence filtering, and cross-validation with GNSS vertical and horizontal components. QC outcomes are incorporated into dataset-level metadata and maintained across the publication pipeline, enabling downstream users to interpret deformation fields with full awareness of their uncertainties, data gaps, and correction histories. Data packaging and publication follow the digital-object strategy established for seismological datasets. GNSS time series and LOS/vertical displacement products are stored in HDF5 containers linked to human-readable CSV metadata tables, whereas SINEX files guarantee long-term interpretability in internationally adopted geodetic frameworks. All geodetic products receive DOIs, version numbers, and open licenses, certifying both FAIR Findability/Accessibility and TRUST Sustainability/Transparency.

These quality-control and provenance practices directly enhance the reliability of seismological observations by reducing false signals and improving sensitivity to subtle deformation patterns. The synergy between GNSS and InSAR – including projection of GNSS time series into satellite LOS and joint temporal analysis – allows independent validation of deformation signals and strengthens confidence in the interpretation of transient and/or localized ground motion. Such integrated, quality-controlled datasets are essential for advancing statistical analyses of deformation rates, detecting low-amplitude signals, and supporting physics-based modeling of active tectonic and volcanic processes.

3.3 Integration with European service providers

HOMEROS aspires to demonstrate the alignment of Greek seismological and geodetic resources with major European research infrastructures and Open Science services. Within the project, selected datasets and workflows were implemented as pilots to evaluate their alignment with major European research infrastructures and Open Science services. These pilot activities provide examples of how domain-specific workflows can support cross-disciplinary discovery,

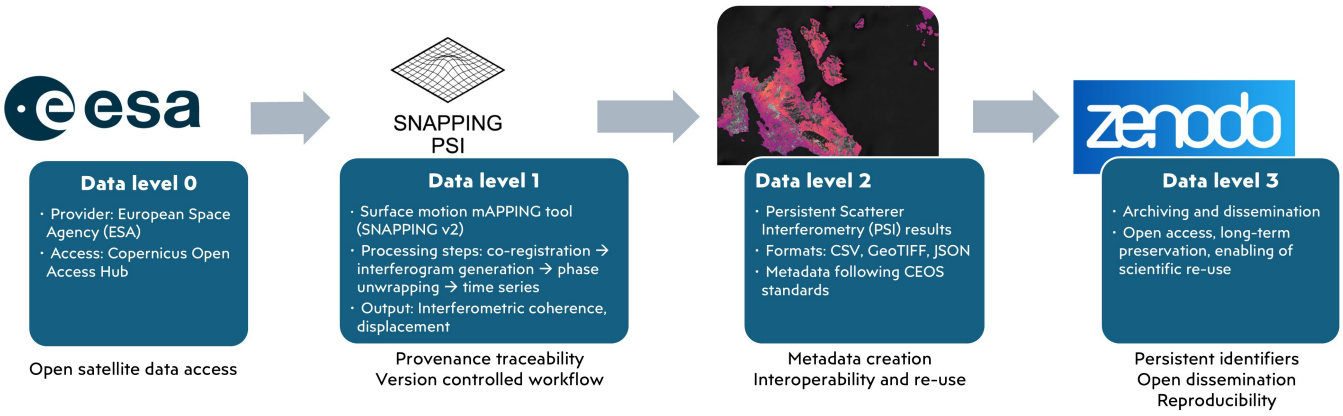


Figure 8 HOMEROS InSAR data processing and harmonization workflow, from open SAR acquisitions (Level 0) through Persistent Scatterer Interferometry (PSI) processing and LOS displacement estimation (Level 1), to standardized PSI products and metadata (Level 2) and their long-term archiving and open dissemination through Zenodo (Level 3).

machine-actionable access, and long-term scientific reusability. As part of the OSCARS (Open Science Clusters Action for Research & Society; https://oscars-project.eu) framework, HOMEROS serves as one of the Solid Earth demonstrators illustrating how domain-specific research workflows can be standardized, documented, and exposed through EOSC. By building reproducible pipelines, harmonized metadata structures, and openly accessible datasets, HOMEROS contributes to OSCARS' broader goal of increasing the readiness level of disciplinary services for integration into cloud-based federated research environments. This role is particularly relevant for data-intensive seismological and geodetic applications, where automated access, scalable processing, and clear provenance are prerequisites for advanced statistical analyses and machine-learning–based methods. The project also benefits directly from OSCARS policy guidelines, which ensure that HOMEROS outputs follow community-aligned practices for licensing, persistent identification, and interoperable publication. The resulting practices and resources provide a basis for future integration with EOSC services.

Integration with European Plate Observing System (EPOS; https://www.epos-eu.org) provides an important link between the HOMEROS architecture and the broader European research infrastructure landscape. EPOS provides the primary European framework for distributing seismological, geodetic, geological, and volcanological resources and the HOMEROS pilot activities were designed with consideration of relevant EPOS metadata standards. This provides a basis for evaluating the suitability of selected waveform archives for their intended use. For seismological waveform data and earthquake catalogues, the pilot workflows use FDSN StationXML, QuakeML, and waveform delivery mechanisms compatible with those used by EPOS Seismology services. For geodetic resources, selected GNSS station metadata, processed displacement time series, and SINEX solutions were prepared with reference to the EPOS GNSS Product Guidelines, providing a basis for future integration with the corresponding European services. Additionally, EIDA (https://www.orfeus-eu.org/data/eida/) provides an established pathway for data access and dissemination. HOMEROS leverages national EIDA nodes (AUTh and NOA) for the acquisition and distribution of L1 waveform data, which subsequently become inputs to the seismological dataset pipelines. By using EIDA-compliant APIs and adhering to its metadata-quality requirements, the pilot workflows can make use of established European data-access mechanisms. EIDA also provides established machine-to-machine (M2M) mechanisms for querying waveforms, station metadata and earthquake catalogues, facilitating the intergration of HOMEROS datasets andtheir future reuse by external users.

For GNSS data, the HOMEROS pilot activities make use of the metadata and data-management approaches associated with EPOS GNSS Data & Product Services and the M^{3}G metadata service, with selected GNSS resources being prepared and documented using persistent identifiers and structured metadata. These practices are intended to improve discoverability, interoperability, and future automated use of the data. Further integration of HOMEROS GNSS resources with European services remains subject to their publication and incorporation into the relevant infrastructures.

HOMEROS also extends its integration into the broader Open Science ecosystem through its planned alignment with the European Open Science Cloud (EOSC). The HOMEROS pilot implementations follow metadata, persistent-identification, and publication practices that are compatible with the broader objectives of EOSC and European Open Science initiatives. The resulting resources are intended to support future integration into EOSC-related services and catalogues, subject to the availability and adoption of the relevant integration pathways. Such future integration could facilitate the discovery of HOMEROS datasets beyond the immediate Solid Earth research community.

To provide an integrated overview of how HOMEROS activities align with the research-data lifecycle and the broader Open Science ecosystem, Table 2 summarizes the key actions performed at each stage – planning, acquisition, harmonization, analysis, dissemination, and long-term stewardship – along with the tools,

Key Activities	Open Science Enablers & Outputs
Planning & Data Collection • Mapping of available resources (EPOS, Copernicus, national networks) • Creation of Data Management Plans • Selection of FAIR-aligned practices	• Standard formats: QuakeML, StationXML, SINEX, HDF5
Data Integration & Analysis • Development of reproducible workflows • Metadata structuring and harmonization within selected pilot datasets • Quality control of seismic, GNSS, and InSAR data	• Harmonized metadata schemas • Machine-actionable workflows (M2M-ready) • Hybrid data packaging (HDF5 + CSV) • Institutional Git repositories
FAIR Outputs & Dissemination • Publication of validated datasets • DOI assignment and metadata enrichment • Open licensing	• Zenodo communities • HARDMIN repository • CC-BY / CC-BY-SA licenses
Preservation & Reuse • Long-term archiving • Continuous FAIR/TRUST improvement • Supporting reproducibility and interoperability	• EPOS & ENVRI-Hub • EOSC EU Node • Versioned datasets with DOIs

Table 2 Summary of HOMEROS activities and goals across research and data-lifecycle stages.

standards, and infrastructures that enable FAIR and TRUST-aligned implementation. This table consolidates the project's technical and organizational contributions into a unified framework, highlighting the maturity of HOMEROS workflows and their interoperability within the national and European research infrastructure landscape.

4 Perspectives and Challenges

The HOMEROS project demonstrates how a coordinated Open Science approach can significantly enhance the management, interoperability, and reuse of solid Earth observations in Greece. However, implementing FAIR and TRUST principles across the full research-data lifecycle also highlighted significant technical, organizational, and cultural challenges that must be addressed to ensure long-term sustainability of research – data stewardship.

A central lesson is the importance of managing the full end-to-end lifecycle of Solid Earth research resources. The project demonstrated that FAIRness must be supported from the earliest stages – data acquisition, sensor metadata preparation, and quality control – to downstream workflows such as harmonization, analysis, publication, and long-term archiving. In practice, this requires consistent metadata models, persistent identifiers (PIDs), and clear provenance tracking from first ingestion to final dissemination. Within the pilot implementations considered by HOMEROS, differences in metadata completeness, structure, and documentation were identified as practical challenges for the harmonization and reuse of observational resources. The project therefore focused on documenting these characteristics and on defining more consistent approaches for metadata preparation and data publication. By standardizing formats (MiniSEED, StationXML, RINEX, SINEX, GeoJSON, NetCDF) and adopting version-controlled repositories for code and datasets. HOMEROS established a more consistent framework for data and code management across the considered workflows, with the aim of supporting reproducibility and reuse. These practices provide a basis for future systematic evaluation of reproducibility across different use cases. This lifecycle-oriented perspective provides an important basis for improving the traceability of processing steps and for documenting the uncertainties associated with observational and derived products, thereby supporting their subsequent use in statistical analyses and hazard-related interpretations.

Equally important is the issue of storage, archiving, and long-term repository trustworthiness. HOMEROS highlighted the fragmented landscape in Greece, where data are stored across institutional servers, short-term project databases, and national infrastructures. Through the integration of Zenodo, HARDMIN, European Infrastructures nodes, and institutional repositories, the project advanced toward a more resilient and federated ecosystem. International community infrastructures (e.g., International Seismological Centre; ISC, International Federation of Digital Seismograph

Networks; FDSN) may provide additional complementary pathways for long-term access and dissemination of seismological resources. Yet challenges remain – long-term storage planning is often limited, disaster-recovery mechanisms vary among institutions, and the sustainability of national repositories depends on fluctuating funding structures. Differences in sensor types, acquisition protocols, and legacy metadata resulted in significant harmonization work, even before analysis or integration with OSCARS, EPOS, or EOSC services. While HOMEROS successfully demonstrated workflows for integrating seismic waveforms, GNSS time series, InSAR displacement fields, and geological data layers, sustaining this level of harmonization requires ongoing community coordination, shared vocabularies, and continuous standardization efforts.

Beyond technical barriers, the project underscored the importance of organizational and cultural factors. Adoption of Open Science practices remains uneven across Greek research institutions, and researchers often lack incentives for investing time in metadata enrichment, documentation, and data publication with open licenses. HOMEROS served as a catalyst by showcasing the benefits of FAIR-compliant workflows, including improved discoverability, simplified reuse, transparent provenance, and enhanced scientific visibility within European infrastructures. However, the long-term impact of these efforts will depend on systematic training, sustained support for data-management roles, recognition of data as a first-class research output, and institutional policies embedding Open Science into everyday research practice.

Looking ahead, HOMEROS establishes a strong foundation for further advancing Greece's integration into the European Open Science ecosystem. Future work should focus on operationalizing automated FAIR assessments, ensuring long-term repository sustainability, expanding machine-actionable metadata, and developing unified national policies for data licensing and preservation. By continuing to refine these components throughout the full data lifecycle, Greece can move towards a more coherent, interoperable, and future-proof framework for solid Earth research. In this context, further development will also focus on refining the conceptual and implementation-level descriptions of data products, ensuring that they are consistently characterized as computational or scientific data products rather than as formal metadata models in the strict DataCite sense. This will help avoid terminological ambiguity and ensure closer alignment with established community standards.

5 Summary

The HOMEROS project demonstrates how Open Science principles can be translated into practical workflows to strengthen the management, harmonization, and reuse of seismological and geodetic data in Greece. By focusing on improved consistency, documentation, and selected reproducible workflows, the project provides pilot examples for turning heterogeneous datasets into better documented and more reusable research outputs.

An important component of the work focused on seismological data. Within HOMEROS, earthquake waveform data, parametric seismicity catalogues, and seismic hazard products were organized using widely adopted community standards and formats, complemented by enriched metadata and clear documentation of their processing and production workflows. At the same time, reproducible processing pipelines were developed to cover the full workflow, from waveform acquisition and quality control through earthquake catalogue generation and hazard modelling. These workflows make it easier to understand how results are derived, assess their quality, and reuse them in new studies. Publishing the datasets through open repositories, together with versioning and the persistent identifiers, further enhances their discoverability, traceability, and reuse in applications such as seismicity analysis and probabilistic hazard assessment.

In parallel, the work on geodetic data highlights the importance of consistency in metadata, processing strategies, and data dissemination. In particular, the harmonization of GNSS datasets – especially those generated by the newly installed stations in Lefkada and Kefalonia – illustrates a transition from traditional observational archives towards interoperable, well-documented, and reusable digital data products. These time series are not treated simply as stored measurements, but as part of workflows that can be directly used in multi-hazard analyses. Supported by clear metadata, open access, and transparent processing workflows, these datasets facilitate both detailed local studies and broader regional investigations across the eastern Mediterranean.

More broadly, HOMEROS demonstrates that improving data usability requires a lifecycle – wide approach, encompassing all stages from acquisition and quality control through publication and long-term preservation. It also highlights that technical solutions alone are insufficient; consistent documentation practices, clear provenance, and alignment with established community standards are equally essential for ensuring that data remain accessible, interpretable, and reusable over time.

Overall, the project demonstrates how Open Science principles can be integrated into everyday research practices in the Solid Earth sciences. Its results contribute to the development of more reliable, well documented, and reusable datasets, support reproducible research, and strengthen the connection between Greek observational infrastructures and the wider European research ecosystem.

The manuscript provides a comprehensive summary of the project results and expanded descriptions of the publicly accessible HOMEROS resources. These include seismological catalogues and hazard datasets published through the HOMEROS Zenodo community; machine-actionable seismic-hazard outputs and the associated PSHA Jupyter Notebook workflow; the seismological machine-learning demonstrator implemented through reproducible Jupyter environments and the virtual laboratory; and harmonized GNSS resources and metadata

deposited through HARDMIN. The manuscript also describes how these outputs are connected to EPOS, EIDA, GNSS Data and Product Services, M^{3}G, OSCARS, and EOSC, thereby clarifying their relevance and potential reuse beyond the immediate project consortium.

Our study presents HOMEROS as an applied Open Science data-stewardship implementation for seismological and geodetic resources in Greece. The Introduction has been streamlined to state the project goals more directly, while the implementation sections provide concrete examples of how FAIR and TRUST principles are translated into operational practices, including standardized metadata, persistent identifiers, provenance documentation, quality-control procedures, reproducible workflows, open licensing, versioned datasets, and repository-based dissemination. The manuscript also explicitly distinguishes between practices demonstrated through HOMEROS pilot implementations and broader activities that remain under development.

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Data and code availability

The datasets, resources and supporting material described in this manuscript have been archived and are publicly available through the HOMEROS project's Zenodo repository (https://zenodo.org/communities/homeros/records?q=&l=list&p=1&s=10&sort=newest), and where applicable, through other repositories and services such as HARDMIN (https://catalogue.hardmin-dev.hellink.gr/dataset/79c13cef-bb0b-496e-98ca-ea024d6e2a12). The manuscript provides direct access links for the resources currently available.

Competing interests

The authors declare that they have no competing financial or non-financial competing interests.

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Appendix A. PSHA Data Model

Herein (Table A1), we present a detailed description of the proposed data model developed in the framework of HOMEROS. There are three main field groups: (a) "node_" characterizes grid or points of interest, (b) "hazard_" includes the actual simulated hazard values and accompanying information, and, (c) "meta_" contains related metadata.

Attribute	Data Type	Output	Description
node_id	string	All	Node identifier
node_longitude_deg	float	All	Longitude in decimal degrees (WGS84)
node_latitude_deg	float	All	Latitude in decimal degrees (WGS84)
hazard_im_type	string	All	Intensity measure type
hazard_statistic	string	All	Statistic of the hazard estimate (e.g., "mean" or "weighted mean")
hazard_value	float	All	Value of the intensity measure type
hazard_unit	string	All	Unit of hazard value
hazard_return_period_yr	integer	Maps and UHS	Return period (in years)
hazard_poe	float	Hazard curves	Probability of exceedance
hazard_timeframe	integer	Hazard curves	Timeframe of the probability of exceedance (in years)
hazard_period_s	float	UHS	Spectral period (in s)
meta_source_models	string	All	References, names or identifiers of seismic source models used (semi-colon separated)
meta_gmm_models	string	All	References, names or identifiers of ground motion models used (semi-colon separated)
meta_focal_mechanisms	string	All	Treatment of focal mechanisms
meta_site	string	All	Site conditions
meta_publication_doi	string	All	DOI of the associated publication
meta_dataset_doi	string	All	DOI of the dataset

Table A1 Descriptions of the proposed data model for simplified hazard outputs. Each attribute is accompanied by its description, data type and corresponding hazard output, i.e., hazard maps, Uniform Hazard Spectra (UHS) and hazard curves.