# PubDAS: a PUBlic Distributed Acoustic Sensing datasets repository for geosciences

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## Abstract

During the past few years, Distributing 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 mine, seafloor), spanning from several days to several years, offering both continuous and triggered active source recordings, and totalling up to ∼90 Tb of data. This manuscript 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.


## 1 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 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 unravelling the complexity of fault zones, sedimentary basins, or volcanoes (Schmandt & Clayton, 2013; Mordret et al., 2013; Ben-Zion et al., 2015; Z. 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 (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 (IRIS) Data Management Center (DMC) is growing at an exponential rate (e.g., Kong et al., 2019). As of April $1^{st}$, 2022, the IRIS-DMC hosted ∼882 TB (IRIS, 2022), and following the current trend, we expect it to double in the next three years. Yet, this 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 ultra-dense arrays of sensors measuring real-time vibrations at 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 (J. B. 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 recent DAS experiments is poised to intensify in the coming years given the wider availability and decreasing cost of DAS interrogators (Lindsey & 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.

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 US National Science Foundation (NSF) sponsored research or by special repositories maintained by other federal sponsors including US Department of Energy's with the Energy Data Exchange (EDX; 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 10s to 100s 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 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 paper we introduce PubDAS, a public repository presently hosting 8 DAS datasets, for a total of $\sim$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 mine, seafloor) and some datasets are continuous, spanning from several days to several years (Fig. 1A) while 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 for the geoscience community.

## 2 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 interrogator unit in its sim-

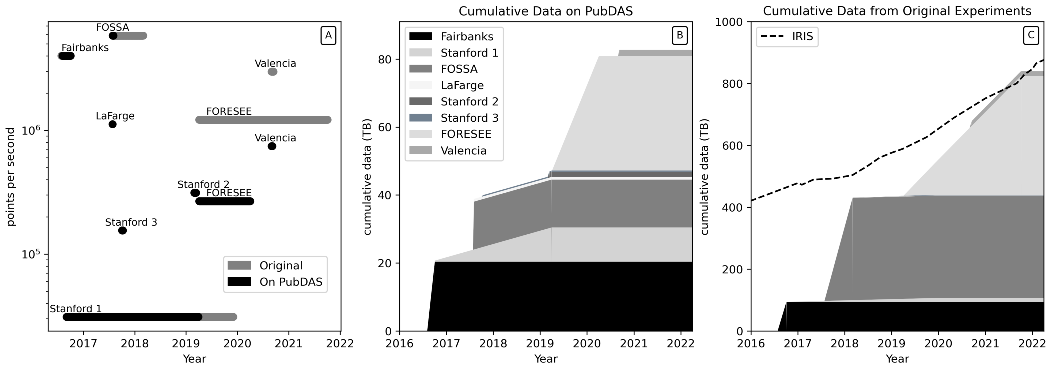


**Figure 1.** A) Time span versus data points per second for all experiments available in PubDAS. Some datasets are provided in full, some have been trimmed, and others have been downsampled to keep a reasonable data volume shown in (B). B) Cumulative data volume for all the datasets available on PubDAS. D) Cumulative data volume for all original datasets and comparison with the data volume available for download from the IRIS-DMC (IRIS, 2022). Fairbanks: Fairbanks Permafrost Experiment array; FORESEE: Fiber-Optic foR Environment SEnsEing 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 IUs; Valencia: Valencia Array.

plest 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 interrogator unit probes the cable via short pulses of laser light and typically measures the Rayleigh back-scattered 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 a vibration, the resulting phase shift is quasi-linearly proportional to the changes in path length over the gauges (Grattan & Sun, 2000). The gauge length defines the spatial resolution of the measurement, while the channel spacing defines the measurement density. Typically, both the gauge length and the channel spacing can vary from $\sim$5 to $\sim$40 m and from $\sim$0.25 to $\sim$20 m, respectively. Note that 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 tradeoffs and drawbacks that can interfere with data when selecting recording parameters. For example, a larger gauge length lowers spatial resolution but may also decrease statistical uncertainty in measurements over the gauges (E. R. 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, & 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 (E. R. 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 & 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 ultra-dense 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 (E. R. 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; Z. J. Spica, Perton, et al., 2020; van den Ende & 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).

## 3 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; Y. Li et al., 2021). Rapidly, particular attention was paid to repeatable vertical seismic profile imaging (Molenaar et al., 2012; Daley et al., 2013; Mateeva et al., 2012; Mateeva, Lopez, et al., 2013; Mateeva, Mestayer, et al., 2013), micro-seismicity 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 in 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; J. B. Ajo-Franklin et al., 2019; Lindsey & Martin, 2021). Furthermore, the DAS instrument response appears to be broadband (e.g., Lindsey et al., 2017; Jousset et al., 2018; J. B. Ajo-Franklin et al., 2019; Lindsey, Rademacher, & 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; Zeng et al., 2017; Lindsey et al., 2017; Lancelle et al., 2021), the inside of the San Andreas fault (Lellouch, Yuan, et al., 2019b, 2019a), glaciers (Walter et al., 2020; Hudson et al., 2021; Fichtner et al., 2022), and densely populated urban centers (Lindsey, Yuan, et al., 2020; Z. J. Spica, Perton, et al., 2020; Yuan et al., 2020; Shragge et al., 2021; Zhu et al., 2021). It has also shown promise in the context of various monitoring applications, notably for detecting earthquakes (Lindsey et al., 2017; Z. Li & Zhan, 2018; Lellouch, Yuan, et al., 2019a), monitoring landslides (Iten, 2012), recording volcanic activity (Klaasen et al., 2021; Currenti et al., 2021; Nishimura et al., 2021; Jousset et al., 2022), characterizing permafrost thaw (J. Ajo-Franklin et al., 2017; Cheng et al., n.d.), estimating blasts or explosions (Zhu et al., 2021; Mellors et al., 2021), and recording weather-ground events (Zhu & Stensrud, 2019; Shen & Zhu, 2021a). DAS recordings were also used for ambient noise interferometry (e.g., Zeng et al., 2017; E. R. Martin & Biondi, 2017), offering the possibility to retrieve repeatable signals (i.e., Rayleigh and Love waves) for near-surface characterization (E. Martin, Biondi, Karrenbach, & Cole, 2017; J. B. Ajo-Franklin et al., 2019; Dou et al., 2017) and aquifer monitoring (Rodríguez Tribaldos & Ajo-Franklin, 2021). In addition, subsea telecommunication fibers have been used to monitor ocean dynamics (Lindsey et al., 2019; Sladen et al., 2019; Williams et al., 2019, 2022) but also to detect earthquakes (Lior et al., 2021; Z. J. Spica et al., 2022) and acoustic phases (Rivet et al., 2021; Ugalde et al., 2022; Z. J. Spica et al., 2022), image the near-shore subsurface (Z. J. Spica, Nishida, et al., 2020; Z. J. Spica et al., 2022; Cheng et al., 2021; Williams et al., 2021; Viens et al., 2022), assess detailed nonlinear ground motion amplification (Viens & Spica, 2022), or precisely locate the sources of microseisms (Xiao et al., 2022).

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

| Name | IU | T. span (d) | Format | Sps (hz) | Vol. (Gb) | GL (m) | CL (m) | CS (m) | units |
|---|---|---|---|---|---|---|---|---|---|
| Fairbanks | iDAS | $59^{\star}$ | TDSM | 1,000 | 10,441 | 10 | 4,000 | 1 | $\dot{\epsilon}$ |
| FORESEE | iDAS-v2 | 365 | HDF5 | $125^{\div}$ | 29,338 | 10 | 4,900 | 2 | $\dot{\epsilon}$ |
| FOSSA | iDAS-v2 | 7 | TDSM | 500 | 11,680 | 10 | 23,300 | 2 | $\dot{\epsilon}$ |
| LaFarge | iDAS | $2^{\star}$ | SEG-Y | 1,000 | 45 | 10 | 1,120 | 1 | $\dot{\epsilon}$ |
| Stanford-1 | ODH3 | 940 | SEG-Y | 50 | 18,908 | 7.14 | 2,500 | 8.16 | $\epsilon$ |
| Stanford-2 | ODH3 | 14 | SEG-Y | 250 | 2,887 | 20 | 10,200 | 8.16 | $\epsilon$ |
| Stanford-3 | ODH4 | 6 | SEG-Y | $\sim$ | 92 | $\sim$ | 2,500 | 8.16 | $\epsilon$ |
| Valencia | A1-R | 7 | HDF5 | $250^{\div}$ | 3,213 | 30.4 | 50,000 | 16.8 | $\dot{\epsilon}$ |

**Table 1.** List of the data sets currently available on PubDAS and their main characteristics. IU: Interrogator Unit; T. Span: Time span in days; Sps: Samples Per Second in Hertz; Vol.: Volume in Gigabytes; GL: Gauge Length in meters; CL: Cable Length in meters; CS: Channel Spacing in meters; $\dot{\epsilon}$: strain rate; $\epsilon$: strain; A $\star$ means data contain active sources. A $\sim$ means that this value may vary; $^{\div}$: means the dataset is downsampled. Name abbreviations are the same as in Fig. 1.

## 4 Characteristics of the repository

PubDAS currently includes 8 datasets recorded with different instruments and acquisition settings (Fig. 1 and Table 1). All 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 FORESEE and Valencia arrays, which have been downsampled to 125 and 250 Hz, respectively, using a anti-aliasing low-pass filter. This is the only pre-processing applied to these datasets. Table refT1 summarizes some of the key features of the datasets.

### 4.1 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 (USACE) Cold Regions Research and Engineering Laboratory (CRREL; Fig. 2). The array consists of a 2D grid of hybrid tactical fiber cables installed in trenches between 20 and 40 cm deep. 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 2 months during the thaw process.

The site and heating experiment are described in (Wagner et al., 2018) while the active source monitoring activities are documented in (J. Ajo-Franklin et al., 2017) and (Cheng et al., n.d.). 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 an iDAS-v2 interrogator (Silixa LLC) at 1 kHz and a 1 m spatial sampling with a 10-m gauge length. Data is saved in native measurement units (proportional to strain rate). While 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.

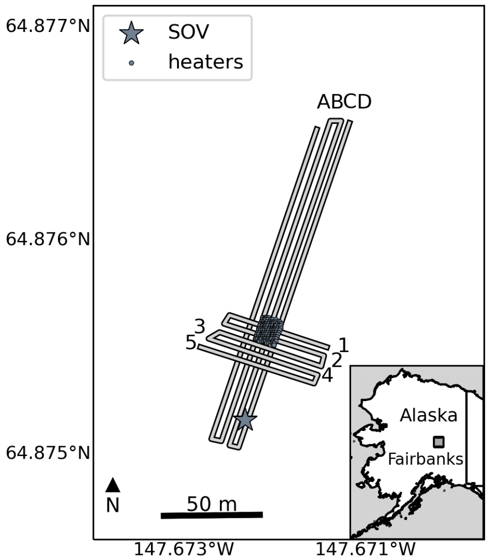


**Figure 2.** Map of the Fairbanks Permafrost Experiment Array. The letters and numbers refer to the line labels. Only the channels at the end of each line have been tap tested. SOV: Surface Orbital Vibrator.

### 4.2 The Fiber-Optic foR Environment SEnsEing (FORESEE) Array

The FORESEE array is located in central Pennsylvania in the Valley and Ridge Appalachians region (Fig. 3). The array consists of an iDAS-v2 interrogator and a $\sim$ 5-km long single-mode dark fiber installed underneath the Pennsylvania State University campus. The fiber shown in Fig. 3 is made of two individual fibers that were spliced together around channel 1340. The cable sits in buried concrete conduit at depths ranging between 1 and 10 m. Continuous strain-rate measurements were performed between April 5, 2019, and October 4, 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 to 604) is located in a quiet off-campus area and the rest of the array is 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-year experiment, the array recorded a variety of transient signals, including global and regional earthquakes, thunderquakes (Zhu & Stensrud, 2019; Hone & 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 & 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.

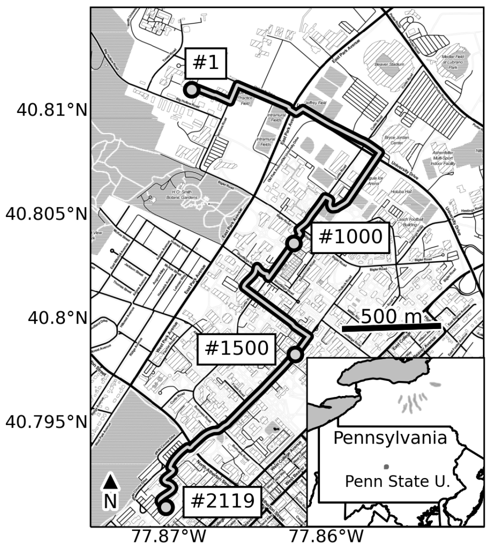


**Figure 3.** Map of the Fiber-Optic foR Environment SEnsEing (FORESEE) Array.

In PubDAS, data acquired during the first year of the experiment (i.e., April 5, 2019 - March 14, 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 Hz to 125 Hz.

### 4.3 The Fiber Optic Seismic Super Array (FOSSA)

The FOSSA experiment was conducted on the Sacramento River flood plain, north and west of Sacramento, CA. The experiment utilized a 27 km section of dark telecommunications fiber, part of DOE's ESnet network, connecting West Sacramento with the town of Woodland (Fig. 4). Data of usable quality was recorded on approximately 23.3 km (11,648 sampling locations, 2m spacing). The experimental targets were monitoring regional seismicity and characterizing near-surface structure using ambient noise methods. Data were collected between July 28, 2017 and January 18, 2018, at an original sampling rate of 500 Hz, generating a total of 210 TB of raw uncompressed data. J. B. 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 conduit buried in 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 to 4 m). The response of the fiber was also explored through comparison to a co-located broadband inertial sensor by (Lindsey, Rademacher, & Ajo-Franklin, 2020) for both teleseismic events and microseism energy.

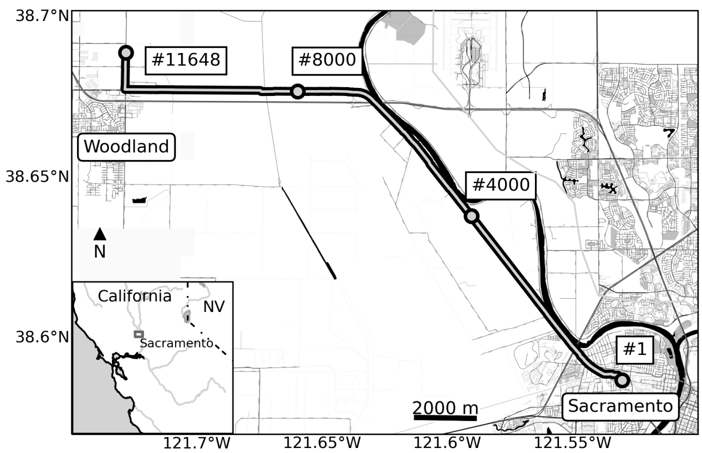


**Figure 4.** Map of the Fiber Optic Seismic Super Array (FOSSA).

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 towards Woodland, the fiber follows Interstate 5. In addition, the cable is sometimes co-linear 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 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 teleseismic earthquakes, is available for download.

### 4.4 LaFarge-Conco Mine Array

The LaFarge-Conco mine is a Limestone and dolomite mine located in North Aurora, IL (Fig. 5). 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 by 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 meters on a side and in height. The rock is blasted from the formation most weekdays in mid-afternoon. Rocks are then hauled by truck up a decline 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.

The DAS array was located in the north section of the first level of the mine as shown in Zeng et al. (2021). A ∼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 grove and covered with fine rock powder, and in Loop 3 the top strand was placed without cover. The DAS 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

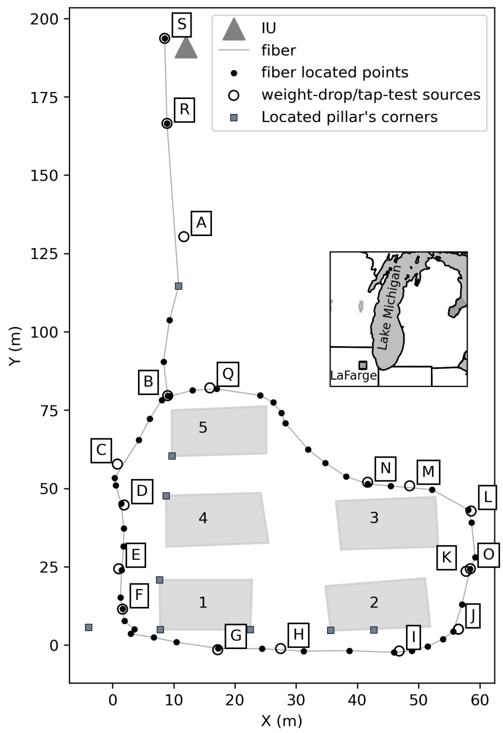


**Figure 5.** Map of the LaFarge-Conco Mine array. The numbered grey areas represent the mine pillars.

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 Fig. 5. Also, 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 poorest arrivals were recorded by the loose cable.

### 4.5 Stanford 1 – Stanford Campus Array:

The Stanford campus array in California (Fig. 6) was created using a fiber cable loosely deployed in an air-filled PVC 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 Dr. and Via Ortega, and south of Allen on Via Pueblo. The fiber location was calibrated with tap tests as described in details in (E. Martin, Biondi, Cole, & Karrenbach, 2017). Continuous recordings were acquired using an OptaSense ODH-3 IU at 50 Hz between September 2nd 2016 and March 31st 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, E. R. 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

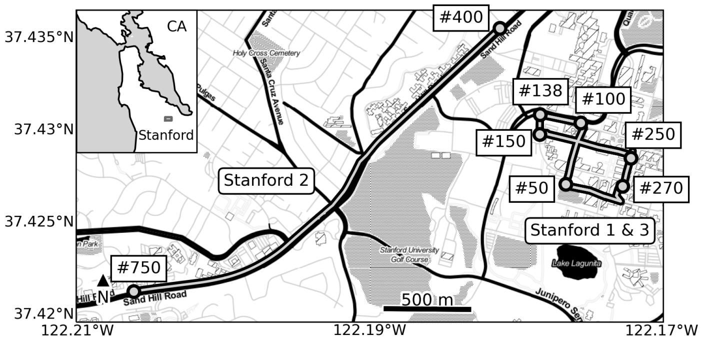


**Figure 6.** Map of the different Stanford arrays. Stanford 1 and 3 recorded the same fiber loop on main campus but with different IUs. Stanford 2 was recorded around Palo Alto.

array provide a unique opportunity to monitor long-term variations of the ambient seismic field generated by natural and anthropological sources (E. R. Martin & Biondi, 2018; E. R. Martin, Huot, et al., 2018; Huot et al., 2017), 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 (Z. J. 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 & Biondi, 2018).

### 4.6 Stanford 2 – Sandhill Road Array:

Stanford 2, starting from 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, CA (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). 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 March 1 and 14, 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 SLAC (Channel #750). The section of the array between channels 400 and 750 (Fig. 6) provides the highest SNR. The location of the channels along this segment were calibrated by driving a dedicated car at 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 (VOS) and roadside DAS using this array.

### 4.7 Stanford 3 - Stanford Campus with two IUs

Stanford 3 was a temporary dual IU experiment on Stanford campus between October 5, 2017 and October 13, 2017, using the same Stanford 1 cable loop. Besides the OptaSense ODH-3 model that recorded since 2016, this experiment attached an additional IU, the

OptaSense ODH-4 model, that started interrogating using acquisition parameters identical to the ODH-3. Both 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 ODH-3, and the high-quality ODH-4 data were used for H/V spectral ratio analysis (Z. J. Spica, Perton, et al., 2020). Three broadband seismometers were contemporaneously installed in building basements by the USGS within the cable loop (U.S. Geological Survey, 2016) and collected ground motion data for comparison.

### 4.8 Valencia Array

The Valencia-Islalink experiment (Z. Spica et al., 2020) used a pre-installed 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 September 1st to September 15th, 2020, a Febus Optics IU 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 9,189 m are on land. This is easily confirmed with 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. The data from September 1st to September 7th are contin-

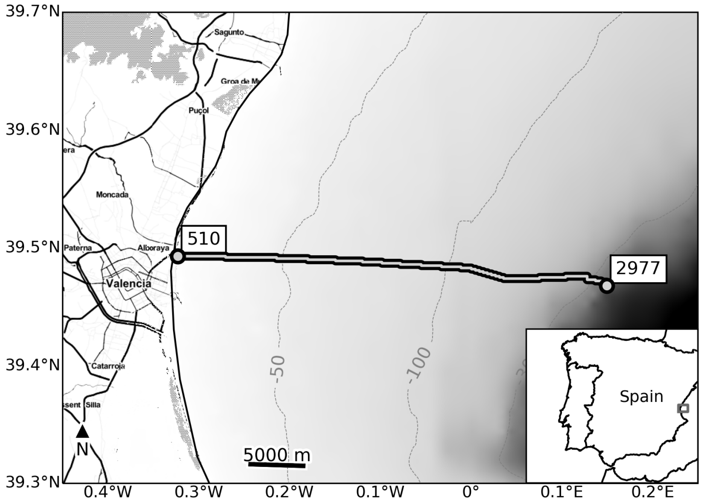


**Figure 7.** Map of the Valencia arrays showing the undersea channels.

uous and available on PubDAS. The remaining week was less complete with the presence of numerous recording gaps and was therefore not published.

## 5 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 man-holes) 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/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. GPS and tap tests (or airguns in oceans; Takano et al. (2021)) are used to precisely locate channels; 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 on their working principles, optical chains, and running algorithms are not fully accessible to users. While 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, phases) over a broad range of measurement lengths. Moreover, some IUs pre-process raw data on the fly before writing them to a hard drive while other IUs simply save the raw data. Depending on the system, some 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. Due to the large range of parameters described above, a single measurement campaign can result in the collection of a large volume of metadata. Therefore, standard seismic metadata (e.g., SEED) 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. Note that 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). While 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.

## 6 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 non-profit software as-a-service provider (Foster, 2011), using the link provided in the Data and Resources section. Globus is free, easy-to-use, and provides secure and high-performance file transfer between storage systems (Chard et al., 2017; Ananthakrishnan et al., 2015). In short, Globus can be seen as 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 Web Services, the National Science Foundation XSEDE systems, and many US 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 notifies users of completions and problems. While 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 multi-user server available as a native linux package. Users are also able to use Globus python API 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 toward a step-by-step guide on "how to log into Globus and use it to transfer files" is provided in the Data and Resources section.

Globus Connect Personal is designed to work automatically with common firewall settings. However, very strict firewall policies – i.e., 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 (UDP) ports. A link explaining how to configure the firewall policy for Globus Connect Personal is also provided in the Data and Resources section.

Currently, the UM has 400 Gbps of internet bandwidth allowing up to several PB/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 use of an institutional fiber connection rather than home internet for dataset retrieval. We have tested download and upload speeds for several data sets between institutions. A summary of our experience is shown in Table 2.

These results shows that even with a low-speed connection (e.g., ∼20mb/s), the optimization of the data transfer with Globus still provides performance acceptable for retrieving the test datasets.

| 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 |

**Table 2.** Examples of data upload and download using Globus and using different network speeds. UM: University of Michigan; CSM: Colorado School of Mines, USA; UNAM: Universidad Nacional Autónoma de México, Mexico; IGN: Instituto Geográfico Nacional, Spain; ERI: Earthquake Research Institute, Japan; CTC: Cordova Telephone Cooperative, Alaska, USA; Caltech: California Institute of Technology, USA.

## 7 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, while 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 since every dataset has its own requirements, 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. Note that 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.

| Short Name | Approx. Vol. (Gb) | Location | T. Span (d) | Access |
|---|---|---|---|---|
| DAS4Microseism | 182 | Svalbard, Norway | 42 | doi:10.18710/VPRD2H |
| DAS4Whale | 37.6 | Svalbard, Norway | 2 | doi:10.5281/zenodo.5823343 |
| RAPID | 26,000 | Offshore Pacific City, OR | 5 | piweb.ooirsn.uw.edu/das/ |
| PoroTomo$^{\star}$ | 81,000 | Brady Hot Springs, NV | 15 | doi:10.15121/1778858 |
| FORGE 2C$^{\star}$ | $\sim$ | Milford, Utah | $\sim$ | tinyurl.com/2p8epnn5 |
| Marcellus$^{\star}$ | $\sim$ | Morgantown, WV | $\sim$ | www.mseel.org/ |
| Garner Valley$^{\star}$ | 165 | California | 1 | doi:10.15121/1261941 |
| Levee Workshop* | 0.741 | Black Hawk, LA | 1 | doi:10.17603/ds2-c96x-pg70 |
| Belgium | 1.3 | Zeebrugge, Belgium | 1 | doi:10.22002/D1.1296 |
| Monterey Bay | 0.565 | Moss Landing, CA | 4 | tinyurl.com/ynab86bc |
| SAFOD | 1.54 | San Andreas Fault, CA | $\sim$ | tinyurl.com/yc49swp4 |
| FORESEE | 28,670 | State College, PA | 180 | tinyurl.com/499mn4pa |

**Table 3.** Non-exhaustive list of other DAS datasets available for download on other platforms. A $\star$ means that the data contain active sources. A $\sim$ means that this value may vary or is unknown.

## 8 Conclusions and future steps

This paper presents the first large-scale open-source repository where several DAS datasets from multiple application areas are publically 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 better understand the Earth.

Currently, ~90TB of DAS data are hosted at the University of Michigan, 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 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 recent breakthroughs in high-performance computing and machine/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.

## 9 Data and Resources

The PubDAS Globus endpoint at UM is accessible via the following link: `https://app.globus.org/file-manager?origin_id=706e304c-5def-11ec-9b5c-f9dfb1abb183&origin_path=%2F`. Instructions to download and run Globus Connect Personal are accessible via the following link: `www.globus.org/globus-connect-personal` Globus Connect Personal basic tutorial is also available on Youtube via the following link `www.youtube.com/watch?v=bpnVcAN99WY` The step-by-step guide to log in and transfer files with Globus is accessible via the following link: `docs.globus.org/how-to/get-started/`. The firewall policy for Globus Connect Personal is accessible via the following link: `docs.globus.org/how-to/configure-firewall-gcp/`. The complete Globus documentation is accessible via the following link `docs.globus.org/`. For any question about Globus, please work directly with your Information and Technology specialists.

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