FAIR Data Practices for Marine Ecological Time Series

NSF EarthCube Research Coordination Network

REPORT

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Other participating time series programs: Oceanic Flux Program, Monterey Bay time series, Munida time series, Ocean Weather Station M, Cape Verde Ocean Observatory, Line P program, Icelandic & Irminger Seas time series, Rothera time series, Gulf of Trieste time series, Candolim Time Series, Arabian Sea time series, Bay of Bengal time series, Maine DMR Boothbay Harbor time series, South Florida Ecosystem Restoration Research Project, Ellett Array, Coastal Ocean Acidification Cruises (East, West, Gulf of Mexico coasts), North Inlet Estuary Zooplankton Time Series, Atlantic Meridional Transect

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1. Background & Workshop Aims

Long-Term Perspectives on Marine Ecosystems

Marine ecosystems are experiencing unprecedented rates of change associated with rising atmospheric carbon dioxide (CO_2) levels and greenhouse gas forced climate change, including concurrent shifts in temperature, circulation, stratification, nutrient input, oxygen (O_2) content, and ocean acidification. Marine food webs comprise a delicate balance between primary producers, intermediate consumers, and top predators. Since the early to mid-20th century, shipboard marine ecological time series (METS), or sustained repeat measurements of physical, biogeochemical, and biological processes, have documented changes in ocean biogeochemistry (e.g., Bograd et al., 2008; Church et al., 2013; Bates et al., 2014), ecosystem state (e.g., Taylor et al., 2012; Edwards et al., 2013; Barton et al., 2016), and organism phenology (Asch, 2015; Hunter-Cevera et al., 2016). Decades of research have demonstrated that the ocean varies over a range of time scales, with anthropogenic forcing contributing an added layer of complexity. In a growing effort to distinguish between natural and human-induced variability and their interconnections, METS measurements have taken on renewed importance, representing one of the few long-term, temporally-resolved observing assets scientists have to characterize and quantify marine ecosystem responses to and feedbacks on a highly dynamic and changing climate system. METS programs have been heavily leveraged across the international ocean science community to conduct curiosity-driven interdisciplinary research and served as test beds for the development of new sensors and methodologies. They provide valuable seagoing opportunities and hands-on training for the next generation of ocean scientists, as well as a forum for collaboration among nations to grow and share capacity. In addition to their high temporal resolution, integration of data across multiple time series and with other ocean data assets provides the opportunity to obtain a broader spatial perspective and explore causal links between natural climate variability, anthropogenic pressures, and marine ecosystem changes. Data synthesis and modeling efforts within and across METS represent powerful research and ecological assessment tools (e.g., O'Brien et al., 2017; Lange et al., 2024).

The Challenges of Sustained Time Series Measurements

Ocean time series programs face many challenges, most notably the availability of adequate and stable funding and operational resources to support the collection of observations and adequate time and human resources to conduct robust data quality assurance and quality control (QA/QC) and curation. Sustained time series observations rely on the availability of dedicated infrastructure (e.g., research vessels, sediment traps, moorings, data and informatics, etc.) that requires advance planning, scheduling, and continual maintenance to support smooth operations. Many time series stations provide critical access to the sea for ancillary oceanographic research projects, so interruptions of operations or data streams can have ripple effects in the oceanographic community. In a funding environment that typically prioritizes innovative, curiosity-driven science and supports projects on 3- to 5-year timelines, it is a challenge to maintain uninterrupted funding for ocean time series programs.

The resultant data gaps, changes in sampling frequency, and high personnel turnover can compromise data quality and scientific utility of the data sets. Furthermore, numerous disconnected databases and interfaces for accessing data make it difficult for potential users outside the immediate METS community to find and use these datasets. Limited data access, discoverability, reporting, and interoperability represent a barrier to analyses within and across METS. Standardized guidelines on METS sampling and analytical methods (Lorenzoni and Benway, 2013), data and metadata reporting protocols, data sharing culture, and data citation practices are needed to track and expand time series data usage and enable comparative studies across METS stations. It is this set of data-related challenges that the METS community seeks to address.

Addressing Time Series Data Challenges

In September 2019, a small National Science Foundation (NSF) EarthCube-sponsored workshop was held to conduct a gap analysis of METS cyberinfrastructure and provide a much-needed forum for discussion of key issues and barriers surrounding Findable, Accessible, Interoperable, and Reusable (FAIR) data (Wilkinson et al., 2016) for shipboard time series (Benway et al., 2020). During the workshop, participants identified and discussed the following METS cyberinfrastructure challenges:

Lack of community-vetted, universal data and metadata reporting guidance for core ecological variables (e.g., methodological information, definitions, vocabulary, units, precision, associated errors, etc.).

- Need to apply tools (e.g., controlled vocabularies) to enhance interoperability across the many different data repositories that hold METS datasets
- Understanding the difference between FAIR vs. open data (neither implies the other)
- Data latency and availability
- Need for flexible, human-readable data formats and interfaces that can increase discoverability to serve a broader range of users
- Lack of data citation standards and best practices

There is an urgent need to develop consensus on community-adopted data and metadata reporting standards that will make these data more FAIR. This needs to be a coordinated community effort as time series programs often do not have the human or financial resources to take on this necessary task. FAIR provides the key principles to make data effectively sharable with the wider time series community (not to be confused with open data, e.g., Jati et al., 2022). The most urgent recommendation from the workshop was to pursue a sustained community initiative to bring together ocean and data science expertise. This type of effort is needed to build consensus on mechanisms to increase data discoverability (F) and develop flexible formats and interfaces that aid in both human and machine access (A), common vocabularies (F, I), data citation guidelines (F, R), and data and metadata reporting standards (I, R) to better support scientific and broader applications of METS data. These outcomes formed the basis for this METS Research Coordination Network (RCN).

The ocean data landscape is complex and evolving, but existing and emerging tools and capabilities are making the goal of FAIR more achievable for METS datasets than ever before (Fig. 1, Bloch Haimson et al. 2025). To apply some of these capabilities to METS datasets, an NSF EarthCube-funded METS RCN was established in 2021 with the primary mission of assembling expertise in ocean and data science. The specific objectives of the METS RCN were to:

- Co-develop and build consensus around FAIR data solutions for ship-based ocean time series
- Broaden METS data users and applications
- Build capacity for METS data analysis, statistics, and data-model integration

Small group virtual and in-person meetings throughout the RCN life cycle have enabled members of the time series and data science communities to ideate and co-develop tools and resources such as draft metadata reporting templates for commonly measured ecological parameters and targeted guidance for METS data generators for adopting FAIR-enabling practices, methods, and tools. Descriptions of these templates and how to access them are provided in Chapter 3 of this report.

The METS RCN has engaged with the IODE Global Search Hub to develop a draft pattern (Chapter 3) that will allow time series metadata to be exposed on the web in a structured way using JSON-LD schema.org markup. The resulting structured metadata record can be published by data providers (e.g., BCO-DMO) and harvested by the Global Search Hub's Ocean Data and Information System (ODIS, https://www.odis.org/) where it can then be discoverable by the broader international community. ODIS provides an interoperability layer and supporting technology, allowing ocean data from various stakeholder information systems to interoperate with one another.

Parallel to this effort, a METS RCN leadership team member led the development of a pilot Synthesis Product for Ocean Time Series (SPOTS) (Lange et al., 2024, see Chapter 4) with funding from EuroSea. SPOTS includes data from 12 Eulerian ship-based time series stations that are representative of unique marine environments within the Atlantic, Pacific, Mediterranean Sea, Nordic Seas, and the Caribbean Sea. The focus of the pilot is on the following core set of biogeochemical essential ocean variables (GOOS EOVs) commonly measured by ocean time series programs: Oxygen, dissolved inorganic nutrients, inorganic carbon, particulate matter, and dissolved organic carbon. The SPOTS data product required careful assessment of data and metadata across the 12 sites, which provided the initial use case for the metadata templates.

METS RCN FAIR Data Workshop

As its final community activity, the METS RCN hosted an invitational FAIR Data Workshop that convened 60 (45 in person, 15 virtual - see Participant list, Appendix 1) time series program representatives, informatics and data management experts, and data repository managers. The goals of the workshop were to:

1. Build capacity and provide tools to guide FAIR implementation for marine ecological time series, including a FAIR data primer to help METS PIs learn more about their (and their repositories') roles in implementing FAIR data practices
2. Share and refine draft metadata templates for commonly measured ecological and biogeochemical parameters
3. Share & discuss tools/resources for data visualization, synthesis & analysis, citation (DOI - Digital object identifier), decision support
4. Update time series sampling and analytical methods recommendations
5. Build community - share science outcomes, challenges & opportunities

The workshop agenda (Appendix 1) included a mix of plenary and poster sessions, breakout discussions, and small group activities and demonstrations that mapped directly to these goals. Ultimately, we want these data sets to be as discoverable as possible to increase and broaden their visibility and use, which helps sustain funding.

The remainder of this report describes key processes and outcomes (FAIR Data Primer, metadata reporting templates) of the RCN, highlights novel tools for data visualization, data analysis, and broader applications of METS datasets, and summarizes actionable recommendations for the time series community to elevate METS visibility, adopt FAIR practices, and enable robust METS data analysis.

Find recordings of the workshop on YouTube, workshop agenda and participant list in Appendix 1.

2. Applying FAIR Data Practices: The METS FAIR Data Primer Principles and Applications

Introduction to FAIR Data Principles

A set of guidelines for making data Findable, Accessible, Interoperable and Reusable (FAIR) were developed and published by Wilkinson et al. 2016 and mapped to the ocean disciplines by Tanhua et al. 2019, which are now popular in the data lifecycle processes of national and global data centres and repositories. A goal of FAIR Data Principles is to align the interfaces, standards and documentation of data, reducing the barriers to data reuse, and thereby maximizing the value of generated data. Wilkinson et al. (2016) note that "Good data management is not a goal in itself, but rather is the key conduit leading to… data and knowledge integration and reuse by the community after the data publication process." What constitutes 'good data management' is, however, largely undefined, and is generally left as a decision for the data and/or repository owner. Wilkinson et al. emphasize both human-driven and machine-driven activities because although humans have an intuitive sense of 'semantics' (the meaning or intent of a digital object) they can not "scale up" to accommodate the intersection of large, complex data sets, and therefore need to rely on computational agents to closely approximate human interpretation of contextual cues. One key use for FAIR data practices is to help computers scale up. However, FAIR Data Principles "do not suggest any specific technology, standard, or implementation-solution; moreover, the Principles are not, themselves, a standard or a specification." Instead, they act as a guide to data publishers and stewards to assist them in technical choices that improve the state of data's findability, accessibility, interoperability, and reuse, thus pushing for continual improvement and alignment with FAIR over time. This means that FAIR potentially has a different implementation in different communities with initiatives such as FAIR Implementation Profiles (FIP) attempting to document FAIR specifics by community.

FAIR principles were presented to workshop participants in an accessible way that defined each principle in relation to their role in the collection, reporting and sharing of time series data, and to demonstrate the value of increasingly FAIR data in time series data integration for analyses. In addition, workshop steering committee members developed and presented a FAIR primer as a reference and resource tailored for data producers and repositories to assist them in creating data that is more FAIR.

Roles and responsibilities

Understanding the role of data producers and repositories in the effort to make data more FAIR is crucial. The level of resources, types of science, and use cases for data producers will vary by a wide margin. The level of responsibilities of data producers and repositories will also be distributed for each of FAIR Data Principles.

FINDABILITY

F1. (meta)data are assigned a globally unique and persistent identifier; F2. data are described with rich metadata (defined by R1 below); F3. metadata clearly and explicitly include the identifier of the data it describes; F4. (meta)data are registered or indexed in a searchable resource

In most cases, Repositories will provide the technical infrastructure and data expertise needed to assign globally unique and persistent identifiers and enable web technologies for robust access and searching. In conjunction, data producers have the incredibly important task of creating rich metadata based on their intimate understanding of the science, including everything that data users will need to know to understand the comparability of the data.

The COPDESS Enabling FAIR data project defined the base level of achieving findable as assigning a DOI to datasets and using ORCID identifiers to identify people. Best practices development aimed at improving "Findable" is on-going through community initiatives-such as the Research Data Alliance (RDA)'s *Complex citations working group*.

ACCESSIBILITY

A1. (meta)data are retrievable by their identifier using a standardized communications protocol; A1.1 the protocol is open, free, and universally implementable; A1.2 the protocol allows for an authentication and authorization procedure, where necessary; A2. metadata are accessible, even when the data are no longer available.

Accessibility is likely to be mostly or entirely addressed by a repository, as it is primarily concerned with the web protocols used to access the data and the state of the records.

INTEROPERABILITY

I1. (meta)data use a formal, accessible, shared, and broadly applicable language for knowledge representation; I2. (meta)data use vocabularies that follow FAIR principles; I3. (meta)data include qualified references to other (meta)data.

Interoperability is a shared challenge for data producers and repositories, because, while repositories will represent the vocabulary and language of knowledge representation, the actual definitions need to be provided or confirmed by data producers. Deciding on the use of established controlled vocabularies is most effective when data producers work in collaboration with Repositories.

REUSABLE

R1. meta(data) are richly described with a plurality of accurate and relevant attributes; R1.1. (meta) data are released with a clear and accessible data usage license; R1.2. (meta)data are associated with detailed provenance; R1.3. (meta)data meet domain-relevant community standards.

The feature that makes data Reusable in a FAIR context is the level of detail about the dataset provided to users. Users need to know exactly how, where, and when data were collected and which techniques were used to produce each measurement. They need to know how the data were processed and QA/QC'd, which software and versions were used, and any other details about data analysis. This is typically the place where data producers need to invest the most time. For all data producers, but particularly in time series projects, getting everything documented in an organized and consistent way can be daunting, but increases the value of the work immensely. Yet, at present there is limited METS community consensus on many aspects of data curation, and human and financial resources are often limited.

A note on repositories and FAIR
Research repositories use accreditation schemes such as *CoreTrustSeal* or *FAIR sharing* tools to assess and monitor the FAIRness of data exposure. Such services are useful tools for helping a researcher choose a data repository that is appropriate for their type of research output.

FAIR Data Primer

There are many tools available to researchers to create data that is more FAIR. There are four general categories that are most useful to create robust descriptive data records: metadata standards, controlled vocabularies, supported data formats, and persistent identifiers. The table below illustrates how the main ideas of FAIR data can be achieved with these tools.

Tools	Findable	Accessible	Interoperable	Reusable
General Idea	The data is assigned a persistent identifier and indexed for discovery.	The metadata is accessible using the persistent identifier via a standardized protocol.	Metadata and data are available in standard open formats.	The data is richly described, meeting domain-relevant standards for reuse.
Metadata Standards	Comprehensive metadata in a structured format ensures data can be located.	A repository will leverage metadata standards to ensure discoverability and accessibility.	Metadata standards ensure consistent structure across datasets.	Well-structured metadata provides clear documentation for reuse.
Controlled Vocabularies & Classifications	Controlled terms for consistent naming and classification improve findability.	A repository will leverage controlled vocabularies to improve discoverability and access.	Standardized vocabularies ensure consistent interpretation of data fields.	Standardized terms make it easier for data users to understand and reuse content.
Supported Data Formats	Open, standard data formats allow for downstream processing and discovery.	A repository will leverage open, supported data formats to facilitate reuse.	Open data formats ensure that data is formatted for interoperability.	Consistent data formatting ensures datasets can be reused across systems.
Persistent Identifiers	The use of PIDs allows indexing systems to disambiguate important concepts of a dataset, such as people, locations, and species and allows more meaningful links to be made.	A repository will leverage persistent identifiers to make data accessible.	PIDs allow for the retrieval and integration of contextual information in structured formats, as needed for new research purposes.	Using appropriate PIDs ensures accurate, consistent identification of important elements, making data more reliable and suitable for future use.

Table 1. FAIR data primer (Mickle et al., 2026) developed by METS RCN leadership to assist time series practitioners in accessing tools and resources that support and enable data Findability, Accessibility, Interoperability, and Reusability.

This table is the introduction to the more detailed METS Workshop [FAIR Data Primer](). This FAIR Data Primer (Mickle et al., 2026) contains additional material breaking down producer and repository roles for each category, examples of how FAIR data tools might be implemented for each category, and a list of additional resources.

Similarly, controlled vocabularies, such as the British Oceanographic Data Centre (BODC) Parameter Usage Vocabulary and the Climate and Forecast (CF) standard names parameter vocabulary, are created and maintained by communities of users who have similar needs using a documented governance system. As a system of established shared definitions, controlled vocabularies should provide identifiers to map terms, since like species names, the exact wording may change over time. They also enable machine readability and disambiguate one local meaning from another- facilitating data interoperability. For instance, many standard parameter names might provide too much room for interpretation in a global, interdisciplinary context, so researchers can choose to map their "temp" parameter to a vocabulary that specifically defines it as "water temperature". Sometimes this will be implemented at the project database level, other times by a repository.

The use of open and standardized formats promotes interoperability between systems and scientific disciplines, enabling data to be reused and reinterpreted in different research contexts. These formats ensure that data are represented and stored consistently, making it easier to transform or integrate with other datasets. It also makes the data more useful for common tools and workflows. Examples include CSV, TSV, NetCDF, and PDFa. These format standards are governed by international bodies and are non-proprietary, which gives them a high level of reliability for data producers and consumers. Data producers can greatly improve their accessibility by providing an open, standardized data format or working with a repository to provide one.

Persistent Identifiers (PIDs) are long-lasting, unique, reference IDs that resolve to digital objects or information about a digital object. They are community-driven and authoritative. They are also used to disambiguate information about specific digital objects. PID examples include: Open Researcher & Contributor Identifiers (ORCIDs), National Center for Biotechnology Information (NCBI) BioProject numbers, World Registry of Marine Species (WoRMS) AphiaIDs, DOIs, and ISBNs. Not only do PIDs map directly to a defined entity (similar to a controlled vocabulary term), they can also be used to draw up-to-date contextual information about that entity, creating a network (graph, fabric, etc.) of related information and their relationships. For example, through this interconnected PID network, an ORCiD record cannot only be used to obtain current name information about authors but also about the related publication DOIs linked to an author's ORCiD record.

3. Getting Our Data Houses in Order

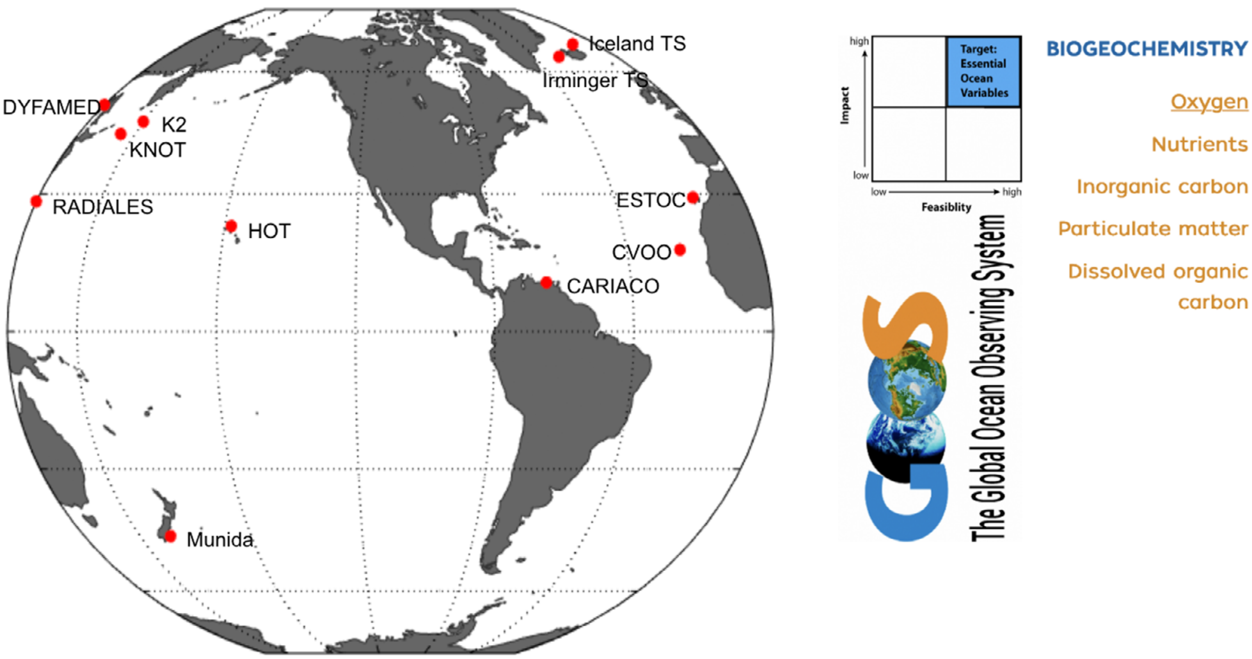
Introduction

Many marine ecological time series projects have developed their data reporting strategies and content organically over time to support their evolving research goals and objectives, typically corresponding to a specific user community associated with each time series site. Despite the work of the Global Ocean Observing System (GOOS) to facilitate advances in the standardization of time series data collection, processing, and reporting, barriers still remain in the community's ability to discover, access and interpret/integrate time series data at scale, a major challenge for synthesizing time series data across the global ocean. Initial progress was made during a METS EarthCube-funded workshop in 2019 to identify the persistent gaps in data infrastructure (Benway et al., 2020) that would facilitate more effective integration and synthesis of time series data. Here, a common data model and standardized metadata for reporting core time series variables emerged as a high priority need.

Developing METS Metadata Templates

The process and benefits of structured, consistent metadata reporting was well documented for SPOTS time series data by the work of Lange et al. (2024) (Fig. 1). SPOTS includes consistent formatting and semantics that enhance intra- and inter-station comparability while implementing FAIR principles and open data practices. This presented an opportunity and initial use case for the METS RCN to work towards comparable metadata reporting templates for ecological parameters that could improve discoverability and reuse by increasing interoperability of time series data. The METS RCN group leveraged the SPOTS biogeochemical semantic framework to develop detailed metadata reporting templates for marine ecological parameters commonly measured by time series programs.

Biological Time Series Data Synthesis Product (SPOTS)



www2.whoi.edu/site/mets-rcn/ts-data-product/ **doi.org/10.5194/essd-16-1901-2024**

Figure 1. Global distribution and biogeochemical variables included in the SPOTS pilot data product. Adapted from Lange et al. (2024).

In April 2023, the RCN hosted a hackathon in Boston, MA, bringing together Principal Investigators and researchers from the Hawaiian Ocean Time series (HOT), Bermuda Atlantic Time Series (BATS), the Narragansett Bay Long-term Plankton Time Series projects along with data professionals from BCO-DMO, IODE Ocean Data and Information System (ODIS), and BODC to collaborate on the creation of data type-specific metadata reporting frameworks. The group mapped out sample collection and analysis workflows (Fig. 2, top), identified key observational metadata required to support interoperability and reusability, and began drafting metadata models for chlorophyll, metazooplankton biomass, and primary production using the biogeochemical semantic metadata templates as a guiding example. Following the hackathon, the group worked with PIs of the Oceanic Flux Program (OFP) to develop metadata reporting templates for particulate fluxes from sediment traps, which are commonly deployed by time series programs (Fig. 2, bottom). Members of ODIS collaborated during the template development and provided support for issue tracking. By leveraging ODIS-led strategies that employ schema.org, the resultant metadata can be harvested by ODIS for global discovery.

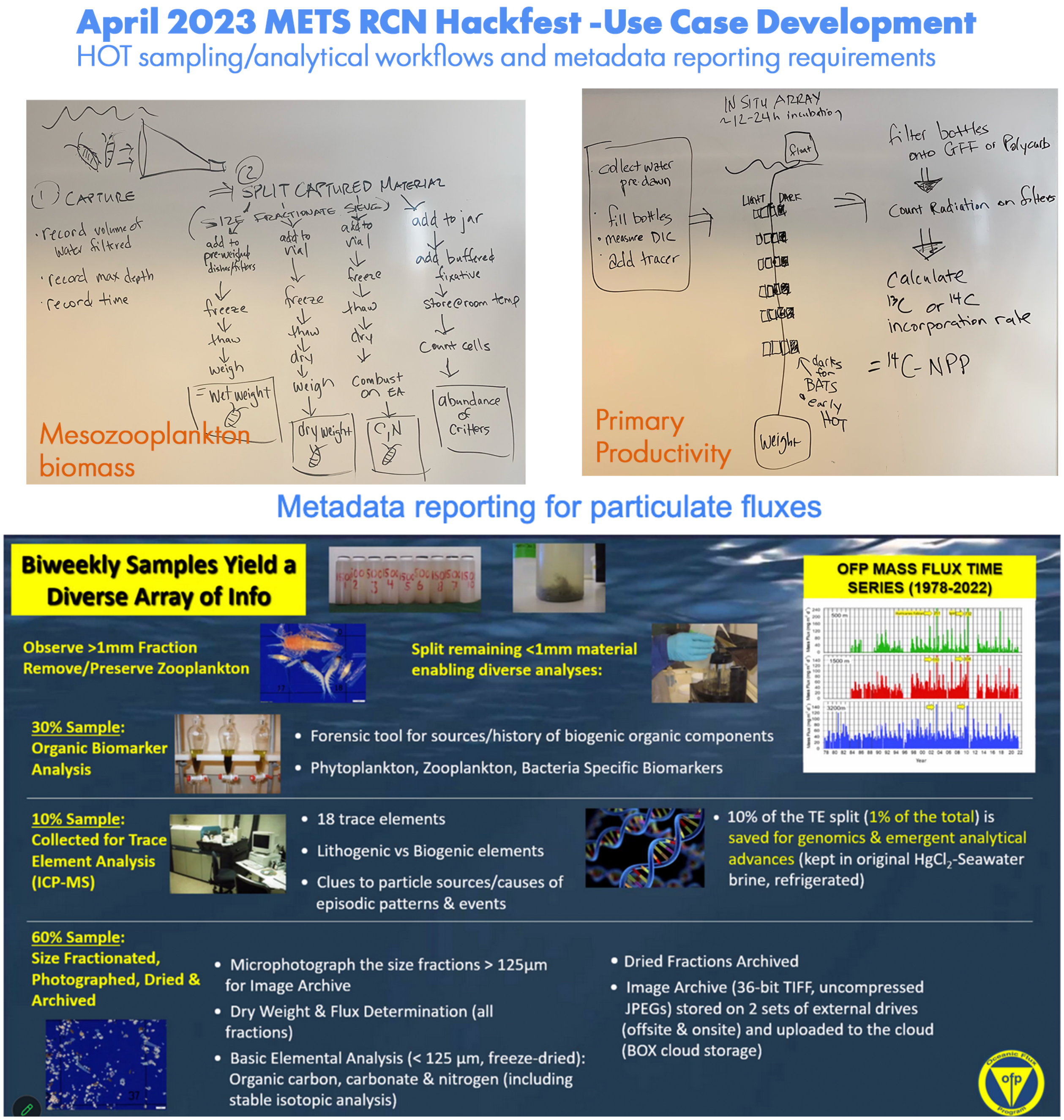


Figure 2. Sampling and analytical work flows for TOP: Mesozooplankton biomass and primary productivity, using the Hawai'i Ocean Time series (HOT) as the exemplar and BOTTOM: Particulate fluxes, using the Oceanic Flux Program (OFP) as the exemplar.

During the hackathon, efforts to map ecological variables such as chlorophyll to and across CF and BODC controlled vocabularies (Fig. 3) illustrated typical inconsistencies in reporting across variables such as units, which helped to inform metadata template development. As a case study, biogeochemical parameters collected at HOT were mapped to the CF vocabulary and added several new terms, including chlorophyll and pigments, particulates (C, N, P, Si), sinking mass fluxes, N_2O, and $\delta^{15}N$ and $\delta^{13}C$.

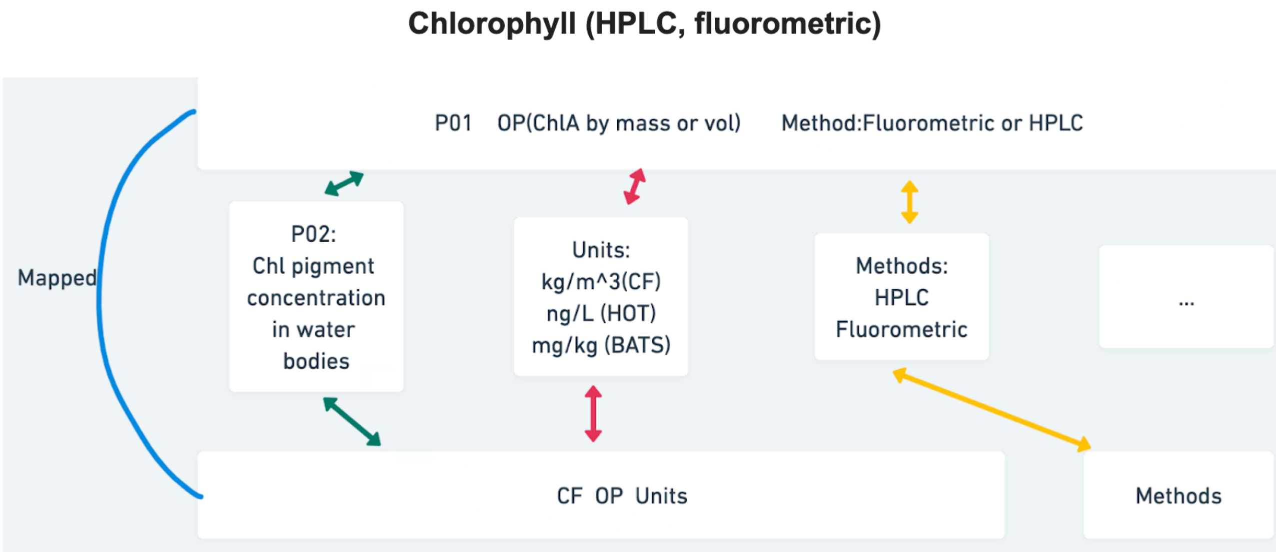


Figure 3. METS RCN mapping exercise for the ecological variable chlorophyll using controlled vocabularies from BODC and CF.

These draft metadata templates for chlorophyll, mesozooplankton biomass, primary productivity, and particulate fluxes were all shared among time series programs during the workshop. The final metadata templates are available for download at https://zenodo.org/communities/mets-rcn/records.

Improving Data Discovery Through ODIS

The METS RCN recognizes the need to improve time series data discovery across data repositories and global search engines as a first critical step in elevating their overall FAIRness. Focusing on the socio-technical challenges of aggregating metadata across global time series stewards, the Bermuda workshop identified the use of the schema.org vocabulary as the most effective strategy to gather and publish machine-readable metadata with the broadest reach. Following guidelines at Science-on-Schema.org (Shepherd et al, 2024) and the Ocean InfoHub Project (Fils et al., 2024), participants arrived at a low-cost mechanism for describing time series metadata using a collaborative Google Sheets document.

The document allows time series stewards to share metadata for the following concepts - Time Series Project, Cruises, Locations, Awards, People, Organizations, Datasets, Variables, and Data Files. Each concept is represented in the sheet as a single tab (or sheet). Each tab represents a class or concept in the Schema.org vocabulary and each column represents a Schema.org property associated with its respective class/concept. Importantly, every sheet has an identifier column where each cell in that column must be unique. Then, these identifiers are used in other sheets for corresponding properties that then link concepts to each other - Cruises to People, Datasets to Cruises, Variables to Datasets, Organizations to People, etc.

Simple parsing code (Shepherd et al, 2025) in Google Colab was written to transform the Google Sheet into Schema.org data encoded as JSON-LD, a JSON-based Resource Description Framework

(RDF) encoding. Because RDF encodes and encourages semantic links between its data elements, the Google Sheet, transformed into RDF, can generate a network graph (See Figure 4) that can be used to analyze communities and correlations in the data.

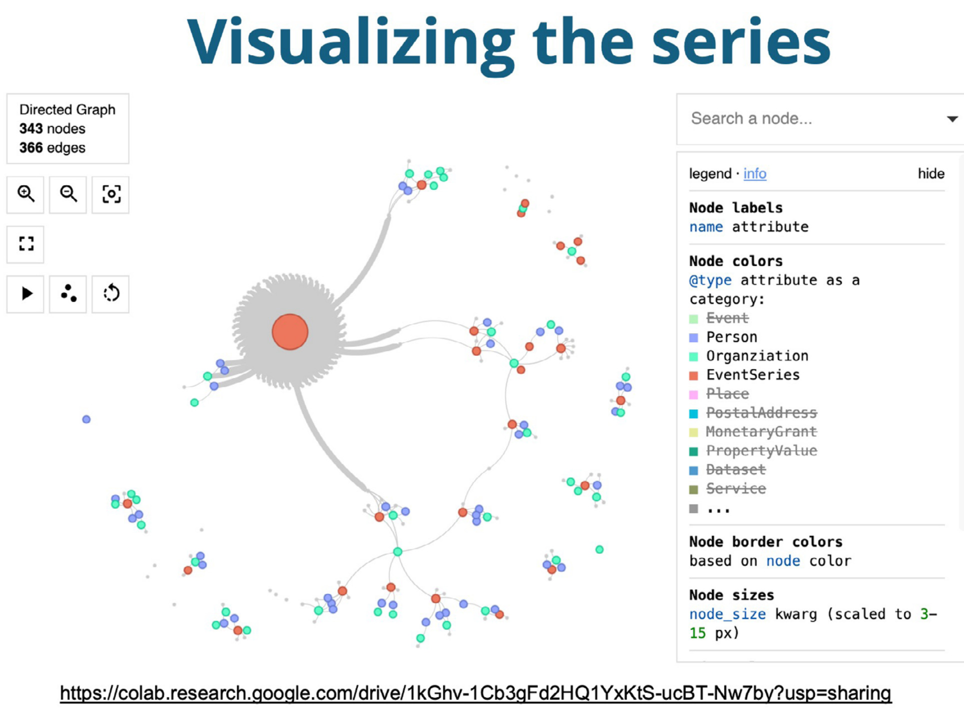


Figure 4. A network diagram of the Time Series Google sheet as participants begin to link and reuse shared concepts in their own metadata with each other. This diagram shows correlations between Organizations and People as they are related across different time series. (Figure retrieved from Shepherd et al, 2025)

With the Schema.org metadata encoded as JSON-LD, the OceanInfo Hub Project and its parent initiative The Ocean Data & Information System (ODIS), can publish this metadata to be exposed to global search engines as well as the international oceanography community. ODIS is a coordinated program at The International Oceanographic Data and Information Exchange (IODE) of the Intergovernmental Oceanographic Commission (IOC) of UNESCO.

The continued success of this work will depend upon two additional efforts:

1. **Adoption and integration of the templates by time series projects** into their local workflows to bring consistency to data and metadata reporting and employ the standards that will facilitate discovery and interoperability across time series data; and
2. **Funding for collaborating repositories to implement the templates** (e.g., BCO-DMO for US NSF-funded time series programs, NOAA National Centers for Environmental Information [NCEI]) to generate and expose the resulting RDF for harvest by ODIS, thereby facilitating discovery and effective reuse of METS data.

4. Outcomes of FAIR Implementation

Data visualization tools

webODV

webODV is the browser-based counterpart of the widely used Ocean Data View (ODV) desktop software for the analysis and visualization of marine and environmental data. Within METS, we have set up a dedicated webODV instance at https://hot.webodv.awi.de to provide access to the HOT data. SPOTS data were retrieved from BCO-DMO (https://www.bco-dmo.org/dataset/896862) and integrated into webODV. The conversion from BCO-DMO format to ODV sought to preserve as much information as possible. This includes, for example, links in the metadata to the original BCO-DMO sources and the METS RCN project. Furthermore, we maintained the data-variable links to the NERC vocabulary service and quality flags, which can be used in webODV for detailed data filtering and quality control.

During the workshop, the SPOTS dataset in webODV was presented, along with several visualization and data download options. In addition, new functions in ODV-online were demonstrated, which allow seamless data exchange between different webODV servers using a simple real-time copy/paste procedure. This functionality is particularly useful for comparisons, validation studies, quality control, and more. As a practical example, Argo data were copied from https://argo-webodv.vm.fedcloud.eu/ into a HOT dataset at https://hot.webodv.awi.de/ to perform a comparison study.

Looking ahead, an extension of webODV discussed was ensuring compatibility with ODIS and schema.org standards. In this context, a webODV API capable of importing and exporting ODIS/schema.org-compliant data will support future work with METS data, once the data have been converted to and implemented within ODIS.

BGC-Argo

The Biogeochemical-Argo (BGC-Argo) Program (https://biogeochemical-argo.org/) is a network of biogeochemical sensors onboard Argo profiling floats. The program is a member of the OneArgo Program which includes the Core Argo and Deep Argo Programs. The motivation of this network is to maintain a global ocean monitoring system for a variety of biogeochemical parameters while also providing open access data to any and all users interested in using BGC-Argo data. The goals of this program are guided by the Argo Steering Team and Argo Data Management Team, and requires strong global collaboration from the over 16 nations who participate. FAIR practices allow the program to collaborate internationally, provide open-source data to users across a large spectrum of experience levels, and contribute to studies and projects..The METS workshop provided a platform to demonstrate the overlaps and complementarity between the BGC-Argo Program and METS. BGC-Argo often deploys new float platforms or sensor types in regions of well-observed time series to allow for historical data validation of new technologies. In return, the spatial and temporal frequency of BGC-Argo floats allows to fill in gaps between time series sampling and provide further context on spatial and temporal variability around time series stations.

During the METS workshop, two BGC-Argo Program resources available to the METS community were demonstrated. This included a demonstration of accessing and visualizing BGC-Argo data through web-ODV as well as a walk-through of a new toolbox called the OneArgoToolbox, which is designed to make BGC-Argo data easy to access, download and visualize amongst many other useful tasks. Attendees of the OneArgoToolbox session practiced accessing the BGC-Argo data using NERC vocabulary to locate the BGC-Argo data they would like to use, and experimented with the different additional arguments like quality flags, time ranges, and plot types that make visualize data. In addition, the session sparked discussion on use cases of this toolbox like data validation and small-scale variability comparisons. The OneArgoToolbox is available for free download at https://github.com/NOAA-PMEL/OneArgo-Mat. While the session demonstrated the Matlab compatible toolbox, advancements are being made on the Python and R compatible toolboxes to expand access to users of different coding languages.

METS Data Analysis: Challenges & Solutions

One of the first challenges in analyzing and intercomparing METS data comes from their wide variety of sampling frequencies and methods. Sampling frequencies can be hourly or daily (e.g., moorings and pier mounted samplers), weekly (e.g., estuarine or HAB monitoring programs), monthly (e.g., shipboard programs such as HOT and BATS - this approach is quite common because it provides a full seasonal overview), or semi-annually to decadally (e.g., global ship surveys or work in remote regions or areas with seasonal ice cover). While standardized sampling methods are common for hydrographic and biogeochemical variables (e.g., temperature, salinity, nutrients, carbon), the methods used to collect plankton variables vary greatly and depend on the original purpose of the sampling. For example, a time series focused primarily on tracking fish larvae might use a 300-500 µm mesh net, while a time series focused on smaller copepods would probably be 200 µm or less. The sampling frequency and intensity may also change seasonally within a time series program, especially if it increases sampling to focus on periods of heavy fish spawning or meroplankton production. Even with identical methods, there comes the challenge of how to meaningfully compare trends from a 10-year time series with a 50-year time series.

The IOC-UNESCO International Group for Marine Ecological Time Series (IGMETS, https://igmets.net) introduced one approach to addressing these challenges, featuring an analysis of over 340 ship-based time series ranging from 10-30 years in length, including varying subsets of variables such as temperature, oxygen, nutrients, diatoms, copepods, and total zooplankton biomass. The IGMETS methodology (O'Brien et al., 2017) addressed differences in frequency by binning the data to monthly and annual averages. Differences in duration were addressed by subsetting the data into time windows. Finally, differences in methods were addressed by using ratio-based anomalies and relative rates of change. IGMETS's unitless approach enabled different methods and even different variables to be compared temporally and/or spatially. For example, this method might reveal that during the last 10 years, copepod abundances increased by a factor of 1.4 while diatom abundance and chlorophyll concentrations decreased by a factor of 3, but when looking at the last 30 years, all three variables were decreasing over time and lower than their 30-year averages.

The IGMETS methodology is based on 20+ years of multiple time series intercomparison studies and methods development by SCOR Working Group 125 (e.g., Mackas et al. 2012, Mackas & Beaugrand 2010), the ICES Working Group on Zooplankton Ecology (e.g., https://wgze.net, O'Brien at al. 2013), and COPEPOD (https://copepod.org, O'Brien and Oakes 2020). These methods all attempted to balance inclusivity (of participating time series) with the capabilities of the data sets available. For example:

- There are considerably more time series of 10-20 years in length (i.e. allowing for better spatial coverage in an ocean-wide or global study), but in many ocean regions, clear climate signals are not evident in METS variables until 30+ years of data are available. Longer time window studies might reveal more but generally have fewer time series included.

» Most of the longest running time series are limited to a few sampling cruises per year. While these data are suitable for interannual studies and comparisons, they may not be useful in monthly or seasonal studies. Further, due to ship time logistics, most monthly time series are along coastlines and not in open water.

» With the exception of the Continuous Plankton Recorder survey, most of the longest running (50+ years) zooplankton time series only include total biomass measurements. While total biomass can illustrate long term changes in total zooplankton production, the (often shorter) species abundance time series are needed to determine what is causing these changes and how they shape the food web. For example, an increase in total zooplankton biomass might appear "good", unless it is due to increases in gelatinous species that mask a decrease in key fisheries-supporting copepod species (e.g., Heneghan et al., 2023). Importantly, many of the longest running biomass time series have used total displacement volume, while Japan and some of Europe have used wet mass. Both methods are extra sensitive to gelatinous species (which are mostly water). However, more modern sampling programs usually do dry mass or carbon mass, which reduces the signal of gelatinous (i.e. dry = no water) vs. crustacean-based changes in biomass. Even a "better" total dry mass biomass time series will not reliably indicate which groups/species are disappearing or growing. Microscope- and/or optically-based, taxonomically-explicit methods are still needed to make this assessment.

METS Data Product Example: SPOTS

During the METS workshop, SPOTS's pilot was presented and advertised to the wider METS community. SPOTS's metadata templates that were developed to create ODIS nodes for the stations included in SPOTS's pilot were discussed, and some of the general building blocks are now adapted from the wider METS community for inclusion in ODIS.

SPOTS enhances data readiness (Lindstrom et al., 2012) and implements FAIR data practices for all included stations by making BGC EOV (meta-) datasets from all included stations consistent, comparable, and ready to use. In particular, the SPOTS implementations of ERDDAP (Environmental Research Division's Data Access Program) and ODIS demonstrate important steps forward in adopting FAIR data practices. As an important first step, more time series stations becoming an ODIS node is crucial, for each individual station and for the continuation of SPOTS and a FAIR METS community. SPOTS can act as an automated data broker that synthesizes data beyond all METS ODIS nodes.

Broader Applications

The SyncED-Ocean project (Synchronising Earth Observation and Modelling Frameworks Towards a Digital Twin Ocean) was a demonstration of an environmental digital twin that closely coupled modelling capabilities and multi-domain data collection for a prolonged period in the summer and autumn of 2024. SyncED-OCEAN aimed to enhance understanding of phytoplankton bloom dynamics by integrating satellite Earth Observation (EO) data with in-situ measurements from autonomous, crewed, and fixed platforms. The project deployed a two-way digital twin system that assimilated multi-source data in near real-time, guided autonomous underwater vehicles via automatically generated mission plans. This architecture provided a testbed for evaluating the practical implementation of FAIR data principles in a complex marine monitoring context.

SyncED-Ocean's federated data architecture played a central role in ensuring data findability and accessibility. By providing a framework that allowed standards to be followed by each data-creating community, the project provided a harmonized and machine readable collection of near-real time datasets that could be accessed by all data consuming applications within the project.

SyncED-Ocean integrated contributions from multiple scientific communities, each with distinct data standards and workflows. Through the application systems engineering approaches and adherence to shared metadata and quality protocols, the project enabled data exchange and assimilation into the virtual twin model.

One outcome of the SyncED-Ocean deployment was the recording of observations and lessons throughout its development and deployment (Mansfield et al., 2025). These lessons informed improvements in system design, particularly in managing trade-offs between data quality and timeliness, a key consideration for closed-loop digital twin systems. Moreover, the emphasis on human-in-the-loop visual monitoring tools ensured that data and system logic remained transparent and interpretable, supporting future reuse in both operational and research contexts.

By applyingFAIR principles throughout its architecture, from data collection and calibration to modeling and visualization, SyncED-Ocean demonstrated how environmental digital twins can deliver high-impact outcomes.

The project's success in pulling together quality flagged data from a range of communities in near real time underscores the importance of FAIR data principles in enabling time series data to be used in emerging marine monitoring systems, paving the way for future deployments that leverage machine learning and autonomy to protect and understand marine ecosystems.

5. Recommendations & Next Steps

Expanding and supporting the METS community

Improving communication and coordination mechanisms

Regular opportunities for connection are needed to ensure an enduring vibrant, productive, and collaborative METS community. Sustained international coordination could facilitate convergence towards common frameworks for data management and publication, reducing the current fragmentation between observation platforms and programs. This would optimize the technical and semantic interoperability of time series. Coordination, training, and open tools are fundamental. In-person and virtual gatherings across time zones are essential for standardization and training on tasks like metadata reporting, FAIR tools and tutorials, sharing new science outcomes and/or methodological updates to continue the momentum of the METS RCN. These interactions would also be requisite for existing time series with disparate data models to move towards FAIR data practices without unrealistic investments of personnel and financial resources.

Improving knowledge transfer and exchange

Technical visits and exchanges are valuable for community building and enhancing the collective capacity of the time series community. Technical exchange programs can play a key role in strengthening international communities of practice, facilitating convergence towards shared protocols for data collection, management and publication. Such opportunities are especially impactful for smaller METS programs, providing access to and training in new "state-of-the-art" technology, best practices and quality control procedures, sharing datasets, and setting the stage for collaborative research. This enhances the consistency and comparability of time series, whilst strengthening local capacities in quality control and data management. Entraining information science communities in such efforts can help infuse emerging technologies and practices into disciplinary METS applications. Data infrastructures and repositories should be actively engaged to help support METS data management and publication. Incorporating such exchanges into the funding of individual METS, as well as identifying international exchange opportunities through groups like NF-POGO represents a small investment with a large community- and capacity-building payoff.

Data liaison concept: Enhancing connections between data collection and data science

There is a need for mechanisms to forge better connections between the data collection world and the data management world. One suggested mechanism for achieving these connections is the identification and funding of individuals or institutions with expertise in both domains, who can bridge the communication gaps that inevitably arise when diverse disciplines interact. Building personal connections is crucial for building trust and establishing a solid foundation for this initiative. A "data liaison"—a person or group knowledgeable about (meta) data and trained in metadata collection—can facilitate face-to-face interactions with METS seeking to modernize their data models. These liaisons will help both parties engage and discuss their work effectively, ideally speaking the language of the institution being visited.

Initially, the role of the data liaison will involve in-person visits to meet with PIs who manage time series. The goal is to communicate the value of their time series, emphasizing the importance of making them more discoverable and future-proof through metadata reporting, while also ensuring that PIs receive appropriate credit for their contributions. Data liaisons could feasibly be supported by individual grants to facilitate this role or ideally through a research coordination.

To build trust, the data liaison will conduct one-on-one meetings and focus on the significance of metadata. They will conduct interviews to obtain a basic subset of data, gaining intimate knowledge of which metadata columns can be entered into the system. This support will help PIs fill out the metadata for their time series. The focus is on humanizing the metadata preparation process, which will eliminate many potential problems and errors later on, smoothing the process of preparing data for submission. Importantly, the data liaison will not collect actual data unless the PI explicitly requests assistance with that.

These data liaisons will work for one or two years, serving as continuous points of contact to identify and collect metadata for as many marine time series as possible. This ongoing support will enhance and improve the overall quality of data management within the oceanographic community. The end goal is to aggregate standardized metadata for as many globally distributed METS as possible for entry into ODIS. This effort would pave the way towards continued development of data products such as SPOTS and synthetic ecological assessments such as IGMETS.

Training in and support for implementing FAIR data practices

Many mature METS need access to and training in the use of FAIR tools and practices to document and share legacy datasets they already have. Most METS do not have dedicated resources to support the time and effort required and many are operating with data formats and metadata conventions developed decades ago. The METS RCN provided community engagement across the data and ocean science communities and championed tangible tools and approaches for achieving FAIR data systems. Sustaining and amplifying this effort and socializing its products and outcomes (beyond the lifetime of and time series programs involved in this RCN) will require continued investment of time and resources in collaboration and capacity building. We need to train ourselves and the next generation to take charge of entering this data into the system. Generational continuity is essential, so integrating knowledge and approaches for FAIR data systems should start in graduate school. Hackathons are effective hands-on activities to generate connections and expand knowledge in this area.

Documenting and harmonizing methodologies for synthesis

Documentation of methods as part of METS metadata reporting is essential for enabling reuse. Continual comparison of METS sample collection and analysis protocols is helpful for optimizing methods, assessing the comparability of datasets, and enabling analysis and synthesis across METS sites. However, it should be noted that comparative analyses across sites are still possible without strict standardization of methods, as demonstrated by the Long-Term Ecological Research (LTER) Network. From an ecological perspective, information on relative changes in biomass and trends between time series can be just as valuable as having absolute change values.

Improving and expanding funding models

Funding models for time series data vary significantly between nations, funding sources, and specific time series. Government sources provide mechanisms for ensuring future funding; however, this often depends on individual countries, as each government sets its own monitoring mandates, which can vary in duration. The current reliance on short-term contract funding is not sustainable and poses challenges in securing consistent financial support. Changes in governmental policies and mandates increasingly seek to demonstrate societal benefits. Consequently, time series will need to justify their contributions to society, particularly in the U.S. and other European countries. Some time series are sustained due to ongoing "hot issues," such as harmful algal bloom monitoring, marine heatwaves and ocean acidification. It is essential to justify the importance of this data to industries such as fisheries, transportation, deep-sea mining, and tourism, to secure future government funding.

Moreover, there is a need for unconventional funding sources, particularly from the private sector and philanthropic organizations. To achieve this, we may need to shift the narrative surrounding time series data beyond just long-term climate change, which has rarely been the impetus for initial funding of METS. The private sector must recognize that time series data are available and valuable. For example, marine carbon removal initiatives, a relatively new and growing field, require robust time series data, and insurance companies can utilize these data for risk assessments and predictive modeling.

Communicating the value of time series more broadly

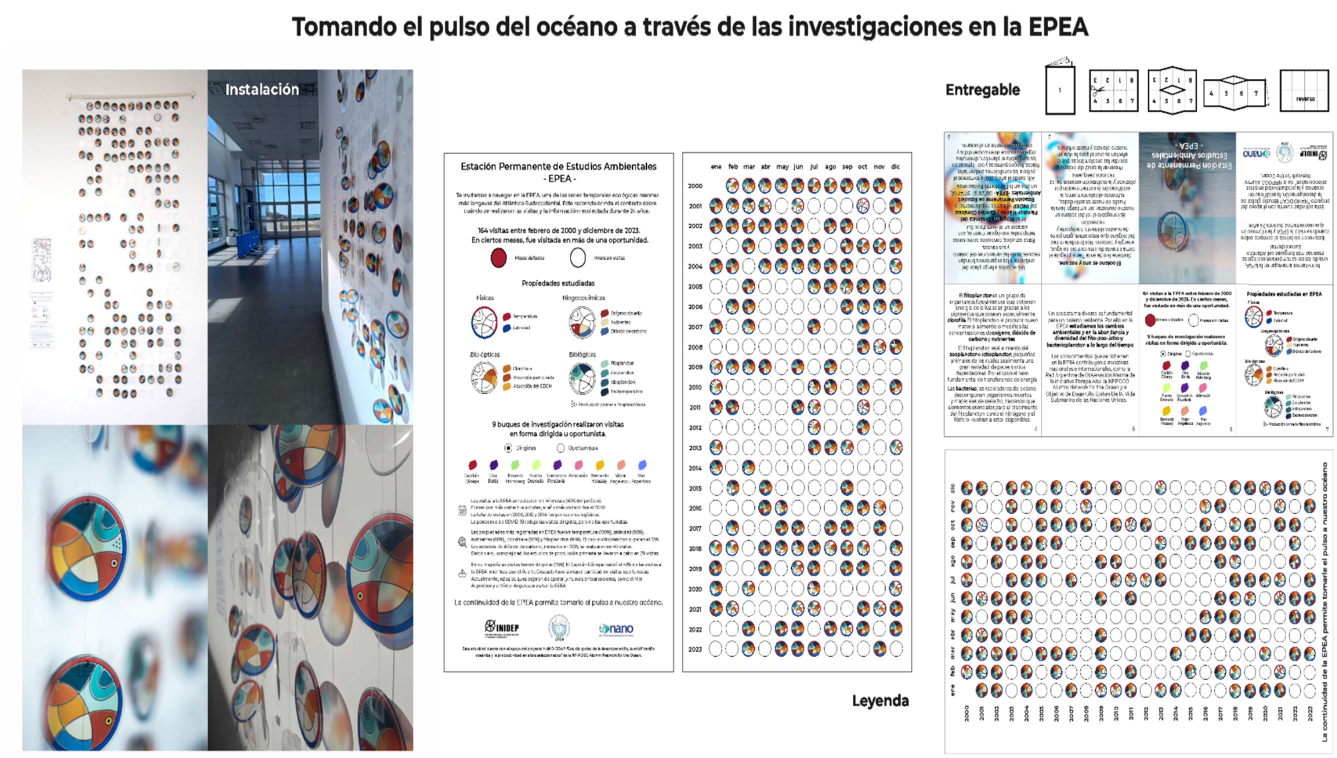


Figure 5: Art installation led by C. Berghoff highlights ecosystem changes over time (2000-2025) as recorded by observations of the EPEA time series in coastal waters of Argentina. Based on the artistic visualization, a [web application] was developed to allow users to explore the observations through their metadata. The application is automatically updated after each visit to the EPEA station.

We need to highlight the importance of and elevate the visibility of time series observations on local and regional scales. Time series observations are not just applicable to research on climate and marine ecosystem change; they also provide information on socioeconomically important indicators such as harmful algal bloom activity, fishery health, pollution, hypoxia, acidification, and carbon uptake and durability in mCDR field trials.

The utility of METS for outreach, education and engagement of the public can also not be understated. Fully realizing the value of the datasets requires connecting with potential users outside the academic research community. Some METS have hosted successful education and outreach programs to expand their reach in the community. For example, Plymouth Marine Laboratory has conducted virtual reality tours that allowed people to "walk through the data," and Munida TS Station invites people to participate in a cruise, providing a high level of detail about the time series. Education and outreach efforts should be aggregated and shared so that we can replicate and perpetuate these efforts.

Often, time series are asked to demonstrate their value to the public, but showing this value can be challenging and difficult to conceptualize. It is necessary to initiate a cultural shift to attract broader public interest and improve ocean literacy to convey the impact. Exhibitions/communications, collaborations with artists, and other innovative ways to make time series more accessible (marketing, branding, visibility, community connection) are essential. We should apply Tilden's Principles of learning and environmental stewardship (Tilden, 1957) to understand, appreciate, and advocate for the importance of these time series data. Engaging all ages—exciting children and adults alike—contributes to the well-being of people now and in the future.

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7. Appendix: Workshop Materials

METS-RCN
EarthCube RCN for Marine Ecological Time Series

International Workshop: FAIR Data Practices for Ship-based Marine Ecological Time Series

April 22-25, 2025 (ASU/BIOS, Bermuda)

WORKSHOP AGENDA

Tuesday, April 22	Agenda is in local Bermuda time ADT (UTC-3)
7:30	Breakfast (Grotto Bay Resort served in the Hibiscus Restaurant) - to-go and sit down options available
8:15-8:45	Transport to BIOS (2 pick-ups)
Introduction: Setting the Stage	
9:00-9:05	**Welcome remarks** (Bill Curry, President and CEO, Bermuda Institute of Ocean Sciences)
9:05-9:30 *streaming*	**Introduction to the Marine Ecological Time Series Research Coordination Network (METS-RCN)** (Heather Benway, WHOI/OCB & Danie Kinkade, WHOI/BCO-DMO) Hanson Hall for all plenary content - RCN overview, pre-workshop survey results, and **workshop goals and deliverables:** 1. Build capacity & provide tools to guide FAIR implementation for marine ecological time series 2. Share metadata templates for commonly measured ecological and biogeochemical parameters 3. Share & discuss tools/resources for data visualization, synthesis & analysis, citation (DOI), decision support 4. Update time series sampling & analytical methods recommendations 5. Build community - share science outcomes, challenges & opportunities
9:30-10:00 *streaming*	**Why do we need FAIR?** (Adam Shepherd, WHOI/BCO-DMO) - intro to FAIR challenges, informatics primer, **GOAL 1**
10:00-10:20 *streaming*	**Introduction to METS FAIR Data Primer** (Danie Kinkade/Audrey Mickle, BCO-DMO/WHOI) - **GOAL 1**

10:20-10:40 *streaming*	**Relevance & visibility: ODIS Ocean InfoHub background & demonstration** - raising the visibility of ocean time series data, realizing their broader significance & cross-disciplinary applications (Pier Luigi Buttigieg, AWI) **GOAL 1**
10:40-11:00 *streaming*	**Synthesis Product for Ocean Time Series (SPOTS): A novel use case** (Nico Lange, NORCE) **GOAL 3**
11:00-11:10	Stretch your legs and grab a coffee/tea!
11:10-11:35 *streaming*	**Short summary of FAIR data concerns (pre-workshop survey results) followed by open discussion/Q&A** **GOAL 5** • Open vs. FAIR • Hurdles to implementing FAIR (for data generators & repositories) • FAIR as a continuum
11:35-12:00 *streaming*	**Participant Introductions**
12:00-13:30	Lunch (BIOS Cafeteria) - **BIOS gift shop is open, drink ticket purchases for poster session later**
FAIR Examples	
13:30-13:45 *streaming*	**Biogeochemical-Argo** - highlight ecological float measurements and calibration procedures, process of achieving FAIR (Ken Johnson, MBARI)
13:45-14:00 *streaming*	**OceanSITES** - calibrating moored time series using ship-based ecological data, process of achieving FAIR (Raquel Somavilla, Instituto Español de Oceanografía, virtual)
Introducing the Metadata Templates - GOAL 2	
14:00-14:10 *streaming*	**The motivation: Why did we create these templates?** (Nico Lange, NORCE)
14:10-14:20 *streaming*	**Implementing the templates: A human perspective** - bringing together BODC, ODIS, and SeaDataNet to achieve OIH visibility (Justin Buck, NOC)
14:20-14:30 *streaming*	**The process: Variables and workflows** (Angelicque White, Univ. Hawai'i)
14:30-14:40 *streaming*	**Instructions for reviewing templates** - participants will rotate among parameter stations to get an introduction to the metadata template for each parameter, ask Qs and provide feedback, also cycle through the data/informatics experts to talk about FAIR Data Primer

14:40-16:00	**Metadata template review** - participants will rotate to different "stations" focused on specific variables below to get an introduction to the metadata template for that variable, ask Qs and provide feedback (facilitated by Angel, Nico, Heather, Rut (virtual), Danie, Audrey) **GOAL 2** • **Chlorophyll, Mesozooplankton Biomass, Primary Productivity** (Hawai'i Ocean Time series Study (HOT) exemplar) - Hanson Hall • **Particulate fluxes** (carbon, nitrogen, phosphorus, opal, lithogenics, etc., Oceanic Flux Program (OFP) exemplar) - Sunderman Room (virtual) • **Biogeochemical parameters** (carbon, nutrients, oxygen, etc.) - MAGIC Room **FAIR Data Primer One-on-One** - chat with an informatics expert to learn more & ask Qs about METS FAIR Data Primer (facilitated by Adam, Pier Luigi, Justin, Charlotte) - Ryker Room **GOAL 1** *Virtual participants can review the metadata templates and METS FAIR Data Primer independently & participate in discussion at 16:00*
16:00-16:30 *streaming*	**Metadata templates - initial impressions & discussion** • Gather feedback on the template from participants • Identify hurdles to implementation • What are the next steps to distribute and socialize the templates?
16:30-18:00	**Poster and networking session** (Hors d'oeuvres & cash bar) **GOAL 5** (posters can remain up throughout the meeting for additional viewing during breaks)
17:3-18:00	Transport back to Grotto Bay Resort, dinner on your own (restaurant list)
Wednesday, April 23	
7:30	Breakfast (Grotto Bay Resort served in the Hibiscus Restaurant) - to-go and sit down options available
8:15-8:30	Transport to BIOS (2 pick-ups)
9:00-9:15 *streaming*	**Introduction to the day** - questions/comments about metadata templates
9:15-11:00	**Metadata template review** - participants will rotate to different "stations" focused on specific variables below to get an introduction to the metadata template for that variable, ask Qs and provide feedback (facilitated by Angel, Nico, Heather, Rut (virtual), Danie, Audrey) **GOAL 2** • **Chlorophyll, Mesozooplankton Biomass, Primary Productivity** (Hawai'i Ocean Time series Study (HOT) exemplar) - Hanson Hall • **Particulate fluxes** (carbon, nitrogen, phosphorus, opal, lithogenics, etc., Oceanic Flux Program (OFP) exemplar) - Sunderman Room (virtual) • **Biogeochemical parameters** (carbon, nutrients, oxygen, etc.) - MAGIC Room **FAIR Data Primer One-on-One** - chat with an informatics expert to learn more & ask Qs about METS FAIR Data Primer (facilitated by Adam, Pier Luigi, Justin, Charlotte) - Ryker Room **GOAL 1** *Zoom participants can review the metadata templates and METS FAIR Data Primer independently*

11:00-12:00 *streaming*	**Open Discussion: Ocean science meets data science** - what should be our tangible outcomes/next steps to promote awareness & use of these tools in the global ocean time series community (metadata templates, METS FAIR data primer)? **GOALS 1, 2**
12:00-13:30	Lunch (BIOS Cafeteria)
13:30-13:50 *streaming*	**Open vs. closed data: Understanding the data collection challenge** (relevant reading: **Big Data, Little Data, No Data**) (Justin Buck, NOC)
13:50-14:00	Q&A/Discussion
14:00-14:20 *streaming*	**Intermediate data sharing solutions to support synthesis science:** *Plankton Life Form Extraction Tool* (PLET) & *International Group for Marine Ecological Time Series* (IGMETS) (Todd O'Brien, COPEPOD) **GOAL 3**
14:20-14:30 *streaming*	Q&A/Discussion
14:30-15:10	Break
15:10-15:15	Kick off small group demos & tutorials (Heather give instructions)
15:15-17:00	**Small Group Demonstrations & Tutorials** (two 45-min. sessions so you should participate in two of the three activities) - Wednesday tutorial assignments • ***BGC Argo data access tutorials*** - product synergies between ship based time series and float data (Nicola Guisewhite & Ken Johnson, MBARI) - MAGIC Room **GOAL 3** • ***International Group for Marine Ecological Time Series (IGMETS) & Plankton Life Form Extraction Tool (PLET) tutorials*** - intermediate data sharing solutions to promote synthesis (Todd O'Brien, COPEPOD) - Ryker **GOAL 3** • ***Updating biogeochemical and biological time series methods recommendations*** (Bermuda 2012 workshop, updated METS parameters list, updating recommendations in Lorenzoni & Benway, 2013) (Heather Benway, Angel White, Rod Johnson) - Hanson Hall **GOAL 4**
17:00-17:15	Participant reactions to tutorials
17:15-17:45	Transport back to Grotto Bay Resort **- optional BIOS tour for the late bussers!**
18:30	Gather at The Swizzle Inn for appetizers and networking time, dinner on your own
Thursday, April 24	
7:30	Breakfast (Grotto Bay Resort served in the Hibiscus Restaurant) - to-go and sit down options available
8:15, 8:30	Transport to BIOS (2 pick-ups)
9:00-9:15 *streaming*	**Introduction to the day** - questions/comments
9:15-9:30 *streaming*	**Data Citation & Metrics of Success:** Ensuring time series datasets are credited and that provenance to original data is preserved -case study: Complex Data Citation Working Group (Justin Buck, NOC) **GOAL 3**
9:30-10:00 *streaming*	Q&A and data citation brainstorming discussion
10:00-10:15	Stretch your legs and grab a coffee/tea!

10:15-12:00	**Small Group Demonstrations & Tutorials** (two 45-min. Sessions so you should participate in two of the three activities) - Thursday tutorial assignments • ***Synthesis Product for Ocean Time Series (SPOTS) -*** extra insights and future development (Nico Lange, NORCE & Kim Currie, NIWA joined virtually by Adrienne Sutton, NOAA & Maciej Telszewski, IOCCP) Sunderman Room **GOAL 3** • ***Data visualization tools*** - BGC-Argo (Nicola Guisewhite & Ken Johnson, MBARI), Plotly & Dash (Marina Frants, SIO), webODV and SPOTS (Sebastian Mieruch, AWI) MAGIC Room **GOAL 3** • ***Broadening applications of marine ecological time series data -*** case study: In situ ocean data digital twin for decision support (Thomas Mansfield, PML) Ryker Room **GOAL 3**
12:00-13:00	Lunch (BIOS Cafeteria)
13:00-13:30	Work on Event Series entries (time series programs) Adam share code for converting entries to schema.org
13:30-15:00	**Future Needs:** Ideate in small groups on novel tools & resources to support the ocean time series community (FAIR data and metadata tools, data products (like SPOTS), community building activities (like IGMETS), methods/data intercomparison, etc.) (Breakout group assignments, note assigned **leader** and **notetaker** roles) • ***Group 1*** Sunderman Room • ***Group 2*** MAGIC Room • ***Group 3*** Ryker Room • ***Group 4*** Hanson Hall
15:00, 15:30	Transport back to Grotto Bay Resort and free time to explore (informal networking) **GOAL 5 - optional 20 min. BIOS tour for the late bussers!**
18:30-21:30	Workshop Dinner - Island BBQ! (Grotto Bay Resort)
Friday, April 25	
7:30	Breakfast (Grotto Bay Resort served in the Hibiscus Restaurant)
8:15, 8:30	Transport to BIOS (2 pick-ups)
9:00-10:30 *streaming*	Report out on previous day's *Future Needs* breakout discussions (10-15 minutes per group) followed by open discussion • ***Group 1*** Reporter: B. Cataletto • ***Group 2*** Reporter: S. Van de Velde • ***Group 3*** Reporter: S. Ólafsdóttir • ***Group 4*** Reporter: C. Berghoff
10:30-11:00	Stretch your legs and get a coffee/tea!
11:00-12:00 *streaming*	**Develop METS workshop report outline & plans for other products** (metadata templates, FAIR Data Primer, updated methods recommendations, etc.)
12:00-13:00	Adjourn workshop and farewell lunch (BIOS Cafeteria)
13:00	Transport back to Grotto Bay Resort, orchestrate shuttles to airport

Participant List

First Name	Last Name (Surname)	Affiliation
Heather	**Benway**	WHOI
Carla	**Berghoff**	INIDEP
Leocadio	**Blanco Bercial**	Bermuda Institute of Ocean Sciences - Arizona State University
Marguerite	**Blum**	Monterey Bay Aquarium Research Institute
Alexander	**Brearley**	British Antarctic Survey
Justin	**Buck**	National Oceanography Centre
Pier Luigi	**Buttegieg**	AWI
Bruno	**Cataletto**	OGS, Italy
Eloise	**Chambers**	ASU-BIOS
Kim	**Currie**	NIWA
Bill	**Curry**	ASU-BIOS
Marina	**Frants**	Scripps Institution of Oceanography
Rebecca	**Garley**	ASU-BIOS
Melchor	**González Dávila**	IOCAG
Nicola	**Guisewhite**	MBARI
Helmke	**Hepach**	GEOMAR
Rod	**Johnson**	ASU-BIOS
Kenneth	**Johnson**	MBARI
Danie	**Kinkade**	WHOI/BCO-DMO
Nico	**Lange**	NORCE
Paul	**Lethaby**	ASU-BIOS
Mike	**Lomas**	Bigelow Laboratory
Mai	**Maheigan**	WHOI
Thomas	**Mansfield**	Plymouth Marine Laboratory
Rebecca	**May**	ASU-BIOS
Claire	**Medley**	ASU-BIOS
Audrey	**Mickle**	WHOI/BCO-DMO
Sebastian	**Mieruch**	AWI
Charlotte	**Miskin-Hymas**	British Oceanographic Data Centre, National Oceanography Centre
Enrique	**Montes**	NOAA
Kate	**Morkeski**	Woods Hole Oceanographic Institution
Todd	**O'Brien**	COPEPOD
Sólveig	**Ólafsdóttir**	Marine and Freshwater Research Institute, Hafnarfjörður, Iceland

Al	**Plueddemann**	WHOI
John	**Porter**	UVA
Nicole	**Poulton**	Bigelow
Digna	**Rueda-Roa**	USF
J Magdalena	**Santana-Casiano**	IOCAG
Adam	**Shepherd**	WHOI / BCO-DMO
Dominic	**Smith**	ASU-BIOS
Josh	**Stone**	Univ South Carolina
Emma	**Stuart**	ASU-BIOS
Sebastiaan	**Van de Velde**	Univ Otago
Di	**Wan**	Fisheries & Oceans Canada
Angelicque	**White**	University of Hawaii at Manoa
Virtual Attendees		
Nicholas	**Bates**	ASU-BIOS
Luiz C:	**Cotovicz Jr.**	Leibniz Institute for Baltic Sea Research Warnemünde (IOW) - Germany
Dana	**Gerlach**	BCO-DMO
Ricardo	**Letelier**	NSF Biological Oceanography
Frank	**Muller-Karger**	University of South Florida
Margaret	**O'Brien**	UCSB
Fernando	**Pacheco**	UH
Rut	**Pedrosa**	MBL
Damudar	**Shenoy**	NIO
Ingunn	**Skjelvan**	NORCE Norwegian Research Centre
Raquel	**Somavilla**	Instituto Español de Oceanografía
Cynthia	**Suchman**	NSF Biological Oceanography
Adrienne	**Sutton**	NOAA PMEL
Maciej	**Telszewski**	IOCCP
Annie	**Wong**	Scripps Inst. Oceanography
Liza	**Wright-Fairbanks**	NOAA Ocean Acidification Program

Learn more at https://www2.whoi.edu/site/mets-rcn/