

PubDAS: A PUBLIC Distributed Acoustic Sensing Datasets Repository for Geosciences

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Abstract

During the past few years, distributed acoustic sensing (DAS) has become an invaluable tool for recording high-fidelity seismic wavefields with great spatiotemporal resolutions. However, the considerable amount of data generated during DAS experiments limits their distribution with the broader scientific community. Such a bottleneck inherently slows down the pursuit of new scientific discoveries in geosciences. Here, we introduce PubDAS—the first large-scale open-source repository where several DAS datasets from multiple experiments are publicly shared. PubDAS currently hosts eight datasets covering a variety of geological settings (e.g., urban centers, underground mines, and seafloor), spanning from several days to several years, offering both continuous and triggered active source recordings, and totaling up to ~90 TB of data. This article describes these datasets, their metadata, and how to access and download them. Some of these datasets have only been shallowly explored, leaving the door open for new discoveries in Earth sciences and beyond.

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Introduction

Seismology is an observational science heavily reliant on massive time-series datasets. Seismologists typically use seismograms to image the Earth's interior and to understand its dynamic processes. Depending on the instrument, most seismic sensors measure ground motion in terms of acceleration, velocity, or displacement. Some instruments are equipped with one vertical and two orthogonal horizontal channels to characterize the vector components of ground motion. In all cases, seismometers record the ground motion at a particular place as a function of time. The perception of how the Earth's properties vary across measurement sites is often not characterized, except in rare experiments utilizing dense arrays.

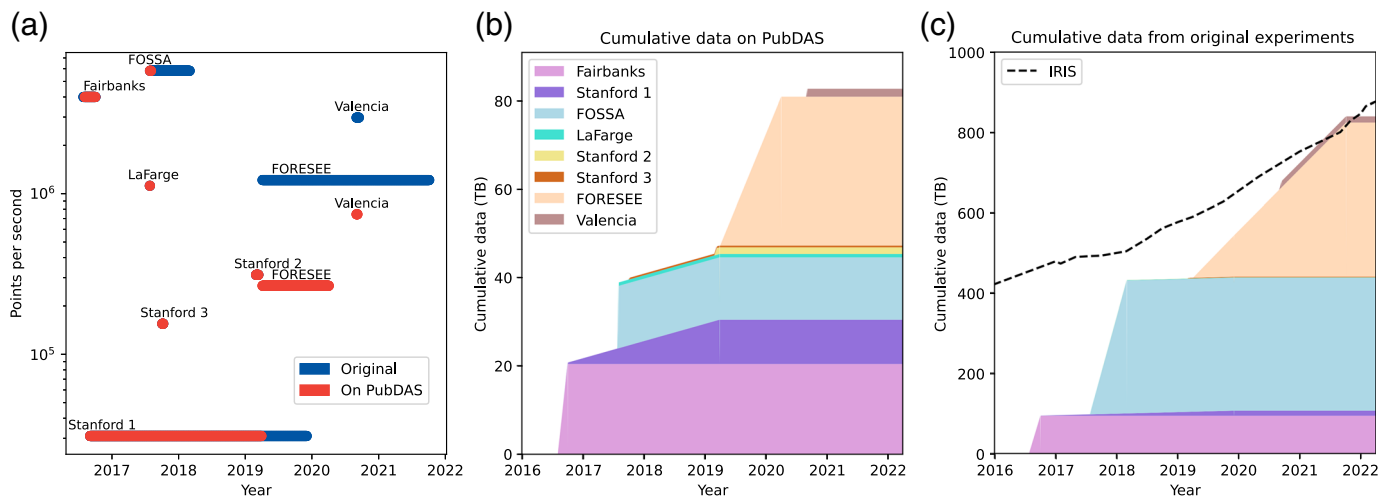
Global and regional seismic networks provide high-quality waveforms over a broad range of frequencies. Some networks have been installed for several decades and have considerably advanced our knowledge of the Earth's interior (Lay et al., 1998; Ritsema et al., 1999; Boué et al., 2013). However, they suffer from poor scalability, as their deployment, maintenance, and operation require great and ongoing effort and resources, particularly in remote areas. In the last decade, we have seen a shift in seismic instrumentation with the development of cheap, portable, and stand-alone geophones (Hammond et al., 2019). Although they provide lower quality measurements,

seismologists have used them to obtain dense spatial coverage useful for unraveling the complexity of fault zones, sedimentary basins, or volcanoes (Mordret et al., 2013; Schmandt and Clayton, 2013; Ben-Zion et al., 2015; Spica et al., 2018; Castellanos et al., 2020). Overall, we are seeing an acceleration in the rate of data acquisition and increasingly higher density measurements, facilitated by advances in autonomous sensors

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(e.g., “nodal seismometers”) and other new techniques (e.g., Ben-Zion *et al.*, 2015; Sweet *et al.*, 2018). As a result, the seismic data available for download on the Incorporated Research Institutions for Seismology Data Management Center (IRIS-DMC) is growing at an exponential rate (e.g., Kong *et al.*, 2019). As of 1 April 2022, the IRIS-DMC hosted ~882 TB (Incorporated Research Institutions for Seismology [IRIS], 2022), and, following the current trend, we expect it to double in the next three years. This trend is also observed at other large seismological data centers such as the Réseau sismologique et géodésique français and the GEOForschungsNetz (Quinteros *et al.*, 2021). Yet, such a trend is expected to accelerate further due to the rapid emergence of a new seismic measurement method called distributed acoustic sensing (DAS; Fig. 1).

DAS is a measurement technology that turns fiber-optic cables into ultradense arrays of sensors measuring real-time vibrations at a high sampling rate (Hartog, 2017). It measures high-fidelity wavefields over tens of kilometers—a product that was previously only possible through industrial seismic experiments. For a given time period, DAS datasets can produce orders of magnitude more data than traditional passive seismic experiments. For example, the Fiber-Optic Sacramento Seismic Array (FOSSA) experiment (Ajo-Franklin *et al.*, 2019) recorded seven months of continuous wavefield at 500 Hz every 2 m and over 25 km, and generated close to ~300 TB of raw and minimally processed secondary data (Fig. 1c). This dataset alone would represent ~34% of the total current IRIS-DMC database, if it were hosted there. The rapid data accumulation resulting from the recent DAS experiments is poised to intensify in the coming years, given the wider availability and decreasing cost of DAS interrogators (Lindsey and Martin, 2021). The anticipated petabyte-per-year influx and the lack of policies in place regarding information technology and national security requirements (e.g., Federal Communications Commission, United States Navy) put public data centers in a challenging position, as they cannot currently accept large DAS data inflows.

Figure 1. (a) Time span versus data points per second for all experiments available in PubDAS. Some datasets are provided in full, some have been trimmed, and others have been down-sampled to keep a reasonable data volume shown in panel (b). (b) Cumulative data volume for all the datasets available on PubDAS. (c) Cumulative data volume for all original datasets and comparison with the data volume available for download from the Incorporated Research Institutions for Seismology Data Management Center (IRIS-DMC) (IRIS, 2022). Fairbanks, Fairbanks Permafrost Experiment array; FORESEE, Fiber-Optic for Environment SENSing array; FOSSA, Fiber Optic Seismic Super Array; LaFarge, LaFarge-Conco Mine array; Stanford 1, Stanford campus array; Stanford 2, Sandhill Road array; Stanford 3, Stanford Campus with two interrogator units (IUs); Valencia, Valencia array. The color version of this figure is available only in the electronic edition.

Public data centers are the cornerstone of open science. They strive to share data, knowledge, and information within the scientific community and the wider public, thereby stimulating scientific research and advancing our understanding of the world (Ramachandran *et al.*, 2021). Accordingly, many institutions and even scientific journals have adopted policies that encourage or require scientists to make data available through such data centers. Public data within seismology and applied geophysics is typically disseminated by way of the IRIS-DMC for the U.S. National Science Foundation (NSF)-sponsored research or by special repositories maintained by other federal sponsors, including the US Department of Energy with the Energy Data Exchange (U.S. Department of Energy, 2022a) and Geothermal Data Repository (GDR; U.S. Department of Energy, 2022b). For research funded outside of these organizations, no cost-effective options are available for making datasets in the 10–100 s of TB scale publicly accessible, given the existing financial and structural models of general-purpose repositories. The current bottleneck on public seismic data archives slows the pursuit of exciting scientific discoveries that might be facilitated by existing but inaccessible

DAS datasets. This is further exacerbated by the fact that access to DAS instrumentation is exclusive to a few research groups that can either afford to purchase or rent an instrument. Currently, community instrument pools are considering avenues to support DAS instrument access. Public data archive infrastructure has yet to be created to match these instrumentation investments.

In this article, we introduce PubDAS—a public repository presently hosting eight DAS datasets, for a total of ~90 TB. In the near future, we expect PubDAS to grow and ultimately migrate toward well-established data centers. However, as it stands today, PubDAS aims to temporarily help the seismological community find a home for critical DAS datasets and hopefully foment discoveries in Earth sciences. The datasets cover a variety of geological settings (e.g., urban centers, underground mines, and seafloor), and some datasets are continuous, spanning from several days to several years (Fig. 1a), whereas others provide triggered active source recordings. We expect that these datasets will have applications beyond the purposes for which they were originally recorded.

In the following sections, we first review the working principles of DAS and its current fields of application in Earth sciences. We then present the main characteristics of the different datasets and discuss their metadata. Then, we describe how to access PubDAS and discuss other DAS datasets already available online. To conclude, we discuss future steps and envision the broader impact that PubDAS could have on the geoscience community.

Overview of the DAS Recording Systems

DAS systems are a combination of an interrogator unit (IU) connected to a standard fiber cable (i.e., single mode) and a data storage unit. While the IU in its simplest form is an optical interferometer, the cable serves as both a distributed extensional strain (or strain rate) sensor and a means of transmitting its own data to the storage unit. The IU probes the cable via short pulses of laser light and typically measures the Rayleigh backscattered photons over successive fiber segments. The zone of the fiber that the pulse averages over is referred to as a gauge length. When the fiber is stationary, such Rayleigh backscattering is constant; however, when the fiber is distorted due to vibrations, the resulting phase shift is quasi-linearly proportional to the changes in path length over the gauges (Grattan and Sun, 2000). The gauge length defines the spatial resolution of the measurement, whereas the channel spacing defines the measurement density. Typically, both the gauge length and the channel spacing can vary from ~5 to ~40 m and from ~0.25 to ~20 m, respectively. Channels may overlap if the gauge length is larger than the channel spacing. Depending on the manufacturing design, the IU may operate in the time or the frequency domain and record vibration information either in terms of strain or strain rate, accordingly.

Even though the technology is constantly improving, in some cases approaching the quality of classical inertial sensors (e.g., geophones) on a point-for-point basis, there are trade-offs and drawbacks that can interfere with data when selecting recording parameters. For example, a larger gauge length not only lowers spatial resolution but may also decrease statistical uncertainty in measurements over the gauges (Martin, 2018). In addition, the gauge length has an effect on the amplitude response by generating zero strain notches at frequencies that are a multiple of the gauge length (Dean *et al.*, 2017; Jousset *et al.*, 2018; Lindsey, Rademacher, and Ajo-Franklin, 2020). Except in special cases, DAS typically has a lower signal-to-noise ratio (SNR) and a more limited angular sensitivity than standard geophones (Martin, Lindsey, *et al.*, 2018). In addition, both the fibers and the cables (one or several fibers are enclosed in a cable) vary in design, depending on several technical and logistical requirements (Soga and Luo, 2018). While the optical fiber composed of coated silica glass controls the light propagation, the cable has an impact on the coupling with the ground (Daley *et al.*, 2013) and can impact data quality. These drawbacks are largely compensated by the benefits of having ultradense time series of permanently installed and highly resistant seismic sensors in logistically challenging locations, communicating over large distances, and running on a single power source (Martin, Lindsey, *et al.*, 2018).

There are many more technical details about DAS measurements and their comparison to standard instruments (e.g., Papp *et al.*, 2017; Wang *et al.*, 2018; Spica, Pertou, *et al.*, 2020; van den Ende and Ampuero, 2021). In this communication, we only describe the basic working principle to note that, depending on the IU and the input parameters, the recorded data are specific to each experiment. All these parameters and cable characteristics (when known) should be taken into account in data processing and interpretation. For an extensive overview of the working principles of DAS, we refer the reader to Hartog (2017).

Overview of the Current Fields of Application in Earth Sciences

The vast majority of seismic recordings with DAS were initially operated by the energy industry with many pilot experiments performed in downhole environments (e.g., Mestayer *et al.*, 2011; Parker *et al.*, 2014; Lellouch, Horne, *et al.*, 2019; Li *et al.*, 2021). Rapidly, particular attention was paid to repeatable vertical seismic profile imaging (Mateeva *et al.*, 2012; Molenaar *et al.*, 2012; Daley *et al.*, 2013; Mateeva, Lopez, *et al.*, 2013; Mateeva, Mestayer, *et al.*, 2013), microseismicity monitoring during hydraulic fracturing (Bakku, 2015; Karrenbach *et al.*, 2017), and fluid flow monitoring through hydrocarbon production (Daley *et al.*, 2013). It is only over the past few years that experiments started to focus on fibers deployed on the near surface, with applications designed for shallow seismic characterization and passive seismology (Zhan, 2020). Since

then, several applications have demonstrated the consistency between earthquake waveforms recorded by DAS and conventional seismometers (e.g., [Lindsey et al., 2017](#); [Wang et al., 2018](#); [Ajo-Franklin et al., 2019](#); [Lindsey and Martin, 2021](#)). Furthermore, the DAS instrument response appears to be broadband (e.g., [Lindsey et al., 2017](#); [Jousset et al., 2018](#); [Ajo-Franklin et al., 2019](#); [Lindsey, Rademacher, and Ajo-Franklin, 2020](#)), which opens the door to imaging the Earth across different scales. For example, [Yu et al. \(2019\)](#) recorded earthquake's surface waves down to 200 s.

Among the many different fields of application, DAS has now been used to characterize geothermal sites ([Reinsch et al., 2015](#); [Lindsey et al., 2017](#); [Zeng et al., 2017](#); [Lancelle et al., 2021](#)), the inside of the San Andreas fault ([Lellouch, Yuan, et al., 2019a, b](#)), glaciers ([Walter et al., 2020](#); [Hudson et al., 2021](#); [Fichtner et al., 2022](#)), and densely populated urban centers ([Lindsey, Yuan, et al., 2020](#); [Spica, Perton, et al., 2020](#); [Yuan et al., 2020](#); [Shragge et al., 2021](#); [Zhu et al., 2021](#)). It has also shown promises in the context of various monitoring applications, notably for detecting earthquakes ([Lindsey et al., 2017](#); [Li and Zhan, 2018](#); [Lellouch, Yuan, et al., 2019a](#)), monitoring landslides ([Iten, 2012](#)), recording volcanic activity ([Currenti et al., 2021](#); [Klaasen et al., 2021](#); [Nishimura et al., 2021](#); [Jousset et al., 2022](#)), characterizing permafrost thaw ([Ajo-Franklin et al., 2017](#); [Cheng et al., 2022](#)), estimating blasts or explosions ([Mellors et al., 2021](#); [Zhu et al., 2021](#)), and recording weather-ground events ([Zhu and Stensrud, 2019](#); [Shen and Zhu, 2021a](#)). DAS recordings were also used for ambient noise interferometry (e.g., [Zeng et al., 2017](#); [Martin and Biondi, 2017](#)), offering the possibility to retrieve repeatable signals (i.e., Rayleigh and Love waves) for near-surface characterization ([Dou et al., 2017](#); [Martin, Biondi, Karrenbach, and Cole, 2017](#); [Ajo-Franklin et al., 2019](#)) and aquifer monitoring ([Rodríguez Tribaldos and Ajo-Franklin, 2021](#)). In addition, subsea telecommunication fibers have not only been used to monitor ocean dynamics ([Lindsey et al., 2019](#); [Sladen et al., 2019](#); [Williams et al., 2019, 2022](#); [Viens and Spica, 2022](#)) but also to detect earthquakes ([Lior et al., 2021](#); [Spica et al., 2022](#)) and acoustic phases ([Rivet et al., 2021](#); [Spica et al., 2022](#); [Ugalde et al., 2022](#)), image the near-shore subsurface ([Spica, Nishida, et al., 2020](#); [Cheng et al., 2021](#); [Williams et al., 2021](#); [Spica et al., 2022](#); [Viens, Perton, et al., 2022](#)), assess detailed nonlinear ground-motion amplification ([Viens, Bonilla, et al., 2022](#)), or precisely locate the sources of microseisms ([Xiao et al., 2022](#)).

The former nonexhaustive list of studies suggests that DAS will likely play an important role in seismology and many other fields in Earth sciences in the near future.

Characteristics of the Repository

PubDAS currently includes eight datasets recorded with different instruments and acquisition settings (Fig. 1; Table 1). All the datasets provide continuous measurements from several hours to several weeks. Possible gaps in the datasets originate

from temporal recording issues or were planned as such during field measurement. Most of the datasets are provided in their raw original format as direct outputs from their respective IUs. The two exceptions are the Fiber-Optic for Environment SEnsEing (FORESEE) and Valencia arrays, which have been downsampled to 125 Hz and 250 Hz, respectively, using an antialiasing low-pass filter. This is the only preprocessing applied to these datasets. Table 1 summarizes some of the key features of the datasets.

The Fairbanks Permafrost Experiment array

The Fairbanks Permafrost Experiment array is located outside of Fairbanks, Alaska, on the Fairbanks Permafrost Experiment Station, Farmer's Loop Site, operated by the US Army Corps of Engineer's Cold Regions Research and Engineering Laboratory (Fig. 2). The array consists of a 2D grid of hybrid tactical fiber cables installed in trenches between 20 and 40 cm depth. The array was installed to monitor an active heating experiment where a section of permafrost was thawed using an in-ground heating system. DAS data were recorded on the array using both active and passive sources for a period of two months during the thawing process. The site and heating experiment are described in ([Wagner et al., 2018](#)), whereas the active source monitoring activities are documented in [Ajo-Franklin et al. \(2017\)](#) and [Cheng et al. \(2022\)](#). The data available on PubDAS are for the four road parallel lines (A, B, C, D), each approximately 180 m in length and traversing the heating experiment, as well as the five shorter road perpendicular lines (1, 2, 3, 4, 5). The data were recorded using a Silixa iDAS-v2 IU at 1 kHz and a 1 m spatial sampling with a 10 m gauge length. Data are saved in native measurement units (proportional to strain rate). Although both active and passive data were acquired, the curated PubDAS dataset is for the active experiment, which records sequential shots from a single surface orbital vibrator (SOV), swept multiple times every evening to allow for timelapse monitoring of environmental processes. Geophone data recording the SOV sweeps, useful for deconvolution, are also archived.

The FORESEE array

The FORESEE array is located in central Pennsylvania in the Valley and Ridge Appalachians region (Fig. 3). The array consists of a Silixa iDAS-v2 interrogator and a ~5 km long single-mode dark fiber installed underneath the Pennsylvania State University campus. The fiber shown in Figure 3 is made of two individual fibers that were spliced together around channel 1340. The cable sits in a buried concrete conduit at depths ranging between 1 and 10 m. Continuous strain-rate measurements were performed between 5 April 2019 and 4 October 2022, with a 500 Hz sampling frequency, a 10 m gauge length, and 2 m channel spacing. The first 2137 channels along the cable have been accurately located with tap tests. The first-third of the array (i.e., channels 1–604) is located in a quiet

TABLE 1

List of the Data Sets Currently Available on PubDAS and Their Main Characteristics

Name	IU	Time Span (Days)	Format	Samples per Second (Hz)	Volume (GB)	Gauge Length (m)	Cable Length (m)	Channel Spacing (m)	Units
Fairbanks	Silixa iDAS-v2	59*	TDMS	1,000	10,441	10	4,000	1	ϵ
FORESEE	Silixa iDAS-v2	365	HDF5	125 [†]	29,338	10	4,900	2	ϵ
FOSSA	Silixa iDAS-v2	7	TDMS	500	11,680	10	23,300	2	ϵ
LaFarge	Silixa iDAS	2*	SEG-Y	1,000	45	10	1,120	1	ϵ
Stanford-1	OptaSense ODH3	940	SEG-Y	50	18,908	7.14	2,500	8.16	ϵ
Stanford-2	OptaSense ODH3	14	SEG-Y	250	2,887	20	10,200	8.16	ϵ
Stanford-3	OptaSense ODH4	6	SEG-Y	[†]	92	[†]	2,500	8.16	ϵ
Valencia	Febus Optics A1-R	7	HDF5	250 [‡]	3,213	30.4	50,000	16.8	ϵ

HDF5, Hierarchical Data Formats version 5; IU, interrogator unit; SEG-Y, Society of Exploration Geophysicists “Y”; TDMS, Technical Data Management System; ϵ , strain rate; and ϵ , strain. Name abbreviations are the same as in Figure 1.

*Data contain active sources.

[†]This value may vary.

[‡]Dataset is downsampled.

off-campus area, and the rest of the array is located on the main campus with stronger anthropogenic noise. [Zhu et al. \(2021\)](#) describe how to calibrate the DAS recordings to particle velocity using earthquake waveforms from a nearby broadband seismometer. Throughout the 2.5 yr experiment, the array recorded a variety of transient signals, including global and regional earthquakes, thunderquakes ([Zhu and Stensrud, 2019](#); [Hone and Zhu, 2021](#)), and mining blasts ([Zhu et al., 2021](#)). In addition, anthropogenic signals common to urban environments were also detected, such as cars, footsteps, and live music events ([Shen and Zhu, 2021b](#)). The long duration of the experiment also allows exploration of the effect of seasonal environmental variations, and provides critical information on surface and subsurface processes.

In PubDAS, data acquired during the first year of the experiment (i.e., 5 April 2019–14 March 2020) are available. During this time, the recordings were interrupted several times due to unexpected power outages, and data files were rewritten to keep consistency in hdf5 format during preprocessing. The FORESEE array is the largest dataset on PubDAS, even though the data have been downsampled from 500 to 125 Hz.

The FOSSA

The FOSSA experiment was conducted on the Sacramento River flood plain, north, and west of Sacramento, California. The experiment utilized a 27 km section of dark telecommunications fiber, part of department of energy’s ESnet network, connecting West Sacramento with the town of Woodland

(Fig. 4). Data of usable quality were recorded with a Silixa iDAS-v2 on approximately 23.3 km (11,648 sampling locations, 2 m spacing). The experimental targets were monitoring regional seismicity and characterizing near-surface structures using ambient noise methods. Data were collected between 28 July 2017 and 18 January 2018, at an original sampling rate of 500 Hz, generating a total of 210 TB of raw uncompressed data. [Ajo-Franklin et al. \(2019\)](#) describe how some sections of the fiber were mapped using sequential impact tests at the surface and provide other details about the field installation of the equipment. As discussed in [Rodríguez Tribaldos and Ajo-Franklin \(2021\)](#), the cable was largely deployed within a conduit buried in the soil at depths of 1–1.5 m. Some sections were also placed in shallow horizontal boreholes beneath roads and railway tracks, again in conduit but slightly deeper (3–4 m). The response of the fiber was also explored through comparison to a collocated broadband inertial sensor by [Lindsey, Rademacher, and Ajo-Franklin \(2020\)](#) for both teleseismic events and microseism energy.

The fiber used in the FOSSA experiment traverses several distinct settings of development with different installation and noise characteristics. The fiber starts in an urban area and continues into a section of farmland near the Sacramento River. After bending westward toward Woodland, the fiber follows Interstate 5. In addition, the cable is sometimes colinear with a heavily used rail corridor. The surficial aquifer is influenced by both natural precipitation, irrigation, and river stage, which can influence soil properties; [Rodríguez Tribaldos and Ajo-Franklin \(2021\)](#) used

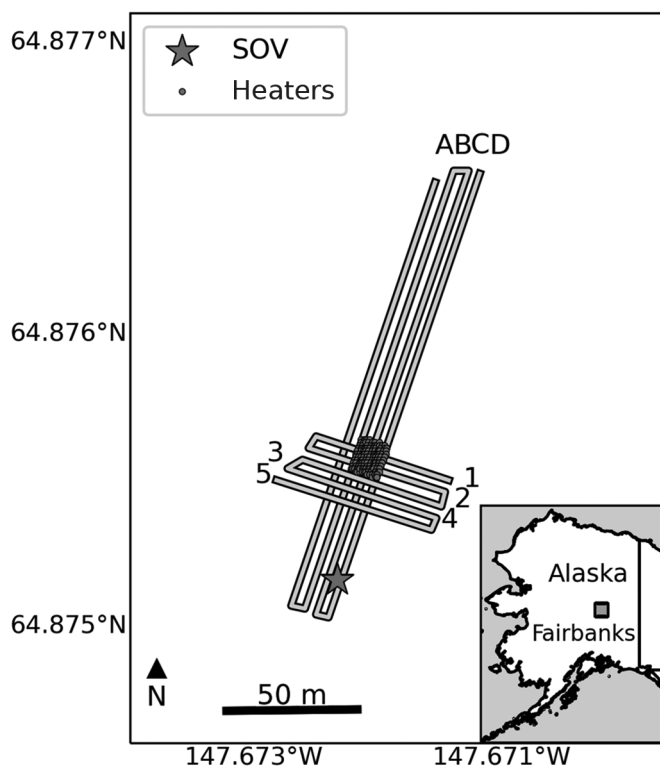


Figure 2. Map of the Fairbanks Permafrost Experiment array. The letters and numbers refer to the line labels. Only the channels at the end of each line have been tap tested. The inset map shows the location of the array (gray square) in the state of Alaska, U.S.A. SOV, surface orbital vibrator.

the dataset to monitor the aquifers using ambient noise interferometry. The quality and diversity of the wavefield recorded allowed [Nayak et al. \(2021\)](#) to produce mixed-sensor cross correlation between regional seismometers and strain-rate DAS recordings. In PubDAS, at present, one week of continuous raw data that contains a variety of signals, including large tele-seismic earthquakes, is available for download.

The LaFarge-Conco mine array

The LaFarge-Conco mine is a Limestone and dolomite mine located in North Aurora, Illinois (Fig. 5; [Wang et al., 2017](#)). The layout consists of north and south sections, which are connected by underground passageways beneath Interstate 88. This room-and-pillar mine occupies a wedge-shaped footprint that is approximately 1500 m long $\times$ 500 m wide at the I-88 dividing line. The mine includes four levels down to a depth of about 80 m. Pillars are approximately 20 m on a side and in height. The rock is blasted from the formation most weekdays in midafternoon. Rocks are then hauled by truck to the north-west entrance for processing. Background noise from mine truck traffic and conveyor belts is observed during the DAS experiment, except when the mine was cleared for blasting.

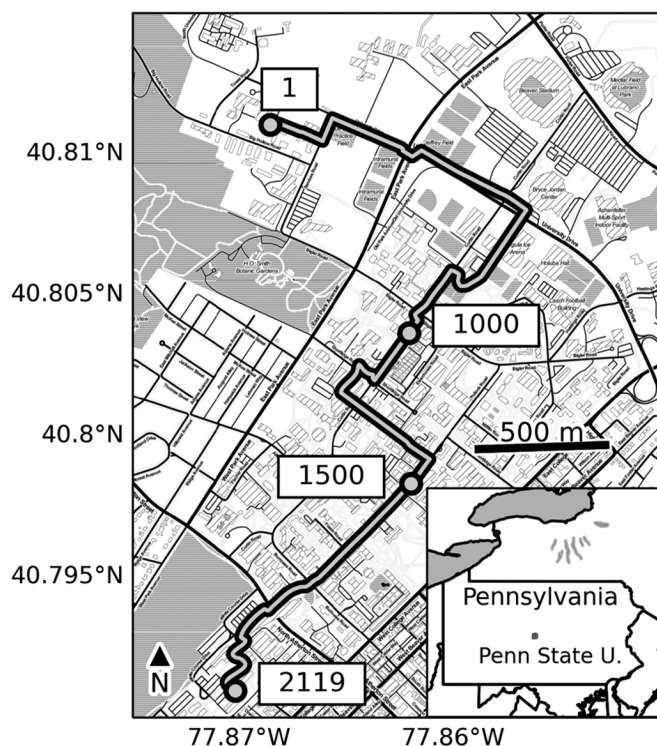


Figure 3. Map of the FORESEE array. The inset map shows the location of the array (little gray square) in the state of Pennsylvania, U.S.A.

The DAS array was located in the north section of the first level of the mine, as shown in [Zeng et al. \(2021\)](#). A $\sim$ 1120 m of tactical fiber-optic cable was laid down over three layers along an L-shape loop. In loop 1, the cable was secured in a groove cut in the floor using a pavement saw and then covered with self-leveling concrete. Two additional loops were placed above the cemented cable. Loop 2 was placed in the groove and covered with fine rock powder, and in loop 3 the top strand was placed without cover. A Silixa iDAS interrogator was set up in a tent near a pillar a few meters west of the cable layout. Power was supplied by a generator, but batteries were used during blasting testing to limit vibrational noise. Several locations along the DAS cable were tap tested to associate the DAS channel number with the surface position of the cable ([Zeng et al., 2021](#)). A 23 kg weight providing 208 J of energy was the seismic source at the lettered stations in Figure 5. In addition, two mine blasts at distances of about 200 and 450 m from the DAS array were used to test the feasibility of monitoring stress changes from travel-time changes. The sharpest *P*-wave arrivals were recorded by the cemented cable, and the poorest arrivals were recorded by the loose cable.

Stanford 1—the Stanford campus array

The Stanford campus array in California (Fig. 6) was created using a fiber cable loosely deployed in an air-filled polyvinyl

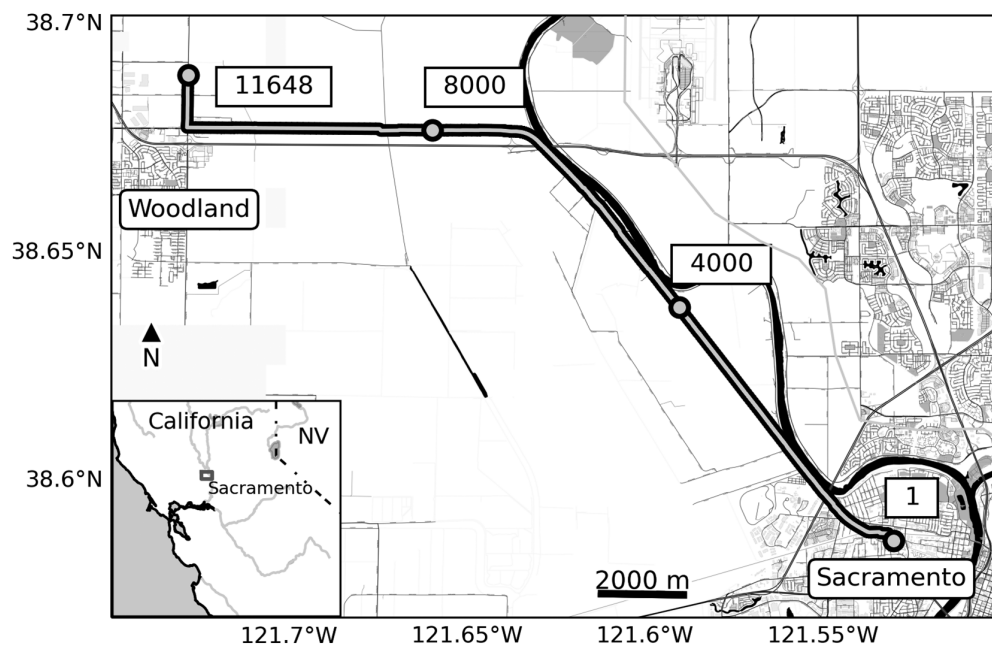


Figure 4. Map of the FOSSA. The inset map shows the location of the array (gray square) in the state of California, U.S.A.

chloride conduit (~12 cm wide) in the same way other fiber cables are installed around campus. The fibers were pulled along these conduits accessible through manholes (small underground rooms). The coupling between the cable and the surrounding medium relies exclusively on gravity and friction when the fiber sits in the conduits. In manholes, the fiber was zip-tied to a bracket on the side of the wall. In addition, 45 m of fiber was spooled up and strapped to the wall (with a vertical and horizontal component) at campus drive, and Via Ortega and south of Allen on Via Pueblo. The fiber location was calibrated with tap tests as described in detail in (Martin, Biondi, Cole, and Karrenbach, 2017). Continuous recordings were acquired using an OptaSense ODH-3 IU at 50 Hz between 2 September 2016 and 31 March 2019, for a total of 626 channels. With 940 days available for download, this dataset offers the longest time span in PubDAS.

Through this experiment, Martin *et al.* (2017) and Biondi *et al.* (2017) showed that the DAS technology can be used to record seismic data directly from a free-standing telecommunication cable. The data from this array provide a unique opportunity to monitor long-term variations of the ambient seismic field generated by natural and anthropological sources (Huot *et al.*, 2017; Martin, Huot, *et al.*, 2018; Martin and Biondi, 2018), to analyze hundreds of earthquakes as well as numerous quarry blast waveforms (Biondi *et al.*, 2017; Lindsey *et al.*, 2017; Fang *et al.*, 2020), to monitor infrastructure (Fang *et al.*, 2020), and to image the shallow subsurface in a populated urban area (Spica, Perton, *et al.*, 2020). This dataset also enables extensive exploration of the application of

machine learning and deep learning algorithms on high-volume DAS data for effective event detection and automatic data processing (e.g., Huot and Biondi, 2018).

Stanford 2—the Sandhill road array

Stanford 2, starting in December 2019, was the natural extension of Stanford 1. It scaled up the initial proof-of-concept of Stanford 1 array to a citywide deployment around Palo Alto, California (Biondi *et al.*, 2021). With a cable length of 10.2 km and a channel spacing of 8.16 m, the array counts a total of 1250 channels (Fig. 6) recorded with an OptaSense ODH3 interrogator. The data volume write rate was approximately

101 GB/day. Two full weeks of raw data with all 1250 channels originally sampled at 250 Hz and recorded between 1 and 14 March 2020 are available on PubDAS. About 350 channels were located along the relatively straight Sandhill Road section between the quiet portion of the array near Stanford Hospital (channel 400) and Stanford Linear Accelerator Center (channel 750). The section of the array between channels 400 and 750 (Fig. 6) provides the highest SNR. The locations of the channels along this segment were calibrated by driving a dedicated car at a constant velocity at night along the fiber (Yuan *et al.*, 2020). Lindsey, Yuan, *et al.* (2020) used this array to detect hundreds of thousands of individual vehicles and monitor urban activity levels during the early stages of the COVID-19 pandemic. Yuan *et al.* (2020) investigated a cost-effective urban infrastructure monitoring system by combining vehicle onboard sensing and roadside DAS using this array.

Stanford 3—the Stanford campus array with two IUs

Stanford 3 was a temporary dual IU experiment on Stanford campus between 5 and 13 October 2017, using the same Stanford 1 cable loop. Besides the OptaSense ODH-3 model that recorded since 2016, this experiment attached an additional IU—an OptaSense ODH-4 model that started interrogating using acquisition parameters identical to the ODH-3. Both the IUs collected data concurrently using the same settings for three days, and then a set of various gauge lengths and sampling rates were tested on the ODH-4 individually. The experiment shows better data quality in ODH-4 recordings than

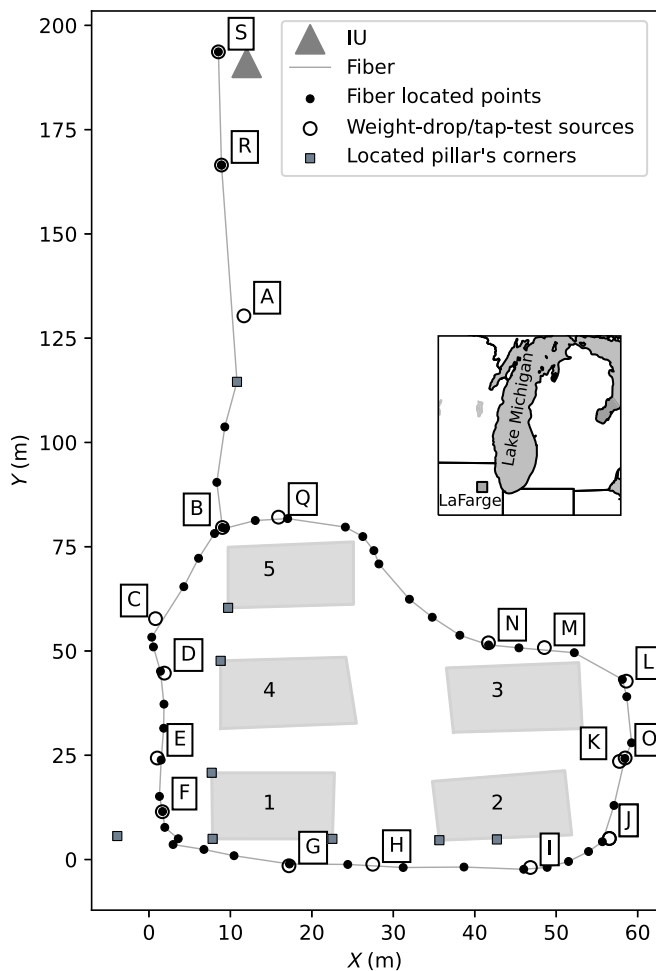


Figure 5. Map of the LaFarge-Conco Mine array. The numbered gray areas represent the mine pillars. The inset map shows the location of the LaFarge-Conco Mine (gray square) in the state of Illinois, U.S.A.

ODH-3, and the high-quality ODH-4 data were used for horizontal-to-vertical spectral ratio analysis (Spica, Perton, *et al.*, 2020). Three broadband seismometers were contemporaneously installed in building basements by the U.S. Geological Survey within the cable loop (U.S. Geological Survey, 2016) and collected ground-motion data for comparison.

The Valencia array

The Valencia–Islalink experiment (Spica *et al.*, 2020) used a preinstalled telecommunication fiber-optic cable operated by IslaLink Holding Iberia S.L. and connecting the Spanish peninsula to Mallorca Island from Valencia to Palma de Mallorca (Fig. 7). From 1 to 15 September 2020, a Febus Optics A1-R interrogator was connected to the Valencia side to sample the first 50 km of the cable. The cable location provided by the cable operator indicates that the first 9189 m are on land. This is easily confirmed by the observation of characteristic traffic noise in the record sections. According to the

installation report, the remaining 40,811 m are buried ~1 m below the Mediterranean seabed. This is also confirmed by the observation of strong marine gravity waves and the secondary microseism in the record sections (Xiao *et al.*, 2022). Data were acquired at a sampling frequency of 1000 Hz, with a gauge length of 30 m and a spatial resolution of 16.8 m, resulting in a dense seismic array of 2977 channels. To lower the repository's volume, we downsampled the data to 250 Hz using a tenth-order Chebyshev low-pass filter below 125 Hz. We also truncated the original hour-long files into 10 min files to facilitate download and data handling. The data from 1 to 7 September are continuous and available on PubDAS. The remaining week was less complete with the presence of numerous recording gaps and was therefore not published.

Metadata

To measure Earth vibrations with DAS, fiber-optic cables should be fully coupled to the ground. In principle, good coupling with the surrounding medium can be obtained by burying cables in the ground, and detailed logs of the burial process should be made available. In practice, cables might not be locally coupled to the ground (e.g., cables locally hanging along electricity lines or zip-tied loops in manholes), and coupling conditions are generally unknown or poorly constrained. In addition, DAS measurements of a fully coupled cable are impacted by the cable manufacturing properties. For example, cables deployed on the ocean floor need to withstand extreme pressure conditions and are typically heavier with multiple fiber strands, a steel jacket, and a copper core. This contrasts with cables laying at the surface of the Earth, which can simply be protected by a thick plastic jacket, and borehole deployments, which sometimes include specific components to avoid fiber breakage during deployment. The design of optical fibers also controls the sensitivity of the measurement and other features, such as polarization and attenuation. In addition to fiber and cable manufacturing properties, information about potential splicing of the fiber is critical as it can dramatically increase the attenuation along the fiber. Finally, locating the precise position of the DAS channels is essential for Earth science purposes. Global Positioning System and tap tests (or air-guns in oceans; Shinohara *et al.*, 2021) are used to locate channels precisely; however, when working with telecommunication cables, details about the cable deployments are often uncertain and incomplete or even classified.

Most IUs are patented, and the exact details of their working principles, optical chains, and running algorithms are not fully accessible to users. Although all IUs use laser pulses, the physical properties of such pulses may differ (repetition rate, length, and shape of the pulses), leading to a different signal (e.g., strain, strain rate, and phases) over a broad range of measurement lengths. Moreover, some IUs preprocess raw data on the fly before writing them to a hard drive, whereas other IUs simply save the raw data. Depending on the system, some

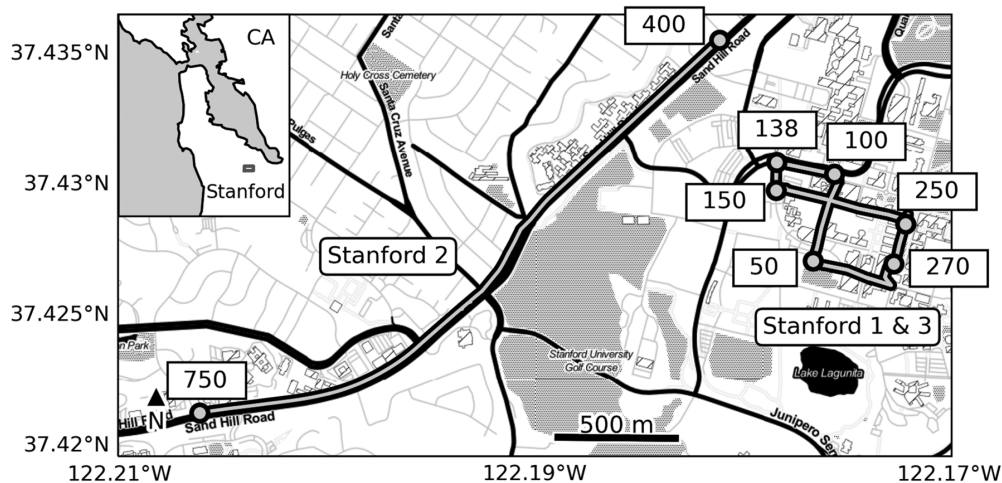


Figure 6. Map of the different Stanford arrays. Stanford 1 and 3 recorded the same fiber loop on main campus but with different IUs. Stanford 2 was recorded around Palo Alto. The inset map shows the location of the arrays (gray square) in the state of California, U.S.A.

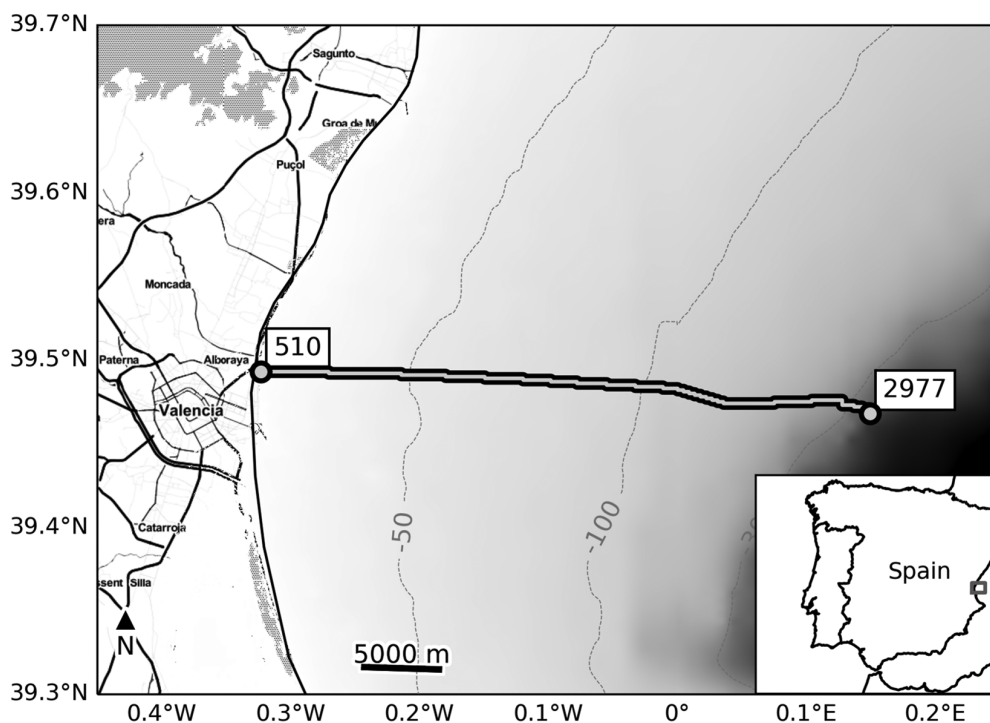


Figure 7. Map of the Valencia arrays showing the undersea channels. The inset map shows the location of the array (gray square) in Spain.

parameters may be adjustable or fixed and imposed (e.g., the gauge length) by the manufacturing design of the IU. Finally, IUs can easily be switched, and several IUs can be used on one single cable.

During an ideal measurement campaign, analysts should collect both the fiber and associated cable metadata as well as the IU metadata, including acquisition parameters.

Because of the large range of parameters described earlier, a single measurement campaign can result in the collection of a large volume of metadata. Therefore, standard seismic metadata (e.g., SEED, stationXML) and file formats (e.g., SAC, SEG-Y) are not well-suited for DAS experiments, because they cannot hold all the acquisition parameters needed for the proper characterization of an experiment. Obtaining a metadata model that fits all the requirements for DAS experiments is challenging and still open to discussion. Recently, [Mellors et al. \(2022\)](#) and the Data Management Working Group from the DAS Research Coordination Network suggested a first version of a common metadata standard for archival purposes, regardless of the data format. In an effort to test, improve, and standardize the DAS metadata, the PubDAS team follows these guidelines, and each dataset comes with a pdf document called “Metadata.” The “Metadata” files are purely parameter oriented and allow the end user to have a quick overview of the measurement parameters when available or known. The metadata files contain fields that are left blank when the information is unknown for a given dataset. For additional details about metadata files, structure, and description of the parameters, we refer the reader to [Mellors](#)

[et al. \(2022\)](#). Although a standardized metadata architecture offers some structure and coherence among datasets, it does not provide useful recommendations for the end user to start processing the data. Therefore, each dataset comes with a complementary “README” file that provides more practical information about the data, such as which script to use to read the files, a list of citable references, a link to a license file,

acknowledgments, or detailed explanation about the various files (other than DAS) shared in a directory.

Data Formats

In PubDAS, most datasets are shared in their raw formats as if they were direct outputs of their respective interrogators. The two exceptions are the Valencia and FORESEE arrays that have been downsampled. During this preprocessing step, the data structures have been slightly reorganized by updating sampling rate parameters, removing blank or unused parameters provided by the IU, reducing original file length, and so on.

As shown in Table 1, the repository hosts three different file formats, including Technical Data Management System (TDMS), Hierarchical Data Formats version 5 (HDF5), and the Society of Exploration Geophysicists “Y” (SEG-Y) format. Both TDMS and HDF5 provide a three-level hierarchical organization. These file formats are like containers for an organized collection of objects, offering great flexibility to accommodate and tune many different recording parameters for a given DAS experiment. Both TDMS and HDF5 include a top-level object (e.g., file name or IU serial number) enclosing an unlimited number of groups that are analogous to a file system directory. These groups operate like dictionaries with keys and values, and can be organized in separated groups or subgroups. Each group can contain an unlimited amount of channels or datasets for TDMS and HDF5, respectively. These channels and datasets are array-like collections of data elements and/or metadata. SEG-Y files are standard, but old file formats largely used to store and exchange geophysical data (Hagelund and Levin, 2017). The files are organized as a succession of headers and a variable number of same-length data traces. Two headers are required (number of samples per trace and number of traces) but can only host two bytes, which is sometimes not enough to represent the large number of samples and traces found in DAS arrays. Yet, these values can be backcalculated by knowing other file and experiment parameters. However, this workaround makes SEG-Y files noncompliant for large DAS studies, and extra mapping information in the text header (EBCDIC) is often necessary.

There are numerous open-source libraries allowing users to read and write TDMS, HDF5, and SEG-Y files. Yet, they are not all adapted for geophysical processing and, more particularly, for DAS experiments. Depending on the dataset and associated format, PubDAS users will find interest in using seismology-specific libraries such as ObsPy and Pyrocko (Krischer *et al.*, 2015; Heimann *et al.*, 2017) or participate in the development of DAS-specific libraries like the DAS Data Analysis Ecosystem (Chambers *et al.*, 2022). Nonetheless, as they stand today, none of these libraries guarantee a universal handling of all the PubDAS datasets, requiring users to work on a case-by-case basis. For this reason, and to offer an easier jump start for new DAS users, all PubDAS datasets come with a simple dedicated script allowing users to read a

given dataset. These scripts are provided in the same folder hosting each dataset and can be downloaded along with the data (see the [How to Access PubDAS?](#) section).

Because there is no consensus on which data format is the most suitable and flexible for DAS studies, our goal is to provide data in their original format to raise awareness of the pros and cons of each format. By doing so, we hope to extend the debate to a broader community and boost innovation among practitioners.

How to Access PubDAS?

PubDAS is hosted by the Advanced Research Computing division of the Information and Technology Services at the University of Michigan (UM). The repository is located on a cost-optimized, high-capacity, and large-file storage service called “Locker.” PubDAS is accessible through “Globus,” which is a nonprofit software-as-a-service provider (Foster, 2011), using the link provided in [Data and Resources](#). Globus is free, easy to use, and provides secure and high-performance file transfer between storage systems (Ananthakrishnan *et al.*, 2015; Chard *et al.*, 2017). In short, Globus can be seen as a self-service data portal and point-and-click data management tool that allows researchers to focus more on science and less on technology. It is rapidly being adopted by many large institutions across the globe, such as Amazon webservices, the NSF XSEDE systems, and many U.S. national laboratories and universities.

Globus facilitates data transfer by handling all the complex aspects of large-scale transfer. For example, it uses multiple parallel transmission control protocol (TCP) streams to achieve high throughput and automatically tunes parameters to maximize bandwidth usage without interfering with current use. Globus also coordinates authentication at source and destination, while providing automatic fault recovery and notifying users of completions and problems. Although Globus cloud-hosted service coordinates data transfers, the end-user only relies on the Globus Connect Personal software to enable fast and reliable data transfers between institutional servers or personal workstations. The Globus Connect Personal software is available as a lightweight single-user agent that can be easily deployed on Windows, Mac, and Linux computers. Globus Connect Server also exists as a multiuser server available as a native Linux package. Users are also able to use Globus Python application programming interface clients for data access and transfer. After downloading and installing the software, users must register their desired storage as a Globus “endpoint,” which uniquely identifies and maps the data access interface. The endpoint also includes metadata such as ownership, name, and other descriptions. Once the endpoint is set up either on a server or a personal workstation, end users can download the PubDAS data set of their choice. A link to a step-by-step guide on “how to log into Globus and use it to transfer files” is provided in [Data and Resources](#).

TABLE 2

Examples of Data Upload and Download Using Globus and Using Different Network Speeds

Origin	Destination	Files Transferred	Bytes Transferred	Effective Speed (MB/s)	Time
UM	CSM	1585	509.02 GB	491.76	17 m 15 s
UM	UNAM	2744	5.94 TB	102.73	16 h 5 m 5 s
IGN	UM	1	240.08 GB	29.05	2 h 15 m 55 s
ERI	UM	7389	15.64 TB	90.81	1 d 23 h 50 m 40 s
CTC	UM	8868	2.91 TB	21.74	1 d 13 h 17 m 27 s
UM	Caltech	3241	1.08 TB	163.22	1 h 51 m 8 s

Caltech, California Institute of Technology; CSM, Colorado School of Mines; CTC, Cordova Telephone Cooperative; ERI, Earthquake Research Institute; IGN, Instituto Geográfico Nacional; UM, University of Michigan; and UNAM, Universidad Nacional Autónoma de México.

Globus Connect Personal is designed to work automatically with common firewall settings. However, very strict firewall policies, that is, the ones that block outbound connections, will hinder this behavior. In this case, the end users may have to work with their network or security administrators to open specific outbound TCP and User Datagram Protocol ports. A link explaining how to configure the firewall policy for Globus Connect Personal is also provided in [Data and Resources](#).

Currently, the UM has 400 GBPS of internet bandwidth, allowing up to several PB per day of file transfer between multiple devices and multiple locations simultaneously. Of course, the download of data will critically depend on available end-user bandwidth. For this reason, when possible, we recommend the use of an institutional fiber connection rather than a home internet for dataset retrieval. We have tested the download and upload speeds for several data sets between institutions. A summary of our experience is shown in Table 2. These results show that, even with a low-speed connection (e.g., ~20 MB/s), the optimization of the data transfer with Globus still provides performance acceptable for retrieving the test datasets.

Public DAS Data beyond PubDAS

Many researchers and institutions have started to share their DAS datasets with the scientific community. For example, the Department of Energy's GDR hosts two frequently cited DAS datasets: PoroTomo ([University of Wisconsin, 2016](#)) and FORGE 2C ([University of Utah Seismograph Stations, 2022](#)). Yet, although tens of terabytes of data have already been made available online, research groups generally publish individual datasets. The lack of a centralized platform makes it difficult for the end user to navigate the flow of information and the complexity of each platform, because every dataset has its own requirements and its own metadata reporting, and might not be equally advertised to the broader scientific community. In an effort to centralize the available datasets online and acknowledge the work of our peers, we summarize their availability in Table 3. Only relatively large datasets are reported. Small data examples shared to support the works published

in journal publications are not reported. For more information about these datasets, we invite the reader to refer to the URL's provided in Table 3.

Conclusions and Future Steps

This article presents the first large-scale open-source repository where several DAS datasets from multiple application areas are publicly shared. The individual datasets have been curated and organized to provide more structure to scientists keen to explore new frontiers in geosciences. All the datasets have already been tested and explored to some extent, which resulted in several publications ensuring that the quality of the recorded signals is sufficient for many seismological applications. Nonetheless, some datasets have only been explored superficially, offering tremendous opportunities for new discoveries by other research groups without current DAS data access. For example, we believe that some of the datasets can be used to understand the relationship between DAS and conventional seismometry, to provide further constraints on fault zones and dynamic environmental changes, and to develop new tools for urban monitoring. In addition, we hope that the open-access component of this project will accelerate progress in seismology and geosciences, and facilitate training, validation, and performance comparisons. More importantly, we hope that PubDAS will ease the adoption of best practices when using DAS data and allow a broader community to take part in the ongoing efforts to understand the Earth better.

Currently, ~90 TB of DAS data are hosted at the UM, and there are plans to add new datasets upon the conclusion of some experiments and publication embargoes. The PubDAS team has secured support through the end of 2026 and will continue exploring possibilities to share these data in the long term. In parallel, we will seek opportunities to collaborate with more recognized data centers that could host the rapidly increasing amount of DAS data recorded around the world.

With terabytes of data being collected daily around the world, seismology is more than ever a data-driven science. DAS and optical fiber sensing, in general, open a new chapter

TABLE 3

Nonexhaustive List of Other Distributed Acoustic Sensing (DAS) Datasets Available for Download on Other Platforms

Short Name	Approximate Volume (GB)	Location	Time Span (Days)	Access
DAS4Microseism	182	Svalbard, Norway	42	doi: 10.18710/VRD2H
DAS4Whale	37.6	Svalbard, Norway	2	doi: 10.5281/zenodo.5823343
RAPID	26,000	Offshore Pacific City, Oregon	5	URL: piweb.ooirsn.uw.edu/das/
PoroTomo*	81,000	Brady Hot Springs, Nevada	15	doi: 10.15121/1778858
FORGE 2C*	†	Milford, Utah	†	URL: tinyurl.com/2p8epnn5
Marcellus*	†	Morgantown, West Virginia	†	URL: www.mseel.org/
Garner Valley*	165	California	1	doi: 10.15121/1261941
Levee Workshop*	0.741	Black Hawk, Louisiana	1	doi: 10.17603/ds2-c96x-pg70
Belgium	1.3	Zeebrugge, Belgium	1	doi: 10.22002/D1.1296
Monterey Bay	0.565	Moss Landing, California	4	URL: tinyurl.com/ynab86bc
SAFOD	1.54	San Andreas fault, California	†	URL: tinyurl.com/yc49swp4
FORESEE	28,670	State College, Pennsylvania	180	URL: tinyurl.com/499mn4pa

*Data contain active sources.

†This value may vary or is unknown.

in resolving fine-scale variations of the seismic wavefield that were until recently unobservable, making the technology one of the greatest advances in geophysical instrumentation since digitization. Along with the recent breakthroughs in high-performance computing and machine and deep learning, DAS is now offering the big data essential to expand our knowledge of the physics behind Earth's heterogeneous interior and surface processes. We hope that PubDAS will act as a bridge between scientific communities, and will facilitate the accessibility to a broader and more diverse body of knowledge.

Data and Resources

The PubDAS Globus endpoint at University of Michigan (UM) is accessible via the link https://app.globus.org/file-manager?origin_id=706e304c-5def-11ec-9b5c-f9dfb1abb183&origin_path=%2F. All users need a Globus account to access the PubDAS endpoint. Instructions to download and run Globus Connect Personal are accessible via the link www.globus.org/globus-connect-personal. Globus Connect Personal basic tutorial is also available on YouTube via the link www.youtube.com/watch?v=bpnVcAN99WY. The step-by-step guide to log in and transfer files with Globus is accessible via the link docs.globus.org/how-to/get-started/. The firewall policy for Globus Connect Personal is accessible via the link docs.globus.org/how-to/configure-firewall-gcp/. The complete Globus documentation is accessible via the link docs.globus.org/. For any questions about Globus, please work directly with your Information and Technology specialists. All websites were last accessed in December 2022.

Declarations of Competing Interests

The authors declare that they have no conflicts of interest recorded.

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