The Global DAS Month of February 2023

Andreas Wuestefeld* *et al.*

Abstract

During February 2023, a total of 32 individual distributed acoustic sensing (DAS) systems acted jointly as a global seismic monitoring network. The aim of this Global DAS Month campaign was to coordinate a diverse network of organizations, instruments, and file formats to gain knowledge and move toward the next generation of earthquake monitoring networks. During this campaign, 156 earthquakes of magnitude 5 or larger were reported by the U.S. Geological Survey and contributors shared data for 60 min after each event's origin time. Participating systems represent a variety of manufacturers, a range of recording parameters, and varying cable emplacement settings (e.g., shallow burial, borehole, subaqueous, and dark fiber). Monitored cable lengths vary between 152 and 120,129 m, with channel spacing between 1 and 49 m. The data has a total size of 6.8 TB, and are available for free download. Organizing and executing the Global DAS Month has produced a unique dataset for further exploration and highlighted areas of further development for the seismological community to address.

Cite this article as Wuestefeld, A., Z. J. Spica, K. Aderhold, H.-H. Huang, K.-F. Ma, V. H. Lai, M. Miller, L. Urmantseva, D. Zapf, D. C. Bowden, *et al.* (2023). The Global DAS Month of February 2023, *Seismol. Res. Lett.* **XX**, 1–9, doi: 10.1785/0220230180.

Goals

Global Seismometer Networks (GSNs) have greatly contributed to our understanding of the Earth. Originally established to help monitor nuclear tests, the World-Wide Standardized Seismograph Network (WWSSN) was set up in the 1970s (Oliver and Murphy, 1971) and supplanted by the GSN and IMS (International Monitoring System, respectively). Additional networks were subsequently established, notably GEOSCOPE and GEOFON in the 1980s and 1990s, respectively. Ringler *et al.* (2022) give an excellent history of global networks. In recent years, technological advancement made distributed acoustic sensing (DAS) with fiber-optic cables available to the seismological research community (e.g., Lindsey and Martin, 2021). DAS systems owned by the research organizations are recording for a broad variety of research projects globally. In addition, DAS systems record continuously for commercial purposes, monitoring for example trains, pipelines, and oil fields.

DAS systems have the advantage over seismometers of measuring vibrations not at a single point, but rather at a multitude of positions along a fiber. Current technology allows up to 170 km of fiber to be monitored with a single "interrogator" system (Waagaard *et al.*, 2021). Furthermore, the existing telecommunication fiber infrastructure can be used, reducing costs for example in urban environments (e.g., Spica, Perton, *et al.*, 2020) or giving access to the currently sparsely monitored ocean floor (Spica, Nishida, *et al.*, 2020). However, one of the most pressing scientific need toward a global network of DAS systems is a better understanding of the characteristic transfer function for each installation: how does this vary along the cables, by manufacturer, cable type, deployment style, and so forth. Establishing this would allow for magnitude determination and more. A dataset comprised of various systems recording the same events might facilitate such research.

In this article, we present the efforts of the DAS community toward the next generation of GSN based on fiber optic sensing: A "Global Fiber Sensing Network," or GFSN. Thus, we declared February 2023 as the first "Global DAS Month." This campaign aimed to address the following questions:

1. Is there interest in the community to collaborate toward a GFSN?
2. How can large amounts of data be efficiently shared?
3. What are the bottlenecks to an effective GFSN (e.g., data format, data storage, and legal access)?

More generally, such datasets may allow the community to develop tools for augmenting global monitoring systems with DAS installations. Notably, research is required to standardize DAS cable transfer functions, which will allow event magnitude determination. Furthermore, the benefits of high channel counts of DAS cables for event localization needs to be formalized.

Initial feedback from various academic and commercial actors indicated a strong interest from the community in a GFSN. Therefore, we laid out the framework for the Global

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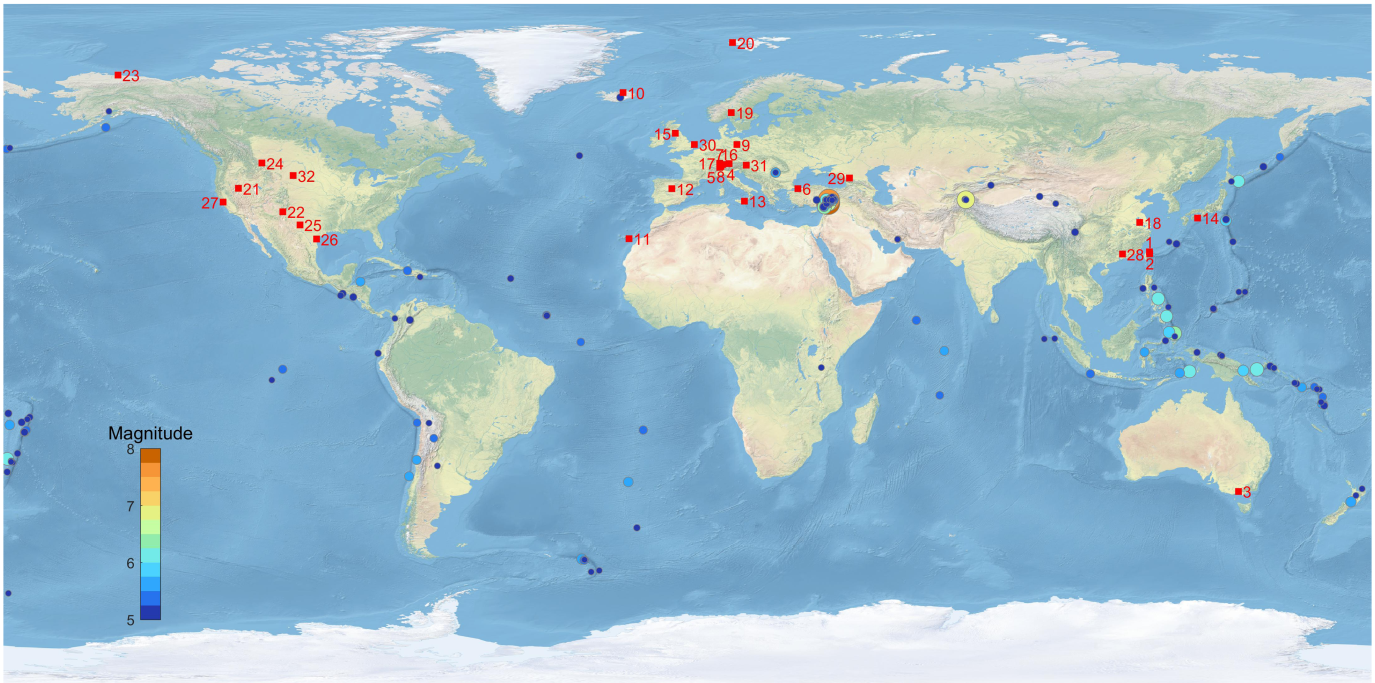

Figure 1. Map of systems contributing to the Global distributed acoustic sensing (DAS) Month of February 2023. The red squares indicate the location of the various DAS systems with numbers according to the ID in Table 1. Also shown are the locations of the 156 earthquakes with $M \geq 5$ that occurred during February 2023, with size and color proportional to event magnitude. The color version of this figure is available only in the electronic edition.

DAS Month of February 2023: during the campaign month, all available DAS systems in different regions of the globe share periods of identical time windows. We focused on windows around events with $M \geq 5$, as reported by the U.S. Geological Survey (USGS). Based on historical averages, we anticipated 150 events. A 1 hr window after the reported source time was considered sufficient to capture the most interesting parts of the wavetrains for most system distances. To limit data volume, we suggested a temporal sampling rate of 100 Hz and spatial sampling of 20 m. In case the systems recorded with other parameters, postrecording down-sampling has been applied to obtain the desired parameters by the vast majority of contributors. Other recording parameters were left to be adjusted by the user for their specific needs.

In addition to these triggered event files, continuous data are considered useful for some research topics. Thus, we declared 14 February 2023 00:00–23:59 UTC as the "Global DAS Day," or the period during which 24 hr of continuous data shall be shared (at 50 Hz). Many of the systems did contribute to this effort. More data may be available from the contributors upon request.

Data Overview

In total, 156 events with $M \geq 5$ were reported by the USGS during February 2023. See Figure 1 for a map of earthquakes and locations of contributing DAS systems. Europe, and especially the Alps, are well covered with DAS systems, whereas other parts are more sparsely sampled. Notably, South America, Africa, and Antarctica have no contribution. However, this heterogeneous distribution of systems can be seen as an opportunity to allow investigation on various coverage scales. Figure 2 gives a close-up view of the cable paths of each contribution. Two destructive earthquakes occurred on 6 February 2023 with magnitudes 7.8 and 7.7, respectively, as part of the Kahramanmaraş sequence in Türkiye and Syria (Dal Zilio and Ampuero, 2023). These events are part of the Global DAS Month dataset (Jousset *et al.*, 2023). Figure 3 shows a single trace of selected DAS systems of the event at 6 February 2023 01:17:34, sorted by distance to the event. We also show the theoretical arrival times of various phases.

The dataset comprises (at the time of writing) of 6.8 TB of data from 32 individual DAS systems from 10 different vendors. Additional contributions may become available in the future. The total cable length is 666 km, providing 44,883 channels. Systems represented a range of cable emplacement styles, including shallow burial, borehole, subaqueous, and existing dark fiber. The suggested temporal and spatial sampling rates were not strictly enforced. Limitations in recording and processing capabilities of the various systems resulted in a heterogeneous database with sampling rates ranging from 50 to 1000 Hz, and channel spacing varying between 1 and 49 m. Table 1 gives an overview of the datasets contributing to the Global DAS Month campaign. Additional supporting material for each dataset includes a ReadMe.txt with information about the installation, as well as a coordinate file with the

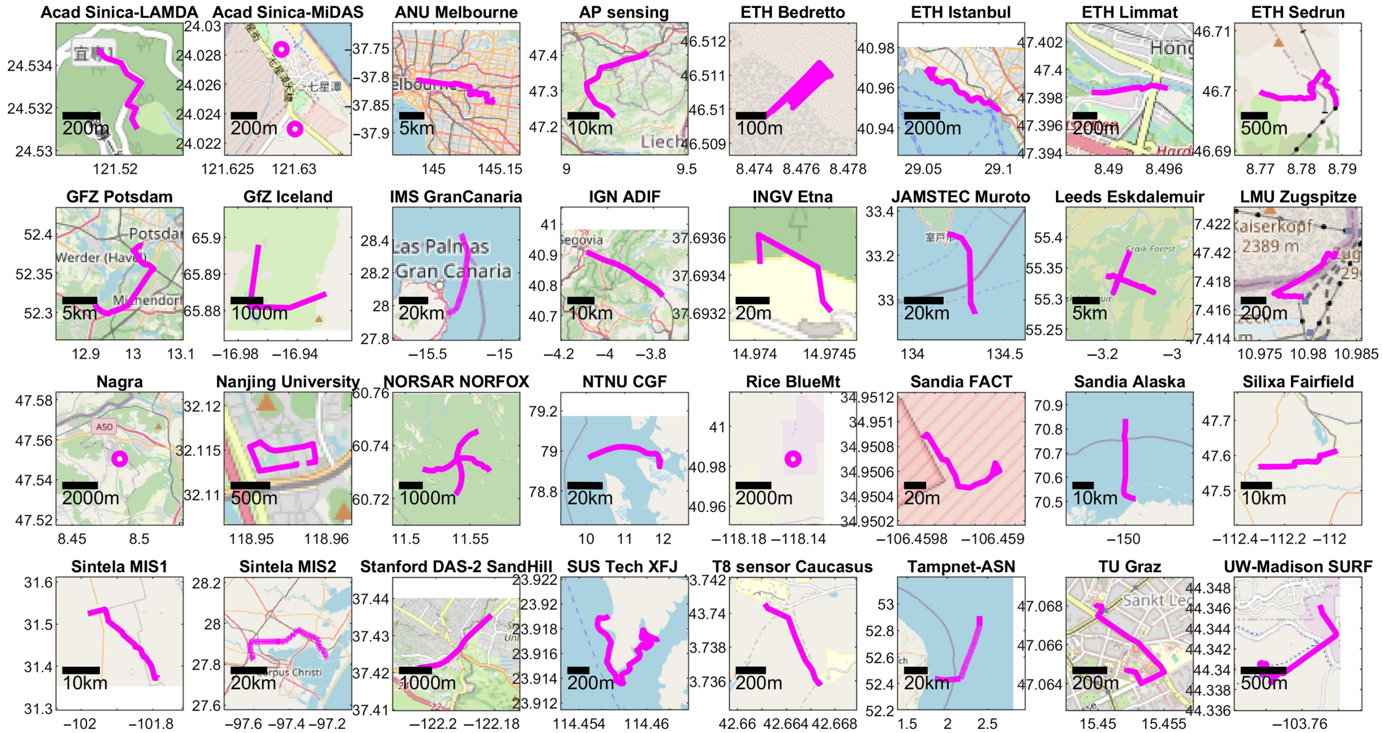

Figure 2. Individual layouts of the contributions. Boreholes are indicated as circles. The color version of this figure is available only in the electronic edition.

locations of the individual channels. The data are uploaded to PubDAS in native interrogator format or a postprocessed form to give strain or strain-rate data. Example functions for reading the data into computers have been provided with each dataset.

Data access

Data are hosted in PubDAS, an open repository managed by the Advanced Research Computing division of the Information and Technology Services at the University of Michigan (UM; Spica *et al.*, 2023). In the future, the data might migrate to a different server once the infrastructure for DAS data has been established at a suitable organization. PubDAS can be accessed using the link provided in Data and Resources and via the nonprofit software-as-a-service provider, Globus (Foster, 2011). Globus offers secure and high-performance file transfers between storage systems and is free and easy to use. It simplifies data management, allowing researchers to focus on science rather than technology. Globus coordinates data transfers by handling complex aspects such as parallel transmission control protocol streams and authentication at the source and destination. It also provides automatic fault recovery and notification of completions and problems. Users can deploy the lightweight single-user agent, Globus Connect Personal software, on Windows, Mac, and Linux computers for fast and reliable data transfers. In addition, users can register their desired storage as a Globus “endpoint,” which includes metadata such as ownership, name, and descriptions. After endpoint setup, end-users can download their preferred PubDAS dataset. A step-by-step guide on how to log into Globus and use it to transfer files is available in Data and Resources. See Spica *et al.* (2023) for more information about PubDAS.

Data acknowledgment

The Global DAS Month of February 2023 comprises a broad assemblage of independent fiber deployments and data collections, each in turn enabled by the effort of a distinct suite of individuals and organizations. To acknowledge those within the nested layers of efforts and allow for tracking of data usage, we turned to the strategy employed by seismic network operators and encouraged the generation of a digital object identifier (doi) for each dataset (see Table 2). This approach has been recommended and enabled by the International Federation of Digital Seismograph Networks (Clark *et al.*, 2014). There are known issues to address with seismic network dois, including journal limits on references and inconsistent use (Staats *et al.*, 2023); however, their routine use is gaining traction within the seismological community.

Key Areas for Further Development

This campaign can be considered a great success because it brought together the seismological DAS community, as well as raised awareness among commercial actors on the needs for seismological research datasets. These include considerations such as easy access to patch panels, publishable cable locations, as well as cable deployment details. The latter is of particular importance to determine the transfer function. To routinely

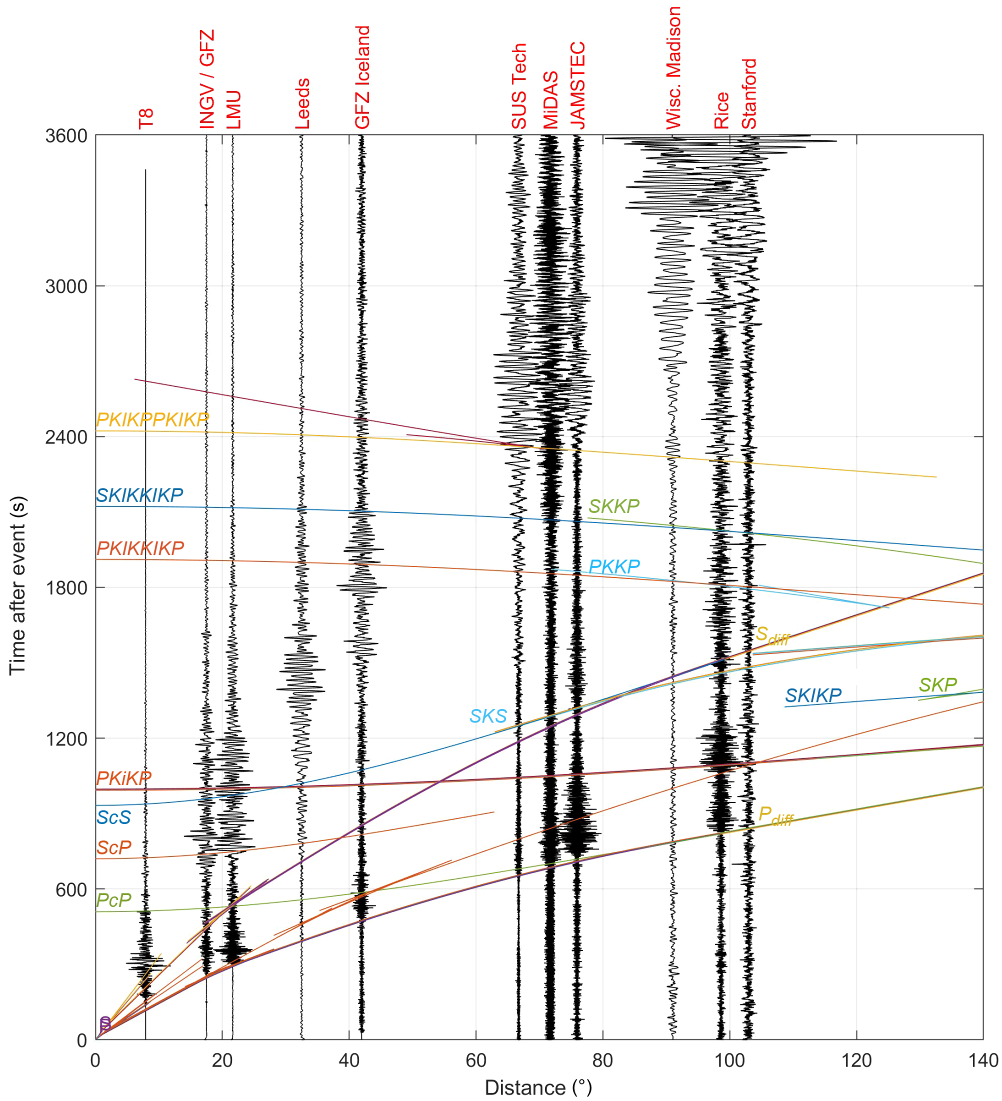

Figure 3. Individual strain-rate traces of selected systems of the 6 February 2023 01:17:34 Türkiye event, plotted against hypocentral distance. Also shown are theoretical phase arrivals. Traces are filtered between 0.1 and 3 Hz and normalized to the maximum absolute value of the first 2400 s after origin time. The color version of this figure is available only in the electronic edition.

share DAS data, in the same way seismometer data are shared now, four main topics still need further coordination:

Data format

Data are provided in various formats, sometimes specific to the interrogator manufacturer or the providing organization. Having such a heterogeneous database was a conscious decision: Although a homogeneous data format would have been preferable from a data analysis perspective, no common and agreed upon data format was established among the community at the time of this campaign. Rather, a heterogeneous dataset with various readers will provide a unique collection of the available approaches. For each individual dataset, an example code to read in that specific format is provided on the download server. Such a collection can help build the foundation of a common "GFSN format," which picks the best parts of each available solution. Most data are shared in an HDF5-format variant (see Table 1), either homegrown, manufacturer developed, or industry specific. Thus, HDF5 seems to offer very suitable features. The members of the DAS Research Coordination Network working group on Data Management have developed a metadata model while engaging significant community feedback (Lai *et al.*, 2023).

Channel coordinates

A concern of some data providers was the public sharing of coordinates of the individual channels. Commercial fiber cables are often considered critical infrastructure and can provide data within difficult to access areas. Similarly, monitored pipelines can offer a unique seismological dataset for their unprecedented lengths. Finally, long and deep boreholes from oil fields offer a different kind of unique data. Unfortunately, the exact path for such infrastructure is considered sensitive information and there is understandable hesitancy to share. In the Global DAS Month, we addressed these concerns in two ways: geographical coordinates could be shared either with a truncated number of digits or as Cartesian coordinates relative to the start point. Truncated coordinates have their limits in the resolution, considering a channel spacing of ~20 m. On the other hand, relative coordinates have little value for teleseismic event analysis. In the end, all contributions shared the cable locations with sufficient details. However, without sensitivity concerns, many more datasets may have become available.

Legal considerations

The Global DAS Month suggested the use of the license "By-attribution noncommercial creative commons 4.0" (BY-NC-CC4.0). Some data owners may have different licenses, as specified in the

TABLE 1
List of Contributions

ID	Provider (Site)	Instrument	Format	*dx* (m)	Length (m)	*n*Chnl	GL (m)	*f* Samp (Hz)	Size (GB)
1	Academia Sinica (LAMDA)	Silixa iDAS	mSEED	2	810	405	10	1,000	177
2	Academia Sinica (MiDAS)	Silixa iDAS	mSEED	4	1,196	299	10	1,000	214
3	ANU	Silixa iDAS2	Custom H5	20.0	25,000	6,252	10	100	62
4	AP sensing	AP sensing	APS (H5)	19.6	44,500	2,270	10	100	115
5	ETH (Bedretto)	FEBUS A1-R	FEBUS (H5)	2	4,500	2,250	20	100	124
6	ETH (Istanbul)	Silixa iDAS	ProdML	16	8,000	500	10	100	96
7	ETH (Limmat)	Silixa iDAS	ProdML	20	800	40	10	100	3.3
8	ETH (Sedrun)	Silixa iDAS	ProdML	20	3,100	155	10	125	29
9	GFZ (Potsdam)	Silixa iDAS2	Custom H5	20.0	18,600	930	10	100	469
10	GFZ (Iceland)	Silixa iDAS2	Custom H5	4.0	17,000	4,250	10	100	121
11	ICM CSIC/Canalink	Aragón Photonics	Custom H5	20.0	65,000	3,248	10	50	110
12	IGN/ADIF	Aragón Photonics	Aragón (H5)	10.0	36,000	3,616	10	100	1,800
13	INGV/GFZ	Silixa Carina	Custom H5	1.0	320	271	2	100	29
14	JAMSTEC	AP sensing	custom H5	49.0	120,129	2,450	40	100	467
15	Leeds/AWE	FEBUS A1-R	custom H5	19.2	7,507	391	50	100	90
16	LMU Munich	Silixa iDAS2	ProdML	20.4	1,062	52	10	100	13
17	Nagra	FEBUS A1-R	mSEED	19.6	1,225	400	10.2	100	11
18	Nanjing University	Wuhan optical	DAT	5.0	3,800	757	5	100	105
19	NORSAR	ASN OptoDAS	ASN (H5)	10.0	12,250	1225	20	100	185
20	NTNU CGF	ASN OptoDAS	ASN (H5)	24.5	50,000	2040	8.2	100	866
21	Rice University	Silixa iDAS2	custom H5	20.4	2,430	120	10	100	41
22	Sandia National Laboratory (FACT)	Silixa iDAS	TDMS	1	152	152	10	100	105
23	Sandia National Laboratory (Alaska)	Silixa iDAS	TDMS	24.6	37,096	1,509	10	100	182
24	Silixa	Silixa iDAS-MG	ProdML	20.4	28,400	1,393	30	100	156
25	Sintela (MIS1)	Onyx	ProdML	19.2	33,254	1,732	11.2	100	287
26	Sintela (MIS2)	Onyx	ProdML	19.2	51,187	2,666	11.2	100	439
27	Stanford University	Optasense ODH-3	custom H5	8.2	2,856	350	16	100	125
28	SUS Tech	Silixa iDAS-MG	NPY	20.4	3,000	147	10	100	15
29	T8 sensor	T8 DAS Dunay	T8 (H5)	19.2	700	36	20	100	4.6
30	Tampnet/ASN	ASN OptoDAS	ASN (H5)	20.0	80,000	4,000	20	125	889
31	TU Graz	FEBUS A1-R	FEBUS (H5)	9.6	2,600	271	20	100	62
32	University of Wisconsin-Madison	OptaSense ODH-4	Custom H5	4.0	3,432	858	16	100	382

Columns indicate, respectively, an ID number; the data providing organization (with project name in brackets if multiple datasets are provided by that organization); interrogator manufacturer and model; file format (note that some formats are used only internally in the respective organization); channel spacing (m); the total cable length (m); number of channels; gauge length (m); temporal sampling rate (Hz); and data volume (GB). Further information about each installation and cable can be found in the accompanying README files on the download server.

respective ReadMe.txt files. Feedback particularly from commercial data owners indicate that this license might be too open in some cases. Any future GFSN should consider a license that is acceptable for nonacademic data owners.

Permanent storage

DAS generates enormous amounts of data, depending on cable length and acquisition parameters in the order of TB per day. Most seismological data centers are not used to, or currently equipped to, store such volumes permanently. This problem is similar to the limitations encountered by the early seismometer networks. Thus, it seems appropriate that in the near future any GFSN will require only "time-windowed" or triggered data. A longer time window (>60 min) may be interesting in future coordinated monitoring endeavors to fully capture event signals for global monitoring applications.

The drawback of the time-windowed storage approach is that ambient noise studies typically require much longer windows. This is addressed in the Global DAS month by having the "Global DAS Day" of 24 hr of continuous data. More continuous data may be stored with the data provider and shared upon request.

Conclusion

The Global DAS Month of 2023 resulted in a unique dataset of 156 $M \geq 5$ earthquakes recorded on up to 32 DAS systems worldwide. For each event 60 min of data are available with a variety of spatial and temporal sampling rates, in various formats, and most importantly, in various deployment conditions. The efforts in collecting the dataset will be valuable in future decisions on sharing and storing DAS data.

We hope that data from the Global DAS Month will initiate DAS research, development, and collaboration with the now available datasets. The open-access aspect of this initiative, despite adding logistical complication, should expedite advancements in seismology and geosciences, streamline the process of training, validating, and comparing performance, and most importantly, simplify the integration of optimal practices when utilizing DAS data. We anticipate this dataset will be useful for research into coupling conditions and sensitivity of the different deployments, as well as detection thresholds as function of distance. Furthermore, directional response of installations and earthquake radiation patterns can be investigated. The ultimate objective of this campaign is to enable a wider community to participate in ongoing seismological DAS research.

Data and Resources

The Global distributed acoustic sensing (DAS) month dataset is accessible via Globus to reach the PubDAS endpoint under the DAS-Month-02.2023/folder. A step-by-step guide for logging in and transferring files is available at docs.globus.org/how-to/get-started/. To access the PubDAS Globus endpoint at University of Michigan, available at https://tinyurl.com/PubDAS. Please note that a Globus account is required to access the PubDAS endpoint, and instructions for downloading and running Globus Connect Personal are available at www.globus.org/globus-connect-personal. The firewall policy for Globus Connect Personal is available at docs.globus.org/how-to/configure-firewall-gcp/. The complete Globus documentation is available at docs.globus.org/. For any questions about Globus, it is recommended to work directly with the Information and Technology specialists of your organization. Most dataset contribution are associated with a digital object identifiers (dois), see Table 2. These dois are required to be cited when a dataset is used. All websites were last accessed in November 2023.

Declaration of Competing Interests

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

Acknowledgments

Significant community engagement took place under the umbrella of the distributed acoustic sensing (DAS) Research Coordination Network (National Science Foundation [NSF] Grant Number EAR-1948737). Initial discussion was supported by the Air Force Research Laboratory through Grant Number FA9453-21-2-0018. A. W. thanks all contributors for discussing data formats. Z. J. S. acknowledges support from the NSF through Grant Number EAR2022716. The Global DAS Month relied on voluntary contributions from various organizations, and the authors are grateful to them for making this possible. Each institution, as referred to their number in Table 1, acknowledge the following: [1] thank Kuo-Lung Wang, Ching-Chou Fu, and Chin-Shang Ku for field support. Funding support from the Academia Sinica Career Development Award (Grant Number AS-CDA-111-M01). [2] thank the MiDAS team, Chin-Jen Lin, and Chin-Shang Ku from IESAS for technical support and data management. This grant is supported by Academia Sinica Grand Challenge Program (Number AS-GC-109-11). [3] thank InPAC lab at RMIT and AARTNet for providing access to the ALIRT fiber. AuScope and the Australian Government enabled the project via the National Collaborative Research Infrastructure Strategy (NCRIS). [4] thank Schweizerische Südostbahn AG for providing data access. [5] thank the Bedretto BULGG for providing access to their borehole fibers, and the Bedretto Team and FEBUS optics for their continued support. [6] thank ETH, and specifically the ETH-Domain grants for Open Research Data (ORD) Explore projects for funding. [8] thank Disentis Bergbahnen for the access to their fiber-optic systems and continuous support before, during and after the acquisition, as well as the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie Grant Agreement Number 955515. [10] thank Landsvirkjun for providing access to the geothermal site and the telecom cable; Project funding by Helmholtz Association, and geoPuR project funded by the European Regional Development Fund (ERDF) and the "Investitions und Landesbank Brandenburg" (ILB) under the contract 85037956, and Improve ETN from the Horizon 2020 research and Innovation program under the grant agreement 858092, and and SPIN ITN from the horizon 2020 research and Innovation program under the Marie Skłodowska-Curie Grant Agreement Number 955515. This work was also supported by the European Union's Horizon 2020 Research and Innovation Program (Geo-INQUIRE

TABLE 2
List of Installations with Their Associated Digital Object Identifiers (DOIs), for Referencing

ID	Provider	Site	Latitude	Longitude	DOI
1	Academia Sinica	LAMDA	24.535	121.520	http://doi.org/10.7914/rbr9-8z88
2	Academia Sinica	MiDAS	24.023	121.630	http://doi.org/10.7914/k56t-4215
3	ANU	Melbourne	−37.807	144.970	http://doi.org/10.25914/kf96-nb26
4	AP sensing	St Gallen	47.227	9.197	http://doi.org/10.7914/g0ed-5e68
5	ETH	Bedretto	46.511	8.476	http://doi.org/10.7914/8t1v-6j63
6	ETH	Istanbul	40.970	29.058	http://doi.org/10.7914/kfkm-x182
7	ETH	Limmat	47.399	8.496	http://doi.org/10.7914/42kw-r383
8	ETH	Sedrun	46.697	8.788	http://doi.org/10.7914/bvm7-mh78
9	GFZ	Potsdam	52.385	13.020	http://doi.org/10.5880/GFZ.2.2.2023.001
10	GFZ	Iceland	65.898	−16.966	http://doi.org/10.5880/GFZ.2.2.2023.002
11	ICM CSIC	Canalink	27.949	−15.381	http://doi.org/10.7914/73k1-1369
12	IGN/ADIF	Guadarrama Mt	40.909	−4.092	http://doi.org/10.7914/66dw-7d40
13	INGV/GFZ	Etna	37.693	14.975	http://doi.org/10.7914/j0yz-kj67
14	JAMSTEC	Muroto	33.297	134.190	http://doi.org/10.7914/42rp-t560
15	Leeds/AWE	Eskdalemuir	55.336	−3.198	http://doi.org/10.7914/3320-5s03
16	LMU Munich	Zugspitze	47.417	10.980	http://doi.org/10.7914/SN/X6_2021
17	Nagra	Stadel	47.550	8.485	http://doi.org/10.7914/1s1g-c426
18	Nanjing University	Xianlin Campus	32.114	118.960	http://doi.org/10.7914/2hnj-ex83
19	NORSAR	NORFOX	60.735	11.540	http://doi.org/10.21348/d.no.0004
20	NTNU CGF	Svalbard	78.943	11.868	http://doi.org/10.7914/1b8m-rj75
21	Rice University	Blue Mt.	40.984	−118.150	http://doi.org/10.7914/0w0x-gj96
22	Sandia National Laboratories	FACT	34.951	−106.460	http://doi.org/10.7914/m8py-h687
23	Sandia National Laboratories	Alaska	70.511	−149.871	–
24	Silixa	Fairfield	47.613	−111.980	http://doi.org/10.7914/1hnc-1250
25	Sintela	MIS1	31.524	−101.980	–
26	Sintela	MIS2	27.830	−97.614	–
27	Stanford University	Sand Hill	37.436	−122.180	http://doi.org/10.1190/tle39090646.1
28	SUS Tech	Xinfengjiang	23.919	114.460	http://doi.org/10.7914/bqgg-xx98
29	T8 sensor	Caucasus	43.741	42.662	http://doi.org/10.7914/t8my-dk69
30	Tampnet/ASN	Lowestoft Cable	52.439	1.845	http://doi.org/10.7914/c236-ds38
31	TU Graz	Graz	47.068	15.450	http://doi.org/10.7914/8a5m-zk74
32	University of Wisconsin-Madison	SURF	44.346	−103.760	http://doi.org/10.7914/h4eb-bh32

The location of interrogators is also given (see Fig. 1). Note that the details about the installation and cable path are available in the download package of each contribution.

Grant Number 101058518). [11] are indebted to CANALINK-Canarias submarine link S.L. for allowing the use of the optical fiber and Aragón Photonics for the acquisition support. [12] thank Aragón Photonics for providing an HDAS interrogator and ADIF for allowing the use of an optical fiber. They also acknowledge Hugo F. Martins, Resurreccion Antón, and Daniel Minguez Prado for their support during the data preparation and processing. [13] are indebted to Istituto Nazionale di Astrofisica for providing their facilities for fiber cable installation at Serra La Nave Observatory. They also acknowledge Rosalba Napoli, Mario Pulvirenti, Daniele Pellegrino, and Marcello D'Agostino for their help in the fieldwork and data storage. [15] thank David Green for project support, and Stewart Poole and

Gareth Phillips for extensive field support at Eskdalemuir. Funding support from AWE/Blacknest, and NERC Grant Numbers NE/T012684/1, NE/X005496/1, and NE/S00677X/1. University of Leeds Fiber-Optic Sensing Facility loan UOL-FOF-0002. [16] thank Silixa for providing an iDAS interrogator and acknowledge support through the German Research Foundation (Grant Number LI3721/2-1), ERC-Advanced Project ROMY, UFS Schneefernerhaus GmbH and A1 Telekom Austria AG. [18] thank Yong Chen, You-Yi Ruan, Tao Wang, and Wei Liu for their support during field instrumentation and data processing. Funding support from the National Natural Science Foundation of China (Grant Number 42225702). [19] thank the Norwegian research council for partially funding the NORFOX array under Grant Number 296486. [20] thank CGF (Grant Number 309960) and the Research Council of Norway for funding the acquisition. They also thank ASN for the support during the acquisition and Sikt for accessing the fiber optic cables. [21] acknowledge Fervo Energy and particularly Aleksei Titov, Sireesh Dadi, and Jack Norbeck for generous access to the DAS fiber in Blue Mountain well 73-22. [22] full acknowledgements are provided in the SandiaNL-Coupling dataset's README.txt. [24] thank 3 Rivers Communications for their kind hospitality. [25] thank OptaSense Inc. for loaning the interrogator unit and the Stanford ITS fiber team for crucial help with the Stanford DAS-2 experiment. [28] thank all colleagues from the Geophysics team of the Department of Ocean Science and Engineering, SUSTech, particularly Zhen Guo, and Yongshun John Chen, for providing crucial support in the Xinfengjiang DAS project. [29] thank all colleagues from Sternberg Astronomical Institute, Moscow State University, for accommodating the equipment at their facility in Caucaus and providing technical assistance. [30] thank Tampnet and ASN for permission to publish the results. [31] thank the central IT Services of Graz University of Technology for providing access to the telecommunication cable. [32] thank N. Lord, D. Fratta, A. Chavarria, R. Sutyla B. Pietzyk, L. Scott, J. Tollefson, M. Hephner, T. Artz, and W. Roggenthen for DAS deployment and AFRL and University of Wisconsin-Madison for funding.

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Manuscript received 2 June 2023
Published online 27 November 2023