

Deploying the First Regional DAS Seismic Network in a High-Hazard European Region: The Case of Northeastern Italy



Giuseppe Davide Chiappetta^{*1}, Valerio Poggi¹, Paolo Comelli¹, Stefano Parolai^{1,2}, Andrea Magrin¹, Enrico Magrin¹, Alessio Compagno¹, Simone Galvi¹, Davide Cuzzolin³, Francesco Fabbro³, Paolo Perucci⁴, Andrea Buttol⁴, and Matteo Picozzi^{1,5}

Abstract

Distributed acoustic sensing (DAS) is rapidly emerging as a powerful complement to conventional seismic monitoring, enabling dense spatial sampling over tens of kilometers using existing fiber-optic telecommunication infrastructures. In this study, we present the design, implementation, and initial performance of a regional-scale DAS seismic monitoring network integrated within the operational framework of the Seismological Research Center of OGS in north-eastern Italy. The system is built upon dark fiber segments of a public telecommunication network and interrogated by multiple DAS units, covering several hundred kilometers of optical fiber and producing tens of thousands of virtual sensing channels. We describe the end-to-end workflow developed to support continuous DAS acquisition in an operational environment, including data conversion from proprietary formats to standard seismological archives, channel aggregation strategies, metadata handling, and real-time streaming through SeedLink and International Federation of Digital Seismograph Networks services. Attention is given to practical constraints related to data volume, latency, channel naming, and integration with existing seismic monitoring infrastructures. Using representative examples, we illustrate the capability of the network to record teleseismic and local seismic signals, to characterize spatially variable seismic noise conditions along fiber routes, and to contribute to earthquake location when combined with conventional seismic stations. These case studies highlight both the opportunities and current limitations of distributed acoustic sensing (DAS) for regional seismic monitoring, including issues related to channel localization, directional sensitivity, and effective sensing range. The presented network represents one of the most extensive operational DAS deployments for seismic monitoring in Europe to date. Our results demonstrate the feasibility of integrating large-scale DAS systems into routine monitoring activities and provide a reference framework for future developments toward multisensor, fiber-optic-based seismic observatories.

Cite this article as Chiappetta, G. D., V. Poggi, P. Comelli, S. Parolai, A. Magrin, E. Magrin, A. Compagno, S. Galvi, D. Cuzzolin, F. Fabbro, *et al.* (2026). Deploying the First Regional DAS Seismic Network in a High-Hazard European Region: The Case of Northeastern Italy, *Seismol. Res. Lett.* **XX**, 1–21, doi: [10.1785/0220260094](https://doi.org/10.1785/0220260094).

Introduction

The southeastern Alps represent one of the most seismically active regions in Europe, where ongoing convergence between the Adriatic microplate and the Eurasian plate sustains a high seismogenic potential, allowing the occurrence of moderate-to-large earthquakes with magnitudes reaching $M_w \sim 6.5$ to 7. Geodetic observations confirm ongoing crustal shortening at rates of the order of a few millimetres per year, indicating persistent strain accumulation within a complex continental collision setting (D'Agostino *et al.*, 2005; Metois *et al.*, 2015; Serpelloni *et al.*, 2016; Villani *et al.*, 2024). This combination of historical seismicity, active deformation, and structural

1. National Institute of Oceanography and Applied Geophysics – OGS, Udine, Italy, <https://orcid.org/0000-0001-7925-3243> (GDC); <https://orcid.org/0000-0002-9965-1529> (VP); <https://orcid.org/0000-0002-9084-7488> (SP); <https://orcid.org/0000-0002-7017-0529> (AM); <https://orcid.org/0000-0002-8390-6259> (AC); <https://orcid.org/0009-0005-3308-8648> (SG); <https://orcid.org/0000-0001-8078-9416> (MP); 2. Department of Mathematics, Informatics and Geosciences, University of Trieste, Trieste, Italy; 3. INSIEL S.p.A., Division of Infrastructure and Telecommunications, Network Infrastructure Development, Feletto Umberto, Italy; 4. Regional Government of the Autonomous Region of Friuli Venezia Giulia, Central Directorate for Assets, State Property, General Services and Information Systems, Trieste, Italy; 5. University of Naples Federico II, Naples, Italy

*Corresponding author: gchiappetta@ogs.it

Copyright © 2026. The Authors. This is an open access article distributed under the terms of the CC-BY license, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

complexity makes the region a key natural laboratory for both seismological research and seismic-risk mitigation. Large number deployments of seismic stations such as the Swath-D experiment in the eastern Alps further demonstrated the presence of high-rate microseismicity zones and short-scale fault structures (Heit *et al.*, 2021; Hofman *et al.*, 2023; Petersen *et al.*, 2025), highlighting the strong structural segmentation of the region and underscoring the need for long-term, high-precision, and spatially dense monitoring strategies.

Since the 1976 M_w 6.5 Friuli earthquake, seismic monitoring in northeastern Italy has progressively evolved into a dense and multiparametric observational framework. The SMINO network (“Sistema di Monitoraggio dell’Italia Nord-Orientale”), operated by the Seismological Research Center (CRS) of the National Institute of Oceanography and Applied Geophysics (OGS), integrates broadband seismometers, accelerometers, strong-motion sensors, and Global Navigation Satellite System (GNSS) receivers distributed across the southeastern Alps and the western Dinarides (Bragato *et al.*, 2013, 2021). Despite its maturity and high performance, SMINO, like any network based on point sensors, remains intrinsically limited in its ability to sample the seismic wavefield continuously in space. Fine-scale variations in wave propagation, fault-zone structure, and site response are therefore only partially resolved, particularly in areas where seismicity is distributed across multiple interacting structures and where strong lateral heterogeneities characterize the upper crust.

These limitations have motivated growing interest in complementary monitoring approaches capable of dramatically increasing spatial sampling density without a proportional increase in installed instrumentation. Distributed acoustic sensing (DAS) has recently emerged as a promising technique in this context (Lindsey *et al.*, 2017; Jousset *et al.*, 2018; Ajo-Franklin *et al.*, 2019; Zhan, 2020). DAS exploits phase-sensitive optical interferometry to transform standard fiber-optic cables into arrays of thousands of closely spaced virtual sensors, providing continuous measurements of dynamic strain or strain rate along the fiber. By leveraging existing telecommunication infrastructures, DAS enables ultradense spatial sampling over tens of kilometers, both in urban and remote environments, at a fraction of the cost required to deploy conventional seismic arrays. Over the past decade, DAS has been successfully applied to record local and regional earthquakes, teleseismic phases, ambient noise, and anthropogenic signals in a wide range of geological and infrastructural settings, including urban areas, volcanic systems, mountainous regions, and submarine environments (e.g., Lindsey *et al.*, 2017; Sladen *et al.*, 2019; Walter *et al.*, 2020; Lior *et al.*, 2021; Zhu *et al.*, 2021).

In the Friuli Venezia Giulia region, the potential of DAS for seismic monitoring has been concretely realized within the framework of the Italian National Recovery and Resilience Plan (PNRR) project ITINERIS, through a collaboration between OGS, the regional information and communication

technology (ICT) company INSIEL S.p.A. (“INformatica per il Sistema degli Enti Locali”), and the Regional Government of Friuli Venezia Giulia. This collaboration enabled access to several hundred kilometers of dark fiber belonging to the regional telecommunication network, providing a unique opportunity to integrate fiber-optic sensing into an existing, fully operational seismic monitoring infrastructure. Since July 2025, multiple fiber-optic routes departing from key telecommunication nodes have been interrogated in real time, forming a regional DAS network designed not as a temporary experiment but as a persistent component of the monitoring system. This DAS-based infrastructure, hereafter referred to as SMINO-DAS, is integrated with the conventional SMINO network, complementing it by introducing spatially continuous observations across sectors of the region that are of particular tectonic and societal relevance.

This study aims to describe the design, implementation, and initial operational performance of the SMINO-DAS infrastructure and its integration within the routine monitoring activities of CRS-OGS. We focus on the acquisition configuration, channel localization strategy, and data-management workflow developed to handle the large data volumes produced by DAS and to distribute them through standard seismological services alongside conventional seismic data. Furthermore, we present representative examples illustrating the capability of the network to record teleseismic and local earthquakes and to contribute to earthquake location when combined with the existing seismic network. Rather than providing an exhaustive methodological treatment of DAS signal processing, this work documents the practical choices, constraints, and performance of a regional-scale DAS deployment operating under real monitoring conditions.

Seismotectonic Context and Seismicity of Northeastern Italy

The southeastern Alps and the western Dinarides form one of the most structurally complex collision zones in Europe, resulting from the ongoing convergence between the Adriatic microplate and the Eurasian plate. In the narrow corridor encompassing Friuli Venezia Giulia and western Slovenia, north-west-southeast (NW-SE)-trending Dinaric thrusts intersect and interact with east-west (E-W) to north-south (N-S) Alpine structures, producing a dense network of thrust faults, transpressive shear zones, and reactivated Paleozoic to Mesozoic inherited discontinuities (Anderson and Jackson, 1987; Castellarin and Cantelli, 2000; Bressan and Bragato, 2009; Poli and Zanferrari, 2018). This long-lived tectonic interference has generated a highly fragmented crustal architecture, often described as a “cone-in-cone” system of nested wedges and overlapping fault segments (Venturini, 1991; Bressan *et al.*, 1998), in which active structures are locally concealed by Plio-Quaternary deposits, enhancing both structural uncertainty and site-response effects (Carulli, 2006; Barnaba *et al.*, 2010).

Instrumental and historical seismicity indicate that the region is persistently active, with earthquakes occurring predominantly within the upper 10–12 km of the crust and displaying highly variable focal mechanisms. Reverse faulting associated with N–S compression dominates along the Alpine front, whereas strike-slip and locally normal faulting occur in response to strong lateral contrasts in crustal strength and stress orientation (Slejko *et al.*, 1999; Bressan *et al.*, 2012; Viganò *et al.*, 2015; Bressan, Barnaba, Bragato, *et al.*, 2018; Poli and Zanferrari, 2018). In this context, the Friuli–Venezia Giulia region represents a seismically active area, having experienced several noteworthy earthquakes in the past (i.e., the 1348 M_w 7.0 Villach, Caracciolo *et al.*, 2021; the 1511 M_w 6.9 Idrija, Fitzko *et al.*, 2005; and the 1976 M_w 6.5 Friuli earthquake, Slejko *et al.*, 1999), and hosts a complex system of active, potentially seismogenic structures of significant size (Fig. 1).

Since 1976, the seismic record has been characterized by frequent low- to moderate-magnitude earthquakes ($M_w < 5$), with notable exceptions such as the 1998 (M_w 5.6) and 2012 (M_w 5.2) Bovec events in Slovenia. Focal mechanism inversions and space–time clustering analyses reveal sharp spatial variations in stress orientation and a strong degree of fault segmentation, reflecting the mechanical heterogeneity of the crust in the Alpine–Dinaric transition zone (Bressan *et al.*, 2009, 2021; Bressan, Barnaba, Magrin, and Rossi, 2018).

Geodetic observations from GNSS networks indicate that

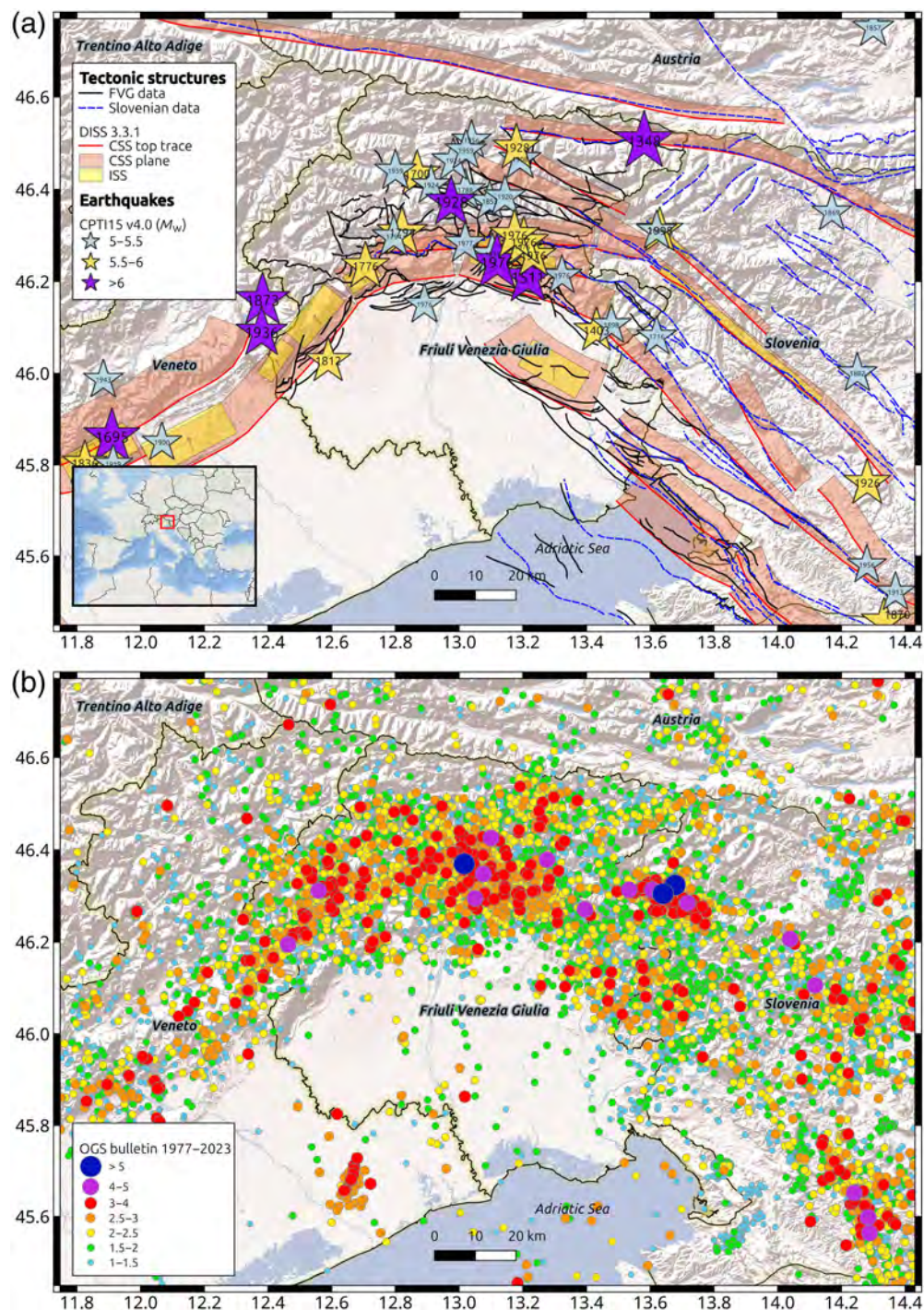
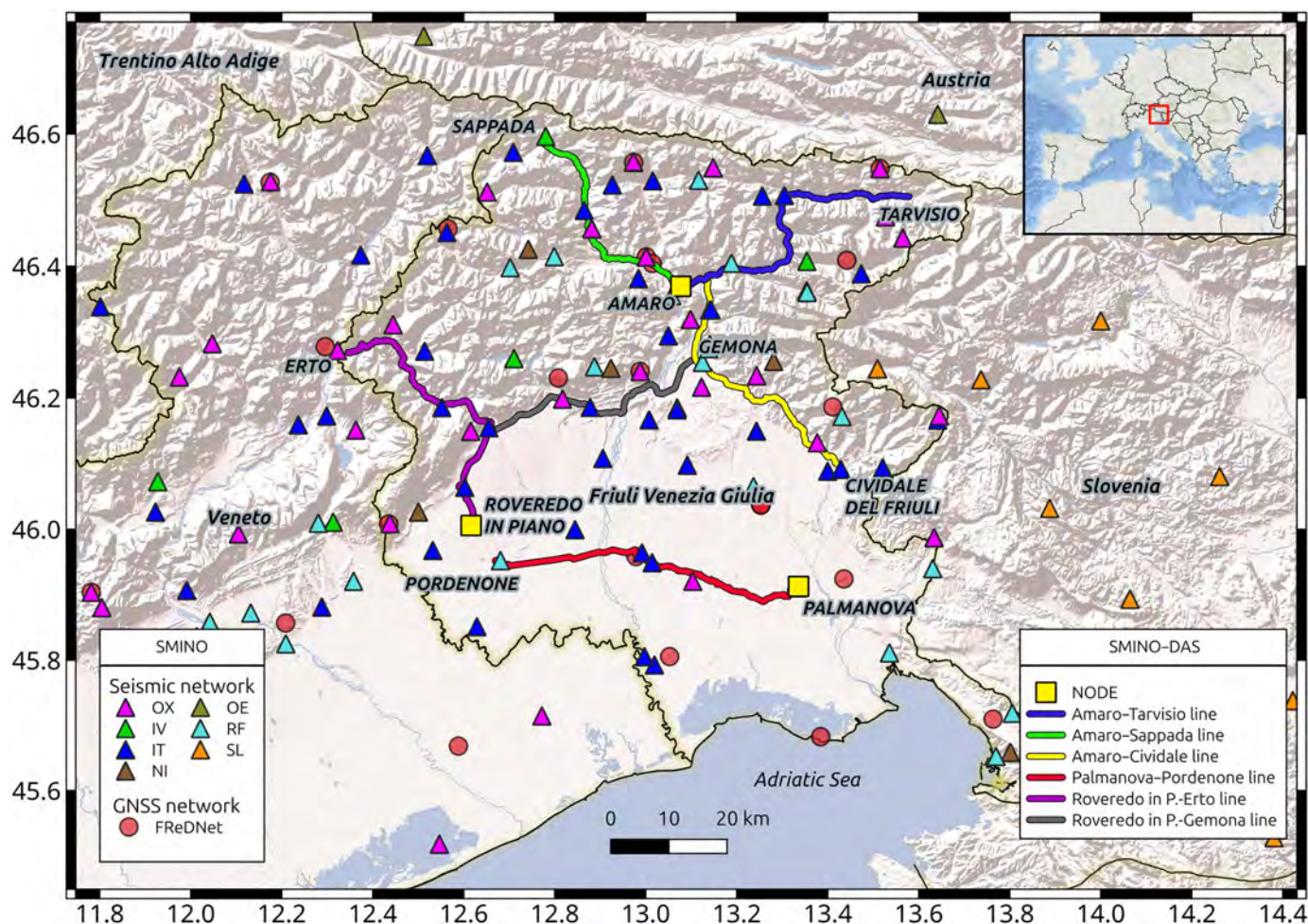


Figure 1. (a) Tectonic framework and historical seismicity of northeastern Italy. The stars indicate earthquakes from the CPTI15 version 4.0 catalog (Rovida *et al.*, 2020, 2022), with only events of moment magnitude $M_w \geq 5$ shown. Major tectonic lineaments are reported according to the Database of Individual Seismogenic Sources (DISS, DISS Working Group, 2025), the Friuli–Venezia Giulia (Marchesini *et al.*, 2023) and the Slovenia (Atanackov *et al.*, 2021) databases. The inset shows the location of the study area within Europe. (b) Instrumental seismicity recorded in the study area from the National Institute of Oceanography and Applied Geophysics (OGS) seismic bulletin since 1977, color coded by magnitude (see legend). The color version of this figure is available only in the electronic edition.



the region accommodates approximately 2 mm/yr of N–S shortening, making Friuli Venezia Giulia one of the most actively deforming sectors of the Alpine chain (D’Agostino *et al.*, 2005; Metois *et al.*, 2015; Serpelloni *et al.*, 2016; Magrin and Rossi, 2020; Tunini *et al.*, 2024). When combined with seismic observations, these data outline a deformation field governed by strong spatial gradients and localized strain accumulation, where seismicity is distributed across multiple interacting fault systems rather than concentrated along a single, well-defined structure. This configuration poses significant observational challenges for conventional seismic networks, as the spatial continuity of wave propagation, fault-zone processes, and site effects is only partially captured by discrete point sensors. In this context, monitoring approaches capable of providing dense and spatially continuous measurements are particularly valuable for improving the characterization of active structures and the interpretation of seismic wavefields in such a complex tectonic environment.

Network Configuration, Data Acquisition, and Workflow

Fiber-optic infrastructure and interrogators

The fiber-optic telecommunication network of the Friuli Venezia Giulia region is managed by INSIEL S.p.A., which

Figure 2. Map of northeastern Italy showing the seismic and Global Navigation Satellite System (GNSS) stations contributing to the Sistema di Monitoraggio dell’Italia Nord-Orientale (SMINO) monitoring network and the fiber-optic routes of the SMINO–distributed acoustic sensing (DAS) infrastructure operated by Seismological Research Center (CRS)–OGS. The triangles indicate seismic stations, color-coded by network affiliation, and red circles denote GNSS stations. The colored lines represent the fiber-optic cables currently interrogated by the DAS system, originating from the main telecommunication nodes and distinguished by route and orientation. The inset shows the location of the study area within Europe. The color version of this figure is available only in the electronic edition.

made available six dark-fiber routes for the implementation of the SMINO–DAS infrastructure. These routes depart from three main telecommunication nodes (i.e., Amaro, Palmanova, and Roveredo in Piano) and extend across different tectonic sectors of the region (Fig. 2). The selected fibers belong to an on-land regional telecommunication network, for which routing, installation conditions, and the locations of joints, bends, and spare coils are well documented.

The experimental infrastructure currently includes six Silixa intelligent Distributed Acoustic Sensor (iDAS) interrogators (version 2), five of which are deployed for continuous

TABLE 1

Summary of the Optical Fiber Links Characteristics Used in the SMINO–DAS Infrastructure, Including Total Length, Linear Extension, Total Measured Attenuation, and Attenuation per Distance from Test Reports Performed with Wavelength 1550 nm

Fiber Route	Total Length (km)	Linear Extension (km)	Interrogated Distance (km)	Total Attenuation (dB)	Mean Attenuation (dB/km)	Label (Used for mseed)
Amaro–Sappada	59.4	54.0	45	14.9	0.251	A
Amaro–Cividale	63.0	57.4	45	15.0	0.238	B
Amaro–Tarvisio	59.2	55.3	45	13.6	0.229	C
Palmanova–Pordenone	65.9	60.1	45	17.0	0.258	D
Roveredo in Piano–Erto	66.5	60.5	45	15.8	0.238	E
Roveredo in Piano–Gemona	69.5	65.4	45	17.0	0.244	F

SMINO–DAS, Sistema di Monitoraggio dell’Italia Nord-Orientale–distributed acoustic sensing.

monitoring. Three interrogators are installed at the Amaro node, providing access to long fiber segments oriented toward the northeast (NE), northwest (NW), and southeast (SE), and intersecting major tectonic lineaments of the region. A fourth interrogator is installed at the Palmanova node and monitors an E–W-oriented fiber crossing the Friulian plain. The fifth interrogator is located at the Roveredo in Piano node and provides access to two fiber branches that share an initial segment (~20 km) before diverging toward the NW and E; at present, only the northwestern branch (toward Erto) is interrogated, whereas the eastern branch is preserved as a backup option. A sixth interrogator is available but not currently active.

All interrogators are synchronized by dedicated Global Positioning System (GPS) receivers to ensure accurate timing and are mounted on vibration-isolation platforms to minimize environmental and instrumental noise. Each unit is connected to a high-capacity local network attached storage system for continuous data storage. Before DAS acquisition, all fiber routes were tested using an optical time-domain reflectometer (OTDR) to determine their effective optical length and to identify localized signal losses. Although attenuation points are present along the fibers, typically below 1 dB/km and varying from line to line, as expected for telecommunication infrastructure, the selected routes were confirmed to be suitable for distributed acoustic sensing.

Acquisition parameters and effective sensing geometry

All interrogators operate with a fixed instrumental gauge length (GL) of 10 m, corresponding to the physical length over which differential strain is measured. Data are acquired at a sampling frequency of 200 samples per second, which is adequate for recording local, regional, and teleseismic signals relevant to routine seismic monitoring.

Raw spatial sampling is set to 2 m, after testing configurations ranging from 2 to 16 m. This value is not chosen to

exploit the maximum spatial resolution technically achievable by the interrogators, but rather as a flexible starting point for defining an effective spatial sampling tailored to regional monitoring requirements. Although meter-scale sampling is possible, such fine resolution is neither necessary nor optimal for the intended applications. In particular, spatial oversampling does not increase the effective information content of the recordings when the instrumental gauge length is fixed and when signal coherence decreases with distance from the interrogator.

The physical fiber lengths range between approximately 59 and 69 km, but the effective operational range of the interrogators is limited to about 45 km. Data acquisition is therefore restricted to this distance for all the lines, as signal quality progressively degrades when the backscattered optical signal approaches the noise floor. With a raw spacing of 2 m, this configuration results in 22,016 channels per interrogated line. This value is the same for all the lines, since the acquisition length is limited in the same way. The mean attenuation, derived from OTDR tests, ranges from 0.229 to 0.258 dB/km (see Table 1 for details).

To define an effective spatial sampling suitable for operational use, adjacent channels are spatially averaged before data dissemination. Spatial averaging increases the effective sensing aperture represented by each virtual channel while preserving the fixed physical gauge length of the instrument, and significantly reduces uncorrelated noise, particularly at large fiber offsets where attenuation and environmental disturbances dominate (Fig. 3). In the current operational configuration, five consecutive channels are averaged, resulting in an equivalent channel spacing of 10 m and an effective fiber length of 18 m represented by each channel. This configuration represents a compromise between spatial resolution, signal coherence, and data volume and is applied consistently across all fiber routes (Table 2). At the same time, it simplifies integration with

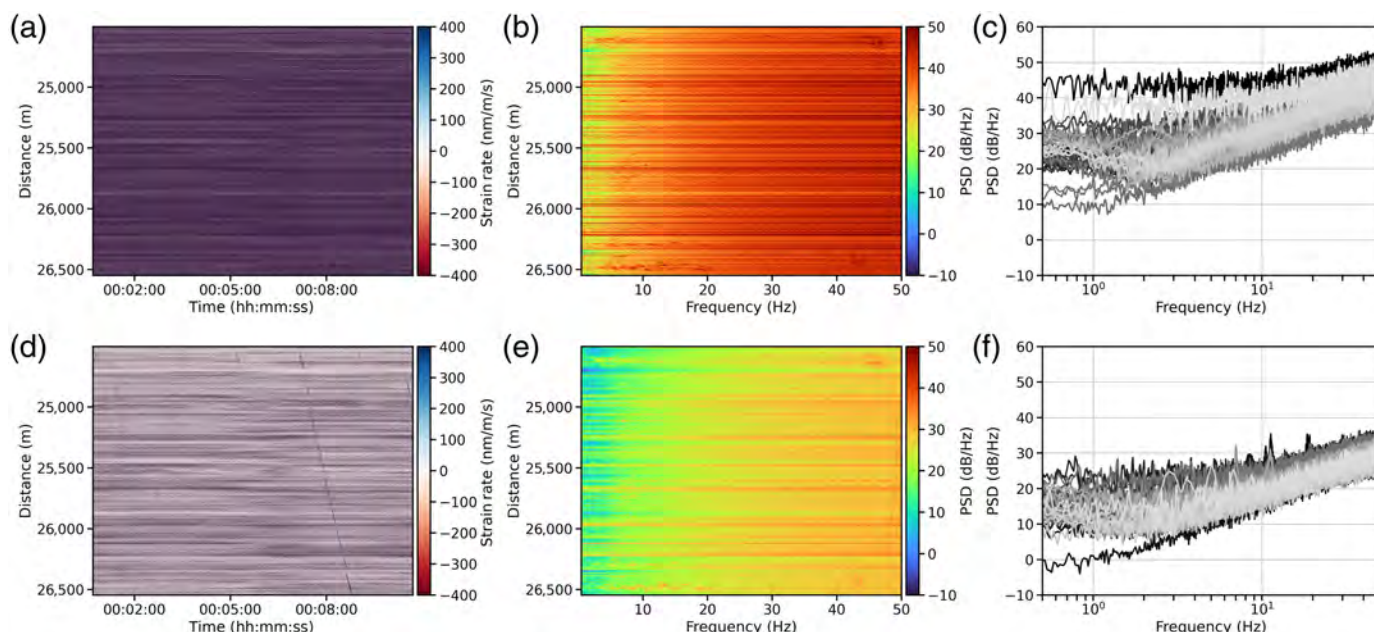


Figure 3. Noise characteristics of a representative DAS fiber segment (a–c) before and (d–f) after spatial averaging across channels. Panels (a) and (d) show strain-rate records as a function of time and distance, panels (b) and (e) display the corresponding frequency–distance representations, and panels (c) and (f) report power spectral density (PSD) estimates for selected channels. The gray tones (light to dark) in plots (c) and (f) indicate channels at increasing distance. Spatial averaging leads to a systematic reduction of background noise across the analyzed frequency

band, while preserving coherent signals propagating along the fiber, such as transient disturbances associated with passing vehicles. The analysis refers to the medium-to-long offset portion of the Palmanova–Pordenone cable, using channels located at distances greater than 24 km from the interrogator, where instrumental noise becomes increasingly significant, and its reduction may be more clearly evaluated. The color version of this figure is available only in the electronic edition.

existing data-handling frameworks and naming conventions by reducing the number of virtual channels, limiting spatial redundancy while retaining coherent wavefield information at scales relevant for regional monitoring, without introducing a significant loss of spatial resolution. Under the current acquisition configuration, the resulting data volume is approximately 760 GB/line/day for raw TDMS files and about 155 GB/line/day for converted MiniSEED averaged data.

Channel localization and coupling assessment

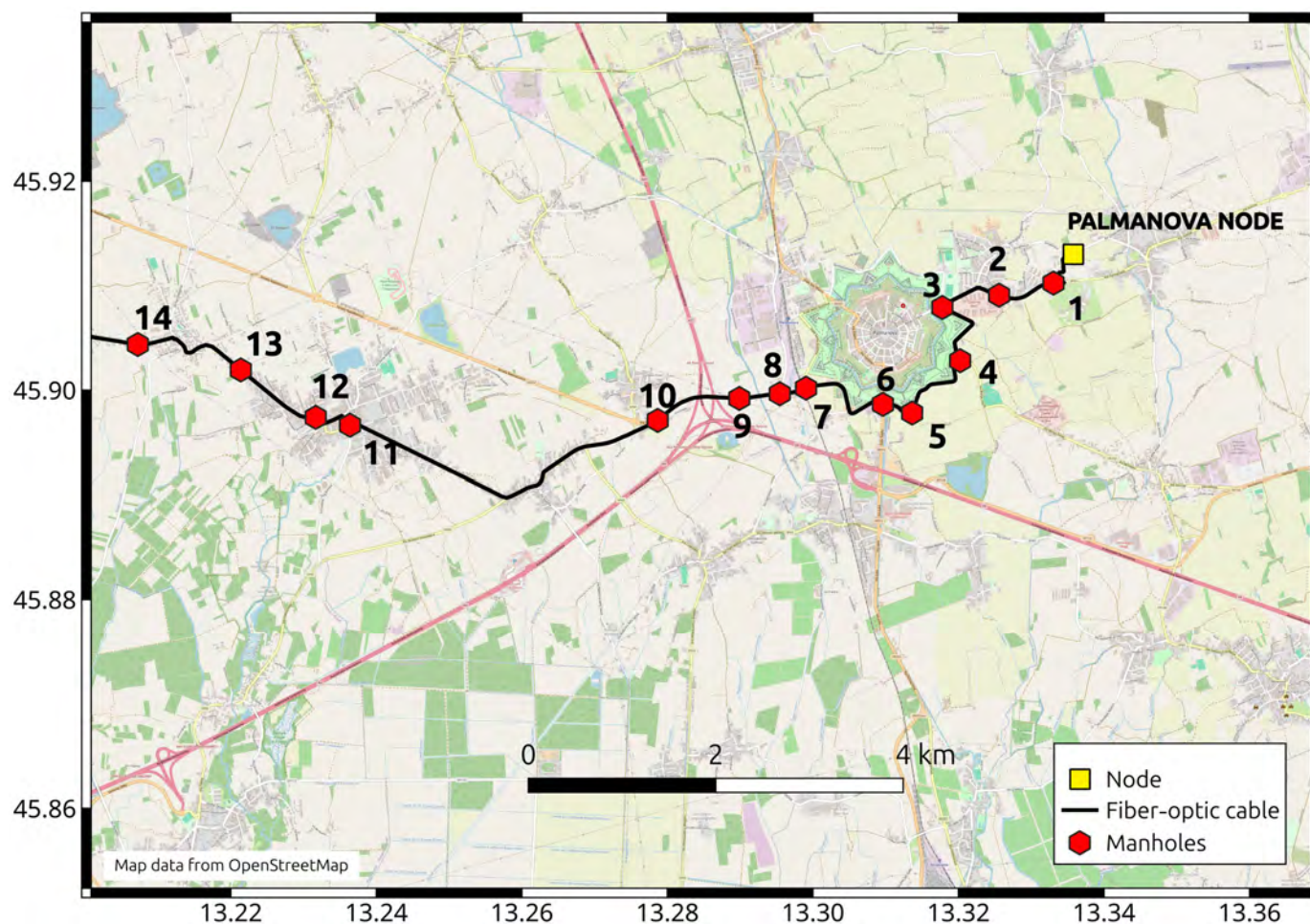
Accurate channel localization is a critical requirement for DAS-based seismic monitoring, particularly in urban telecommunication networks where fiber paths may include spare coils, poorly coupled sections, or segments affected by persistent anthropogenic noise. Although the fiber routes are georeferenced, discrepancies between optical distance along the fiber and geographic position arise due to the presence of spare cable stored in manholes. Recent studies, such as Biondi *et al.* (2022), proposed the use of geolocated moving vehicles to improve DAS channel georeferencing along telecommunication fibers. Although this approach could also be applied to the present infrastructure, its implementation would require dedicated acquisition campaigns, vehicle tracking systems, road access coordination, and additional operational authorizations.

TABLE 2

Summary of the Main Acquisition and Processing Parameters Adopted for the SMINO–DAS Infrastructure, Including Fiber Length, Gauge Length, Spatial Sampling, and Channel Averaging

Acquisition Property	Reference Value
Interrogated fiber length	45 km
Sampling frequency	200 Hz
Raw spatial sampling	2 m
Averaging option/number channels	True/five channels
Raw number of channels	22,016
Final number of channels	4,403
Gauge length	10 m
Fiber length representative of each channel (after average)	18 m
Equivalent spacing (after average)	10 m

The adopted configuration is applied consistently across all fiber routes.



Moreover, in our case, traffic conditions may significantly affect vehicle detectability and signal repeatability. In addition, part of the infrastructure is deployed along railway corridors, where restricted access and operational constraints may further complicate the deployment of such localization surveys. To address the channel localization, two complementary approaches are adopted. First, a correction factor is derived from the ratio between the known linear extension of each route and the total fiber length measured by OTDR (see Table 1). Although the nominal channel positions along the cables are known from acquisition parameters, this factor is used to map them to geographic coordinates, providing an initial localization that enables rapid operational deployment and integration of selected DAS channels into standard earthquake-location procedures.

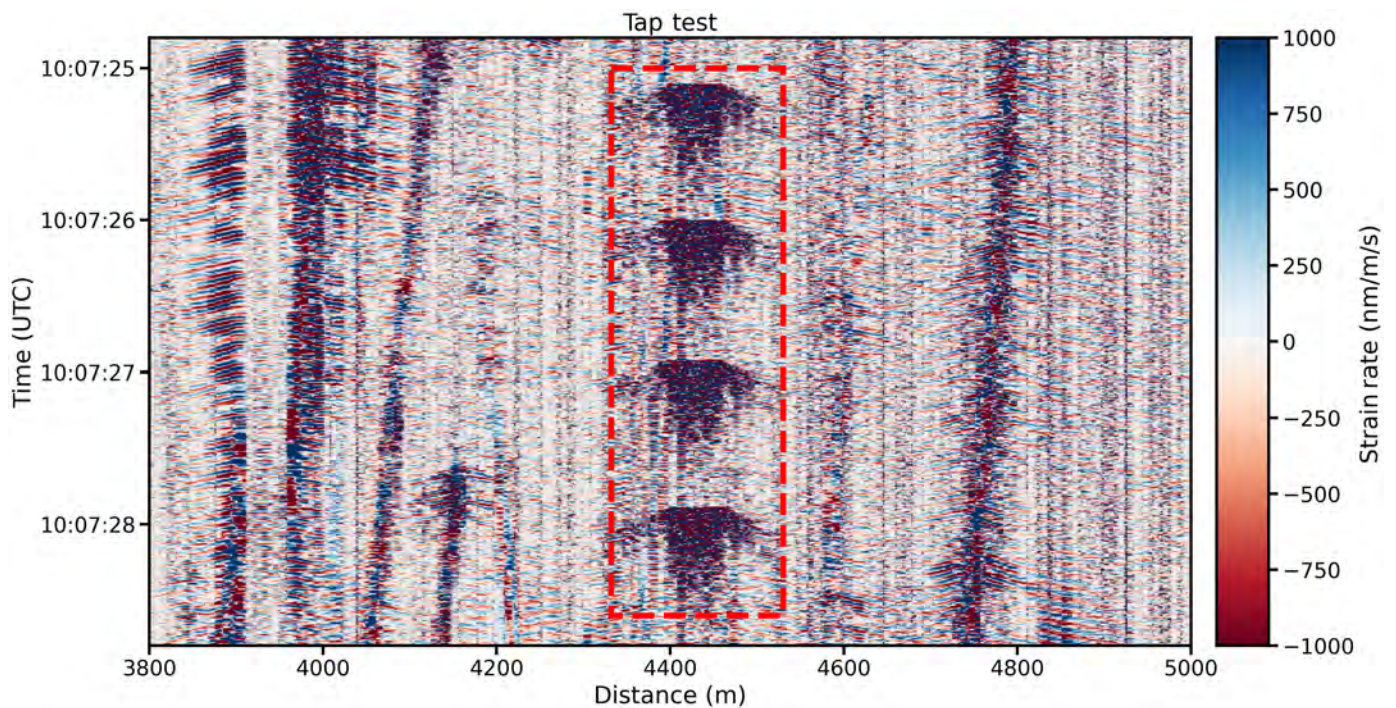
Second, a dedicated tap-test survey is carried out along the interrogated routes to validate channel positions and assess coupling conditions. Hand-operated hammer impacts are applied at known manhole locations and accurately time-stamped (an example in Figs. 4 and 5). Even modest impacts are sufficient to illuminate several tens of meters of fiber, allowing clear identification of channel clusters associated with spare coils. At the current stage, we performed these tests only at selected locations and used the results to validate the indirect channel localization procedure described earlier. Based on the

Figure 4. Spatial distribution of manholes along the first segment of the Palmanova fiber-optic route. Manholes provide access points for inspection and maintenance and host spare fiber coils used to accommodate installation and repair requirements. From a seismic monitoring perspective, these locations correspond to fiber segments that are spatially colocated and typically characterized by elevated noise levels and poor coupling with the surrounding ground. The color version of this figure is available only in the electronic edition.

available validation points, the uncertainty of the current channel localization is estimated to be on the order of 80–100 m. Although this accuracy is sufficient for the preliminary applications presented in this study, including earthquake-location tests and routine monitoring activities, more advanced georeferencing approaches, such as vehicle-based localization surveys, will be considered in future developments for applications requiring higher spatial accuracy.

Data quality assessment and ambient noise characterization

The characterization of seismic noise along the fiber routes is an essential component of the infrastructure validation process and directly informs the selection of acquisition and averaging



parameters. Noise recordings are analyzed both at the level of individual raw channels and after spatial averaging, to evaluate signal coherence along the fiber and identify stable spatial patterns related to coupling conditions and environmental noise sources.

We used spectral analyses to investigate the frequency content of the recorded noise and its spatial variability along each fiber route. Comparisons between raw and averaged data demonstrate that spatial averaging effectively suppresses uncorrelated noise while preserving coherent wavefield components, providing a quantitative justification for the adopted effective spatial sampling. This effect is particularly evident at large offsets from the interrogator, where noise levels increase, and coherent seismic signals become more difficult to detect without averaging (see Fig. 3).

In addition, channel-by-channel noise levels are systematically evaluated using robust amplitude-based metrics computed over day-long recordings. In particular, we systematically evaluate the amplitude of the noise (A) daily through the following metric:

$$A = \log \frac{1}{N} \sum_i^N x_i^2,$$

in which x is the amplitude of the individual sample, and N is the number of samples. The amplitude distribution across channels and days reveals a clear spatial pattern that remains stable over time. Figure 6 shows the result of this analysis performed on the Amaro-Cividale line, considering 34 days of continuous recording. Higher amplitudes are consistently observed at large offsets, where instrumental noise is predominant. Temporal variations are limited and appear coherent, as they affect all channels simultaneously, suggesting day-dependent external conditions (either

Figure 5. Example of a tap test performed along the Palmanova–Pordenone fiber-optic line at the manhole labeled 6 in Figure 4. The record shows strain-rate data as a function of time and distance. The test consisted of four consecutive impacts (highlighted by the red-dashed rectangle), which simultaneously excited approximately 60 m of fiber, producing a flat propagation front that allows the precise identification of the fiber segment associated with the manhole. The color scale represents strain rate. The color version of this figure is available only in the electronic edition.

of natural or anthropogenic origin) rather than instrumental instability. This analysis may also reveal persistent spatial patterns that reflect the physical characteristics of the fiber installation, such as transitions between well-coupled and poorly coupled sections or proximity to anthropogenic noise sources. Beyond their role in defining the acquisition setup, these analyses provide an operational tool for long-term quality control. Persistent changes in noise patterns may indicate variations in coupling conditions or physical modifications of the telecommunication infrastructure, which is particularly relevant when fiber segments are treated as stable seismic sensors over extended periods.

Data conversion, archiving, and dissemination

Continuous strain-rate data acquired by each interrogator are stored locally in proprietary TDMS format on shared storage systems accessible from both the acquisition units and dedicated processing servers. A custom processing workflow is implemented to convert these data into standard seismological formats and integrate them into the routine CRS–OGS monitoring framework (Fig. 7).

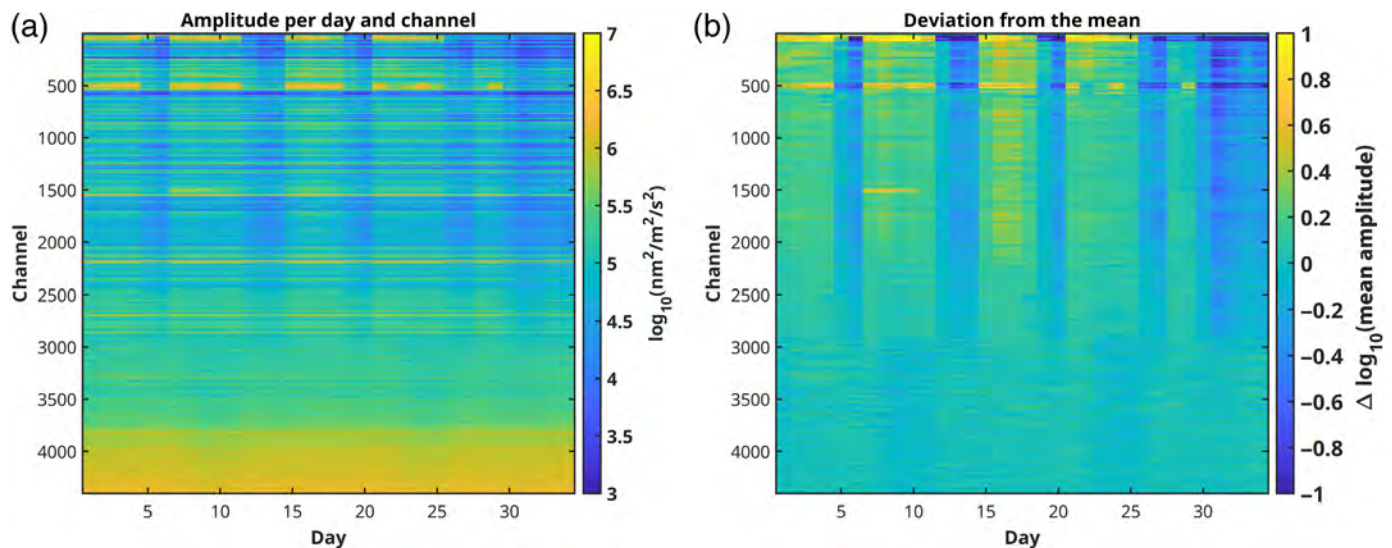


Figure 6. Temporal variation of the average signal amplitude per day, computed from (a) continuous noise recordings along the Amaro–Cividale line, and (b) corresponding relative deviation

from the overall mean. The color version of this figure is available only in the electronic edition.

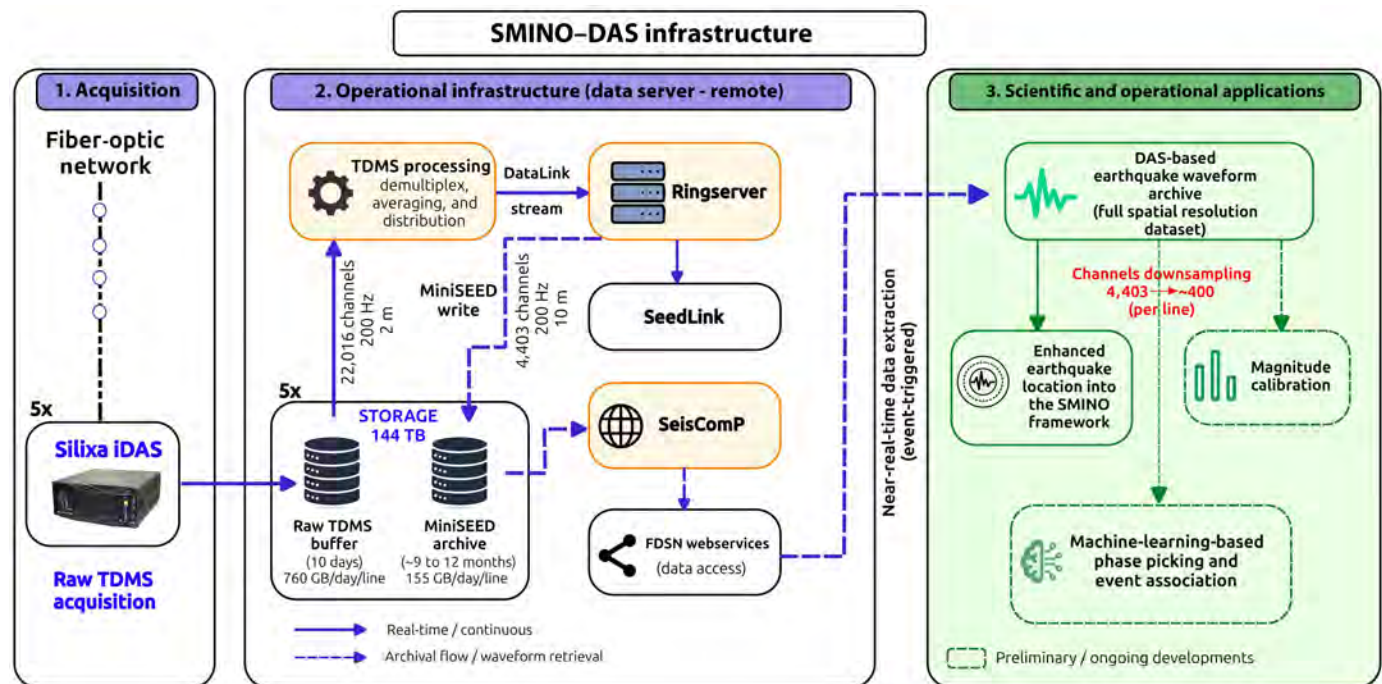


Figure 7. End-to-end data acquisition and dissemination architecture of the SMINO–DAS infrastructure. Strain-rate data acquired by the iDAS interrogators in each network node are stored on a remote data server, demultiplexed and converted into MiniSEED format, and made externally retrievable via SeedLink continuous stream and International Federation of Digital

Seismograph Networks (FDSN) web service. DAS data are then collected in the CRS headquarters, processed together with conventional seismic data, and employed for operational monitoring workflows. The color version of this figure is available only in the electronic edition.

In the first processing step, a Python-based service (`tdms_to_mseed.service`), relying on the `npTDMS` library and `ObsPy` (Beyreuther *et al.*, 2010), automatically detects newly closed TDMS files and demultiplexes them into individual channels corresponding to successive fiber sections. Each channel is treated as a single-component seismic station, with appropriate metadata assigned according to the adopted naming convention. The resulting data streams are converted into 512-byte MiniSEED records and transmitted to a Ringserver instance through the DataLink protocol, enabling both real-time streaming and on-disk archiving.

In the second step, a SeisComP system accesses the local storage and provides standard FDSN web services for data dissemination, allowing DAS recordings to be distributed alongside conventional seismic data using the same operational interfaces. All MiniSEED data are archived locally on a dedicated 144-TB storage system, providing capacity for at least nine months of continuous data per fiber route, complemented by approximately ten days of raw TDMS backup. Data latency is primarily controlled by the duration of the TDMS files and the size of the ring buffer; with the current configuration based on 1-min files, data become available for streaming shortly after file closure, while the ring buffer currently provides access to approximately 1 hr of recent data. Tests with shorter file durations, down to 1 s, have been conducted to assess the feasibility of reducing latency for time-critical applications such as earthquake early warning (EEW).

All averaged DAS channels are currently accessible in real time through the Ringserver/SeisComP infrastructure and ready to be integrated within the regional monitoring framework (4403 channels treated as single-component virtual stations). However, several experimental processing workflows, such as earthquake localization tests (both manual and automatic) and magnitude calibration, typically operate only on reduced subsets of averaged channels to limit computational costs. In practice, at the current stage, these analyses generally use approximately 400 channels per fiber route, with an effective spatial spacing of 100 m. Event-based datasets associated with local earthquakes, including all averaged channels from the available fiber routes, are available upon reasonable request through a dedicated web-based distribution service (see [Data and Resources](#)), whereas continuous full-resolution DAS streams and raw TDMS data are currently retained primarily for internal operational and archival purposes.

Within the current operational framework, routine dissemination relies on MiniSEED data streams and conventional StationXML metadata descriptions. Although this approach does not preserve the full set of DAS-specific metadata highlighted by recent studies (e.g., Lai *et al.*, 2024), it provides immediate compatibility with widely adopted seismological software and acquisition systems pending broader adoption of dedicated DAS metadata standards.

Data Analysis and Preliminary Results

Teleseismic and regional wavefield recordings

Building on the infrastructure configuration and data-quality assessment described in the [Network Configuration, Data Acquisition, and Workflow](#) section, we show here a representative example of a teleseismic earthquake recording acquired by the SMINO–DAS network under routine monitoring conditions. This example is intended to illustrate the sensitivity of the system and its ability to capture the spatial continuity of seismic wavefields along extended fiber-optic paths, rather than to provide a quantitative characterization of seismic amplitudes.

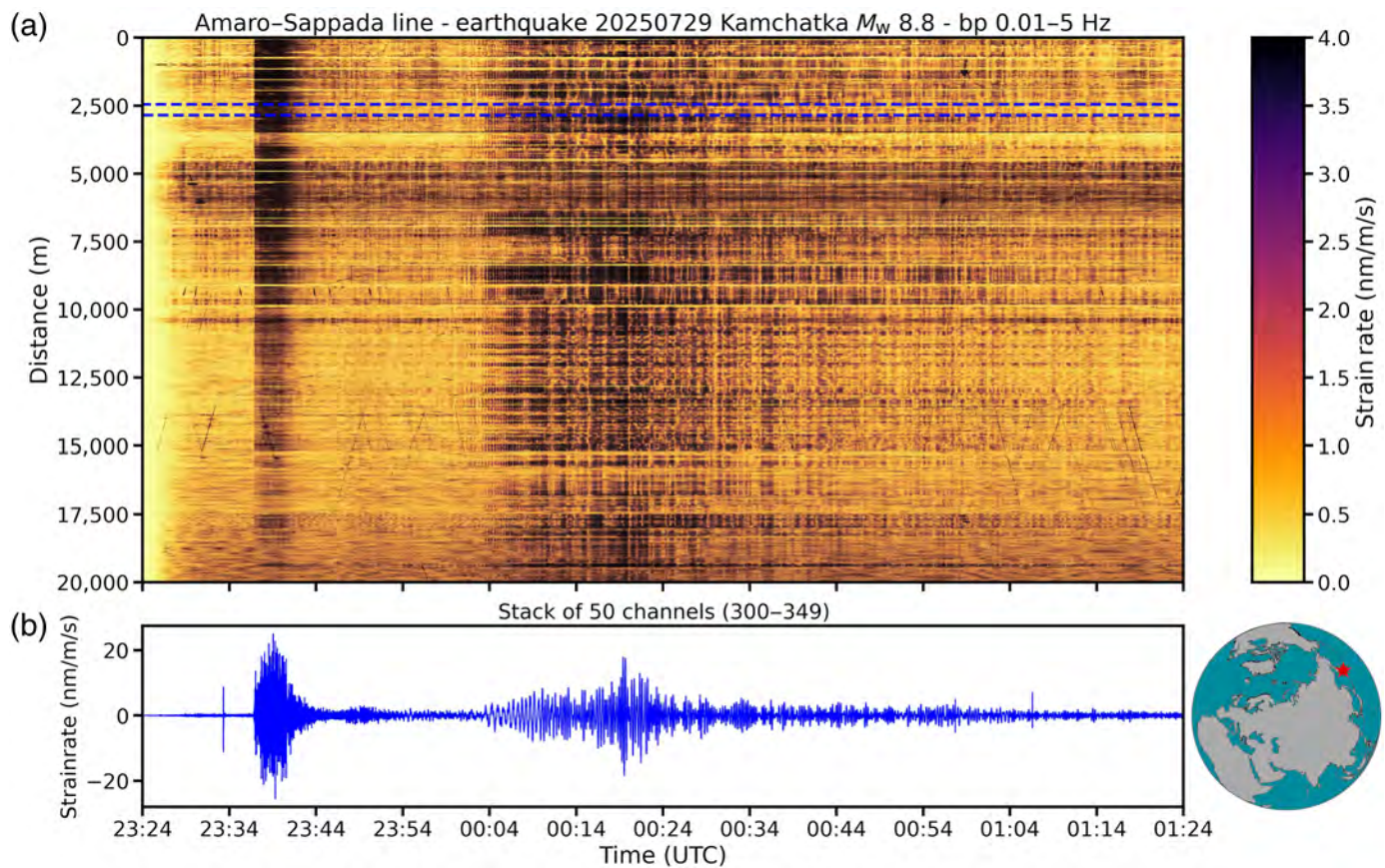
Teleseismic events with moderate-to-large magnitudes generate long-period seismic phases that are well suited for testing the coherence and stability of DAS recordings over tens of kilometers.

Since July 2025, SMINO–DAS has recorded a few teleseismic earthquakes. Figure 8, as an example, shows the recording of the Kamčatka earthquake, M_w 8.8, which occurred on 29 July 2025, at 23:24:52 (UTC). Figure 9, instead, highlights the sensitivity of DAS recordings to different global seismic phases through a comparison with a nearby seismic station (OX.FUSE) and the ak135-based phase interpretation for the same earthquake. Interestingly, the DAS recording shows some clear arrivals of seismic phases seen on both the vertical and horizontal components of the seismometer. The teleseismic recordings consistently show clear arrivals of primary and secondary body waves, as well as long-period surface waves, propagating coherently along the interrogated fiber routes. The spatiotemporal evolution of these phases can be tracked continuously along the fiber, revealing variations in apparent propagation velocity and waveform character that reflect the interaction between the incoming wavefield and the heterogeneous crustal structure crossed by the fiber paths.

The dense spatial sampling provided by DAS allows the observation of subtle changes in waveform coherence and arrival timing along the fiber that are not accessible to conventional seismic networks based on sparsely distributed point sensors. In particular, lateral variations in the recorded wavefield are evident over distances of a few kilometers, highlighting the sensitivity of DAS measurements to local geological and coupling conditions. These observations are consistent across multiple fiber routes and are reproducible for different teleseismic events, indicating stable acquisition conditions and reliable timing synchronization among interrogators. A more detailed analysis of the DAS capability of recording teleseismic phases is out of the scope of this work, being necessary to study the impact of the fiber-optic orientation with respect to the earthquake and ground coupling of the corresponding fiber segment.

Local and regional earthquakes

In addition to teleseismic signals, the SMINO–DAS network routinely records local and regional earthquakes occurring within the Alpine–Dinaric domain. These events, typically



characterized by epicentral distances ranging from a few kilometers to several tens of kilometers, generate higher frequency wavefields and more complex signal patterns along the fiber routes, providing a stringent test of the system under conditions relevant to routine seismic monitoring.

Since July 2025, tens of local earthquakes have been recorded in the region, and a dedicated DAS waveform archive is currently being developed by extracting DAS data from all fiber lines whenever the CRS Antelope system detects an event with magnitude $M_L \geq 0.8$. Our database currently includes more than 200 events in the magnitude range $0.8 \leq M_L \leq 3.9$. Among these, three earthquakes occurred in proximity to the fiber paths and produced particularly clear DAS recordings: the 3 October 2025 M_L 2.9 event (21:19:13 UTC), the 12 October 2025 M_L 3.1 event (07:43:05 UTC), and the 19 December 2025 M_L 3.1 event (20:45:39 UTC); the latter is shown in Figure 10.

For regional earthquakes, DAS recordings commonly exhibit clear and coherent *P*- and *S*-wave arrivals over large portions of the interrogated fiber paths. The dense spatial sampling allows the continuous tracking of arrival times along the fiber, revealing systematic variations in apparent propagation velocity and waveform character as a function of distance from the epicenter. These variations reflect both the geometry of the incoming wavefield and lateral heterogeneities in the crustal structure crossed by the fibers. Compared with teleseismic recordings, regional events show increased sensitivity to local

Figure 8. Teleseismic recordings of the M_w 8.8 Kamchatka earthquake of 29 July 2025, observed along the Amaro–Sappada fiber-optic line. (a) Absolute value of strain-rate data displayed as a function of time and distance along the fiber, band-pass (bp) filtered between 0.01 and 5 Hz. (b) Stacked strain-rate waveform obtained by averaging 50 adjacent channels (channels 300–349), highlighting the main teleseismic phases. The color version of this figure is available only in the electronic edition.

coupling conditions and anthropogenic noise, particularly at shorter periods, emphasizing the importance of the acquisition and averaging strategies described in the [Network Configuration, Data Acquisition, and Workflow](#) section.

Local earthquakes, occurring at short epicentral distances, generally produce more complex wavefields characterized by strong amplitude variability, scattered phases, and pronounced differences in signal coherence along the fiber. In these cases, DAS recordings capture detailed spatiotemporal patterns associated with wavefront curvature and near-source effects that are difficult to resolve with sparse point-sensor networks. The continuous nature of the measurements enables the identification of localized segments along the fiber where waveform characteristics change abruptly, potentially reflecting variations in near-surface structure or coupling conditions.

Where available, qualitative comparisons between DAS recordings and data from nearby broadband and accelerometric stations of the SMINO network indicate consistent arrival

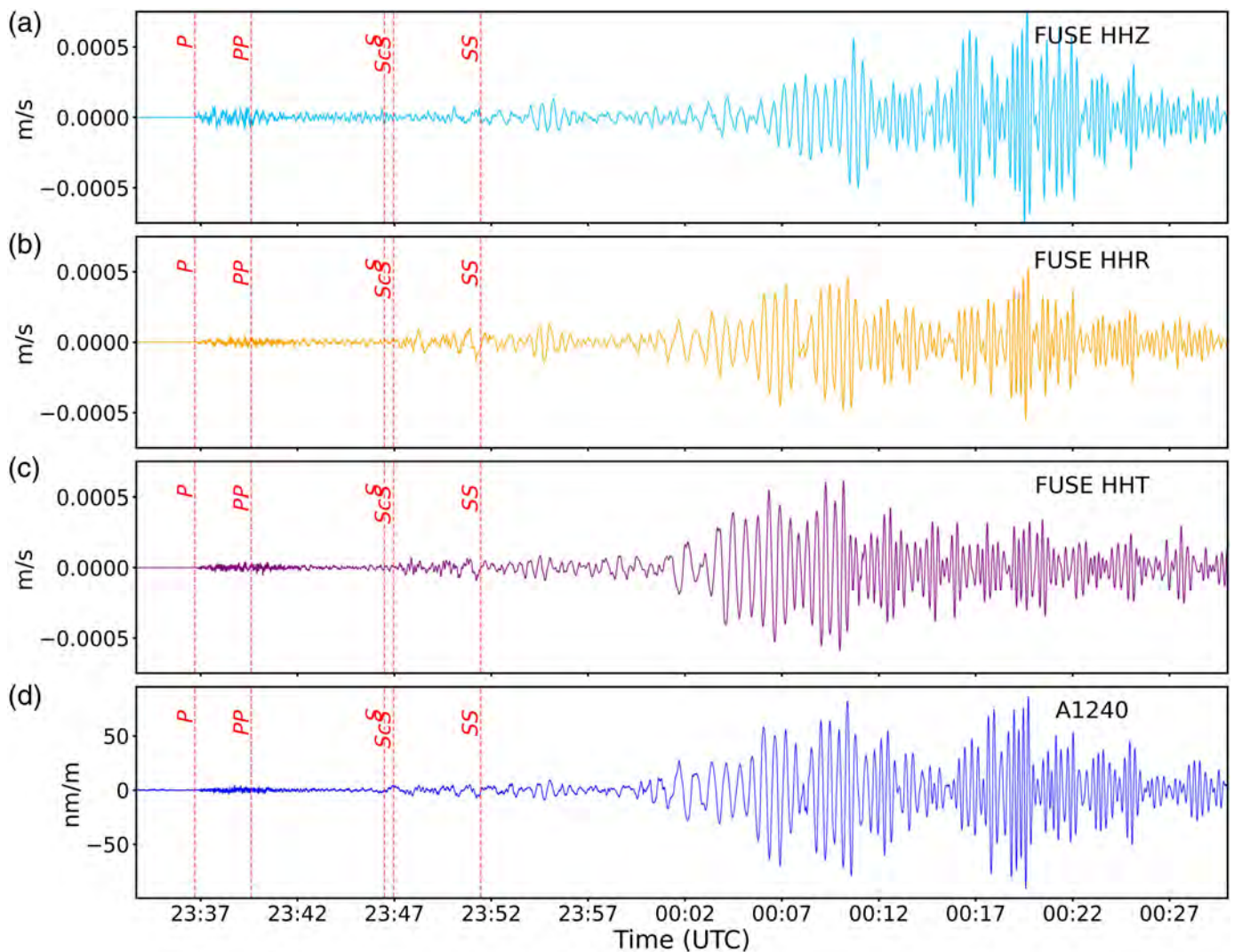


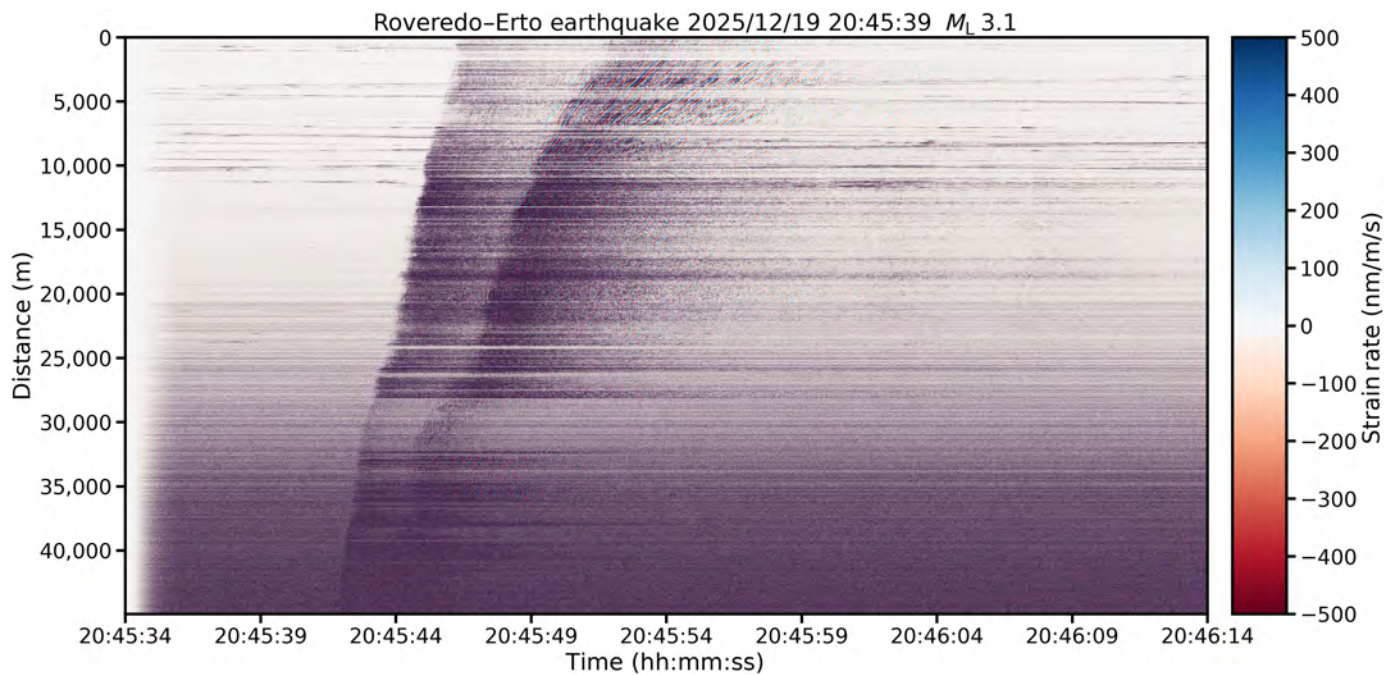
Figure 9. (a–d) Comparison between the teleseismic recordings of the M_w 8.8 Kamchatka earthquake from a representative DAS channel along the Amaro–Sappada line (A1240) and the three-component recordings of the nearest seismic station OX.FUSE. For the seismic station, the horizontal components were rotated according to the local orientation of the corresponding fiber segment. The DAS channel and the seismic station are approximately 500 m apart. The top three panels show ground-motion velocity recorded by the vertical (HHZ, light blue), radial (HHR, yellow), and transverse (HHT, purple) components of the seismic station, and the bottom panel displays the DAS signal after temporal integration. All signals are band-pass filtered between 0.01 and 5 Hz. The dashed vertical lines indicate the theoretical arrival times of major seismic phases, computed using the ak135 global velocity model. The color version of this figure is available only in the electronic edition.

times for both P and S phases, within the expected uncertainties associated with the different measured quantities and sensor characteristics. Although conventional stations provide three-component ground-motion recordings at discrete locations, DAS measurements offer a spatially continuous view of strain-rate variations along the fiber, highlighting complementary aspects of the seismic wavefield. This complementarity becomes particularly evident for local events, where dense spatial sampling helps constrain the evolution of the wavefield between stations.

For both local and regional earthquakes, the effective spatial sampling defined through channel averaging plays a critical role in balancing resolution and signal coherence. Averaged DAS data consistently exhibit improved signal-to-noise ratios (SNRs) at intermediate and long fiber offsets, facilitating the identification of seismic phases across extended distances. At the same time, the retained spatial resolution remains sufficient to capture meaningful variations in waveform properties along the fiber, supporting subsequent analyses aimed at operational applications.

Contribution of DAS data to earthquake location

The dense spatial sampling provided by the SMINO–DAS infrastructure offers the opportunity to explore the contribution of distributed strain-rate measurements to earthquake



location, particularly in regions where conventional seismic networks provide limited azimuthal coverage or sparse station spacing. To assess this contribution under realistic monitoring conditions, we analyze a representative local earthquake recorded simultaneously by the SMINO–DAS network and by the conventional SMINO seismic stations. For this purpose, we analyzed a local earthquake that occurred on 19 December 2025 at 20:45:39 (UTC), $M_L = 3.1$.

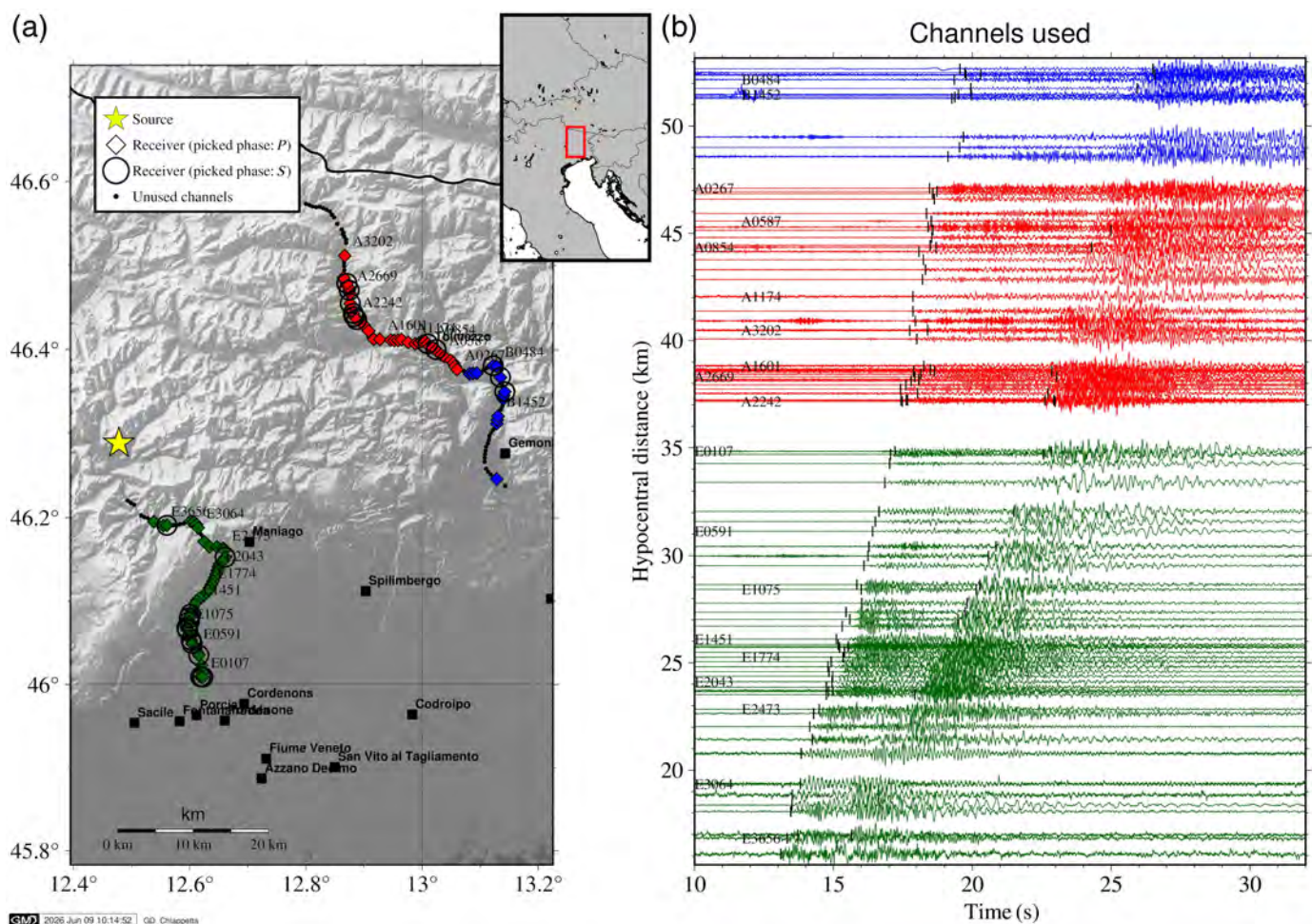
The selected event occurred within the Friuli region and was recorded with sufficient SNR across multiple DAS fiber routes and seismic stations to allow phase picking. Three independent location solutions were computed using the same velocity model and location algorithm: (1) a solution based solely on phase picks from the conventional seismic network, (2) a solution based solely on DAS-derived phase picks, and (3) a combined solution incorporating both datasets. This approach allows a direct comparison of the information content provided by each dataset under otherwise identical assumptions.

For the DAS-based solution, phase picks were extracted from selected channels along the fiber routes. Channel selection was performed automatically through regular spatial subsampling of the DAS data, typically using approximately 400 channels per fiber route with an effective spacing of about 100 m to limit redundancy and correlation among neighboring measurements. In addition, channels located within approximately 100 m of known or suspected manholes were excluded from the analysis to minimize possible effects associated with spare fiber coils and local installation irregularities. Phase picking was performed manually, retaining only channels exhibiting unambiguous phase onsets. No formal signal-to-noise threshold was adopted for channel selection. Instead, waveform quality was evaluated visually, and only arrivals characterized by sufficiently clear onset

Figure 10. Strain-rate recordings of the M_L 3.1 earthquake of 19 December 2025 (20:45:39 UTC), observed along the Roveredo–Erto fiber-optic line. The data are displayed as a function of time and distance along the fiber, with color indicating strain rate in $\text{nm}/\text{m}^{-1}/\text{s}^{-1}$. The color version of this figure is available only in the electronic edition.

times were retained for the location analysis. Arrival-time uncertainties were conservatively estimated during the picking procedure based on waveform quality and onset clarity, while also accounting for the uncertainty related to the directional sensitivity of DAS measurements and for the different nature of strain-rate observations compared to conventional three-component ground-motion records. This procedure resulted in a total of 120 phase picks from three DAS branches (A, B, and E), whereas the remaining branches were considered too distant from the epicentral area to provide reliable constraints (Fig. 11). The location obtained using DAS data alone is characterized by a relatively large azimuthal gap ($\sim 242^\circ$) compared with the solution based on the conventional seismic network. This primarily reflects the near-linear geometry of individual fiber routes, although the use of multiple lines can partially reduce the gap. Despite this limitation, the DAS-only solution provides a well-constrained epicentral position along the direction perpendicular to the fiber alignment and yields a focal depth consistent with that obtained from the conventional network. The depth constraint is primarily controlled by the dense spatial distribution of DAS picks at short epicentral distances, which partially compensates for the reduced azimuthal coverage (Table 3, Fig. 11).

The combined solution, integrating both DAS and conventional seismic data, benefits from the complementary



characteristics of the two datasets. The inclusion of DAS-derived picks increases the number of available observations at short distances, while the seismic network provides broader azimuthal coverage. As a result, the combined solution exhibits reduced location uncertainties, particularly in depth, compared with the solution obtained from the seismic network alone. Residual statistics and formal error estimates reflect this improvement, whereas remaining uncertainties are consistent with the limitations imposed by the velocity model and network geometry. Figure 12 shows the position of the epicenters obtained with the different approaches and the receivers used

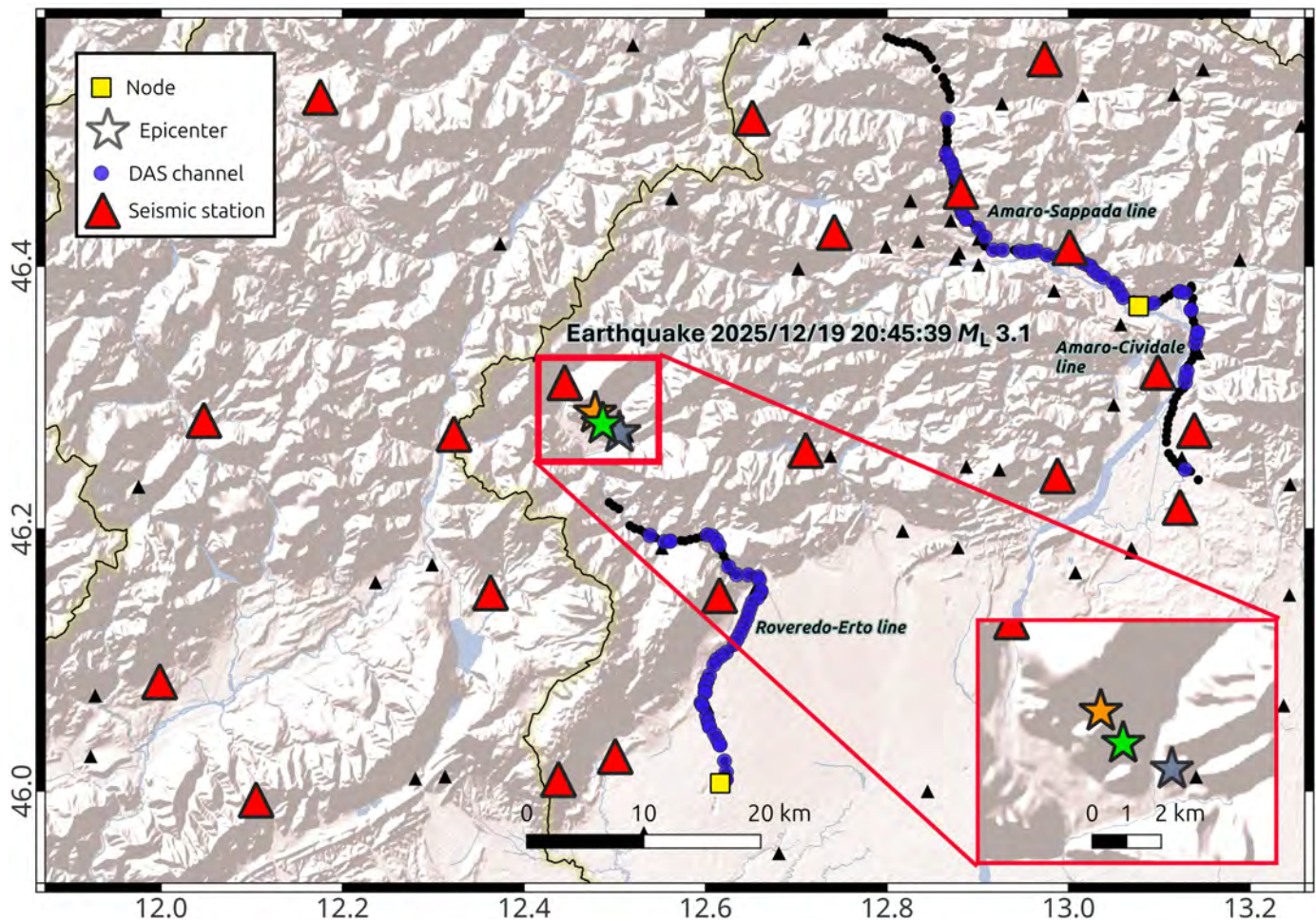
Figure 11. (a) Epicentral map of the analyzed earthquake showing the DAS fiber segments and channels used for the location procedure. The star marks the earthquake epicenter, and symbols along the fiber indicate channels with picked *P*- and *S*-phase arrivals (see legend). The inset highlights the location of the study area in the Italy-Austria border region. (b) Time-distance representation of the strain-rate recordings for the selected DAS channels, displayed as a function of hypocentral distance. Signals are band-pass filtered between 0.1 and 5 Hz. The figure refers to the earthquake location obtained using DAS data only. *P*- and *S*-phase picked arrival times are indicated by black vertical bars. Only a limited number of representative channel labels are displayed for clarity in both panels. The color version of this figure is available only in the electronic edition.

TABLE 3

Comparison of Earthquake Location Solutions Obtained from SMINO, DAS-Only, and Combined Datasets for the 19 December 2025 Event (20:45:40 UTC, M_L 3.1), Including Location Parameters, Data Coverage, and Quality Metrics

Source	Origin Time (UTC)	Latitude (°)	Longitude (°)	Z (km)	Gap (°)	Err H (km)	Err Z (km)
SMINO	2025/12/19 20:45:39.7 ± 0.3 s	46.2733	12.505	12.1	65	0.8	1.1
DAS	2025/12/19 20:45:40.0 ± 0.4 s	46.2883	12.4783	11	242	1.3	1.9
Combined dataset	2025/12/19 20:45:40.0 ± 0.3 s	46.2800	12.4867	11.5	65	0.6	0.4

DAS, distributed acoustic sensing; and SMINO, Sistema di Monitoraggio dell'Italia Nord-Orientale.



(seismic station and DAS channels). The three solutions differ by at most ~ 2.5 km in horizontal distance.

This case study well illustrates the potential of integrating DAS measurements into standard earthquake-location workflows and how their dense spatial sampling can complement conventional seismic observations. At the same time, it highlights the constraints associated with fiber geometry, channel orientation, and coupling conditions, which must be carefully considered when incorporating DAS data into operational location procedures.

Frequency-domain signal-to-noise assessment

A dedicated spectral analysis was carried out to quantitatively compare the resolved frequency band and the frequency-dependent SNR of DAS recordings and a nearly colocated seismic station (Fig. 13). The analysis was conducted using channels along the Roveredo–Erto fiber-optic line and the IT.MOV seismic station, focusing on the M_L 3.1 earthquake described in the previous section and used for the localization tests with different datasets. For this analysis, two time windows were considered, which are representative of the pre-event noise and of the earthquake signal, respectively. The selected signals were processed using consistent strategies for the two systems. For the DAS, two adjacent channels were analyzed jointly to

Figure 12. Map showing the earthquake epicentral locations obtained using the different datasets described in the text (SMINO, DAS-only, and combined solutions) for the 19 December 2025 event (20:45:40 UTC, M_L 3.1). Colored stars indicate epicenters, whereas seismic stations and DAS channels used in the location are shown as red triangles and blue dots, respectively. The inset highlights the area around the epicentral region; the different colors mark DAS (orange), combined (green), and SMINO (grey) solutions. Numerical details of the location results are reported in Table 2. The color version of this figure is available only in the electronic edition.

enhance robustness, whereas for the seismic station only the two horizontal components were considered.

Power spectral densities were computed using 30 s time windows for both noise and signal, applying Hann tapering, logarithmic averaging across segments (and across the two DAS channels and the two components of the station, respectively), and final Konno–Ohmachi smoothing. DAS strain-rate data were corrected for instrument sensitivity and integrated in time to obtain strain (used here for relative spectral comparison), whereas the instrument response of IT.MOV was removed to obtain ground velocity on the horizontal components. Given the different measured quantities, the comparison

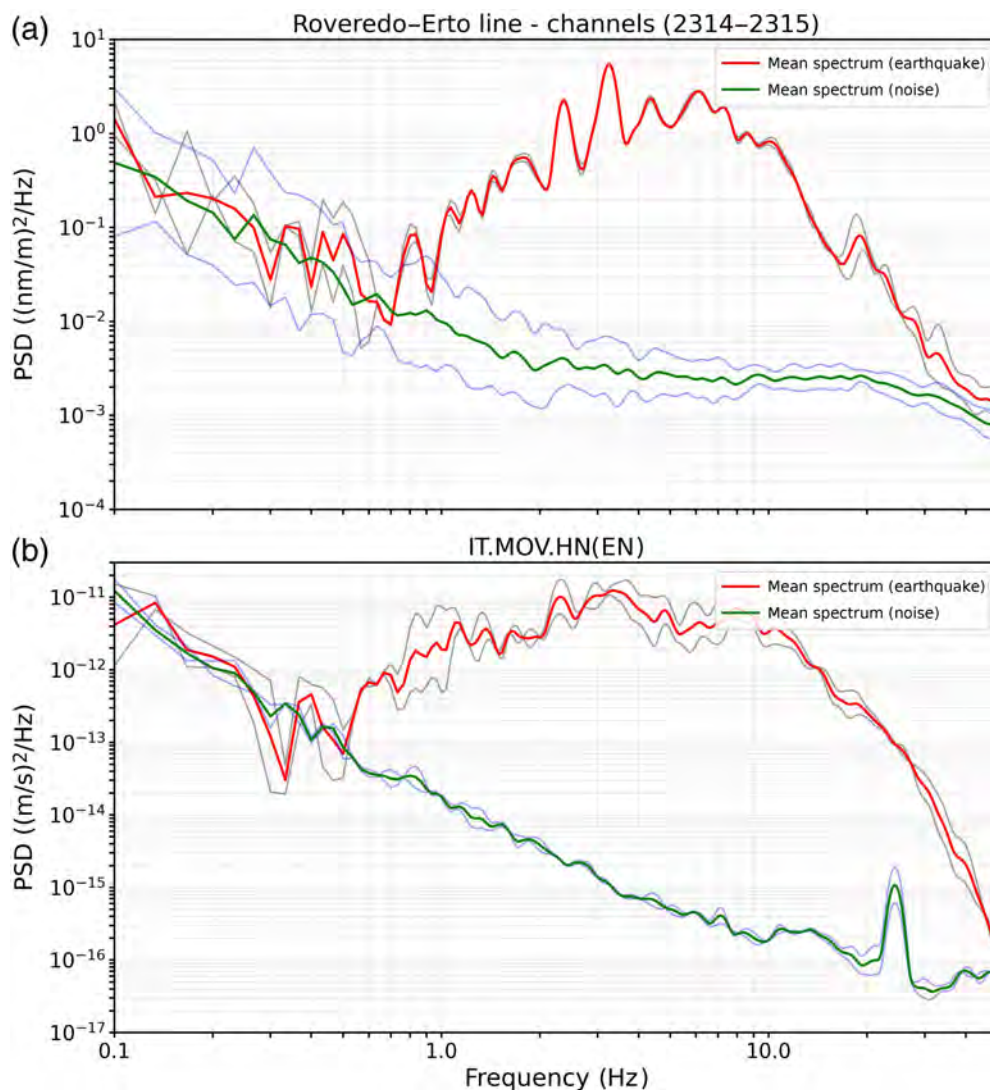


Figure 13. Noise and earthquake PSDs for two DAS channels (a) and the horizontal components (north-south [NS] and east-west [EW]) of the nearly co-located seismic station (b). The earthquake signal (red) emerges above noise (green) across a wide frequency range for both instruments. The light blue and gray curves represent the individual spectra used to compute the average noise and earthquake PSDs, respectively. The color version of this figure is available only in the electronic edition.

is interpreted primarily in terms of detectability (signal emerging above noise) and relative SNR across frequency, rather than absolute spectral amplitudes.

The resulting spectra indicate that, over a broad frequency band, the earthquake signal clearly emerges above the noise level for both DAS and the seismic station, demonstrating comparable detectability (Fig. 13) and similar frequency-dependent SNR trends. At low frequencies, convergence between noise and signal spectra is observed, consistent with ambient noise dominance. Together, these observations support the robustness of DAS for frequency-domain characterization of local seismic signals and confirm its capability to provide SNR and bandwidth estimates that are consistent

with those obtained from nearby conventional instrumentation.

Discussion

The new SMINO-DAS infrastructure created in northeastern Italy through a cooperation between OGS, INSIEL S.p.A, and the Regional Government of Friuli Venezia Giulia represents a step toward the integration of distributed fiber-optic sensing into routine regional seismic monitoring, rather than a short-term experimental deployment. Operating DAS as a persistent component of an established monitoring system imposes constraints that directly affect acquisition strategies, data processing, and the interpretation of the recorded signals. Many of these constraints emerge from the physical characteristics of the sensing principle and from the properties of telecommunication infrastructure, and they must be explicitly considered when assessing the potential and limitations of DAS observations at regional scale.

A central outcome of this study is that the effective information content of DAS data in an operational context is not controlled by the maximum spatial resolution technically

achievable by the interrogators. Although meter-scale channel spacing is possible, the fixed gauge length of the instrument, combined with optical attenuation and increasing environmental noise at large fiber offsets, limits the benefits of very fine spatial sampling. Under these conditions, spatial oversampling does not translate into improved observational capability. The adoption of spatial averaging therefore reflects a physically motivated design choice aimed at enhancing signal coherence and robustness, particularly at long distances from the interrogator, rather than a simple response to data volume or formatting constraints. The ambient noise analyses presented in the [Network Configuration, Data Acquisition, and Workflow](#) section confirm that averaging significantly improves the SNR

while preserving spatial variations relevant for regional monitoring applications.

One of the most distinctive features of the SMINO–DAS infrastructure is the spatial continuity of the measurements, which enables the direct observation of wavefield propagation along extended fiber routes. Teleseismic and regional recordings demonstrate that coherent seismic phases can be tracked over tens of kilometers, revealing lateral variations in arrival timing, waveform character, and apparent propagation velocity. These observations provide a perspective on seismic wavefields that is fundamentally different from that offered by point-sensor networks, where spatial continuity must be inferred indirectly. At the same time, the results clearly show that this added value is intrinsically directional: DAS measurements are sensitive to strain or strain rate projected along the fiber axis, and their response depends on the relative orientation between the fiber and the incoming wavefield. This directional sensitivity is not a processing artefact but a structural property of the measurement, and it strongly conditions the interpretation of DAS data (e.g., [Bozzi et al., 2024](#)).

The earthquake location case study illustrates both the strengths and limitations arising from this geometry. When used alone, DAS-derived phase picks provide dense observations at short epicentral distances but suffer from poor azimuthal coverage due to the essentially linear geometry of individual fiber routes. Therefore, DAS-only locations are primarily constrained perpendicular to the fiber alignment, whereas uncertainties remain large along the fiber direction. Despite this limitation, the dense spatial distribution of DAS picks contributes useful information on focal depth, highlighting the potential of DAS to complement conventional networks in depth-sensitive applications. The combined location solution demonstrates that the integration of DAS and seismic network data is more effective than either dataset alone, with DAS contributing dense near-field observations and conventional stations providing broader azimuthal coverage and three-component ground-motion information. Although a systematic assessment on a larger earthquake dataset is beyond the scope of this study, additional location tests on local earthquakes (magnitude range 0.5–3.9), not shown here, were generally consistent with the improvements illustrated in the presented example. In particular, the enhanced near-source coverage is expected to improve hypocentral depth constraints and azimuthal sampling for local seismicity.

Similar hybrid strategies may also be relevant for future real-time monitoring and EEW applications, where DAS could complement conventional seismic networks through dense near-field observations. Recent developments in DAS-oriented machine-learning and physics-based approaches suggest promising perspectives for improving automatic phase picking, real-time event detection, and low latency capability (e.g., [Zhu et al., 2023](#); [Gou et al., 2026](#); [Ben-Zeev and Lior, 2026](#)). In this context, recent operational workflows have already explored

the operational integration of DAS and conventional seismic stations using selected DAS channels for real-time processing and automatic monitoring (e.g., [Baillet et al., 2025](#); [Biondi et al., 2026](#)). Furthermore, the simultaneous availability of DAS and conventional seismic recordings for the same events provides valuable opportunities for systematic comparisons between strain-rate measurements and standard ground-motion observations, as preliminarily shown in the results presented here and comprehensively investigated in previous broadband DAS response studies (e.g., [Lindsey et al., 2020](#)). These datasets are also essential for evaluating DAS amplitude fidelity and for establishing calibrated magnitude proxies based on DAS measurements, paving the way for the development of local DAS-derived magnitude scales. The spectral analysis discussed earlier further demonstrates the capability of DAS to reliably capture local seismic signals across a broad frequency range, suggesting its complementary value for traditional seismic measurements not only in event location, but also in providing information on the source properties. The role of coupling conditions and infrastructure heterogeneity emerges as a key factor controlling data quality throughout the SMINO–DAS network. Fiber segments installed in different environments, such as ducts, trenches, or tunnels, exhibit systematically different noise characteristics and signal coherence, while spare coils stored in manholes introduce localized artefacts that can severely degrade data usability if not properly identified. The tap-test surveys and noise-based quality metrics described in the [Network Configuration, Data Acquisition, and Workflow](#) section are therefore not ancillary procedures but essential components of the operational workflow, requiring further attention. Unlike conventional seismic stations, which are installed following strict site-selection criteria, DAS deployments inherit the properties of pre-existing telecommunication infrastructure. As a result, data quality varies along the fiber and must be managed through channel selection, spatial averaging, and continuous quality control. The observed temporal stability of spatial noise patterns suggests that, once characterized, fiber segments can be treated as reliable sensing elements, provided that their coupling conditions are explicitly accounted for.

Taken together, these observations indicate that the primary value of a regional DAS infrastructure such as SMINO–DAS lies in its ability to augment existing monitoring systems by providing dense spatial sampling across tectonically complex areas, rather than in replacing conventional seismic networks. From an operational perspective, the centralized architecture of DAS interrogators simplifies maintenance and remote management compared with dense conventional seismic networks composed of many independent stations. In the SMINO–DAS framework, the telecommunication fiber infrastructure, including fiber maintenance, splicing, and line interventions, remains under the responsibility of the network provider, whereas the monitoring activities carried out by CRS–OGS

mainly concern interrogator operation, data-quality control, acquisition continuity, storage, and processing services. The deployment therefore did not require the creation of a dedicated field-maintenance team comparable with that needed for a dense network of independent seismic stations, although existing staff had to be specifically trained for DAS operation and data handling. This operational model is not intended to replace conventional seismic instrumentation, but it provides a favorable ratio between spatial coverage, number of sensing channels, and maintenance effort when pre-existing fiber infrastructure is available.

DAS is particularly well suited for applications that benefit from continuous spatial coverage, including the analysis of wavefield propagation, the investigation of near-surface heterogeneities, and the improvement of hypocentral depth constraints in combination with point sensors. Conversely, applications requiring uniform azimuthal coverage, absolute ground-motion measurements, or detailed focal mechanism analysis remain better served by conventional seismic instrumentation. The results presented here underline the importance of viewing DAS as an additional observational layer within a multisensor framework, strengths and limitations for which must be evaluated in relation to the specific characteristics of the deployed infrastructure.

Conclusions

In this study, we presented the design, implementation, and initial operational performance of the SMINO-DAS infrastructure, a regional-scale distributed acoustic sensing system integrated into the routine seismic monitoring activities of CRS-OGS in northeastern Italy. The infrastructure is conceived and operated to ensure continuous data acquisition, standard-compliant dissemination, and long-term sustainability within an institutional monitoring framework. Built on existing public telecommunication fiber-optic infrastructure and operated in parallel with a mature conventional seismic network, SMINO-DAS represents one of the first attempts in Europe to deploy DAS as a persistent component of regional seismic monitoring rather than as a short-term experimental system.

The results demonstrate that, when operated under realistic monitoring conditions, DAS can provide stable and coherent recordings of teleseismic, regional, and local earthquakes over tens of kilometers. The spatial continuity of the measurements enables direct observation of seismic wavefield propagation along extended fiber routes, complementing the information obtained from point-sensor networks. At the same time, the study highlights that the effective use of DAS at regional scale requires careful consideration of instrumental constraints, particularly the gauge length, optical attenuation at long offsets, and the strong dependence of data quality on coupling conditions inherited from telecommunication infrastructure. These constraints are intrinsic to DAS deployments on telecom fibers

and define the operational framework within which meaningful seismic observations can be obtained.

The analysis of local earthquake recordings and the location case study show that DAS data alone can be limited by the essentially linear geometry of individual fiber routes and by directional sensitivity intrinsic to strain-rate measurements. However, when DAS observations from multiple fiber routes are jointly exploited, accounting for their spatial configuration and orientation, and integrated with conventional seismic data, they contribute valuable near-field information and can improve constraints on hypocentral parameters, particularly depth. This improvement is achieved without modifying standard location algorithms, highlighting the practical compatibility of DAS observations with existing seismological workflows. These results confirm that the primary strength of DAS lies in its complementarity with existing seismic networks rather than in its use as a stand-alone monitoring solution.

From an operational perspective, the SMINO-DAS experience underscores the importance of treating noise characterization, channel localization, and quality control as integral parts of the monitoring workflow. Spatial averaging and channel selection emerge as physically motivated design choices that enhance data usability and sustainability, rather than as secondary responses to data-volume constraints. The SMINO-DAS experience therefore provides a concrete reference for the operational management of noise, coupling heterogeneity, and data selection in regional DAS deployments.

Future developments of the SMINO-DAS infrastructure will focus on expanding spatial coverage through the interrogation of additional fiber routes with diverse orientations, which would mitigate geometric limitations and enhance azimuthal coverage. Advances in interrogator technology, including increased sensitivity and flexible gauge-length configurations, may further improve performance at long offsets. Within this evolving technological landscape, the integration of DAS into multisensor seismic observatories offers a promising pathway toward more spatially resolved and resilient regional monitoring systems, also including ambient and environmental processes monitoring. Within this perspective, the SMINO-DAS infrastructure is already suitable for supporting applications such as enhanced earthquake location, wavefield analysis, and near-real-time situational awareness in seismically active regions, and provides a natural testbed for the development of data-driven approaches, including machine-learning techniques, and also for the complementary use of DAS observations in EEW frameworks.

Data and Resources

The following lists and databases were consulted: (1) CPTI15 is available at <https://emidius.mi.ingv.it/CPTI15-DBMI15/>, (2) DISS database is available at <https://diss.ingv.it/>, and (3) OGS bulletin (since 1977) is available at https://www.crs.inogs.it/bollettino_new/. Some of the software cited across the document are available at <https://pypi.org/>

project/npTDMS/, <https://github.com/EarthScope/ringserver>, and <https://www.seiscomp.de/>. Data from the following networks were used: (1) [IT] Presidency of Council of Ministers—Civil Protection Department (1972). Italian Strong-Motion Network [Data set], International Federation of Digital Seismograph Networks, doi: [10.7914/SN/IT](https://doi.org/10.7914/SN/IT). (2) [OX] Istituto Nazionale di Oceanografia e di Geofisica Sperimentale—OGS (2016). Northeast Italy Seismic Network [Data set], FDSN, doi: [10.7914/SN/OX](https://doi.org/10.7914/SN/OX). Map figures were created using QGIS (<https://www.qgis.org/>). Figure 11 was made using the Generic Mapping Tools version 6.5.0 (<https://www.generic-mapping-tools.org/>). Event-based distributed acoustic sensing waveform datasets associated with local earthquakes, including all spatially averaged channels from the available fiber routes, are available from the authors upon reasonable request. All websites were last accessed in February 2026.

Declaration of Competing Interests

The authors acknowledge that there are no conflicts of interest recorded.

Acknowledgments

The iDAS version 2 optical interrogation units, dedicated servers, and related accessories were acquired within the framework of the Italian National Recovery and Resilience Plan (PNRR), Mission 4 “Education and Research,” Component 2, Investment Line 3.1. The activity is funded by the European Union through the ITINERIS project (Italian Integrated Environmental Research Infrastructures System, IR0000032, CUP B53C22002150006). This work also benefited from the contributions and collaborations established through REG4IA – Regioni per l’Intelligenza Artificiale: Resilienza e Sicurezza del Territorio, a project funded by the Department for Digital Transformation (DTD), with the Autonomous Region of Friuli Venezia Giulia serving as the project beneficiary. Comments and suggestions from two anonymous reviewers contributed to improving the content and the quality of the article. G. D. Chiappetta, V. Poggi, M. Picozzi, and S. Parolai led the research and wrote the text; G. D. Chiappetta analyzed the data and drew the figures. All the authors contributed to the development of the work and to the final editing of the text.

References

Ajo-Franklin, J. B., S. Dou, N. J. Lindsey, I. Monga, C. Tracy, M. Robertson, V. Rodriguez Tribaldos, C. Ulrich, B. Freifeld, T. Daley, *et al.* (2019). Distributed acoustic sensing using dark fiber for near-surface characterization and broadband seismic event detection, *Sci. Rep.* **9**, no. 1328, doi: [10.1038/s41598-018-36675-8](https://doi.org/10.1038/s41598-018-36675-8).
 Anderson, H., and J. Jackson (1987). Active tectonics of the Adriatic region, *Geophys. J. Int.* **91**, no. 3, 937–983, doi: [10.1111/j.1365-246X.1987.tb01675.x](https://doi.org/10.1111/j.1365-246X.1987.tb01675.x).
 Atanackov, J., P. Jamšek Rupnik, J. Jež, B. Celarc, M. Novak, B. Milanič, A. Markelj, M. Bavec, and V. Kastelic (2021). Database of Active Faults in Slovenia: Compiling a New Active Fault Database at the Junction Between the Alps, the Dinarides and the Pannonian Basin Tectonic Domains, *Front. Earth Sci.*, doi: [10.3389/feart.2021.604388](https://doi.org/10.3389/feart.2021.604388).
 Baillet, M., D. Rivet, A. Trabattini, J. Chèze, F. Peix, D. Ambrois, M. van den Ende, C. Vernet, C. Strumia, B. Potin, *et al.* (2025).

Automatic earthquake catalogs from a permanent DAS offshore network, *J. Geophys. Res. Solid Earth* **130**, no. 10, doi: [10.1029/2025JB031565](https://doi.org/10.1029/2025JB031565).
 Barnaba, C., L. Marello, A. Vuan, F. Palmieri, M. Romanelli, E. Priolo, and C. Braitenberg (2010). The buried shape of an alpine valley from gravity surveys, seismic and ambient noise analysis, *Geophys. J. Int.* **180**, no. 2, 715–733, doi: [10.1111/j.1365-246X.2009.04428.x](https://doi.org/10.1111/j.1365-246X.2009.04428.x).
 Ben-Zeev, S., and I. Lior (2026). Physics-based earthquake early warning using distributed acoustic sensing, *Sci. Rep.* **16**, no. 2533, doi: [10.1038/s41598-025-32269-3](https://doi.org/10.1038/s41598-025-32269-3).
 Beyreuther, M., R. Barsch, L. Krischer, T. Megies, Y. Behr, and J. Wassermann (2010). ObsPy: A Python toolbox for seismology, *Seismol. Res. Lett.* **81**, no. 3, 530–533, doi: [10.1785/gssrl.81.3.530](https://doi.org/10.1785/gssrl.81.3.530).
 Biondi, E., G. Tepp, E. Yu, J. K. Saunders, V. Yartsev, M. Black, M. Watkins, A. Bhaskaran, R. Bhadha, Z. Zhan, *et al.* (2026). Real-time processing of distributed acoustic sensing data for earthquake monitoring operations, *Seismol. Res. Lett.*, doi: [10.1785/0220250208](https://doi.org/10.1785/0220250208).
 Biondi, E., X. Wang, E. F. Williams, and Z. Zhan (2022). Geolocalization of large-scale DAS channels using a GPS-tracked moving vehicle, *Seismol. Res. Lett.* **94**, no. 1, 318–330, doi: [10.1785/0220220169](https://doi.org/10.1785/0220220169).
 Bozzi, E., N. P. Agostinetti, A. Fichtner, S. Klaasen, A. Ugalde, B. Biondi, S. Yuan, T. Dahm, M. Isken, P. Paitz, *et al.* (2024). Modelling uncertainty in P-wave arrival-times retrieved from DAS data: Case-studies from 15 fibre optic cables, *Geophys. J. Int.* **239**, no. 3, 1928–1942, doi: [10.1093/gji/ggae364](https://doi.org/10.1093/gji/ggae364).
 Bragato, P. L., P. Comelli, A. Saraò, D. Zuliani, L. Moratto, V. Poggi, G. Rossi, C. Scaini, M. Segan, C. Barnaba, and P. Bernardi (2021). The OGS–northeastern Italy seismic and deformation network: Current status and outlook, *Seismol. Res. Lett.* **92**, no. 3, 1704–1716, doi: [10.1785/0220200372](https://doi.org/10.1785/0220200372).
 Bragato, P. L., D. Pesaresi, A. Saraò, P. Di Bartolomeo, and G. Duri (2013). OGS improvements in the year 2011 in running the northeastern Italy Seismic Network, *Adv. Geosci.* **34**, 5–8, doi: [10.5194/adgeo-34-5-2013](https://doi.org/10.5194/adgeo-34-5-2013).
 Bressan, G., and P. L. Bragato (2009). Seismic deformation pattern in the Friuli-Venezia Giulia region (north-eastern Italy) and western Slovenia, *Boll. Geofis. Teor. Appl.* **50**, no. 3, 255–275.
 Bressan, G., C. Barnaba, P. Bragato, M. Ponton, and A. Restivo (2018). Revised seismotectonic model of NE Italy and W Slovenia based on focal mechanism inversion, *J. Seismol.* **22**, no. 6, 1563–1578, doi: [10.1007/s10950-018-9785-2](https://doi.org/10.1007/s10950-018-9785-2).
 Bressan, G., C. Barnaba, A. Magrin, and G. Rossi (2018). A study on off-fault aftershock pattern at N-Adria microplate, *J. Seismol.* **22**, no. 4, 863–881, doi: [10.1007/s10950-018-9737-x](https://doi.org/10.1007/s10950-018-9737-x).
 Bressan, G., C. Barnaba, A. Peresan, and G. Rossi (2021). Anatomy of seismicity clustering from parametric space-time analysis, *Phys. Earth Planet. In.* **320**, 106787, doi: [10.1016/j.pepi.2021.106787](https://doi.org/10.1016/j.pepi.2021.106787).
 Bressan, G., G. Gentile, R. Tondi, R. D. Franco, and S. Urban (2012). Sequential Integrated Inversion of tomographic images and gravity data: An application to the Friuli area (north-eastern Italy), *Boll. Geofis. Teor. Appl.* **53**, 191–212.
 Bressan, G., G. F. Gentile, B. Perniola, and S. Urban (2009). The 1998 and 2004 Bovec-Krn (Slovenia) seismic sequences: aftershock pattern, focal mechanisms and static stress changes, *Geophys. J. Int.* **179**, no. 1, 231–253, doi: [10.1111/j.1365-246X.2009.04247.x](https://doi.org/10.1111/j.1365-246X.2009.04247.x).

- Bressan, G., A. Snidarcig, and C. Venturini (1998). Present state of tectonic stress of the Friuli area (eastern southern Alps), *Tectonophysics* **292**, nos. 3/4, 211–227, doi: [10.1016/S0040-1951\(98\)00065-1](https://doi.org/10.1016/S0040-1951(98)00065-1).
- Caracciolo, C. H., D. Slejko, R. Camassi, and V. Castelli (2021). The eastern Alps earthquake of 25 January 1348: New insights from old sources, *Bull. Geophys. Oceanogr.* **63**, 335–364, doi: [10.4430/bgo00364](https://doi.org/10.4430/bgo00364).
- Carulli, G. B. (2006). Geological map of the Friuli Venezia Giulia region, available at <https://www.regione.fvg.it/rafv/export/sites/default/RAFVG/ambiente-territorio/geologia/FOGLIA01/allegati/Geofvg.pdf> (last accessed February 2006).
- Castellarin, A., and L. Cantelli (2000). Neo-Alpine evolution of the southern eastern Alps, *J. Geodynam.* **30**, nos. 1/2, 251–274, doi: [10.1016/S0264-3707\(99\)00036-8](https://doi.org/10.1016/S0264-3707(99)00036-8).
- D'Agostino, N., D. Cheloni, S. Mantenuto, G. Selvaggi, A. Michelini, and D. Zuliani (2005). Strain accumulation in the southern Alps (NE Italy) and deformation at the northeastern boundary of Adria observed by CGPS measurements, *Geophys. Res. Lett.* **32**, no. 19, doi: [10.1029/2005GL024266](https://doi.org/10.1029/2005GL024266).
- DISS Working Group (2025). Database of Individual Seismogenic Sources (DISS), Version 3.3.1: A compilation of potential sources for earthquakes larger than M 5.5 in Italy and surrounding areas, *Istituto Nazionale di Geofisica e Vulcanologia (INGV)*, doi: [10.13127/diss3.3.1](https://doi.org/10.13127/diss3.3.1).
- Fitzko, F., P. Suhadolc, A. Aoudia, and G. Panza (2005). Constraints on the location and mechanism of the 1511 western-Slovenia earthquake from active tectonics and modeling of macroseismic data, *Tectonophysics* **404**, nos. 1/2, 77–90, doi: [10.1016/j.tecto.2005.05.003](https://doi.org/10.1016/j.tecto.2005.05.003).
- Gou, Y., R. N. Nof, B. Pardini, and R. M. Allen (2026). Integrating fiber-optic seismic arrays into earthquake early warning systems with the dEPIC framework, *Sci. Rep.* **16**, no. 960, doi: [10.1038/s41598-025-30568-3](https://doi.org/10.1038/s41598-025-30568-3).
- Heit, B., L. Cristiano, C. Haberland, F. Tilmann, D. Pesaresi, Y. Jia, H. Hausmann, S. Hemmleb, M. Haxter, T. Zieke, *et al.* (2021). The SWATH-D Seismological Network in the eastern Alps, *Seismol. Res. Lett.* **92**, no. 3, 1592–1609, doi: [10.1785/0220200377](https://doi.org/10.1785/0220200377).
- Hofman, L. J., J. Kummerow, and S. Cesca (2023). A new seismicity catalogue of the eastern Alps using the temporary Swath-D network, *Solid Earth* **14**, no. 10, 1053–1066, doi: [10.5194/se-14-1053-2023](https://doi.org/10.5194/se-14-1053-2023).
- Jousset, P., T. Reinsch, T. Ryberg, H. Blanck, A. Clarke, R. Aghayev, G. P. Hersir, J. Henningsen, M. Weber, and C. M. Krawczyk (2018). Dynamic strain determination using fibre-optic cables allows imaging of seismological and structural features, *Nat. Commun.* **9**, no. 2509, doi: [10.1038/s41467-018-04860-y](https://doi.org/10.1038/s41467-018-04860-y).
- Lai, V. H., K. M. Hodgkinson, R. W. Porritt, and R. Mellors (2024). Toward a metadata standard for distributed acoustic sensing (DAS) data collection, *Seismol. Res. Lett.* **95**, no. 3, 1986–1999, doi: [10.1785/0220230325](https://doi.org/10.1785/0220230325).
- Lindsey, N. J., E. R. Martin, D. S. Dreger, B. Freifeld, S. Cole, S. R. James, B. L. Biondi, and J. B. Ajo-Franklin (2017). Fiber-optic network observations of earthquake wavefields, *Geophys. Res. Lett.* **44**, no. 23, doi: [10.1002/2017GL075722](https://doi.org/10.1002/2017GL075722).
- Lindsey, N. J., H. Rademacher, and J. B. Ajo-Franklin (2020). On the broadband instrument response of fiber-optic DAS arrays, *J. Geophys. Res.: Solid Earth* **125**, doi: [10.1029/2019JB018145](https://doi.org/10.1029/2019JB018145).
- Lior, I., A. Sladen, D. Mercerat, J.-P. Ampuero, D. Rivet, and S. Sambolian (2021). Strain to ground motion conversion of distributed acoustic sensing data for earthquake magnitude and stress drop determination, *Solid Earth* **12**, no. 6, 1421–1442, doi: [10.5194/se-12-1421-2021](https://doi.org/10.5194/se-12-1421-2021).
- Magrin, A., and G. Rossi (2020). Deriving a new crustal model of northern Adria: The northern Adria crust (NAC) model, *Front. Earth Sci.* **8**, doi: [10.3389/feart.2020.00089](https://doi.org/10.3389/feart.2020.00089).
- Marchesini, A., M. E. Poli, L. Bonini, M. Buseti, C. Piano, M. Dal Cin, G. Paiero, G. Areggi, D. Civile, M. Ponton, *et al.* (2023). Linee guida per l'utilizzo della banca dati georiferita delle faglie attive della Regione Friuli Venezia Giulia, *Gruppo di lavoro Faglie Attive FVG. Servizio Geologico* (in Italian).
- Metois, M., N. D'Agostino, A. Avallone, N. Chamot-Rooke, A. Rabaute, L. Duni, N. Kuka, R. Koci, and I. Georgiev (2015). Insights on continental collisional processes from GPS data: Dynamics of the peri-Adriatic belts, *J. Geophys. Res. Solid Earth* **120**, no. 12, 8701–8719, doi: [10.1002/2015JB012023](https://doi.org/10.1002/2015JB012023).
- Petersen, G. M., L. J. Hofman, J. Kummerow, and S. Cesca (2025). Microseismicity in the Large-N Swath-D Network: Revealing seismic sequences and active faults in the eastern Alps, *J. Geophys. Res. Solid Earth* **130**, no. 2, doi: [10.1029/2024JB030516](https://doi.org/10.1029/2024JB030516).
- Poli, M. E., and A. Zanferrari (2018). The seismogenic sources of the 1976 Friuli earthquakes: A new seismotectonic model for the Friuli area, *Boll. Geofis. Teor. Appl.*, doi: [10.4430/bgta0209](https://doi.org/10.4430/bgta0209).
- Rovida, A., M. Locati, R. Camassi, B. Lolli, and P. Gasperini (2020). The Italian earthquake catalogue CPTI15, *Bull. Earthq. Eng.* **18**, no. 7, 2953–2984, doi: [10.1007/s10518-020-00818-y](https://doi.org/10.1007/s10518-020-00818-y).
- Rovida, A., M. Locati, R. Camassi, B. Lolli, P. Gasperini, and A. Antonucci (2022). Catalogo Parametrico dei Terremoti Italiani (CPTI15), versione 4.0 [Data set], *Istituto Nazionale di Geofisica e Vulcanologia (INGV)*, doi: [10.13127/cpti/cpti15.4](https://doi.org/10.13127/cpti/cpti15.4) (in Italian).
- Serpelloni, E., G. Vannucci, L. Anderlini, and R. Bennett (2016). Kinematics, seismotectonics and seismic potential of the eastern sector of the European Alps from GPS and seismic deformation data, *Tectonophysics* **688**, 157–181, doi: [10.1016/j.tecto.2016.09.026](https://doi.org/10.1016/j.tecto.2016.09.026).
- Sladen, A., D. Rivet, J. P. Ampuero, L. De Barros, Y. Hello, G. Calbris, and P. Lamare (2019). Distributed sensing of earthquakes and ocean-solid Earth interactions on seafloor telecom cables, *Nat. Commun.* **10**, no. 5777, doi: [10.1038/s41467-019-13793-z](https://doi.org/10.1038/s41467-019-13793-z).
- Slejko, D., G. Neri, I. Orozova, G. Renner, and M. Wyss (1999). Stress field in Friuli (NE Italy) from fault plane solutions of activity following the 1976 main shock, *Bull. Seismol. Soc. Am.* **89**, no. 4, 1037–1052, doi: [10.1785/BSSA0890041037](https://doi.org/10.1785/BSSA0890041037).
- Tunini, L., A. Magrin, G. Rossi, and D. Zuliani (2024). Global Navigation Satellite System (GNSS) time series and velocities about a slowly convergent margin processed on high-performance computing (HPC) clusters: Products and robustness evaluation, *Earth Syst. Sci. Data* **16**, no. 2, 1083–1106, doi: [10.5194/essd-16-1083-2024](https://doi.org/10.5194/essd-16-1083-2024).
- Venturini, C. (1991). Neogenic-Quaternary kinematics of the eastern southern Alps (Friuli), *Studi Geol. Camerti Vol. Spec.* 109–116.
- Viganò, A., D. Scafidi, G. Ranalli, S. Martin, B. Della Vedova, and D. Spallarossa (2015). Earthquake relocations, crustal rheology, and active deformation in the central-eastern Alps (N Italy), *Tectonophysics* **661**, 81–98, doi: [10.1016/j.tecto.2015.08.017](https://doi.org/10.1016/j.tecto.2015.08.017).
- Villani, F., A. Antonioli, M. Pastori, P. Baccheschi, and M. G. Ciaccio (2024). Stress patterns and crustal anisotropy in the eastern Alps: Insights from seismological and geological observations, *Tectonics* **43**, no. 3, doi: [10.1029/2023TC008033](https://doi.org/10.1029/2023TC008033).

- Walter, F., D. Gräff, F. Lindner, P. Paitz, M. Köpfl, M. Chmiel, and A. Fichtner (2020). Distributed acoustic sensing of microseismic sources and wave propagation in glaciated terrain, *Nat. Commun.* **11**, no. 2436, doi: [10.1038/s41467-020-15824-6](https://doi.org/10.1038/s41467-020-15824-6).
- Zhan, Z. (2020). Distributed acoustic sensing turns fiber-optic cables into sensitive seismic antennas, *Seismol. Res. Lett.* **91**, no. 1, 1–15, doi: [10.1785/0220190112](https://doi.org/10.1785/0220190112).
- Zhu, T., J. Shen, and E. R. Martin (2021). Sensing Earth and environment dynamics by telecommunication fiber-optic sensors: An urban experiment in Pennsylvania, USA, *Solid Earth* **12**, 219–235, doi: [10.5194/se-12-219-2021](https://doi.org/10.5194/se-12-219-2021).
- Zhu, W., E. Biondi, J. Li, J. Yin, Z. E. Ross, and Z. Zhan (2023). Seismic arrival-time picking on distributed acoustic sensing data using semi-supervised learning, *Nat. Commun.* **14**, no. 8192, doi: [10.1038/s41467-023-43355-3](https://doi.org/10.1038/s41467-023-43355-3).

Manuscript received 20 February 2026

Published online 10 August 2026