Dear Editor and reviewers

We thank you for the positive and constructive reviews and editor recommendations. In particular we are happy that the reviewers find the manuscript interesting and useful, that was indeed our objective.

Below you will find a point-by-point response to your comments and the reviews.

Changes in the MS related to the points raised in the reviews will be indicated by blue text. We have also re-checked for grammatical errors, typos etc.; we have not tracked these changes in the MS.

Finally, we have corrected 3 references. Thanks to the editor for spotting the mistakes during the acceptance process.

Best regards

Helle Pedersen, for the authors

Editor comments

I'm curious if there was any conversation about the use of other identifiers apart from DOIs (like ROR or RRID) as a way to untangle the hierarchy of data centers and networks and stations from the data itself. The FDSN recommends that contributors to the dataset are indicated in the DataCite metadata of the network DOI. But also since December 2023 the new version of the approved FDSN Recommendations indicate that contributing organisations and persons should be identified through their ROR, or ORCIDs.

The MS has been changed by adding the text in bold (section 2.2, line 128):
For example, https://api.datacite.org/dois/10.15778/RESIF.FR provides institutional information about the organizations contributing to the network data as 'DataManager', 'DataDistributor', 'HostingInstitution', he 'DataCurator', 'DataCollector' and'Sponsor'. **FDSN recommends since December 2023 that contributors should be identified by means of persistent identifiers, such as, for example, ROR (Research Organization registry, https://ror.org/), or ORCID (Open Researcher and Contributor ID, https://orcid.org/).**

The FDSN recommends that only the network has an identifier. It is not known to the FDSN that any organisations have created identifiers at station level. In the example you mention, SN stands for 'seismic networks', which has the advantage that this specific string can be searched for DOIS with the 10.7914 prefix. Even this identifiable string (SN) has recently been dropped for DOIs minted by the FDSN.

The MS has been clarified by adding the text in bold (section 2.2, line 150)

By default, anyone who requests an FDSN network code also obtains a DOI from the EarthScope minting service. **At present, the FDSN recommends DOIs for network level only, so organisations who wish to have DOIs or other persistent identifiers at finer granularity, such as station level, need to manage those DOIs independently of the FDSN.**

Sadly we couldn't do this as our tests showed that Scopus, WOS, etc. all yielded very incomplete and inconsistent results. We also interacted with crosscite in this process. There is basically no present solution to the question: 'given a list of N DOIs, provide a reliable citation report'. This is why we chose to use two sources (GJI and AGU) as illustrative examples, to avoid reporting unreliable data. We do not wish to appear aggressive in our discussion on publications, but rather to help collectively move forwards, together with the publishers, which is why we did not state this issue as bluntly in the MS. We acknowledge that this could lead to lack of clarity.

To clarify, we added a new paragraph to Section 5.2 line 465 (new parts in bold)

In the course of this work the authors started by comparing citations through different tools (Scopus, Wos, cross-cite, google scholar) across all FDSN minted DOIs (text string 10.7914/SN, covering 77% of FDSN network DOIs). The outcome was in all cases largely incomplete and incoherent between the different methods. We concluded that there is presently no way of reliably obtaining a comprehensive citation report for a large set of DOIs across peer-reviewed scientific journals. **We therefore focus this section on some illustrative examples.**

From experience, the issue of licence is a tricky one, as also indicated in the manuscript (line 345 in revised MS). Among the people who understand licences, CC-BY (or CC0, depending on country or institutional policies) is indeed a given, but a lot of explanation and knowledge sharing is still required. However, the authors believe that the community is ready for a recommendation on licence policy. We suggest the

elaboration of such a license recommendation (Table 4) and also note (line 371 in revised MS): *FDSN is expected to recommend CC BY or CC0 (a 'public domain declaration', https://creativecommons.org/public-domain/cc0/) as standards for seismic networks.*

We believe that indeed such a community recommendation will improve the uptake of applying licenses in future, similar to what happened with the DOIs, understanding that licensing will also depend on individual countries legislation.

We added, this issue in the abstract, line 33 (new part in bold)

This work highlights best practices and provides a set of recommendations for improving attribution, citation, and FAIRness of seismological waveform data, **the latter including that FDSN should recommend licence on waveform data and a limited set of recommended licences.**

And at the end of Section 3, line 368:

The experience in Europe has helped the seismological community gaining knowledge about licences, and, **despite the difficulties mentioned above, the need to consistently apply licenses is widely acknowledged in the community.** Over the past years, the…

I agree with Reviewer A in the utility of Table 4. I might suggest adding a recommendation regarding the standardization of "data availability statements" in articles, perhaps after "ensure that network citations are included in the reference section" as "ensure that networks are cited in Data Availability Statements" as applied to FDSN, journals, scientists or as appropriate.

We added that line, thank you.

Reviewer B notes that a global map of networks and stations contributing to FDSN would be useful. Please consider adding, or linking to a current map.

Thanks for the suggestion.

The new figure has been added (new Fig. 1) at the end of Section 2.1

Reviewer B also notes the limitations some journals place on the number of references (Section 5.1). This is a growing problem for data and software citation in general apart from seismic networks. What is your preferred solution?

While we have no preferred solution and believe that likely there is no one best option, we are aware of and partially participate in ongoing discussions, e.g., the Complex Citations Working Group of RDA, or direct discussions with journals. A key requirement for any solution is that they must allow 'finding' and reporting on the referenced data sets independent of where the dataset reference actually is.

The MS was modified by:

Adding in the abstract, line 29:

Of specific concern is the limitation on references set by some journals, which renders proper attribution impossible for studies using data from many seismic networks.

Adding the paragraph below at the end of Section 5.2, line 495:

One issue that is currently unresolved is the limit on the number of references currently imposed by some journals. This means that it may not be possible for some studies to cite all contributing datasets, for example when they are built on large and specific selections of data over space and time. Listing the references in Supplementary material or in Data Sections only is not an adequate solution presently, as the citations can not be found, and are not referenced in the citation services. While there is no obvious solution available yet, not citing the data is certainly not the solution. Relevant discussions are currently under way in various initiatives (e.g. RDA Complex Citations Working Group), and a number of alternative ways to address this issue may emerge.

Adding the following text within in the last paragraph of the Conclusions, line 631:

We argue that there should be no limitations on the number of data citations in any scientific journal. Additionally, there are ongoing initiatives to develop tools for two (or multiple) layer referencing, such as the RDA (Research Data Alliance) Complex Citation group (see recommendation by Agarwal et al., 2025). One key requirement to any solution is that they must allow finding and reporting on all referenced datasets, independent of where the dataset reference actually is. Other needs might arise in the future, for example citation of specific equipment and instruments, and other hierarchical discoverability and access needs.

Reviewer A - Tim Ahern

Overview of this Review:
Having been involved in this beginning of the DOI effort 10 years ago it is interesting to see the information in this paper. The adoption of DataCite Digital Object Identifiers (DOIs) has been quite high in the last decade, Having been adopted as a best practice by the FDSN ten years ago, and by having a method in place that makes it easy for network operators to have a DOI minted for both networks operating before 2014 as well as for new networks at the time networks request an FDSN network code (generally required in the seismological community) has been very effective. With 73% of networks having adopted DOIs is excellent, but I am surprised it is not even higher. I do believe that Scientific Journals must be encouraged to require the use of FDSN DOIs when authors are submitting articles and help the FDSN DOIs be even a higher percentage of networks. It is hard to police the use of FDSN DOIs unless the journals start requiring them.

Tim Ahern is perfectly correct on all points. A short comment on the 73%: there are two causes. First, the data centers or FDSN do not, generally, have the right to add a DOI to a network without the agreement of the data producer. This can be exceptionally cumbersome for old networks, in particularly temporary experiments where the project PI may no longer be reachable. It does however lead to an issue we need to think about in the FDSN: Once a temporary experiment data are uploaded to the datacenter, should the datacenter ask for extended rights to manage the DOI, licence, DOI metadata etc. after some period, for example 10 years? The second cause of lacking DOIs is for new networks, where, if FDSN (Earthscope= is not the DOI minter, that there can be a delay between network code creation and the minting of the DOI.

We clarified the text by adding, in section 3.2, line 300, the following text:

There are two main reasons for missing DOIs. The first one is that it is difficult to reach all former temporary network operators or PIs (some of them no longer active) to obtain permission for minting the DOI and to obtain relevant project information to provide relevant DataCite metadata. This raises the question of how to organise datacenter rights to avoid difficulties in the future, such as the update of DataCite metadata for an experiment with an unreachable or non-responsive PI. Second, new experiments that do not rely on FDSN (Earthscope) minted DOIs, may have a lag time after network code creation before minting a DOI, for example waiting until actual project start before creating a permanent identifier.

DOIs are of direct benefit to seismic network operators since they receive credit for the data used from their network when used. This information helps inform funding agencies how important the operation of a particular network is. It was also interesting to see that Data Licenses have not really had similar uptake by the community. Of course, as the authors mention, this has not yet been undertaken seriously by the FDSN but rather was more an initiative in Europe. This does point out that it would be important to have the FDSN embrace the use of licensing, perhaps as an FDSN best practice, as an initiative of the FDSN in the future.

We agree, see our comment to the licensing issue above (AE) and associated text changes.

The concept of Federation is an important one. I personally find it confuses the issue to have a separate European Federation embedded within the much larger worldwide FDSN federated system. I know some of the history of this but I think it would be a benefit to get rid of the need to have a Federation within a Federation. I would encourage the European EIDA to consider moving beyond this somewhat cumbersome construct. Perhaps the authors could identify the reason for having these tiers of federation. I know history and politics most likely play a role.

These are very interesting discussion points but somewhat out of scope of the MS, as the MS works with the present organisational framework. We do acknowledge that the wording was confusing, so we replaced *federation of* European data centers by *collaboration between* European data centers. This also better reflects present reality, where the datacenters of very different sizes in Europe collaborate to, together, make European data distribution more robust. As compared to past times, EIDA and the datacenters of this cooperation presently fully engage in the FDSN strategy, can provide direct technical help, and can support cooperation between datacenters that would, in some cases, be too small to be able to follow evolutions in tools and software. In the context of the MS, we had the advantage of being able to compare 'similar-ish' size systems (Earthscope and EIDA) in terms of strategy for DOIs and publications.

Changes to the text (Section 2.5, line 214)
federation of European data centers replaced by **collaboration between European data centers.**
(see also comment to lines 225-226 below)

Specific Details for the Authors to address.

Line 23: It says 73% of seismic networks have adopted DOIs, it might be better to say that 73% of seismic networks that have an assigned FDSN network code have adopted FDSN DOIs. Many networks around the world are not part of the FDSN and use 2 character network codes that are not FDSN network codes,
Thanks, done. (line 24)

Line 42: The sentence seems to have lost the end. To promote user-defined what???
Corrected (**to promote proper citation of seismic network data**) (line 47)

Line 50-54 The note should be moved to a footnote. It disrupts the thread of discussion and really is of secondary importance.
Thanks, done (bottom page 2)

Line 86 Suggest changing FDSN Metadata to FDSN metadata
Thanks, done (without tracked change)

Line 92-93 Include a URL for FDSN Web Services
As this link is given above in (presently line 77, and further detail is given in section 2.3, we suggest not to add the link also in this paragraph.

Line 141 Suggest has a DOI minting service instead of has a minting service
Thanks, done (line 147)

Line 204-212 The existence of the EIDA sub-federation seems to make the federation of data centers overly complex at least it reads that way. The Federation should be at a different level,that of all FDSN networks.
Line 225-226 Again the confusion caused by the European approach as opposed to the FDSN approach adds to some incoherency to a casual reader. Again I think this contributes little to the article and exposes just political or historical issues. If the routing tables are identical, why is there a need for two of them?
The EIDA routing was set up several years before the FDSN routing ('data center registry') so that users of European data could address their requests to a 'virtual European datacenter' that has a a 'comparable' size to the Earthscope seismological datacenter, rather than locating and requesting data from (then) approximately 10 datacenters. Exporting this routing to FDSN was (and remains) the most cost-efficient way to keep the FDSN routing tables up to date, because the EIDA engineers collectively test and oversee the completeness and correctness of the EIDA routing. We would not have needed to add this technicality in the MS except that, at the time of writing, the FDSN datacenter registry was relatively new, so the synchronization with EIDA had issues, largely identified through the analysis. Also, some networks had routing conflicts with other networks in the FDSN datacenter registry, issues of start and end dates of the networks etc. Many of these errors would have appeared also if each datacenter had directly informed the FDSN datacenter registry. EIDA overseeing the corrective process sped up the solution process

tremendously. The complexity was left in the MS because we report what we actually did at the time of analysis. While almost all the problems are presently solved, we can not from a traceability point of view recast the analysis onto present-day functioning of the system, also because the software, openly available, reflects the algorithm that we used. The upside of the analysis is the ease of identifying EIDA node hosted networks, opening up for easy comparison between the Earthscope and European situation.

To clarify, we modified the sentence in the end of section 2, line 233, from
Note that for this study we used the EIDA routing tables rather than FDSN data center registry in step but as of the date of writing, EIDA routing and FDSN data center registry are coherent.
to
Note that in the analysis for this study we used the EIDA routing tables for European data centers rather than the FDSN data center registry in the 2nd bullet of step 2, as we realized at that time that the relatively new FDSN data center registry still had some issues. At the time of writing, these issues are fixed, and EIDA routing and FDSN data center registry are coherent.

Line 295-296 Wonderful statement of success.

Line 324: Only 8% of networks having a data license is unfortunate. I know this initiative is less mature than the DOI initiative and it would require each network to decide to identify a license. It will be difficult, but the FDSN should make a strong recommendation to use a Data License. It would optimal if there is a default license used by the FDSN and for the FDSN to encourage use of this.
We agree, see our comment to the licensing issue above (AE) and associated text changes.

Figure 3. This seems to be an underwhelming result. It would be useful to add verbiage identifying why such a small number of citations were found. Have journal editors been contacted to try to improve the inclusion of appropriate DOIs used by authors. Have reviewers been told to pay attention to this in data citations?
Lines 465-466. To me it seems the number of citations is quite low and yet the authors seem satisfied with this.
Yes, this has been a continuous effort for now 10 years. Underwhelming is indeed the word. Amazingly, publisher software does not even pick up on a lacking reference in the reference list for a DOI indicated in the Data availability section, acknowledgements or elsewhere in the main body of the MS. We continue to contact journals, editors, associate editors, but this is incredibly painstaking and inefficient, because staff, editors and reviewers are, generally speaking, pretty unaware of this. We have since 2017 been interacting with publishers (with biggest efforts on GJI, AGU and SSA journals, including interacting with scientific editors) and continue to promote citation practices at conferences, articles etc. Once the article is published, we need to make publicity for it and share it. We don't see any easy nor fast pathway towards better results, sadly.

Our formulations were indeed too positive (perhaps trying to keep our spirits up). We modified one sentence referring to Figure 4 (previous Figure 3), and the sentence that the reviewer refers to (new in bold):

(line 470) Figure 4 illustrates that network citations, **whilst much lower than reality of network data usage,** have been increasing since 2015

(line 493) In spite of these various difficulties **and overall low citation numbers,** it is clear that citations are increasing both in quantity and in quality, demonstrating the, **at least partial,** success of the FDSN DOI recommendation for better data citation.

As we state in the text, these community standards support accessibility and interoperability within the (seismological) community. They do, however, not (fully) meet the requirements for (community-independent, multi-disciplinary) machine-actionability, which is one of the key distinctions of the FAIR principles. By machine-actionable, we follow the definition from Wilkinson et al : *Throughout this paper, we use the phrase 'machine actionable' to indicate a continuum of possible states wherein a digital object provides increasingly more detailed information to an autonomously-acting, computational data explorer.* The Wilkinson et al. abstract specifically states: *Distinct from peer initiatives that focus on the human scholar, the FAIR Principles put specific emphasis on enhancing the ability of machines to automatically find and use the data, in addition to supporting its reuse by individuals.* Unlike emerging JSON-LD standards, StationXML contains mostly in-situ fixed content with few external references for a machine to expound further on sources and methods for that content.
We clarified in that paragraph, line 554 (new text in bold):

One core aspect of FAIR, machine-actionability **(see definition by Wilkinson et al., 2016)**, was arguably not given too much conscious thought in those early discussions, likely due to the already well-established data and metadata standards for seismological waveform data that allowed easy Accessibility to and seamless Interoperability of data(sets) within the seismology community globally. **The StationXML metadata are however not machine-actionable in a formal FAIR framework as it contains mostly in-situ fixed content with few external references for a machine to expound further on sources and methods for that content.** Overall, the current seismology community standards and practices well support Findability (data center registry, routing service, sta tionXML metadata providing among others location and timeframe) and Reusability (licence, even though uptake across the community is challenging, and there is yet no community-endorsed recommendation or standard).

Excellent idea, thanks. We took the suggestion further, adding examples and references also from New Zealand and Australia. The CARE sub-section has therefore been significantly extended. **Please see revised MS, Section 6.3 (line 568).** Note that we have not added CARE considerations to the recommendations table, in spite of a longer section on this issue. Having discussions of these issues in international organisations without taking, a priori, steps to include representatives for Indigenous populations in the discussion from the outset may have a negative effect.

Line 552 and Table 4. Very useful.
Thanks

Line 569 Officially the FDSN is not an IASPEI commission. It is said to have the status of a commission. Authors should check with IASPEI for correct naming convention.
FDSN hold commission status within the IASPEI , and it says : "The FDSN also holds commission status within IASPEI (http://iaspei.org/commissions/international-federation-of-digital-seismograph-networks) We added the text in bold in the sentence, line 636.
To address the remaining challenges, the seismological community benefits from an established community governance structure with global reach, FDSN, and other organisations which are commissions of **or hold commission status** in the International Association of Seismology and Physics of the Earth's Interior

Line 601 I believe California Earthquake Data Center should be Northern California Earthquake Data Center
Thanks, corrected.

Reviewer B - Barbara Romanowicz

This paper provides valuable information on the current state of citation and attribution of data from digital broadband networks that participate in the FDSN (Federation of Digital Seismic Networks), an organization founded in 1985 with the initial goals of standardizing instrumentation, and data formats, and developing a system of interconnected data archives for the open distribution of seismological digital broadband data. Over the last decades, capitalizing on the pioneering vision of the founders, it has much grown and evolved with technology and practices. Somewhere along the way, FAIR principles were introduced as a general concept independently. While FDSN was by and large adhering to these principles already, but loosely and informally, an effort was started ten years ago to make the FDSN compliant with the official FAIR principles, and an important step was the adoption of DOIs. The paper is important in that it also provides clear recommendations for users on how to properly cite the data they use. One aspect which is under-emphasized is the tremendous work that went into this analysis and the issues that were found along the way, and many of them fixed or in the process of being addressed. In my opinion, the latter aspect of the study deserves a sentence in the abstract as well as in the conclusions.

Indeed it was a rather big job, and helped us to fix and improve a number of technical issues.

We added the following sentence at the end of the abstract, line 36:

An added value of the assessment was that many minor errors and inconsistencies were identified and fixed at FDSN and in the seismological metadata.

And in the first paragraph of the conclusions, line 608 (new text in bold):

The FDSN implementation of Datacite DOIs has overall been very successful and is supported by FDSN, data centers, and network operators. **A positive effect of the present work was identifying and fixing a number of errors and inconsistencies that had accumulated over the past decades.** Maintaining high quality and coherence between seismological metadata, DataCite metadata and all aspects of FAIR needs continuous effort, and we do not at this stage believe that high quality and coherency is possible with a finer granularity level of DOIs.

I find the paper well written and largely complete. My following comments are meant to be minor Suggestions.

My only general comment is that in my opinion, it would be useful to show a global map of all the networks and stations contributing to FDSN, say, during the year 2024 – such a map can easily be generated from data available at fdsn.org. The reason I think this would be useful is that it would showcase the achievements of the FDSN in providing open, standardized data from all over the world and would point to the glaring issue of lack of availability of data from certain specific countries. I know this may sound political, but I also think it is important to emphasize the tremendous efforts that benefit researchers in these countries, but are not Reciprocated.

Thanks for the suggestion, done (new figure 1)

Abstract: first sentence: it is now almost 4 decades since the FDSN was founded (1986) – rather than "more than 3 decades".

Thanks, done. Also corrected in the Introduction

Introduction:

As one of the main founders of FDSN still alive, I find that giving the link to fdsn.org for historical references is a bit cavalier. I discovered in doing so that what is available at the FDSN website is rather incomplete. The scan of the Romanowicz (1990) report posted on the website is incomplete. The EOS paper describing the founding of the FDSN is not posted: Romanowicz and Dziewonski (1986, EOS, https://doi.org/10.1029/EO067i025p00541). This has motivated me to contact the FDSN and ask them to correct this! This is the paper that should be cited here. The Dziewonski (1990) is really only a short summary piece that of course can be cited in addition**.**

Excellent, thanks for the reference – we are very sorry to have missed it - and for the action with the FDSN. The reference has been added in two sentences of the first paragraph of the introduction (lines 41 and 42).

Reference to SAGE: The text reads "the seismological services that were often referred to as "IRISDMC" were developed under a major NSF facility awarded to operate SAGE". This seems quite incorrect?: the IRIS DMC preceded SAGE by a few decades and was during those decades funded by NSF. IRIS became SAGE only recently in an effort to combine seismological and geodetic facilities supported by NSF.

Thank you for noticing this mistake. It has been changed to

The seismological services that were often referred to as 'IRISDMC' were developed with funding from the NSF to the Incorporated Research Institutions for Seismology (IRIS). After 2018 the NSF funded IRIS to operate the Seismological Facility for the Advancement of Geoscience …

Following the suggestion by Tim Ahern, this sentence is now a footnote (p2)

Section 2.3, first paragraph:

Here again websites are used as citations. I recommend adding references to actual published papers/reports that describe these formats, in particular because… they might have DOI's.

This is unfortunately not possible at the present stage. The formats are evolving and are kept up to date on those websites. That said, the need for versioning, persistent identifiers and continuous access to old versions has been identified as useful - another positive impact of the MS - so hopefully this will be fixed in the near future.

We did not change the text for this point.

Section 4.1:

Point 1 (line 366). Question: does this mean the FDSN-minted DOI for a seismic network can be different from that minted by a national/local organization?

Indeed. The networks ends up having two DOIs, one minted at the FDSN and one by the national organisation. One of them (typically the FDSN minted DOI) then needs to be dereferenced, and the correct one added at FDSN.

To clarify, we added the sentences in bold for that bullet point in section 4.1, line 389

Approximately half of DOI inconsistencies happen at the moment of request of a network code, where by default FDSN mints the DOI. Researchers can inadvertently request an FDSN-minted DOI for a seismic network even if a DOI already exists or will be minted by a national or local organization. **In this case, the FDSN minted DOI then needs to be dereferenced and the network information at the FDSN updated with the correct DOI. The inconsistency is likely to not be detected by the person requesting the network code, so inconsistencies may endure until either the data center or network operator discovers the problem.** This is a small downside to FDSN creating a DOI by default, and this effect is amply counterbalanced by the high DOI coverage in the FDSN as a whole.

Point 2 (line 370). Perhaps a suggestion to request the individual who types in the DOI to type it in twice (as done frequently for passwords)?

Thanks for the suggestion. This new feature request has been passed onto the FDSN.

Section 4.3:

Thanks for pointing out that this was not clear. We have changed the text as follows (new in bold)

On this small subset of networks, we searched for data distribution information at FDSN (manually checking the network information at the website), which is independent of the FDSN data center registry, and we checked whether it was possible to obtain a StationXML file at network level directly from the ~~known~~ data center **indicated on the network page at the FDSN**.

Section 5.1

This is indeed an open issue. See our response to the AE above and associated text changes.

Sorry, the word 'Northern' had for some reason dropped out. Tim Ahern spotted that. We have now added it , you will find ncedc in line 678