Discoverability of open data is critical to Earth system science

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Abstract

There is consensus throughout the Earth system science research community that “open data” is of critical importance. However, discoverability and accessibility are often overlooked, raising the question of how useful archived, but not easily discoverable data are. As part of evaluating databases suitable for our own research data archival, we conducted a data discovery exercise (aggregators and repositories) with search parameters to evaluate (i) feasibility of discovering data, and (ii) number of relevant results found (defined by exact matches to our search). We found that search parameters need more options (and perhaps community driven development of thematic keyword search options), repositories affiliated with funding agencies/large scale research datasets were more likely to reveal relevant results, broad aggregators with poor metadata requirements yield the most irrelevant results, and current practices may drive smaller datasets to disappear thereby promoting a non-inclusive open data world that is not truly open for all. There are encouraging signs, however, whereby commitment to open data practices is leading to datasets becoming public--with due credits--prior to analysis and associated publication. Ideally, making data meet FAIR principles means more than depositing data as a journal or funding requirement: community buy-in and consensus is needed across the spectrum of data generators, hosts, and users to agree on how to best achieve the ideal of data being findable, accessible, interoperable, and reusable.

Keywords: Data, sharing, repository, best practices, metadata

Introduction

Multi-disciplinary Earth-system science is based on generating, synthesizing, and evaluating knowledge and data within and across environmental systems and scales. This requires collaboration across disciplinary and geographical borders (Reid et al., 2009) with accessible and shareable datasets serving a critical role in the process. However, accessibility of datasets largely depends on data curation, metadata assembly, data deposition practices, and data discovery(Popkin, 2019). With various repositories available in the data repository realm [e.g., funding agency mandated data deposition requirements like the United States Department of Energy's Environmental Systems Science Data Infrastructure for a Virtual Ecosystem (ESS-DIVE) for Earth and environmental science research data (Varadharajan et al., 2018), or general data repositories like Zenodo (Nielsen, 2017)], data generators and users have a wide variety of choices for depositing and accessing data, respectively, but no clear guidance on successful data discovery and reusability practices. Furthermore, agency-affiliated repositories like ESS-DIVE have mandatory meta-data standards and consistent data structures that are usually lacking in general repositories. These standards are critical for making data Findable, Accessible, Interoperable, and Reusable (FAIR) (Castelvecchi, 2018; McQuilton et al., 2016; Nature Editorial, 2019; Wilkinson et al., 2016) which is the current gold-standard for ensuring that public data can be used.

As researchers generating data, we conducted a data search exercise to inform ourselves about the data deposition options available to use for an ongoing research project and evaluate which repositories yield data that is both discoverable and useful. Furthermore, our goal was also to evaluate how small datasets not affiliated with programmatic requirements of funding agencies fare in terms of data deposition and discoverability. For example, ESS-DIVE is a great repository, but is necessarily limited to DOE funded datasets. To be beneficial to users, data contributors like us need to ascribe to all aspects of FAIR data practices in addition to data deposition. The first requirement is that data are findable. This is arguably the most critical element of the FAIR principles; if data cannot be found, they cannot be reused. We therefore evaluate the degree to which openly available data can be found (sometimes referred to as 'discovered'), assess whether discovered data aligns with user needs, and discuss the need for community accepted and enacted data-stewardship practices that support small but valuable datasets that may not be affiliated with large research programs to promote open data discovery.

Data search is inherently subjective to the knowledge domain of a scientist and therefore non-uniform amongst users. A general approach is to begin with a thorough literature review for published results and the available data. Keyword-defined searches on platforms such as Google Scholar usually yield literature results that eventually guide readers to databases/repositories. Lack of standardized keyword-based searches means searches are user-defined and highly variable, which may differentially shape search output, and therefore influence downstream access and reuse of relevant data. A second approach is to search known databases including archives/repositories/aggregators with relevant keywords. However, the data hosting platforms may be constrained by available keywords that one can apply. These non-uniform search options therefore present a possibility that searches may yield biased results yielding long-term studies with significant data presence and/or datasets affiliated with programmatic requirements that are more commonly known than small datasets/studies. This has the potential to skew data reuse, with large numbers of short-term and/or non-programmatic datasets being effectively lost. In turn, if individual investigators perceive that their small/non-programmatic datasets will not be reusable, there is little incentive for investing resources into making these data FAIR, leading to a negative feedback loop.

Federal agency mandated data centers like the National Aeronautics and Space Administration (NASA) supported Distributed Active Archive Centers, the National Oceanic and Atmospheric Administration (NOAA) supported National Center for Environmental Information, US DOE supported ESS-DIVE, and the US Geological Survey's (USGS) Earth Resources Observation Systems (EROS) Data Center (Downs et al., 2015) have defined data archiving and search guidelines whereas stand-alone data-repositories like Zenodo and figshare (Scientific Data, 2019) are less structured in terms of data types and metadata requirements with limited directions on data searches. While all archives provide data-hosting and archival of diverse data-types (e.g., geophysical and ecological data) (National Research Council, 1995; Scientific Data, 2019) , the extent to which open data is discoverable and usable is unclear.

We conducted a search exercise across multiple repositories and aggregator databases to evaluate variation in data search outcomes. We observed that data is increasingly being made open ahead of publications, which we believe is a positive sign. However, we discovered that public data is not necessarily findable or usable (i.e., relevant) data. The disparity in data search capabilities and results in terms of keyword usage and the relevance of the search results to our intended search suggests that data generators, data users, and repositories must collaboratively promote FAIR data practices in a coordinated way. Researchers must make efforts to upload data with standardized metadata and themselves evaluate how FAIR their data are. Users have the responsibility of ascribing to FAIR data principles and to help make improvements by engaging with repositories (e.g., help standardize keyword searches and provide feedback about their experiences). Finally, repositories need to consciously choose to operate and implement FAIR data principles by requiring standardized metadata, providing streamlined search parameters, and mandating data formats and file structures. As a community, we need to agree that making data open is not just a publication requirement but meets all principles of FAIR data practices.

Data discovery exercise

The goal of the data discovery exercise was to (i) evaluate the degree to which data are findable, and (ii) identify current challenges in making data FAIR. For the purpose of this opinion piece, we conducted searches across two data aggregators and five repositories for data released/published between 2014-2018. The search focused on soil carbon data for coastal ecosystems in Florida. This was chosen as an example since coastal areas provide significant C storage but are vulnerable to C loss in a warming climate (Osland et al., 2018) and therefore need to be accurately mapped and monitored (Holmquist et al., 2018).

The repositories/aggregators ranged from programmatic [Environmental Data Initiative (EDI), USGS, Oakridge National Laboratory Distributed Active-Archive Center (ORNL DAAC)] to broad-range (Zenodo and Dataverse) archives, as well as data aggregator catalogs (DataONE and Pangaea). These repositories represent data submission options ranging from mandated data format and metadata requirements to no specific data format and metadata structure. We used keywords 'coastal soil carbon', attempted to place filters to restrict the search to sites in coastal Florida, United States, and limit the search to reflect data released between 2014-2018. We did not check for data type deposited (e.g., file type, data analysis codes, and raw vs processed data). A parallel search using the same keywords was conducted in Google Scholar for published research articles to serve as a benchmark of studies in the public domain. The results revealed that: (i) researchers are making their data open by hosting them on repositories, as opposed to only providing them in supplementary material of publications, (ii) irrespective of research scale, openly available data are not necessarily discoverable or usable, (ii) multiple search function options can enhance the data discovery process, (iii) improved metadata standard requirements by repositories stands to improve discoverability and accessibility of data, and (iv) extra attention is needed to improve the metadata for small/short-term datasets so that these data have a high likelihood of being discovered.

Results and Discussion

Data were considered relevant if all individual keywords were found in the search results; exact multi-word phrases were not required. For each search, the data titles and information describing the data were assessed for matches. We consider the brief summary of data to be one type of metadata useful for discovering relevant datasets. For those searches that did not allow keyword searches (e.g., only phrases could be used), the results had to be manually curated to narrow down which datasets were considered relevant. The lack of filters made it challenging to search for relevant data, and the results showed considerable variation across repositories/aggregators in data discovery and usability (Figure 1) with some yielding results irrelevant to keywords provided.

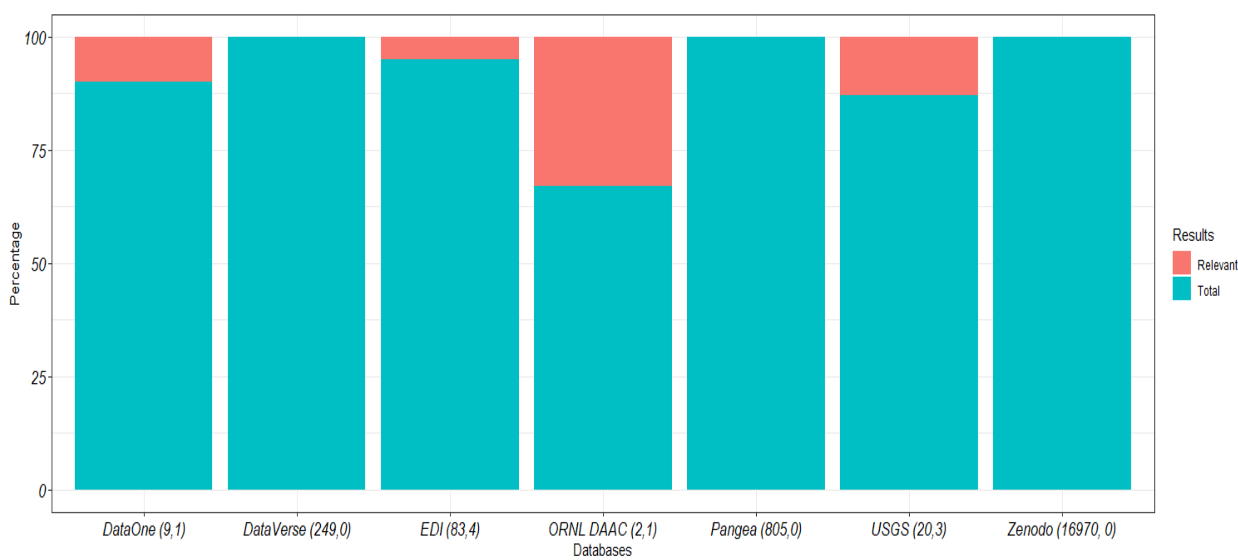

Figure 1. Data discovery and usability percentage with identifiers "coastal soil carbon, Florida, 2014-2018". Parentheses in X axis labels (a,b) indicate total number of results (a) and relevant number of results (b) for each database/repository. Results were considered relevant when all individual search words were identifiable in the title of the dataset, or the metadata brief provided by users, and/or a combination of the two.

Detailed search results including database information, date accessed, data availability, and affiliation with programmatic requirements are provided in Supporting Table S1. The EDI, DataOne, ORNL DAAC, and USGS databases revealed five, ten, thirteen, and thirty-three percent of relevant data, respectively. The broad-range data repositories including DataVerse and Zenodo, and the aggregator catalog Pangea did not reveal any relevant datasets. Surprisingly, these repositories revealed the maximum number of results, most likely a result of a fluid data deposition requirement with no strict metadata and file requirements. For example, a dataset for soil nematode counts appeared in the search result since the word "soil" matched with our search parameters. It is likely that the search algorithm in such cases yields a match to any of the words/search phrases, without strict search parameters to tell the algorithm to "show a result only when all these words are present". Our results suggest a disconnect between data that is openly available and data that is discoverable/usable. That is, having data publicly available on a platform is only a piece of the solution, and needs to be backed up by efficient data discovery and usability.

Making data public without making it discoverable results in data that are not very usable, thereby defeating the purpose of public data. A major hurdle in making data discoverable that we identified in our exercise was lack of user-friendly data-filtering choices. DataONE fared the best in allowing all relevant filters (environment, location, measurement, year) to be used. The USGS data search included a map to focus on location of interest but the filters were broad and did not help narrow the search to soil environments and year-wise searches could not be made due to the absence of a 'time' filter. ORNL DAAC and EDI allowed phrases to be inserted in the search bar but lacked the use of filters. Pangaea only allowed broad level filters to be placed and was not able to narrow down the search to relevant locations or study systems (e.g., soils). It proved difficult to narrow down location, year, and environment in Dataverse and Zenodo. We also discovered that DataONE filtering by a location field or by a geographic map gave different results. This suggests active community engagement is needed to address the current data archival environment.

Data deposition practices influence the metadata labels that get recorded and ultimately matched in database searches. All repositories/archives required a manual curation step of individually checking the search results to discover relevant datasets (for example, results had to be manually evaluated to ensure data searches were only from 2014-2018), primarily because the metadata provided were inadequate for accurate identification. Therefore, metadata labels need to be standardized and informative to show up accurately in search results. As evidenced from the data search exercise, data discovery can be improved regardless of search capabilities within a given archive, etc. if the metadata is standardized and informative. For example, as pointed out earlier, if the location was not explicitly indicated in the metadata, search capabilities in DataOne would exclude the dataset. However, location-relevant records could be found by zooming in on the map feature. This ambiguity in search parameters as well as allowing broad level filters to be used as search criteria is perhaps aimed at providing choices and flexibility to data generators but ultimately results in non-uniform data deposition practices that is less likely to be helpful to data users

To understand how Google Scholar search compared to databases, we examined the first 100 results using the same keywords as used in the database search. The search revealed twelve published articles (Supporting Table S2) as of June 14th 2019, of which only one study (Wilson et al., 2018) had the data discoverable in DataONE. As pointed out in a recent commentary (Castelvecchi, 2018) , Google Scholar searches are not yet linked to their new Dataset Search initiative, with our results showing an opportunity where linking the two will increase the chances of discovering a dataset. All but two of the Google Scholar search results had their data available in the journal article itself, with one study (Hinson et al., 2017) affiliated with a global dataset and the other (Wilson et al., 2018) affiliated with Everglades Long Term Ecological Research site data. This shows a benefit of FAIR data practices: while Google Scholar will only return results that have been published, unpublished but publicly available data can be used with proper credits for research purposes. This open data culture provides credit to data generators, recognizes the power of data-driven research, and adds value to the scientific pursuit.

The Google Scholar and database search results highlighted a disparity between agency-affiliated large projects that can host data in programmatic databases. In contrast, small-scale studies often cannot deposit data in the programmatic databases. This disparity results in data from individual (smaller-scale) research efforts likely to be deposited in repositories with few requirements associated with making data FAIR (e.g., weak metadata standards). This leads to the associated data being difficult to discover and use. It may be that strict deposition policies in the programmatic databases may also deter scientists from uploading data, which prompts researchers to instead deposit data in a repository with few requirements due to limited time and resources.

The commitment to enable FAIR data is essential and promising but needs to be coupled to standardized search capabilities; data may be FAIR in principle, but if not paired with appropriate search capabilities, they cannot be discovered or used (Figure 2). For example, broad search options with inadequate filters reduces data discovery. Simultaneously, poor metadata prevents dissemination, sharing, and reuse of associated data. This problem can be overcome by agreeing as a community on integrated thematic descriptors irrespective of database affiliations, thereby improving data identifier practices and integrating the currently fragmented data ecosystem. To this end, set vocabularies such as the Global Change Master Directory keywords adopted by NASA (GCMD Keyword Governance and Community Guide, 2016) , the Climate and Forecast metadata conventions adopted by the National Center for Atmospheric Research for atmospheric data (Gregory, 2003) , and the Biological, Ancillary, Disturbance and Metadata protocol for the Ameriflux network (Law et al., 2008) exist but the conventions have not been translated to informative metadata identifiers across data archives.

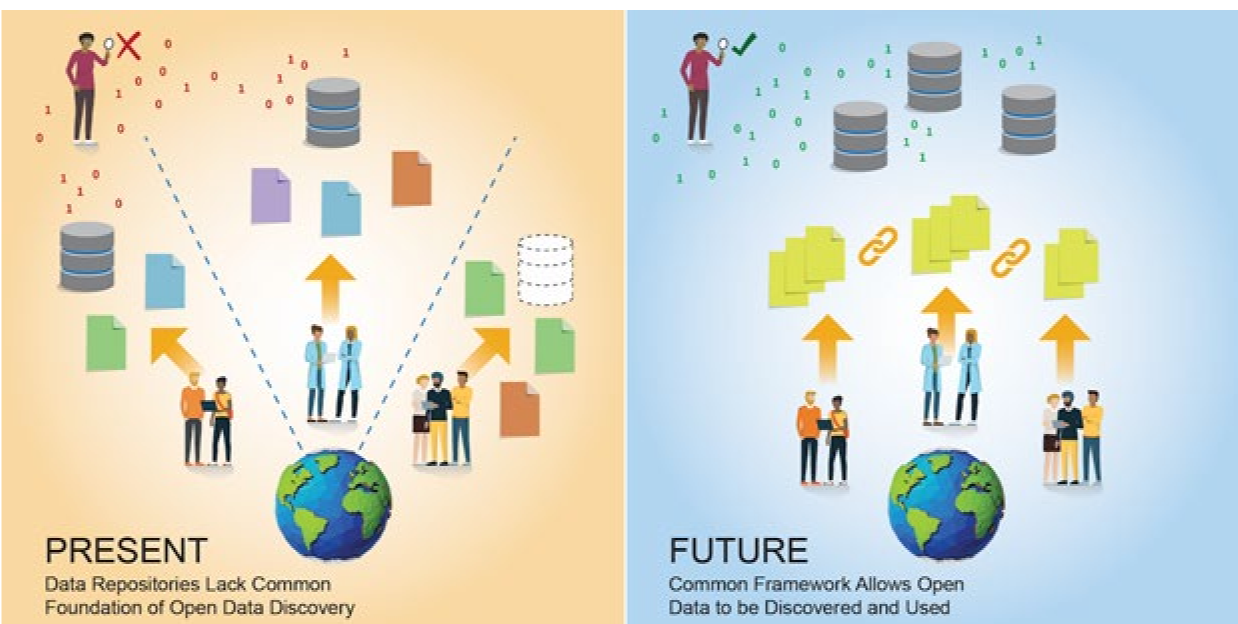

Figure 2. Ascribing to FAIR principles is key to enabling discovery of openly available data, and the architecture of repositories is a key element; data can be FAIR in principle, but not in practice due to limitations in repository search capabilities. The 'Present' panel indicates a fragmented scenario where data discovery is limited due to disparate data sharing and limited search options where the left and middle groups upload their large research data with programmatic requirements (grey cylinder) in different formats while the group on the right share their small research data to stand-alone repositories. The user can discover only one of the datasets. The 'Future' panel indicates a common framework of open data discovery, where irrespective of research scale or repository requirements, openly available data is rich in metadata information, is searchable with dense search parameters, and therefore yields optimum user defined search results.

It is important to consider that the cost of making data FAIR is much higher per bit of data for small stand-alone efforts, relative to large research campaigns that generate significant quantities of data. The preferential use of repositories with few or no standards is not because researchers are lazy. Instead, most research labs do not have the resources to make every dataset FAIR through strict adherence to data and metadata standards. A major need is finding ways to decrease the cost and effort of making 'small data' FAIR. This will require coordinated efforts to standardize metadata deposition requirements and search filters, as well as new cyberinfrastructure that streamlines the logistics of making data FAIR. Furthermore, there is a need for cultural change whereby the scientific norm is data deposition with the intent of maximizing discoverability, rather than merely 'checking a box' to fulfill a publication requirement. Greater multi-way communication is also needed among data generators, repositories, and data users to develop streamlined practices that are useful for the involved parties and that lead to discoverable and usable data.

Conclusion

Inclusive accessibility, discovery, and reusability of data is necessary to ensure data stewardship and the progression of science. The data archival guidance provided by FAIR data principles is aimed at strengthening data stewardship by involving multiple stakeholders. Strides have been made by the Earth-science community to begin implementing FAIR data practices over the past two years (Stall et al., 2019), with researchers, funding agencies, the research community, and publishers adhering to FAIR data practices. However, our results show that there is a significant need to develop mechanisms/tools that minimize the effort and cost needed to make any dataset FAIR. If data are hard to find and when found are hard to use, they are public but are not truly open or FAIR. It is important to invest the time and effort to ensure that data are discoverable through standardized keywords and identifiers. Without such tools, the vast number of ‘small’ datasets generated by individual research groups will effectively die despite being public. The responsibility of researchers go beyond simply depositing data in a public repository. A much broader commitment from the community is needed to promote uniform data deposition, search, recoverability, and usability, irrespective of data deposition in programmatic databases or standalone repositories.

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