Inconsistent Citation of the Global Seismographic Network in Scientific Publications

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Abstract

The highly used Global Seismographic Network (GSN) is a pillar of the seismological research community and contributes to numerous groundbreaking publications. Despite its wide recognition, this survey found that the GSN is not consistently acknowledged in scientific literature and is underrepresented by roughly a factor of 3 in citation searches. Publication tracking is a key metric that factors into operational decisions and funding support for the network; thus, consistent and proper citation of the GSN is important. This study not only serves as a reminder for researchers using GSN observations to cite the network's digital object identifiers (DOIs) but also promotes a community-wide conversation among researchers, journal editors, network operators, and other stakeholders regarding more standardized policies and review processes to ensure seismic networks are properly and consistently recognized for their contributions to research.

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Introduction

The Global Seismographic Network (GSN) is a multiuse scientific facility composed of state-of-the-art permanent stations distributed around the world with broadband and very broadband sensors that provide real-time high-quality seismic data along with ancillary sensors. Observations from the GSN have driven forward geophysical research for decades. These advancements include imaging deep Earth structure (e.g., Kim *et al.*, 2020), illuminating hidden global tsunamigenic events (e.g., Jia *et al.*, 2022), characterizing changes in global anthropogenic noise related to the COVID-19 pandemic (e.g., Lecocq *et al.*, 2020), resolving microseism origins (e.g., Gualtieri *et al.*, 2020), developing innovative environmental seismology for ocean thermometry (e.g., Wu *et al.*, 2020), and detecting and discriminating nuclear explosions (e.g., Voytan *et al.*, 2019). This cross section of recent science highlights a wide range in how data from the GSN are used. These recent publications are also examples that omit formal citation of the GSN in their main article text. Authors of these studies noted encountering journal policy limitations and addressing these by including full and detailed network acknowledgments in the supplementary information and supporting materials; however, these sections are not included in the indexing process of citation databases such as Google Scholar (Google Scholar, 2020–2021). We commend the authors for their published work and their efforts in recognizing the data used, and we also call on the broader community for solutions to enable effective citation tracking.

The GSN is an enduring community resource that can be easily taken for granted, with the use of these data a turnkey process for any seismologist. The funding that supports the GSN is provided jointly by the National Science Foundation (NSF) and the U.S. Geological Survey (USGS). Two-thirds of GSN stations (network codes CU, IC, and IU) are operated by the USGS Albuquerque Seismological Laboratory, and the remaining third (network code II) are operated by the Scripps Institution of Oceanography at the University of California, San Diego, as part of the NSF's Seismological Facilities for the Advancement of Geoscience. The EarthScope Consortium

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(formerly Incorporated Research Institutions for Seismology [IRIS]) provides science program coordination and steward community governance through the GSN Standing Committee (GSNSC). Understanding how the GSN is used in research and monitoring applications can also feed into operational decisions for the network such as upgraded instrumentation, station construction or removal, and new colocated sensors. However, opportunities for better capturing the GSN's utility go beyond network refinement. Like any observational facility (e.g., telescopes, science vessels, and other community accessed infrastructure that supports fundamental science) that is supported through federal taxpayer revenue, the GSN needs continued justification of its importance and relevance to innovative research and societal benefit. In community webinars as recently as February 2022, NSF has been openly evaluating, with input from key stakeholders, the metrics that best capture the overall science impacts (Trowbridge *et al.*, 2022) and performance of its infrastructure (Palanza *et al.*, 2022). These metrics range from tracking citations, alternative metrics (altmetrics), data downloads, degrees awarded, and so forth. Furthermore, the "A vision for NSF earth sciences 2020–2030: Earth in time" report (National Academies of Sciences, Engineering, and Medicine, 2020) specifically recommended the tracking of citations as one of the primary mechanisms to evaluate infrastructure supported by its Division of Earth Sciences, EAR. A lack of consistent citation of the GSN makes citation tracking an inaccurate and unreliable metric for evaluating the facility; however, it is one of the most accepted options at present.

Tracking the use of the GSN data can be accomplished via a variety of techniques, but the two primary avenues are (1) recording mentions and formal acknowledgments of the GSN in publications and (2) tracking the amount of GSN data downloaded from the IRIS Data Management Center (IRIS DMC) archives. As of July 2022, the GSN occupies 28.2 TB or 3.7% of the archived miniSEED time-series data in the IRIS DMC. However, GSN is the dataset highest in demand, with a shipment per byte turnover of 525% in 2021 (Fig. 1), meaning that an equivalent to more than five times the total archive of the GSN was downloaded by users in 2021, a volume consistent with findings by Ringler *et al.* (2020).

Since 1996, IRIS has been curating citation lists through direct author submission and manual searches through field-specific journals. An IRIS citation database was started in 2000 in conjunction with the use of several scholarly search engines, which was further enhanced in 2014 through the categorization of publication by program and network, providing the first broad look at GSN-specific citation (see Data and Resources). To address the importance of seismic networks and seismic data providers as data have become increasingly open and discoverable, in 2014 the International Federation of Digital Seismograph Networks (FDSN) recommended the minting and consistent use of digital object identifiers (DOIs) to track the use of data in publications, reports, proposals, and other applications (International Federation of Digital Seismograph Networks [FDSN], 2014). The GSN (and IRIS) was quick to implement these recommendations, producing DOIs and encouraging their use shortly thereafter (Evans *et al.*, 2015). In practice, it was necessary to create several DOIs to be consistent with the different network codes and network operators that contribute to the global network: CU (Albuquerque Seismological Laboratory [ASL])/U.S. Geological Survey [USGS], 2006), IC (ASL/USGS, 1992), II (Scripps Institution of Oceanography [SIO], 1986), and IU (ASL/USGS, 1988) are all available under the virtual network code "_GSN" defined at the Data and Resources section. DOIs for virtual networks are not currently supported by the FDSN. Because DOIs are further implemented in the field of seismology, functional journal policies and recommendations such as the *Seismological Research Letters* data acknowledgment guidelines (see Data and Resources) and Seismica submission and formatting checklist (see Data and Resources) along with constructive interactions between authors, reviewers, and editors are necessary to encourage proper and effective use of seismic network DOIs.

The work described here has several purposes: (1) to quantify the amount and range of published studies to which the GSN contributes, (2) to track trends in GSN data usage in publications over time, (3) to quantify how reliably the GSN is formally acknowledged in publications, and (4) to raise awareness to the issue of consistent underacknowledgment of the GSN and the data it provides. This study is intended to integrate with a broader community-wide conversation. For example, an October 2022 workshop, "Geophysical Data Citation, Attribution, and Licensing" (Elliot *et al.*, 2022), discussed resolving the gaps in citations across a range of facilities, aiming to increase awareness of such inconsistencies and developing better long-term solutions. Based on these results, we have produced recommendations for achieving more consistent citation of the GSN and how to best monitor the impact of this facility in regard to the GSN's contribution to research.

Methods

The initial goal of this study was to characterize how GSN usage in peer-reviewed scientific publications has changed over time to better understand how reliably the GSN is cited, acknowledged, or even mentioned within scientific research journals and to explore how this changed with increased scrutiny. This was accomplished by conducting several rounds of citation searching, each with a deepening level of detail that included additional search parameters and required increased personnel time (Table 1). Three increasingly detailed Google Scholar searches were conducted by IRIS staff using the search terms suggested by the GSN Program Manager and GSN Standing Committee (GSNSC). Books, theses, dissertations, and conference proceedings were excluded from these searches, focusing on peer-reviewed publications in journals

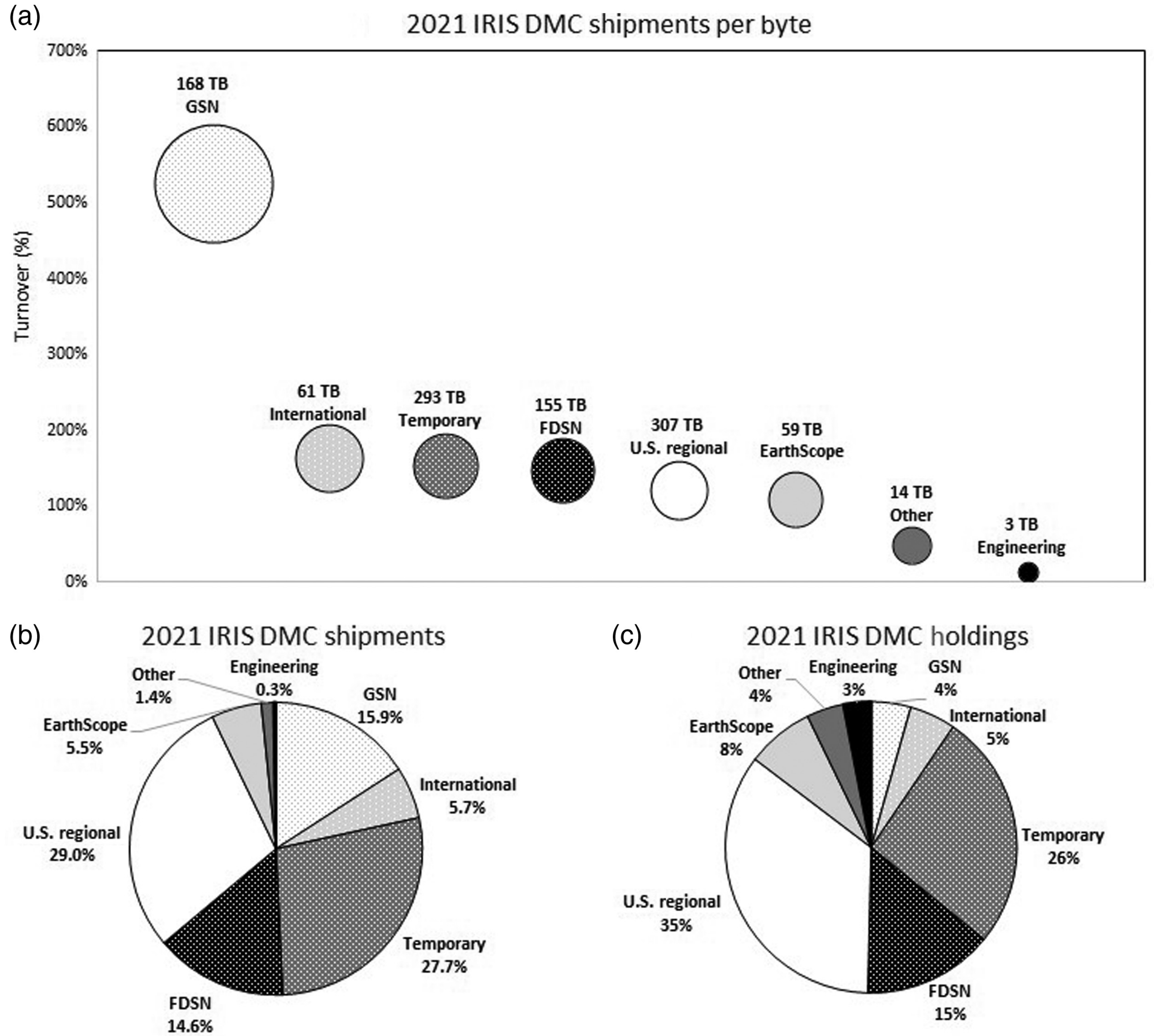

Figure 1. Incorporated Research Institutions for Seismology Data Management Center (IRIS DMC) data shipments (downloads) compared with data holdings (bytes) for 2021. (a) Turnover for different network data classifications, which represent the amount of data that are shipped relative to total data holdings. (b) Total shipped data by network data type. (c) Data holdings by network type. Updated and modified from Ringler *et al.* (2020).

with an impact factor > 1.5 with stated attribution policies. Because the search engine often returned many unrelated or unintended results, all publications were individually examined, and only those with direct acknowledgment or usage of the GSN were included in the citation counts.

A fourth and final round of searching was conducted by the GSNSC that consisted of scientific and technical experts who provide community input and oversight to the operation of the GSN. The GSNSC members have expertise in geophysics and seismology and detailed familiarity with the GSN and the research applications of its data. With this background, committee members were positioned to easily parse articles to discern whether GSN data were actually used in a particular study. This step provides an expert-level review of a journal's holdings. Each member was assigned and reviewed one or more journals from a selection of 11 Earth science publications that met the criteria described earlier. The members fully read each issue, including supplemental materials, from 1 January 2019 to 30 April 2019, to determine which publications used GSN data, and if so, tracking if the data were used directly (waveforms) or indirectly (e.g., models, other catalogs) and if the GSN was cited or referenced and, if so, in what manner (by name, network codes, DOIs, and so on). This level of tracking

TABLE 1
Four Rounds of Citation Searches with Corresponding Search Terms and the Estimated Time Required to Carry Out Each Level of Detail

Total Time Required	Search Terms
~8–12 hr	Round 1: Google Scholar search • Seismic network code "II" • Seismic network code "IU" • International Deployment of Accelerometers (IDA) • GSN (combined with IRIS and USGS) • Global Seismographic (and alternative spellings: seismic, seismologic, and seismograph) network • Station codes for the top 20 most downloaded station data
~16–28 hr	Round 2: Google Scholar search All terms from round 1 as well as the following terms: • Global seismic • Global CMT • Seismic network code "IC" • Seismic network code "CU"
~40 hr	Round 3: Google Scholar search All terms from rounds 1 and 2 as well as the following terms: • GlobalCMT.org • Digital object identifiers (DOIs) for seismic network codes • 10.7914/SN/II • 10.7914/SN/IU • 10.7914/SN/IC • 10.7914/SN/CU
~201 hr*	Round 4: GSNSC search In-depth review and reading of all publications within 11 prominent Earth science journals for the first third of 2019. Search conducted by the GSN Standing Committee members with advanced degrees and expertise with GSN data and usage.†

*Calculated by time spent by six Global Seismographic Network Standing Committee (GSNSC) members extrapolated for the full year.

†Eleven Earth science journals reviewed by the GSNSC: *Bulletin of the Seismological Society of America (BSSA)*; *Journal of Geophysical Research (JGR)*; *Geophysical Journal International (GJI)*; *Seismological Research Letters (SRL)*; *Geophysical Research Letters (GRL)*; *Earth and Planetary Science Letters (EPSL)*; *Physics of the Earth and Planetary Interiors (PEPI)*; *Tectonophysics (TP)*; and *Nature, Science, and Geology*. Global CMT, Global Centroid Moment Tensor; GSN, Global Seismographic Network; IRIS, Incorporated Research Institutions for Seismology; and USGS, U.S. Geological Survey.

was implemented to help determine if there was a correlation between type of data usage and acknowledgment.

Results and Discussion

To track trends in GSN usage in published studies, the initial low-level search was performed for six complete years from 2015 to 2020. By comparing the citation counts from this round 1 search over the six years, GSN usage has been relatively consistent over this timeframe, resulting in ~100 cited publications per year (Fig. 2). As a long-time facility operator, IRIS has regularly conducted first-order citation searches and tracked network and project data shipments from the DMC archive to satisfy NSF reporting requirements. This experience informed our initial assessment that the number of GSN-specific citations was misaligned with IRIS DMC data holdings and shipments for GSN data. We focused the subsequent and more detailed citation searches to years 2019 and 2020 because of the increased time commitment needed for these. As expected, the addition of new search parameters in these additional rounds corresponded with an increase in the total number of relevant citations found per year, with ~1.6 times more citations found for the round 2 search, ~2.4 times for the round 3 search, and ~3.2 times for the in-depth round 4 search performed by the GSNSC (when extrapolated for a full year).

It is worth noting that even the most high-level citation searches, like the full journal reviews performed by the GSNSC, may still not fully capture all the GSN-related citations. This can be seen by directly comparing the most time intensive search engine counts (round 3) with the GSNSC search counts (round 4), with ~18% of citations missed by the GSNSC. Although a direct comparison of the search engine with the GSNSC search may have discrepancies because of differences in journal publication dates versus when articles were first available online, the results indicate that at least a small percentage of GSN-related publications can be missed even with the most thorough of search processes. It is also important to recognize that GSN data are used in an array of research fields that are outside the traditional Earth sciences. These fields include remote sensing, geochemistry, and glaciology, with ~15%–20% of search engine citation counts found in publications outside the 11 Earth science journals examined in this exercise. Thus, the total number of publications using GSN data is likely higher than the ~300 citations per year found in this study.

To fully understand the extent to which GSN data are used independent of search parameters, the GSNSC's journal review tracked if and how the GSN was referenced and if the data were directly or indirectly used. We found ~100 journal articles published from January to April 2019 that relied on GSN data, but only ~25% of them explicitly recognized the GSN in some fashion, such as by directly mentioning the GSN or its network codes by name or by including the DOIs (Fig. 3). Thus, many

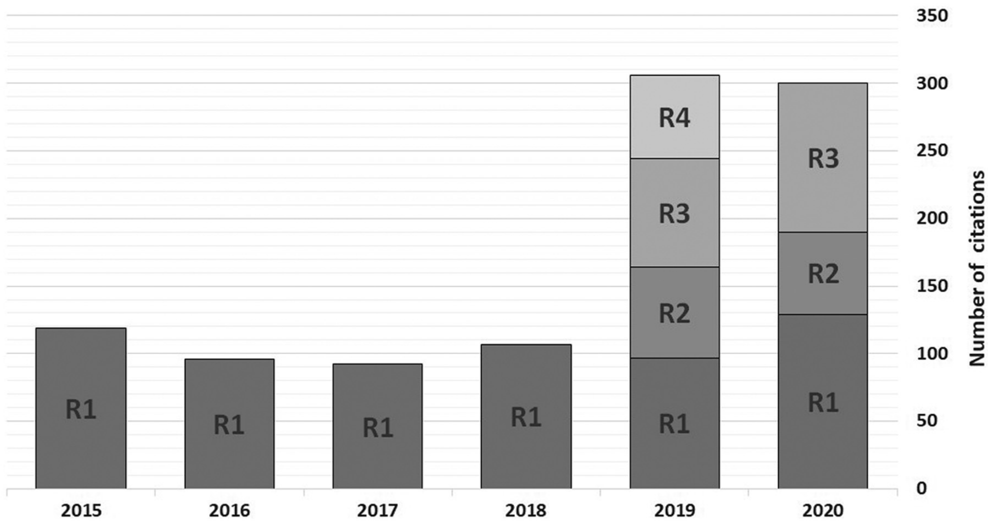

Figure 2. Results from four rounds of citation searches, with rounds 1–3 (R1–R3) conducted using a search engine and round 4 (R4) with the Global Seismographic Network Standing Committee (GSNSC) reviewing all publications in 11 prominent Earth science journals for the period January–April 2019 and extrapolating their four-month count to a full year.

publications that use GSN data and data products cannot be identified using a more general search (e.g., Google Scholar). Furthermore, references to GSN stations or network codes are often embedded within figures or supplementary materials, which creates an additional obstacle for most search engines, scholarly or other.

One of the reasons the GSN may not be reliably or consistently referenced is that its data feed numerous research products and contribute to earthquake catalogs, and some researchers may be unaware of this fact. The search by the GSNSC specifically canvassed and categorized if GSN data were directly used via waveforms or indirectly via the Global Centroid Moment Tensor (Global CMT; Ekström *et al.*, 2012) and the Advanced National Seismic System (ANSS) Comprehensive Catalog produced by USGS National Earthquake Information Center and regional seismic networks (USGS, 2017), finite-fault models, and global tomographic models. This search found that indirect usage of GSN data accounts for ~60% of the articles that used the GSN, with the major contributing data products being the Global CMT and other earthquake catalogs, which themselves had a major overlap (Fig. 4). In the cases in which the GSN is used indirectly, it is almost never referenced or acknowledged.

Conclusion and Recommendations

GSN data are being used widely in scientific research (Ringler *et al.*, 2022). Highlighted examples from a range of recent applications include continent-scale tomography (e.g., Ciardelli *et al.*, 2021), lithospheric radial anisotropy (e.g., Maupin *et al.*, 2022), structure illuminated via earthquake relocations (e.g., Aziz Zanjani and Lin, 2022), analysis of global volcanic eruptions (e.g., Poli and Shapiro, 2022) and their excitation of Earth's normal modes (e.g., Ringler *et al.*, 2023), characterization of great earthquakes with seismic waves (e.g., Jiang and Song, 2022; Metz *et al.*, 2022) or with prompt gravitational signals (e.g., Vallée *et al.*, 2017; Zhang *et al.*, 2020), and investigation of atypical tsunami generation mechanisms (e.g., Sandanbata *et al.*, 2022). Although these example studies do properly acknowledge the GSN, the overall results of our exercise show that there is significant room for improvement to have science journals reliably cite use of the GSN in a manner that can be easily tracked. In addition, the GSN's contribution to data products such as the Global CMT catalog, the USGS ANSS Comprehensive Catalog, and global Earth models is significant and yet rarely acknowledged. Combining a consistent acknowledgment of GSN data usage with better awareness of data products supported by GSN data would allow the scientific reach and, by proxy, the impact of the GSN to be more accurately and objectively captured. In doing so, more complete information would be available to help inform the continued operation and research contributions of the GSN.

Solutions are already available to encourage these outcomes. The authors of research studies using observations from the GSN and other seismic networks in general can cite all applicable network DOIs. Networks should also ensure that they have a DOI registered with the FDSN. If a journal's print version length limit does not allow citing the full network DOIs, a complete list of network citations could be appended in the electronic version of the text. This is different from including a list of stations or network codes, which is often done by authors but does not allow for online search indexing. Incorporating these options into standard operating procedures at journals requires both technical support as well as cultural support, the latter developed through top-down approaches such as editorial communications and guidance to authors and reviewers as well as bottom–up approaches such as fostering an increased professional understanding and responsibility for data acknowledgment. If these practices become uniformly adopted, then tracking the use of the GSN through clear acknowledgment and citation of network

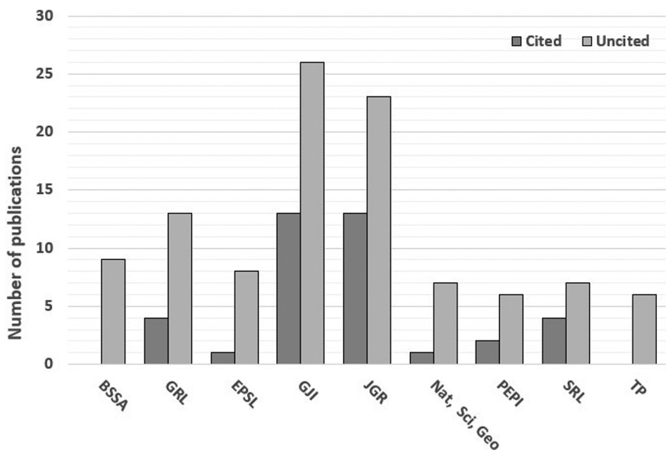

Figure 3. Results of cited (dark gray) versus uncited (light gray) use of the Global Seismographic Network (GSN) in publications from January to April 2019. See Table 1 for journal abbreviations.

DOIs via common search engines would become a straightforward process. In turn, this would allow interested groups to capture the depth and breadth of how data from the GSN are used along with trends in their usage through time. Without these markers, the tracking of publications becomes time consuming and resource intensive; even careful processes rarely yield definitive results and require a high level of subject-matter expertise. In this study, we have demonstrated that a simple literature search underestimates the total publications using GSN data by a factor of at least one-third. Using a multiplier of 3 to estimate the true use of the GSN going forward would allow for time and resources to be directed to other avenues of measuring and assessing this important global facility through science highlights and increased media engagement.

Increasing community-wide awareness and outreach on the citation and acknowledgment of the GSN and other networks would be helpful. By engaging with community members, journal editors, and other seismic network operators, we can inform standard policies, establish review processes, and work toward more consistent citing of the GSN. This new awareness can be used to capture citations of major derivative products of the GSN (e.g., Global CMT). This is a concern common to many large science facilities that may require cross-division best practices and interdisciplinary solutions. Continued engagement between researchers, operators, and funding agencies such as the NSF and USGS would be useful in identifying which metrics are most helpful for assessing the research contribution of the GSN and would keeping an eye on publications to understand how data are being used to make informed network operation decisions to support cutting-edge research.

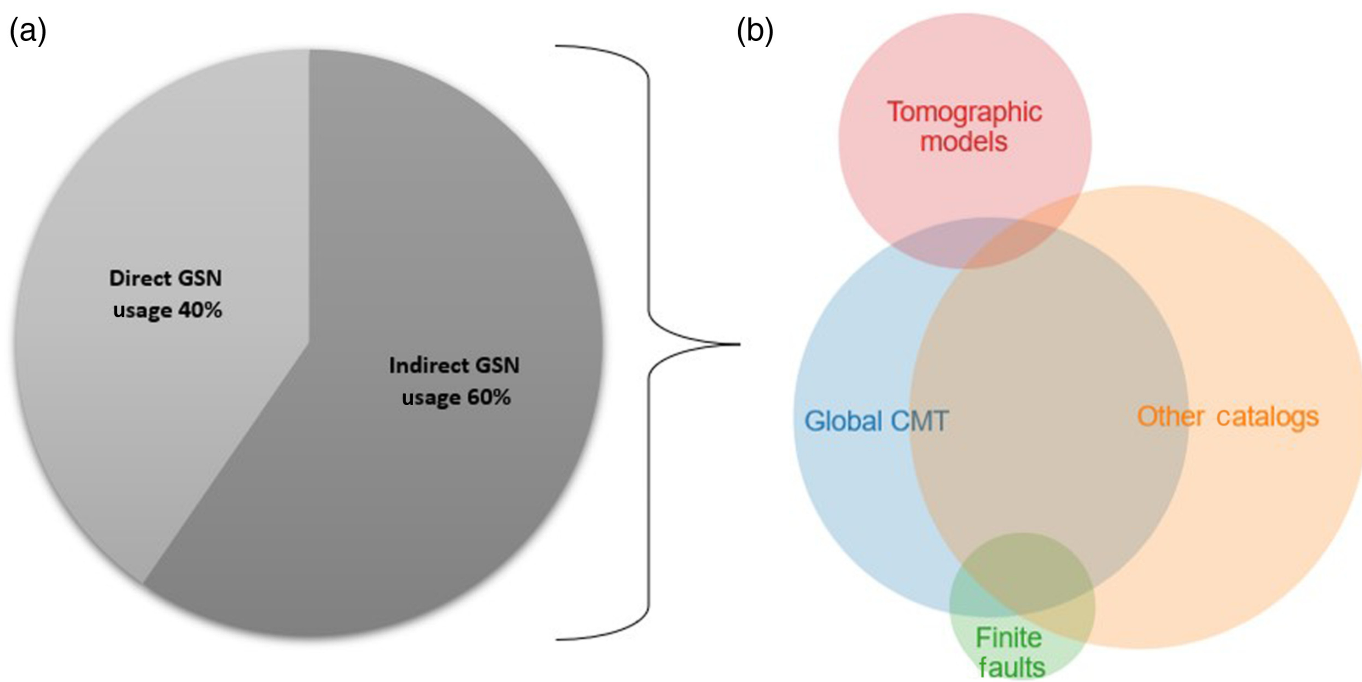

Figure 4. Analysis of the publications identified by the GSNSC as having used GSN data. (a) Fraction of GSN data used directly (i.e., via waveforms) versus indirectly (i.e., via data products). (b) Overlapping circles convey the indirect usage of the GSN via data products, with circle size showing the relative number of publications and degree of overlap showing publications that used more than one data product. The color version of this figure is available only in the electronic edition.

Data and Resources

Data discussed in this article were collected as part of the Global Seismographic Network, which is supported jointly by the National Science Foundation and the U.S. Geological Survey. Data from stations are archived at the Incorporated Research Institutions for Seismology Data Management Center under network code CU (Albuquerque Seismological Laboratory [ASL]/USGS, 2006, available at doi: 10.7914/SN/CU), IC (ASL/USGS, 1992, available at doi: 10.7914/SN/IC), II (Scripps Institution of Oceanography [SIO], 1986, available at doi: 10.7914/SN/II), and IU (ASL/USGS, 1988, available at doi: 10.7914/SN/IU), all available under the virtual network code "_GSN" available at https://ds.iris.edu/mda/_GSN. Data are also made freely available through the International Federation of Digital Seismograph Networks request tools. The other relevant data to this article were available at https://www.iris.edu/hq/iris_citations, https://www.seismosoc.org/publications/srl-authorsinfo, and https://seismica.library.mcgill.ca/author-guidelines. All websites were last accessed in December 2022.

Declaration of Competing Interests

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

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