HOMEROS Open Science: integrated seismological and geodetic ecosystems

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Abstract: The HOMEROS project advances multi-hazard assessment through the integrated use of seismological and geodetic infrastructures within an Open Science framework. This paper presents the seismological and GNSS-based geodetic networks, data products, and processing workflows that underpin hazard monitoring and analysis in tectonically active regions of Greece, with emphasis on the central Ionian Islands and the western Gulf of Corinth. Dense permanent seismic networks provide high-resolution waveform data enabling precise earthquake detection, relocation, and source characterization. Complementary GNSS infrastructures, such as the Hermes network and GL-NKUA cGNSS, deliver continuous observations processed using Precise Point Positioning and kinematic techniques to quantify crustal deformation displacements, and atmospheric parameters. Integrated quality control, standardised processing pipelines, and interoperability through EPOS, EIDA, and institutional repositories ensure compliance with the FAIR data principles. The combined seismological and geodetic datasets support advanced applications, including high-accuracy earthquake catalogues, deformation monitoring, and physics-based ground motion simulations for seismic hazard assessment, demonstrated through seismic crises in the study areas. By harmonising heterogeneous observations and products, HOMEROS enhances reproducibility, data reuse, and collaborative research, providing a robust testbed for multi-hazard assessment in Greece and a transferable model for the broader European and global research community.

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1. Introduction

As the world faces increasingly frequent natural hazards such as earthquakes, floods, and landslides, the HOMEROS initiative, supported by OSCARS (`https://oscars-project.eu/`), aims to advance hazard assessment in Greece by leveraging open science practices and integrating high quality geodetic and seismological data. The project focuses on high-risk critical areas, combining diverse datasets to improve the understanding of multi hazard environments while promoting FAIR data principles and collaborative research.

In the frame of HOMEROS, collaboration between national and international institutions and universities is actively promoted and strengthened, bringing together partners such as the Aristotle University of Thessaloniki, the National and Kapodistrian University of Athens, the University of Patras, and Lund University, fostering interdisciplinary research, knowledge exchange, and strong international academic networking. Within the HOMEROS project, seismological and geodetic infrastructures serve as the backbone for monitoring and analysing natural hazards in multi-risk environments.

Seismological networks provide continuous recording, enabling the detection, location, characterization, and cataloguing of earthquakes whereas geodetic networks deliver high-precision measurements of ground deformation that capture both transient and long-term tectonic processes. Together, these infrastructures supply complementary datasets that are essential for understanding earthquake dynamics, assessing seismic hazards, and identifying interactions with secondary phenomena such as landslides and floods. Their integration within the HOMEROS Open Science framework ensures that hazard monitoring and assessment are both comprehensive and accessible, strengthening scientific knowledge and supporting risk mitigation strategies. In alignment with the FAIR data principles, HOMEROS research teams systematically disseminate a broad range of research outputs to the open scientific community, including conference papers, technical reports, posters, and curated datasets, through the dedicated HOMEROS Zenodo community repository (`https://zenodo.org/communities/homeros`), thereby ensuring transparency, accessibility, and reusability of the generated data and results.

2. Seismological infrastructure

2.1. Seismological network of the central Ionian Islands (CenIonNet)

Data from the dense CenIonNet seismological network strongly support the objectives of HOMEROS, supporting open science by providing high-resolution, high-quality observations that maximise scientific transparency, reuse, and collaborative potential. This happens because a dense seismic array captures detailed spatial and temporal variations in ground motion, enabling robust analysis of earthquake processes, fault dynamics, and seismic hazard. Being publicly shared through HOMEROS platform, these datasets will allow researchers across multiple disciplines and institutions to validate their results, compare methodologies, and develop innovative analysis techniques.

CenIonNet's long-standing open-data architecture is also fully aligned with the HOMEROS commitment to FAIR data principles and reproducible research practices. The network provides an interoperable dataset through EPOS and ENVRI-supported services and other open-science platforms, ensuring that waveform data, metadata, and processing information remain openly discoverable and consistently formatted. In addition, the standardised acquisition and processing procedures implemented at Geophysics Department of Aristotle University of Thessaloniki (GD-AUTh) provide a robust foundation for the development of open and reproducible analysis pipelines, including Jupyter Notebooks developed within HOMEROS, which enable the integration of seismological, geodetic, and other datasets within a unified multi-hazard environment.

Aiming to detail the characteristics of the CenIonNet, we begin with the first prerequisite that is the enhanced detectability of earthquakes. The step forward, which is the highly precise determination of their focal coordinates and magnitudes, is fundamental for rigorous seismological investigations and an indispensable component for the reliable seismic hazard assessment, a sustained societal demand. In the central Ionian Islands, this requirement has led to a long-standing collaboration between GD-AUTh and local authorities. The partnership was initially established with the Local Union of Municipalities of Lefkada, motivated by the 2003 M_w6.2 Lefkada main shock (*Karakostas et al., 2004*), and later continued with the Regional Union of Municipalities of the Ionian Islands (PED-IN), following administrative reorganization. Over the past decades, substantial improvements in network geometry have been achieved through this collaboration, leading to enhanced seismic monitoring across the Ionian Sea region. Since 2007, the local seismological network operated jointly by GD-AUTh and PED-IN has expanded the density and quality of observations in Lefkada, Kefalonia, Ithaki, and Strofades Islands. In its current configuration (up to 12/2025) the network comprises 11 permanent stations, all operating as part of the Hellenic Unified Seismic Network (HUSN, `https://doi.org/10.7914/SN/HL`). Nine out of these stations (namely, DRAG, EVGI, LKD2, NYDR, TSLK, DMLN, PSDA, RTZL, and ITHC) are located in the central Ionian Islands (Lefkada, Kefalonia, Ithaki) and are directly maintained through the GD-AUTh & PED-IN collaboration. Instrumentation at the nine central Ionian Islands stations includes broadband sensors such as CMG-40T (1–100 Hz and 30 s), Trillium Compact 120s, CMG-3ESP 100s, and Colt 60s seismometers, paired with 24-bit digitisers (RT130, Trident, Wrangler), see Table 1.

Table 1. Information on the permanent seismic stations operated jointly by GD-AUTh and PED-IN at the central Ionian Islands (Lekfada, Kefalonia, Ithaki).

Station	**Latitude (°N)**	**Longitude (°E)**	**Elevation (m)**	**Sensor**	**Sampling rate (samples/sec)**
DMLN	38.2385	20.3734	370	CMG-40T	100
DRAG	38.6839	20.5746	348	CMG-40T	100
EVGI	38.6210	20.6560	249	CMG-40T	100
ITHC	38.4622	20.6320	356	Colt	100
LKD2	38.7889	20.6578	485	CMG-3ESP	100
NYDR	38.7135	20.6983	14	CMG-40T	100
PSDA	38.1140	20.5841	48	CMG-40T	100
RTZL	38.0760	20.7715	103	Trillium Compact	100
TSLK	38.8249	20.6554	212	CMG-40T	100

The value of this dense and intensively maintained network has been demonstrated not only in several significant seismic sequences but also in moderate and more subtle seismic episodes. Most notably, the 17 November

2015 M_w6.5 main shock and its foreshock and aftershock sequence southern Lefkada, was evidently the first in Greece to be recorded by such a dense array of nearby stations, enabling high-precision seismicity relocation of the and the detailed delineation of the main rupture and the adjacent activated segments (*Papadimitriou et al., 2017*). Moderate activity since 2019 has provided further evidence of the network's capabilities. An M_w5.4 earthquake on 5 February 2019 north of Lefkada Island was recorded with sufficient detail to locate more than 250 aftershocks, delineating an activated structure extending from the northern Lefkada branch of the KTFZ toward the Adriatic–Eurasian collision belt (*Kostoglou et al., 2020*), thus shedding light at the up to that time unsolved geodynamic pattern of linking the transform KTFZ with continental collision. The 2022 M_w5.5 earthquake southwest of Kefalonia, although offshore, was recorded with sufficient resolution to delineate its aftershock patterns and activated fault structures, demonstrating that seismotectonic processes can be affectively characterised even when activity occurs at considerable distances offshore (*Bonatis et al., 2024*). The February–April 2024 swarm-like activity offshore the northern Kefalonia coastline, provides a further demonstration of the network's capabilities. Dense station coverage, combined with a machine learning workflow, enabled the detection and relocation of approximately ∼2500 earthquakes, achieving a remarkably low magnitude completeness threshold and minimal location uncertainties (*Anagnostou et al., 2025*).

The gradual densification of the network in the central Ionian Islands is clearly reflected in the azimuthal gap distribution (Fig. 1) comparing the network configuration without and with the GD-AUTh and PEDIN stations. The enhanced network geometry provides more balanced coverage from multiple directions, particularly in central Lefkada and central Kefalonia. Overall, the densification of the network has led to a substantial enhancement in azimuthal coverage, yielding heightened stability and precision of hypocentral determinations throughout the central Ionian Islands. The demonstrated capabilities of CenIonNet directly advance the core scientific goals of HOMEROS project, because they support the project's emphasis on dense, high-resolution observations for multi-hazard assessments. In this sense, the central Ionian Islands region constitutes an exemplary natural laboratory for integrated multidisciplinary analyses, in which methodologies can be developed, benchmarked and validated.

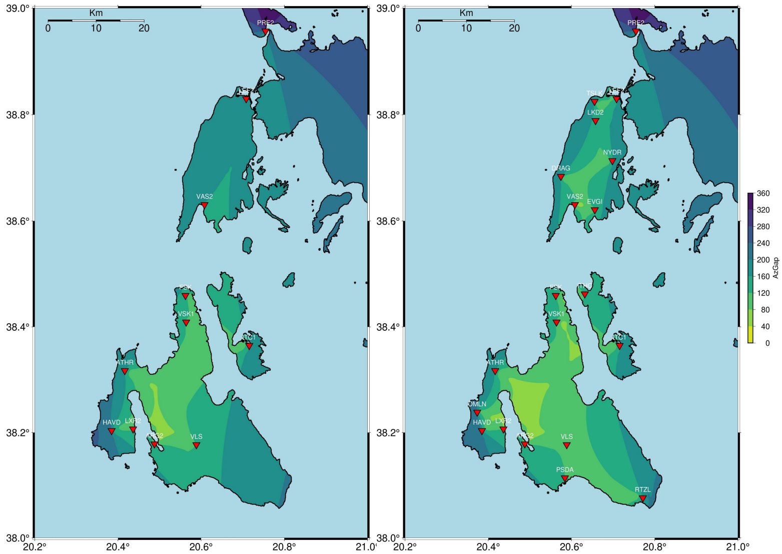

Fig. 1. Azimuthal gap (a) excluding and (b) including the GD-AUTh and PEDIN stations, focusing on the on-island effects of the station coverage.

2.2. Data acquisition and processing

The permanent seismic stations operated jointly by GD-AUTh and PED-IN in the central Ionian Islands are part of the Aristotle University of Thessaloniki Seismological Network (HT) (`https://doi.org/10.7914/SN/HT`), which is a contributing network within the Hellenic Unified Seismological Network (HUSN), since 2008. All waveform data and metadata from HT are openly available through the European Integrated Data Archive (EIDA) and users may access and download them via multiple EIDA services including: a) FDSN web services for direct HTTP requests, b) web-based GUI's provided by EIDA nodes for interactive data selection, and c) client tools that enable automated data retrieval, such as ObsPy (*Beyreuther et al., 2010*). Together, these services guarantee that data remain easily discoverable, consistently formatted and fully accessible for a wide range of applications. Data at the Seismological Station of AUTh are acquired and processed using the SeisComP3, an open – source open-source platform for real-time waveform collection, automatic analysis and data distribution. HOMEROS operates within the existing institutional infrastructure. Revision and reviewing of the automatic locations are performed through SCOLV, the main interactive tool of SeisComP3.

3. Geodetic infrastructure in central Ionian Islands

Geodetic observations based on campaign GPS surveys and continuous GNSS measurements provide direct and robust constraints on crustal deformation before, during, and after seismic events, as well as throughout interseismic periods in this complex tectonic environment. Early studies relied on campaign GPS surveys to investigate regional ground deformation (e.g., *Hollenstein et al., 2006; 2008*), while between 2001 and 2006 the Geophysical Laboratory of the National and Kapodistrian University of Athens (GL-NKUA) established dense local benchmark GPS networks on the islands of Cephalonia, Ithaca, and Zakynthos to document local kinematics (e.g., *Lagios et al., 2007; Sakkas et al., 2014; Papadimitriou et al. 2021*). These networks, based on repeated occupations of geodetic benchmarks, enabled the estimation of horizontal and vertical displacements over multi-year timescales, including co- and post-seismic periods, proving particularly effective in resolving sharp spatial deformation gradients across active fault zones, identifying localised strain accumulation, measuring coseismic offsets, and analysing postseismic relaxation (*Sakkas and Lagios, 2017*). However, their limited temporal resolution restricts the detection of short-lived deformation transients, a limitation addressed by continuous GNSS (cGNSS) observations. The GL-NKUA cGNSS stations are installed on public buildings with antennas mounted on stainless-steel masts and record data at 30 sec sampling intervals. RINEX and raw data files are transmitted hourly to the main laboratory server via FTP, merged into daily RINEX files (versions 2.11 and 3.04), and subjected to quality control using the TEQC algorithm (*Estey and Meertens, 1999*), which verifies header consistency, data completeness, and overall observation quality before the data are forwarded to the HUB repository. Within the HOMEROS framework, the geodetic infrastructure is centred on permanent GNSS/GPS networks, including also stations from the AUTH Hermes network (*Fotiou and Pikridas, 2012*), such as the Lefkas station, with plans for further expansion and densification in areas of elevated natural hazard. These continuous observations, processed using advanced techniques such as Precise Point Positioning (PPP) and kinematic analysis, provide high-resolution displacement time series and deformation maps, significantly enhancing the capability to investigate earthquake cycles, crustal strain accumulation, and coseismic and postseismic processes (*Lazos et al., 2020; 2022*).

The following map (Fig. 2) depicts the geographical distribution of AUTH-HermesNet GNSS stations and the GNSS stations (EVGI, RATZ) that have been installed in the frame of HOMEROS in the Ionian islands, basic information on which is shown in Table 2.

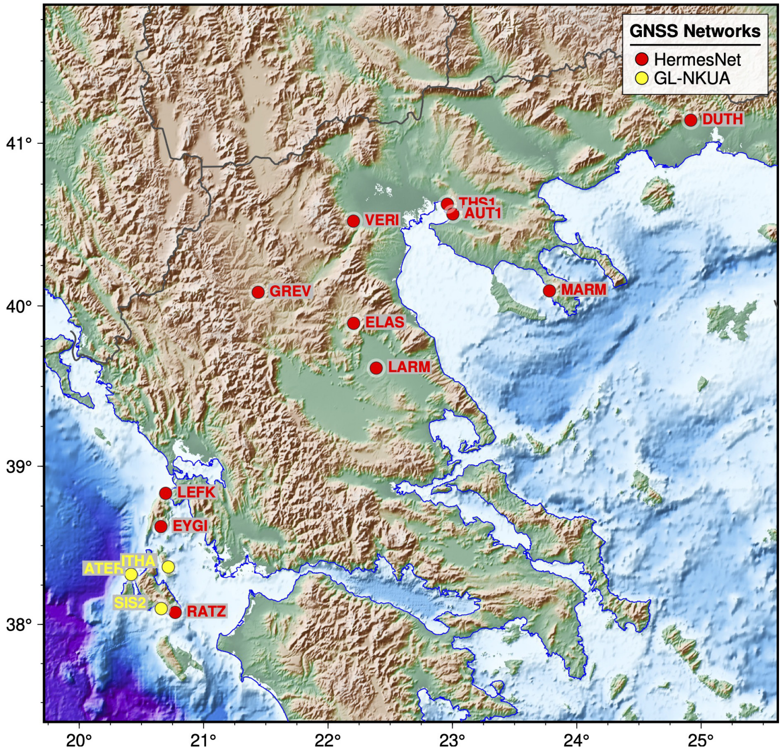

Fig. 2. Geographical distribution of HermesNet and GL-NKUA GNSS stations. Ionian Area stations contribute to HOMEROS Project.

Within HOMEROS, particular emphasis is placed on quality control procedures and data integrity assessment, ensuring that geodetic observations meet the reliability standards required for natural hazards monitoring. Automated quality check pipelines evaluate RINEX completeness, multipath levels, cycle slips, signal-to-noise ratios, and station stability indicators,

Table 2. Hermes Net and GL-NKUA GNSS stations that contribute in HOMEROS project in Ionian islands.

Station	**Longitude (°N)**	**Latitude (°E)**	**Receiver**	**Antenna**
LEFK	20.6947	38.8300	LEICA GR30	LEIAR10
EYGI	20.6564	38.6207	TRIMBLE NETRS	TRM41249.00
RATZ	20.7715	38.0760	TRIMBLE NETRS	TRM41249.00
ATER	20.4166	38.3173	TPS NET-G5	TPSCR.G5 TPSH
SIS2	20.6594	38.1009	TPS NET-G5	TPSCR.G5 TPSH
ITHA	20.7159	38.3646	TPS NET-G5	TPSCR.G5 TPSH

whereas integrity monitoring frameworks detect anomalous behaviour in near–real time. These procedures safeguard the trustworthiness of deformation estimates and enable rapid identification of GNSS data "anomalies" that may be related to emerging geophysical or environmental threats. The integration of these QC and integrity modules ensures that HOMEROS can provide dependable datasets for hazard assessment, early warning, and scientific interpretation. Figure 3 shows a graphical representation of Signal to Noise Ratio (SNR) values for the tracked satellite during a full day recording with an observation interval of 30 sec. Regarding to Figure 3, the GNSS stations are characterised by predominantly unobstructed sky visibility, while the recorded SNR values consistently exceed 40 dB at an elevation angle of 20 degrees on average across satellites, indicating high quality signal reception and favourable conditions for precise and reliable GNSS observations.

Figure 4 illustrates the change in position of the EYGI GNSS station towards the North (δN) and East (δE) for the period from April to December 2025 derived from daily solutions. The range of position differences varies from a few mm up to 25 mm.

GNSS-derived atmospheric parameters, particularly Zenith Total Delay (ZTD) and Integrated Water Vapour (IWV), play a crucial role in enhancing Numerical Weather Prediction (NWP) models. By continuously sensing atmospheric humidity through signal delays, GNSS provides high-temporal-resolution IWV estimates that complement conventional meteorological observations. These data improve model initialization, mesoscale rainfall forecasting, and early-warning systems for extreme weather, such as convective storms and flash floods. Integrating GNSS-IWV observations within NWP

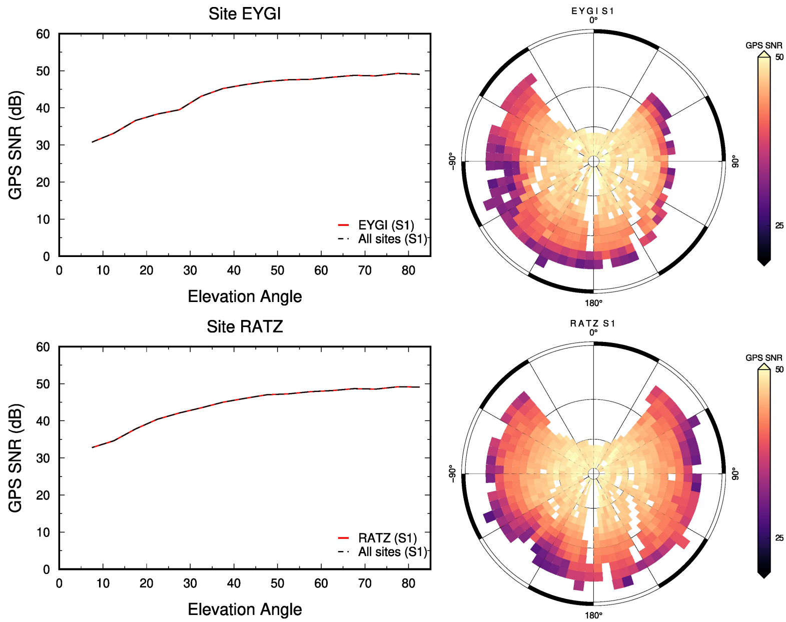

Fig. 3. SNR values for Evgiros (Lefkada) at 01/12/2025 and Ratzakli (Kefalonia) permanent GPS stations at 02/10/2025.

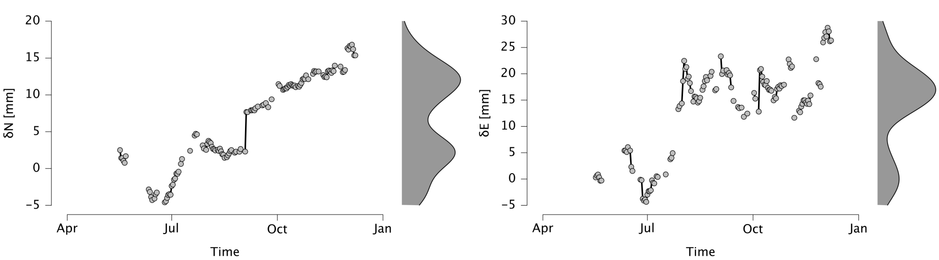

Fig. 4. Position coordinate time series for the North and East components of the EYGI permanent GNSS station, along with the corresponding histograms.

systems also enhances nowcasting and supports multi-hazard assessment by linking atmospheric processes with hydrological and geophysical risks. Therefore, the stations of HOMEROS estimate ZTD and IWV values on a daily basis. Figure 5 shows the Integrated Water Vapour values (kg/m^2) for the GNSS station in Lefkas Island starting from the 1st of June until November 2025.

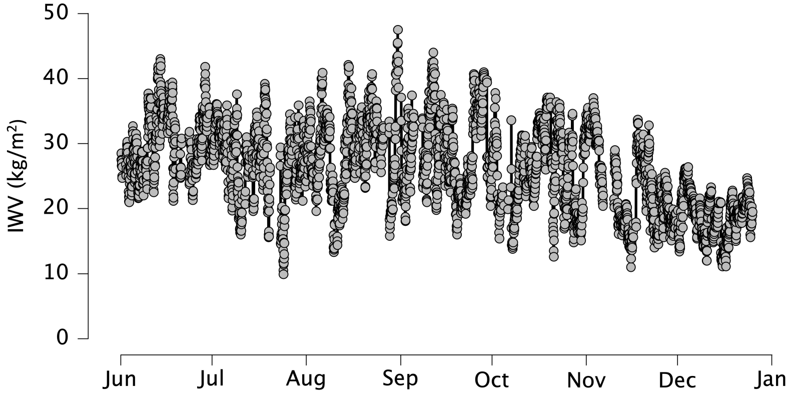

Fig. 5. Integrated water vapour values for the GNSS station in Lefkas Island from June to December 2025.

The RINEX station data is freely available through the research data repository (HARDMIN) of the central library of the Aristotle University of Thessaloniki, where all researchers have access (`https://hardmin.heal-link.gr`).

As already mentioned in previous this intense seismicity accompanied with intense ground deformation makes the region particularly well suited for combined seismological and geodetic investigation. The latter was the reason to be selected as one of the study areas of the HOMEROS project.

To address this limitation, in the mid-2000s the first permanent GNSS stations in the area, were established in the islands of Cephalonia and Lefkada by the National observatory of Athens (*Ganas et al., 2008; Chousianitis et al., 2021*) providing high temporal resolution data of ground motion and better identify the regional kinematic status of the area.

At present, GL-NKUA operates three cGNSS stations in the study area: SIS2 and ATER on Kefalonia, and ITHA on Ithaca (Table 2), disseminating the data via the HOMEROS project.

Continuous observations are essential in the central Ionian Islands, where deformation is strongly influenced by seismic transients. cGNSS time series accurately capture the co-seismic offsets and the post-seismic deformation processes, allow to discrete the tectonic signals from seasonal or environmental effects, providing thus a robust basis for estimating the velocity and strain field of the area in both local and regional scale. On the framework of HOMEROS project GL-NKUA and the Hermes network collaborate not only to deliver daily GNSS data to the community, but also to provide higher-level products, coordinate time series, velocity vectors, and strain filed maps, that support broader scientific use.

The post-processing is performed using the Bernese v5.4 GNSS software (*Dach et al., 2015*). The software allows the estimation of epoch-wise receiver coordinates in Precise Point Positioning mode (PPP) as well as in the double difference mode. Several GNSS stations of the EUropean REference Frame (EUREF) and IGS are processed together with the local GNSS sites, while auxiliary files are introduced in the procedure. The absolute antenna phase centre corrections are used, together with precise orbital solutions from the Center for Orbit Determination in Europe (CODE), and the Vienna Mapping Functions for tropospheric modelling. While FES2014 model (`https://barre.oso.chalmers.se/loading/l.php`; accessed on 17 December 2025) is used for the tide loading corrections. To get the best results the PPP technique used as a first step to get a priori coordinate values, that were consequently introduced in the more precise double difference method for static mode solutions. Several ambiguity strategies are deployed, based on the length of the formed baselines between the GNSS stations. Daily coordinate solutions are evaluated using weekly repeatability; days exhibiting large deviations relative to the weekly solution are excluded. The final processing yields high-precision daily station coordinates in the global IGS2020 reference frame. Station velocities are derived from the daily coordinate time series using MIDAS s/w (*Blewitt et al., 2016*), which provides consistent horizontal and vertical velocity estimates (Fig. 6).

The resulting velocity field and the associated strain fields are closely linked to the seismic behaviour of the study area. As noted above, several main shocks with $M \geq 6.0$, as well as moderate earthquakes with $M \geq 5.0$, occurred during the operational period of the geodetic stations. Focal mechanisms are predominantly strike-slip to oblique, consistent with the kinematics inferred from the GNSS-derived velocity fields. While annual velocity vectors provide vital information of the interseismic deformation and regional strain accumulation, additional insight can be gained by examining baseline length changes between specific station pairs. This approach helps to highlight differential motions between the sites and can better isolate localised deformation across local and regional structures (Fig. 7), resulting

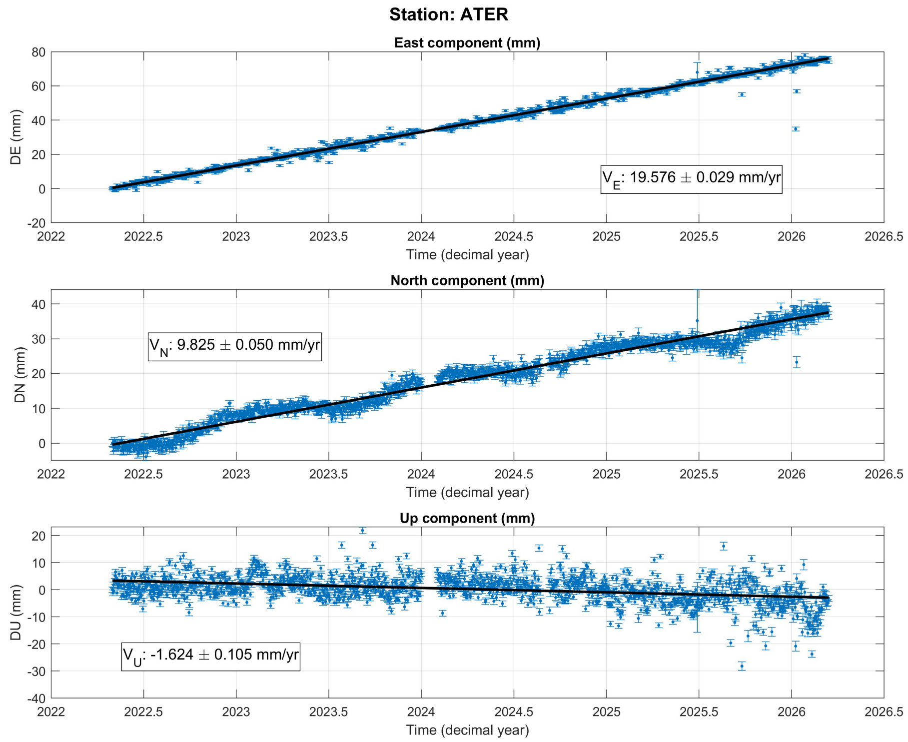

Fig. 6. Time series of the three components of ATER cGNSS station located to Northern part of Palliki peninsula (Cephalonia Island).

to improve the interpretation of the fault interaction through their stress fields, a dominant occurrence in the study area (*Papadimitriou, 2002*).

4. Seismological workflow and earthquake hazard assessment in the Western Gulf of Corinth

4.1. High-accuracy origins

The high seismic activity in the Western Gulf of Corinth (WGoC), a study area of the HOMEROS project, has led to the deployment of a dense seismological network, over the past few decades (*Bernard et al., 2014; Kaviris et al., 2021; Lyon-Caen et al., 2004*). Consequently, the high interest in the area, facilitated by the availability of data provided by the network of

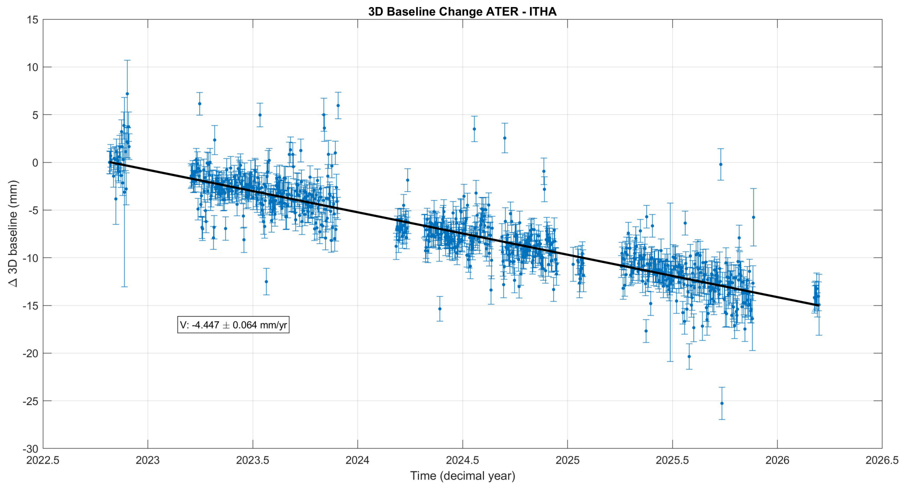

Fig. 7. Baseline changes in between ATER and ITHA stations located in Cephalonia and Ithaca Islands, respectively.

seismological and geodetic sensors, was an important step in the founding of the Corinth Rift Laboratory (CRL), belonging to the Near Fault Observatory (NFO) community in Europe (*Chiaraluce et al., 2022*), supported by the European Plate Observing System (EPOS)[1]. Within the HOMEROS project, we showcase the integration of seismic data from the CRL area with the routine analysis pipeline at the Seismological Laboratory of the National and Kapodistrian University of Athens (SL-NKUA) for real-time earthquake detection. We then showcase the complementary processing chain that builds, upon these routine solutions, a high-resolution relocated seismic catalogue that can be used for robust seismic hazard estimates. This decoupled processing scheme is flexible to be applied at different layers; routine analysis is independent of downstream processes, while relocation and seismic hazard computations can also be performed independently.

The CRL virtual network is composed of stations that belong to various institutions, namely: (a) CL (*Corinth Rift Laboratory Team and EPOS-France, 2013*), (b) HA (*University of Athens, 2008*), (c) HL (*National Observatory of Athens, Institute of Geodynamics, Athens, 1975*) and (d) HP (*University of Patras, 2000*). While the instrumentation itself and accompany-

[1] `https://www.epos-eu.org/tcs/near-fault-observatories`

ing equipment differs amongst institutions and installations, a similar on-site pipeline is followed. Specifically, the analogue signal recorded by sensors is locally converted to digital and transformed into the miniSEED data type to be sent, as packets, to a central collector server via telemetry. The various institutes share data and metadata amongst them. These later become publicly available through European Integrated Data Archive (EIDA) nodes in Greece (*Evangelidis et al., 2021*), for networks HA, HL and HP, and France[2], for network CL.

Waveform data and metadata management is handled by the SeisComP framework (*GFZ, 2008*). At SL-NKUA, we utilise the integrated tools for data exchange through the SeedLink protocol, and the Web-Services (WS) provided by the international Federation of Digital Seismograph Networks (FDSN). After preprocessing (application of cosine taper and bandpass filter), a picker is applied to obtain P and S arrival times and amplitudes for magnitude estimation. If multiple arrival times from different stations cluster together, an association is determined and picks are fed to LocSAT (*Bratt and Nagy, 1991*) to calculate the earthquake location. Magnitude calculations are decoupled and occur independently of the association-location process.

The next step in the routine event location workflow at SL-NKUA is manual revision. An analyst retrieves waveform, pick, amplitude, event and magnitude data through a graphical interface provided by the SeisComP client tools. The analyst then corrects STA/LTA picks and adds missing ones. Similarly, station amplitudes are corrected or added. If an undetected event is observed, the analyst creates a manual origin and picks the relevant arrivals and amplitudes for magnitude estimation. Picking quality and location-magnitude quality is then assessed through a variety of metrics and plots (e.g., time residuals and travel-time curves) to identify potential further corrections. If no additional review is required, the analyst confirms the final origin, which is added to the database. A history of all origins associated with the specific event is available at any time.

To produce higher quality catalogues, earthquake relocation is commonly used in the seismological community, especially in cases of populous earthquake sequences (*Kapetanidis et al., 2015; Kapetanidis et al., 2024; Kapetanidis et al., 2008; Karakostas et al., 2015; Lomax et al., 2025; Pa-*

[2] `https://seismology.resif.fr/eida/`

padimitriou et al., 2015; Serpetsidaki et al., 2023; Shearer et al., 2005). Herein, we summarise the relocation workflow commonly used at SL-NKUA, as demonstrated in *Serpetsidaki et al. (2023)*. Events (with their latest manual origin selected as preferred) and phase arrivals are retrieved from the SL-NKUA's database and are enriched with potentially missing information from the publicly available database of the Geodynamic Institute of the National Observatory of Athens (GI-NOA). New origins are then produced using Hypoinverse (*Klein, 2002*) and a local velocity model (in this case the model proposed by *Rigo et al., 1996*) to receive area-tailored initial locations, as the previous pipeline used a location configuration suitable for all of Greece. For sets of clustered earthquakes, cross-correlation travel time data are calculated which, along with the catalogue travel time data, are used by HypoDD (*Waldhauser, 2001*) to obtain the high-resolution relocated earthquake catalogue. Following, we present the results of the described workflow for the three strongest events of the 2020–2021 earthquake crisis in WGoC (Table 3). Details for this sequence are provided by *Kaviris et al. (2021)*, *Zahradník et al. (2022)*, *Serpetsidaki et al. (2023)* and *Bountzis et al. (2025)*.

Table 3. The three largest events in the HOMEROS dataset, selected for ground motion simulations. Earthquake parameters are adopted from *Serpetsidaki et al. (2023)*.

Origin Time	**Latitude (°N)**	**Longitude (°E)**	**Depth (km)**	$\mathbf{M_w}$
2020-12-23T14:58:24	38.4015	21.9919	8.74	4.6
2021-01-12T22:09:41	38.3786	22.0375	6.91	5.0
2021-02-17T03:36:05	38.3590	21.9383	7.31	5.3

4.2. Ground motion simulations for seismic hazard

High-precision relocated earthquakes origins data are then used to simulate ground motion for sites and areas with no active recording instrument. The results of those simulations can contribute to the local seismic hazard assessment and support the multi-hazard frameworks, which is a core concept of the HOMEROS project. A previous study in the area by *Kaviris et al. (2022)* modelled seismic hazard using a "holistic" approach, i.e., the classic probabilistic method of *Cornell (1988)* and *McGuire (1976)* and the stochastic method of *Boore (2003)*. The study of *Kaviris et al. (2022)* focused on hypothetical activation scenarios for various WGoC faults. We herein demonstrate how earthquake origins can be used to the stochastic finite fault model through the dynamic corner frequency approach, implemented in the EXSIM code (*Motazedian and Atkinson, 2005; Boore, 2009*) to estimate seismic hazard from actual ruptures. This technique has been extensively applied in the Greek region (e.g., *Roumelioti et al., 2017; Giannaraki et al., 2019; Bonatis et al., 2021; Ravnalis et al., 2022*).

The faults associated with the three earthquakes listed in Table 3 were identified based on the work of *Serpetsidaki et al. (2023)*, whereas their geometry was adopted from the latest version of the NOA faults database, called NOAFaults v7.0 (*Ganas et al., 2013; Ganas, 2025*). The subdivisions of the faults into segments of point sources were done using the empirical formula of *Beresnev and Atkinson (1999)* (Eq. 1):

$$\log \Delta l = 0.4\,\mathrm{M} - 2\,, \tag{1}$$

where, Δl is the length of each subfault and M is the moment magnitude of the mainshock.

The stress parameter relates to the actual stress drop during an earthquake and was herein adopted by *Kaviris et al. (2022)* who determined a stress parameter of 30 bars for the WGoC area. Regarding the path effects, the geometrical spreading model by *Atkinson (2004)* was employed, which divides the attenuation slope into three intervals, i.e., <70 km, 70–130 km and >130 km. Anelastic attenuation is related to the quality factor, which is proposed by *Hatzidimitriou (1995)* for the broader Aegean region (Eq. 2):

$$Q\,(f) = 100\,f^{0.8}\,. \tag{2}$$

Finally, site effects were considered by assigning a k_0 value of 0.044, which corresponds to site class C (NEHRP) along with respective site amplification factors per frequency, proposed by *Klimis et al. (1999)*. The choice of class C soil type was based on local soil and geological information from the sites of the available seismic stations. Soil data were obtained from *Taylor et al. (2011)*. As proxy indicators, we evaluated VS30 values by applying the global VS30 model of *Heath et al. (2020)* and by extracting available VS30 measurements for all sensors from the Engineering Strong Motion (ESM[3]) Database (*Luzi et al., 2020*). All parameters are presented at Table 4.

[3] `https://esm-db.eu/#/home`

Table 4. Input data used for each simulation. Strike and dip were taken from the NOA-Faults database (*Ganas, 2025*), length and width are computed using the formulas of *Thingbaijam et al. (2017)* and stress and kappa parameters are adopted from the study of *Kaviris et al. (2022)*.

	Marathias Fault	**Trizonia Fault**	**Psathopyrgos Fault**
Strike (°)	94	95	277
Dip (°)	60	65	40
Length (km)	1.86	3.18	4.76
Width (km)	4.54	6.11	7.64
M_w	4.6	5.0	5.3
Stress parameter (bars)	30	30	30
Kappa	0.044	0.044	0.044

4.3. Products and contribution to multi-hazard assessment

All results that were obtained in the framework of the HOMEROS project are presented as Peak Ground Acceleration (PGA) and Peak Ground Velocity (PGV) values on a dense grid in the WGoC. PGA and PGV are two of the fundamental strong-motion parameters used in engineering seismology. PGA is the seismic hazard metric used in national building codes, usually for a return period of 475 years, whereas PGV is considered to correlate better with structural and non-structural damage. Starting with the first simulation, i.e., the 23rd December 2020 $M_w = 4.6$ Marathias earthquake, the maximum PGA (Fig. 8a) and PGV (Fig. 8b) values are equal to 170 cm/s^2 and 6 cm/s, respectively, and are observed near the epicentre at the northern coast of the Gulf. Ground motions are generally higher in the northern part of the study area.

For the second simulation of the 12th January 2021 $M_w = 5.0$ Trizonia earthquake, the results of the HOMEROS project indicate that the ground motion values are higher, having a peak PGA of 210 cm/s^2 (Fig. 2a) and a peak PGV of 8 cm/s (Fig. 9b). Unlike the first simulation, elevated ground motions are now observed to the southern coast of the WGoC, which is more distant from the epicentre. Finally, the results of the third simulation shown in Table 1 provided peak PGA and PGV values of 170 cm/s^2 and 8.0 cm/s, respectively. The simulation of the third earthquake (17th February 2021, $M_w = 5.3$ Psathopyrgos) generated PGA (Fig. 10a) values

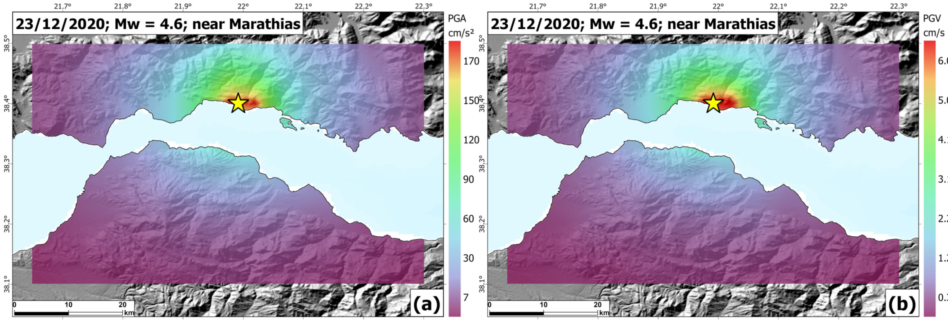

Fig. 8. PGA (a) and PGV (b) results for the first simulation: the 23rd December $M_w = 4.6$ Marathias earthquake. The location of the epicentre has been adopted by *Serpetsidaki et al. (2023)*.

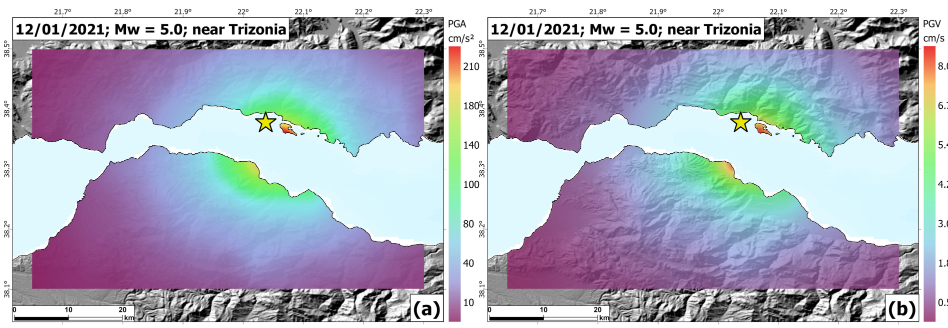

Fig. 9. PGA (a) and PGV (b) results for the second simulation: the 12th January $M_w = 5.0$ Trizonia earthquake. The location of the epicentre has been adopted by the work of *Serpetsidaki et al. (2023)*.

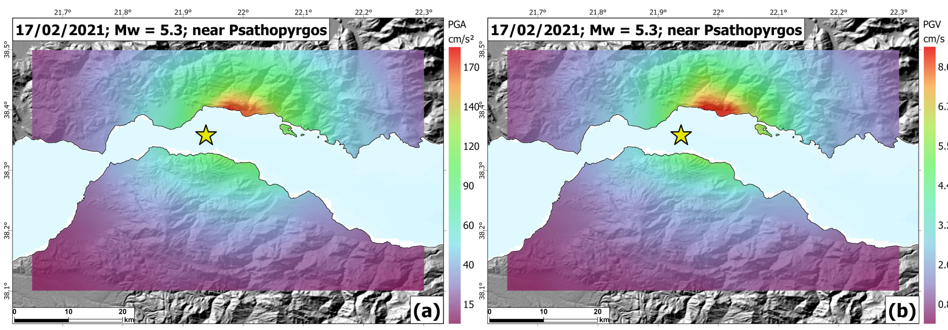

Fig. 10. PGA (a) and PGV (b) results for the third simulation: the 17th February $M_w = 5.3$ Psathopyrgos earthquake. The location of the epicentre has been adopted by the work of *Serpetsidaki et al. (2023)*.

lower than the ones obtained for the Trizonia event, despite its larger magnitude. The simulation of the third earthquake (17 February 2021, M_w 5.3, Psathopyrgos) produced lower PGA values (Fig. 3a) than the Trizonia event despite its larger magnitude. This may be attributed to the fact that the Psathopyrgos fault is dipping northward, and the epicentre is closer to the southern coast of the Gulf. Consequently, the northern coastal areas are farther from the source and experience stronger attenuation than in the Trizonia simulation.

The synergy between these two datasets creates a “robust testbed” for hazard analysis. More specifically, while seismic data captures the sudden release of energy, geodetic data captures both transient and long-term tectonic processes, together providing a full picture of earthquake dynamics. Regarding physics-based simulations, high-precision relocated earthquake catalogues (from seismic data) are used to inform stochastic finite-fault models, which simulate ground motion for areas without active recording instruments to assess local seismic hazard. Therefore, Homeros data using standardised processing pipelines and adherence to FAIR data principles ensure that these integrated datasets are reliable and accessible for multidisciplinary scientific interpretation and risk mitigation strategies.

5. Conclusions

This study demonstrates the value of integrating dense seismological and high-precision geodetic infrastructures within the HOMEROS Open Science framework for multi-hazard assessment in tectonically active regions of Greece. By harmonising heterogeneous observations, standardised processing workflows, and openly accessible data products, HOMEROS establishes a robust, interoperable ecosystem that supports advanced scientific analysis, reproducibility, and cross-disciplinary collaboration.

The seismological component, exemplified by the CenIonNet network in the Central Ionian Islands and the Corinth Rift Laboratory infrastructure in the Western Gulf of Corinth, provides high-resolution waveform data that significantly enhance earthquake detectability, location accuracy, and source characterization. Dense station coverage and standardised real-time and offline processing pipelines enable the construction of high-quality earthquake catalogues, including precise hypocentral relocations that are essential for understanding fault geometry, seismic triggering mechanisms, and spatiotemporal evolution of seismic sequences. These capabilities have been clearly demonstrated through recent seismic crises in both study areas.

Complementary to the seismological observations, continuous GNSS infrastructures from the Hermes network of AUTH and GL-NKUA provide high-temporal-resolution measurements of crustal deformation, capturing interseismic strain accumulation as well as coseismic and postseismic processes. Advanced GNSS processing strategies yield reliable coordinate time series, velocity fields, and strain estimates that are directly linked to the observed seismic behaviour. In addition, GNSS-derived atmospheric products, such as ZTD and IWV, extend the contribution of HOMEROS beyond solid Earth processes, strengthening links to meteorological applications and supporting truly multi-hazard perspectives that include extreme weather and hydrological risks. A key outcome of HOMEROS is the adoption of FAIR data principles through established European infrastructures such as EPOS, EIDA, and institutional repositories. Open access to raw data, metadata, and higher-level products, combined with transparent and reproducible processing pipelines, ensures long-term usability and fosters data reuse across disciplines. Overall, the HOMEROS framework illustrates how coordinated seismological and geodetic infrastructures can function as a unified test bed for multi-hazard assessment. In regions such as Greece, where seismic, landslide, flood, and atmospheric hazards often coexist. Beyond the national scale, the methodologies, workflows, and open-access philosophy developed within HOMEROS are transferable to other regions and contribute to the broader European and international efforts.

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