














# NFDI4Earth

Documentation

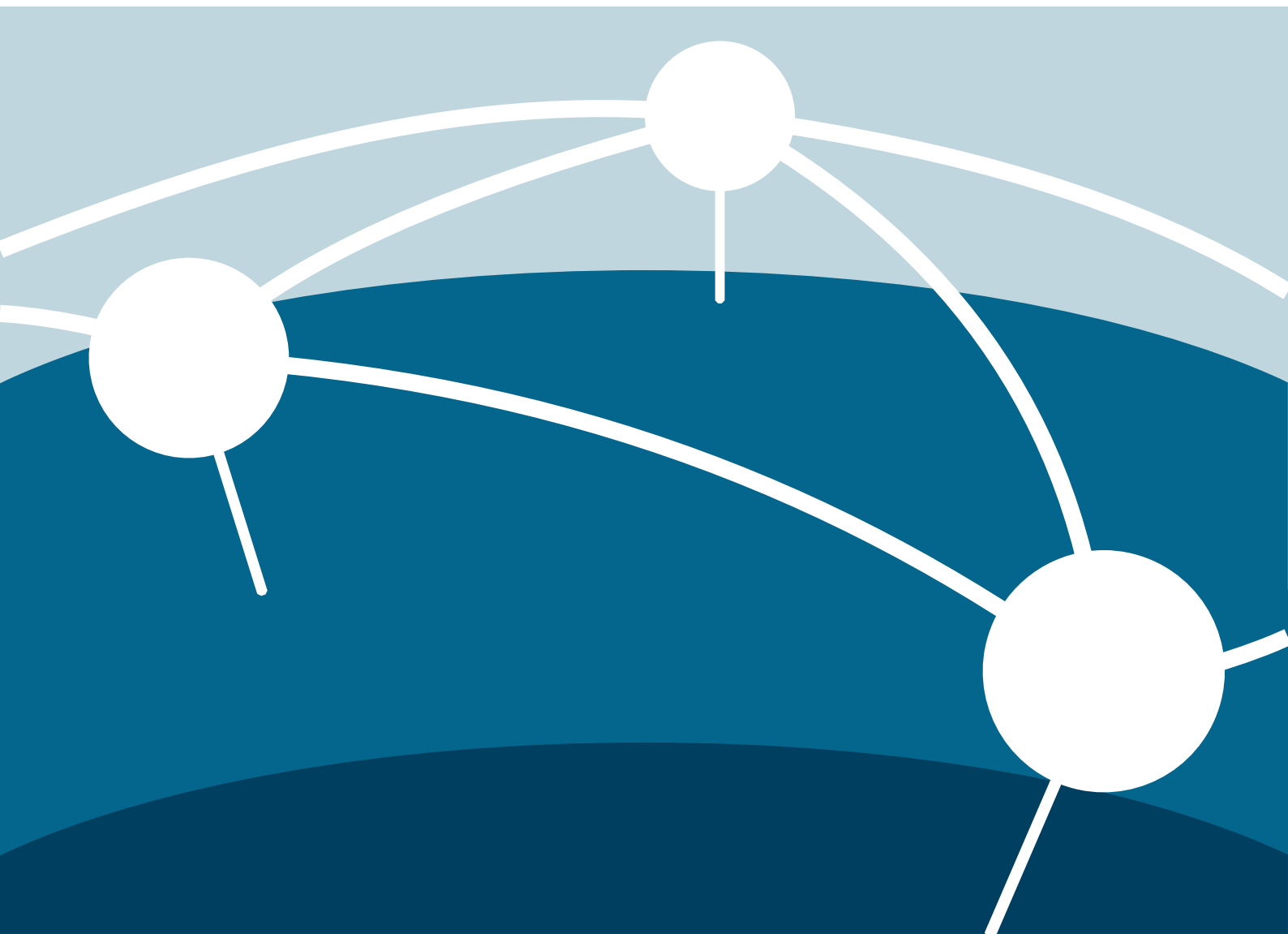
## NFDI4Earth Software Architecture

Christin Henzen  ([christin.henzen@tu-dresden.de](mailto:christin.henzen@tu-dresden.de)), Anna Brauer , Auriol Degbelo , Stephan Frickenhaus , Jonas Grieb , Stephan Hachinger , Ralf Klammer , Claudia Müller , Johannes Munke , Tom Niers , Daniel Nüst , Claus Weiland , Alexander Wellmann 

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[nfdi4earth.de](https://nfdi4earth.de)



## Executive Summary

This document provides a documentation of the NFDI4Earth Software Architecture. The documentation summarizes the major use cases, gives an overview on the requirement analysis approaches for the NFDI4Earth services, points out envisioned quality goals, and introduces potential stakeholders of the architecture. Specifically, the documentation provides externally and internally driven constraints that need to be considered when developing or contributing to NFDI4Earth services. We herewith facilitate, the users to better understand the solution strategy for the NFDI4Earth architecture.

We use the arc42 template for the documentation of software and system architecture. The detailed description of the NFDI4Earth architecture is done by using a blackbox-whitebox approach that describes the major aim, the main functionalities and interfaces of the services as seen by the outward facing properties first (blackbox), e.g., user perspective, and then provides details on the (inner) solutions, e.g., service components, implementations (whitebox).

The envisioned target group of the documentation includes software developers and architects as well as service providers.

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## Introduction and Goals

The mission of NFDI4Earth is to address the digital needs of the Earth System Sciences (ESS) for more FAIRness and Openness<sup>1</sup> in ESS research and in particular in research data management (RDM) practices.

We develop several services, and concepts within NFDI4Earth and reuse/integrate existing services when suitable. By doing so, we enable researchers, data experts, and software specialists to discover, access, analyse, and share relevant Earth data and related publications or tools.

NFDI4Earth supports the following use cases with common services:

1. Discover and explore Earth data sources
2. Support data publication and data curation
3. Solve a research data management problem
4. Create and publish information products, e.g., as services

The architecture of the NFDI4Earth describes the different services built to make resources from the ESS findable, accessible, interoperable and reusable, as well as the requirements for interfaces enabling their interaction.

In NFDI4Earth, we follow the service definition used in the [joint statement of NFDI consortia on basic services](#):

*A service in NFDI is understood as a technical-organisational solution, which typically includes storage and computing services, software, processes, and workflows, as well as the necessary personnel support for different service desks.*

The service portfolio is described in [Section Solution Strategy](#).

## Quality Goals

In this section, we describe quality goals synonymously used as a term to describe architecture goals with a long-term perspective. As the NFDI4Earth Software Architecture is evolving, we envision to regularly evaluate the prioritization of the quality goals. Following the ISO25010:2011<sup>2</sup> on software product quality, we consider the following quality goals for the NFDI4Earth Software Architecture:

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<sup>1</sup> <https://doi.org/10.5281/zenodo.10123879>

<sup>2</sup> ISO25010 Systems and software engineering — Systems and software Quality Requirements and Evaluation (SQuaRE) — System and software quality models. It includes the following quality goals: functional suitability, maintainability, portability, compatibility, usability, and reliability.

- **Functional suitability:** Degree to which the architecture provides functions that meet stated and implied needs when used under specified conditions.
- **Maintainability:** Degree of effectiveness and efficiency with which the architecture can be modified to improve it, correct it or adapt it to changes in environment, and in requirements.
- **Usability:** Degree to which a component of the architecture can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use.

## Stakeholders

We consider the following roles for using the NFDI4Earth Software Architecture Documentation:

Role	Expectations
Internal developers of NFDI4Earth services	Find descriptions and specifications of NFDI4Earth-developed services and integrate the services within their own projects
External developers	Find specifications on how to use existing NFDI4Earth-developed services; Find descriptions on how to add services to the NFDI4Earth infrastructure;

## Architecture Constraints

The following requirements constrain the design and implementation decisions and processes for the NFDI4Earth Software Architecture:

No.	Constraint	Type	Explanation
1	NFDI4Earth Proposal	organisational, strategic and technical	The proposal provides the context and aims of the NFDI4Earth software architecture (see <a href="https://doi.org/10.5281/zenodo.5718943">https://doi.org/10.5281/zenodo.5718943</a> ).
2	NFDI integration and interoperability	technical, strategic	The NFDI4Earth software architecture must fit with relevant activities of the overall NFDI, e.g., with NFDI-wide basic service initiatives.
3	International integration and interoperability	technical, strategic	The NFDI4Earth software architecture will be embedded in international infrastructures.

No.	Constraint	Type	Explanation
4	Developer expertise, research interests, and availability	organisational, technical	The expertise, research interests, and availability of a distributed software developer team affect the software project management as well as the technology decisions.
5	Architecture team	organisational	Software decisions for NFDI4Earth services are made by the NFDI4Earth architecture team on suggestion and on agreement with the measure leads of the relevant service.
6	Developer team	organisational, conventions	NFDI4Earth cross-product implementations, guidance and conventions will be provided by the software developer team.
7	FAIR principles	technical	NFDI4Earth services should support the implementation of the FAIR principles.
8	Programming languages	technical	Services will be developed in an established programming language, e.g., JavaScript, Java, Python, C#, HTML, and follow the basic structures of a sustainable software project, e.g., testing, dependency management, documentation and internationalisation.
9	Free and Open Source Software	technical and strategic	NFDI4Earth services must be provided as Free and Open Source (FOSS) whenever possible. Used open-source solutions must be well established, documented and maintained, e.g., guaranteed by their long-term applicability.
10	Open standards / specifications	technical	NFDI4Earth services will reuse existing (preferably) or define open standards or specifications for all interfaces, when interfaces are relevant for the component.
11	Established software	technical	Chosen software products should represent established solutions, i.e.,

No.	Constraint	Type	Explanation
			they should have been available for several years and be embedded in a software developer network or be used in at least one NFDI4Earth-comparable project.
12	Loosely coupled services	technical	NFDI4Earth services must be loosely coupled using well defined interfaces and separations of concern to allow replacing (partial) software solutions, e.g., due to agile adaptations to user needs, changing requirements, or newly developed NFDI-wide solutions.
13	Software repository	organisational	The source code of the NFDI4Earth services must be managed in a software repository that allows contributions from NFDI4Earth participants.
14	Hosting at TU Dresden	technical, organisational	The NFDI4Earth services are hosted at TU Dresden Enterprise cloud and maintained by following the respective guidelines / regulations ( <a href="https://nfdi4earth.pages.rwth-aachen.de/architecture/devguide/">https://nfdi4earth.pages.rwth-aachen.de/architecture/devguide/</a> ).
15	Containerization	technical	NFDI4Earth services run in virtual containers, whenever possible.

## System Scope and Context

Today, there are numerous scattered and heterogeneous services supporting RDM in ESS. Some of them are project-based and do not have a long-term perspective or are not openly available to all researchers. In addition, the implementation of RDM concepts, FAIR principles and related concepts differ among researchers, institutions, and disciplines. NFDI4Earth contributes to aligning existing and emerging RDM services along FAIR and Openness principles and to working towards a unifying and long-term perspective for services. Thus, NFDI4Earth targets the consolidation and harmonization of research data-related services in ESS and linking these services into the NFDI4Earth software architecture (see <https://doi.org/10.5281/zenodo.5718943>).

The development of the NFDI4Earth architecture is supported and influenced by several external drivers. For instance, the architecture reuses / integrates well-known and accepted existing services, components, and resources from the ESS

community and infrastructure providers. Moreover, the NFDI4Earth architecture benefits and contributes to the activities of the national research data infrastructure (NFDI) in case of 1) consuming / integrating NFDI basic services (see <https://base4nfdi.de/projects>) and 2) developing strategies for reusing / integrating services across NFDI consortia.

The following aspects are beyond the scope of the NFDI4Earth Software Architecture:

- **Guarantee for availability and functional correctness of integrated services:** NFDI4Earth cannot ensure availability and functional correctness of integrated services. However, existing information on both aspects will be made available for the users.
- **Correctness of harvested or linked (meta) data:** Harvested or linked (meta) data are provided as-is by referencing the data source and information on curation / quality assurance when available.
- **Completeness of harvested or linked (meta) data:** NFDI4Earth integrates existing services with no claim to completeness.
- **Up-to-dateness of information:** NFDI4Earth will systematically evaluate several information during the project period. Due to the amount of harvested and provided information, NFDI4Earth will apply different strategies for the different resource types and data sources, e.g., a community approach to update or to notify needs for information update for exclusively provided (within NFDI4Earth manually collected) information.
- **Compliance for specifications and standards:** NFDI4Earth will not check compliance for external sources, but will provide existing information from the providers.
- **Business and operational models and sustainability for existing (external) project-based ESS services after funding:** NFDI4Earth will not host and maintain all existing (external) ESS services after the end of the services' project periods, but will first evaluate a proposed service against relevant functional and non-functional requirements.

## Solution Strategy

NFDI4Earth aims to reuse existing services or parts of the services to build a sustainable infrastructure for the ESS. Moreover, we target identifying and collaborating with sustainable services that act as data sources whenever appropriate and applicable.

The NFDI4Earth software architecture is, thus, organized along a service portfolio. The NFDI4Earth Service Portfolio contains all relevant services including



community services and NFDI4Earth-developed services addressing researchers' needs on the previously mentioned overall use cases.

***Community services** are either disciplinary services offered by NFDI4Earth partners or discipline-agnostic/multidisciplinary services offered by trustworthy providers, both open for community usage.*

***NFDI4Earth-developed services** serve as openly available central support backbone services designed to address ESS researchers' needs in research data management. NFDI4Earth-developed services are developed by a distributed software developer team from NFDI4Earth partner institutions.*

## Community Services

Information on community services was collected using a systematic approach. Taking the different types of provided resources into account, we either assessed data sources for the specific types of resources or performed a landscaping process with manual steps, e.g., conducting interviews with the service providers if there was no proper data source.

Data sources allow the harvesting of existing information via application programming interfaces (APIs). In NFDI4Earth, we harvest information on repositories and archives, data services, datasets, software, documents, standards and specifications, and education and training materials.

Here, we distinguish the following interaction types depending on the data sources' characteristics and scope:

<b>Data source's characteristics and scope</b>	<b>Actions</b>	<b>Example(s)</b>
The identified data source is <b>selected</b> to publish NFDI4Earth-developed resources	NFDI4Earth implements the publishing process, curates the metadata, and harvests the source.	<a href="#">NFDI4Earth Zenodo Community</a>
The identified data source provides relevant (meta)data for the <b>ESS community</b> . Meta(data) is managed and curated via the data source.	NFDI4Earth develops a metadata mapping in close collaboration with the data source and harvests the source.	<a href="#">DLR EOC Web Services Catalog</a>
The identified data source provides relevant	NFDI4Earth recommends managing metadata in the	<a href="#">Research Organisation Registry</a>

Data source's characteristics and scope	Actions	Example(s)
<p>(meta)data for the <b>research community</b>. Meta(data) is managed and curated as a <b>community-effort</b>. There is <b>no need for specific ESS adaptations</b>. By providing and updating information <b>NFDI4Earth contributes to the overall research community</b>.</p>	<p>related data source and assists if needed. Moreover, NFDI4Earth implements a proper harvester and provides an NFDI4Earth-developed workaround for resource providers who are not (yet) able to manage their metadata there, e.g., with manually curated and managed information.</p>	<p><a href="#">(ROR)</a> for the resource type organisations; <a href="#">WIKIDATA</a> to get NFDI4Earth member organisations; <a href="#">RDA Metadata Standards Catalog</a> and <a href="#">Digital Curation Centre (DCC)</a> for standards</p>
<p>The identified data source provides relevant (meta)data for the <b>research community</b>. Meta(data) is managed and curated as a <b>community-effort</b>. Metadata provided by the data source needs <b>regular updates</b> and/or <b>qualified information to tackle researchers' requirements</b>. By registering new resources in the data source, <b>NFDI4Earth contributes to the overall research community</b>, e.g., by facilitating multidisciplinary use cases.</p>	<p>NFDI4Earth recommends managing metadata in the related data source and assists if needed. Moreover, NFDI4Earth and the data source align strategies on updating and improving metadata for the registered services. NFDI4Earth and the data source collaborate on the development of metadata schemas that meet the ESS community's requirements. NFDI4Earth, thus, utilizes the data source to manage metadata and provide a sustainable service and API for metadata harvesting.</p>	<p><a href="#">Registry of research data repositories (re3data)</a> for the resource type repository and archive</p>
<p>The identified data source provides relevant (meta)data for the <b>ESS community</b> and acts as</p>	<p>NFDI4Earth recommends managing metadata in the harvested data sources and assists if needed.</p>	<p><a href="#">Helmholtz Earth and Environment DataHub</a> for the resource type dataset</p>

Data characteristics and scope	source's and	Actions	Example(s)
an <b>aggregator</b> by harvesting relevant metadata from distributed sources. Moreover, NFDI4Earth provides <b>additional community services</b> that act as potential data sources for harvesting and should be integrated.		NFDI4Earth and the data source align implementation strategies, co-develop solutions, such as harvesters, and provide common recommendations, e.g., on metadata schemas and APIs.	

The full list of harvested data sources is available at: <https://knowledgehub.nfdi4earth.de> and will be continuously adapted with respect to the following main goals:

- adding further sources to provide additional high-quality (meta) data or to reduce the number of manually collected (meta) data,
- linking metadata records and minimize duplication of information with respect to the quality of metadata,
- remove a source when it gets harvested by another source that is integrated in the NFDI4Earth software architecture or when the source is no longer maintained.

### NFDI Basic Services

Basic services provide specific community services. Following the general service definition as described in the Introduction, they additionally

- create added values for the consortia and their users
- typically bundle existing services
- are characterized by scalability and sustainable operating models
- must be effective over time and in terms of usage (trackable by KPIs)" (source: <https://base4nfdi.de/process/basic-services>)

Service name	Integration
IAM4NFDI ( <a href="https://base4nfdi.de/projects/iam4nfdi">https://base4nfdi.de/projects/iam4nfdi</a> )	NFDI4Earth needs authentication and authorization in the EduTrain learning management system to track the learner's progress and preferences.

	<p>We thus use the NFDI-AAI-provided AcademicID solution (see: <a href="https://doc.nfdi-aai.de">https://doc.nfdi-aai.de</a>).</p> <p>The integration is implemented as incubator in the IAM4NFDI project (<a href="https://incubators.nfdi-aai.de">https://incubators.nfdi-aai.de</a>).</p>
PID4NFDI ( <a href="https://base4nfdi.de/projects/pid4nfdi">https://base4nfdi.de/projects/pid4nfdi</a> )	NFDI4Earth actively contributes to the PID basic service as principal investigator and with providing use cases and derived requirements.
nfdi.software ( <a href="https://base4nfdi.de/projects/nfdi-software">https://base4nfdi.de/projects/nfdi-software</a> )	NFDI4Earth actively contributes to the basic service as principal investigator and with providing the Research Software Directory.
DMP4NFDI ( <a href="https://base4nfdi.de/projects/dmp4nfdi">https://base4nfdi.de/projects/dmp4nfdi</a> )	NFDI4Earth contributes with a use case to integrate existing services in RDMO.

## NFDI4Earth-developed Services

NFDI4Earth provides five central support services. The **Knowledge Hub** is the backend service that manages structured and interlinked metadata. It stores all metadata in RDF (Resource Description Framework) and is accessible through a SPARQL API. Through the use of the data management middleware Cordra that stores all manually-created and harvested metadata, the architecture supports the management of digital objects at scale and facilitates the mobilization of (ESS) data as FAIR Digital Objects. The **OneStop4All** provides a single entry point to find and explore ESS resources. The communication between the OneStop4All and the Knowledge Hub happens through the Knowledge Hub's SPARQL API and the OneStop4All search index.

The **Living Handbook** stores and manages web-based, interactive articles about topics relevant to the community and the documentation of the NFDI4Earth. It provides an editorial workflow to generate high-quality content for users and ensures giving credit to attract authors. Living Handbook articles are stored in the NFDI4Earth Gitlab, are harvested through the API and made visible in the OneStop4All.

The **EduTrain** learning resources are stored in an instance of the OPENedX learning management system (LMS) and are also harvested through the API.

The **User Support Network** is a distributed helpdesk based on a ticket system (Znuny) hosted at TU Dresden. The network is closely linked to helpdesks of the community services, e.g., the Helmholtz Earth and Environment DataHub.



Figure 1: NFDI4Earth-developed services

The following table provides an overview of chosen approaches and concepts:

Service	Approach(es)	Concept
Knowledge Hub	Question-based approach	The concept is described in the deliverable D4.3.2: <a href="https://doi.org/10.5281/zenodo.7950860">https://doi.org/10.5281/zenodo.7950860</a>
OneStop4All	User-centred design and scenario-based approach	The approach is described in deliverable D4.3.1: <a href="https://doi.org/10.5281/zenodo.10351658">https://doi.org/10.5281/zenodo.10351658</a>
Living Handbook	Scenario-based approach	The approach is described here: <a href="https://git.rwth-aachen.de/nfdi4earth/livinghandbook/livinghandbook">https://git.rwth-aachen.de/nfdi4earth/livinghandbook/livinghandbook</a>
User Support Network	Helpdesk concept based on longstanding practical experiences	The concept is described in the deliverable D2.2.2: <a href="https://doi.org/10.5281/zenodo.7895294">https://doi.org/10.5281/zenodo.7895294</a>
Education and Training Materials and Services (EduTrain)	Focus group, requirement analysis	The concept is described in the deliverable D1.3.1: <a href="https://doi.org/10.5281/zenodo.7940195">https://doi.org/10.5281/zenodo.7940195</a>

## NFDI4Earth-funded Community Software

The NFDI4Earth **Pilots** (<https://nfdi4earth.de/2participate/pilots>) are studies focused on providing solutions for specific needs of the ESS community. They are managed in the NFDI4Earth GitLab<sup>3</sup> and made discoverable through the

<sup>3</sup> <https://git.rwth-aachen.de/nfdi4earth/pilotsincubatorlab/pilots>

OneStop4All and integrated in the NFDI4Earth architecture whenever possible (see Requirements Overview).

The NFDI4Earth **Incubator Lab projects** (<https://nfdi4earth.de/2participate/incubator-lab>) are small blue-sky projects on innovative ESS RDM approaches with an experimental character. They are made discoverable through the OneStop4All and their source code and descriptions<sup>4</sup> are published for reuse by the ESS community.

## NFDI4Earth Virtual Research Environment

NFDI4Earth provides a virtual research environment for the development, piloting, and operation of NFDI4Earth software and services. The Web application service enables to hosting community solutions on an NFDI4Earth provided virtual machine. The service is operational and available at: <https://webapps.nfdi4earth.de>.

NFDI4Earth offers High Performance Computing (HPC) Resources for NFDI4Earth-related activities, such as pilot projects. Resource can be requested by following a structured process as described here:

[https://onestop4all.nfdi4earth.de/result/lhb-docs-HPC-Resources\\_Application.md](https://onestop4all.nfdi4earth.de/result/lhb-docs-HPC-Resources_Application.md)

Our NFDI4Earth helpdesk ([helpdesk@nfdi4earth.de](mailto:helpdesk@nfdi4earth.de)) supports the related tasks.

## Building Block View

### Whitebox Overall System

The NFDI4Earth software architecture provides two services that serve as entry points to several linked NFDI4Earth and community-developed services: the **OneStop4All** as human-readable interactive user interface and the **Knowledge Hub** as machine-interpretable interface.

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<sup>4</sup> <https://git.rwth-aachen.de/nfdi4earth/pilotsincubatorlab/incubator>

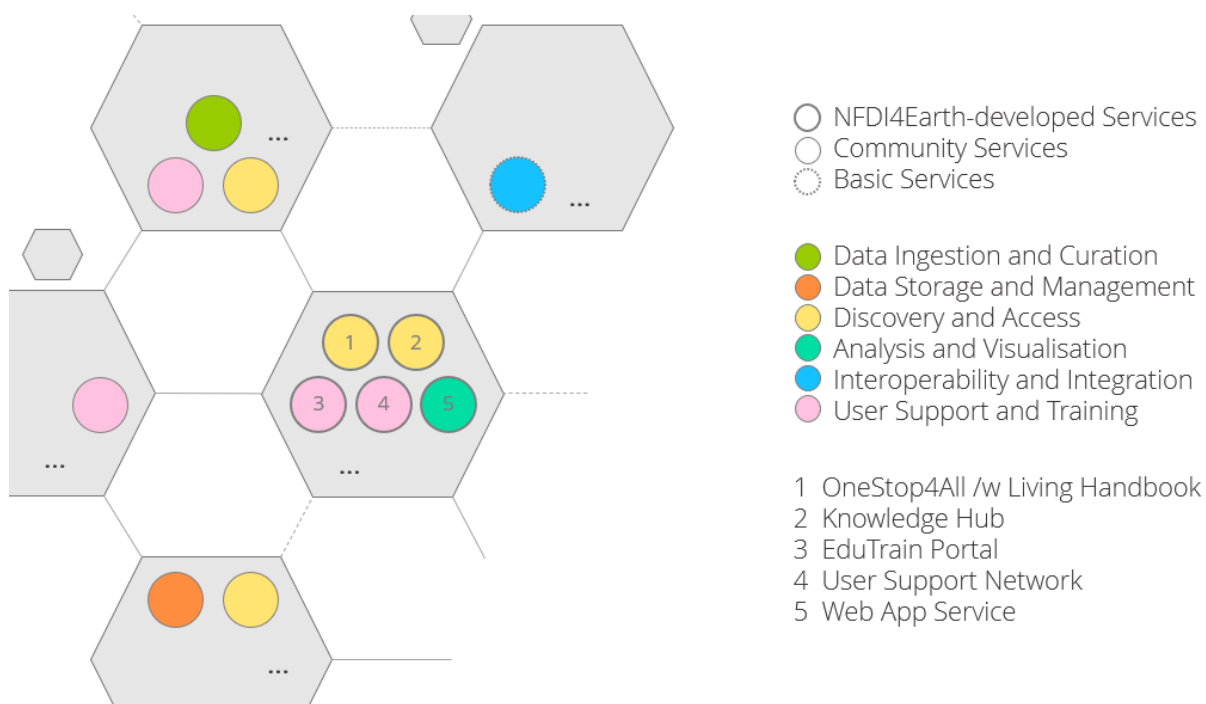


Figure 2: NFDI4Earth Software Architecture

### Blackbox Knowledge Hub

*This blackbox description is based on the Knowledge Hub concept one-pager and concept deliverable (<https://doi.org/10.5281/zenodo.7950859>; <https://doi.org/10.5281/zenodo.7583596>).*

The Knowledge Hub serves as one major backend service of NFDI4Earth. It integrates metadata about ESS resources and is accessed via an API.

Problem	Research products from the Earth System Sciences (ESS) are increasingly difficult to find. There is a need for tools that automate their discovery. 'Research products' is used here as a catch-all term that includes 1) datasets, 2) services, 3) tools, 4) vocabularies, 5) reports, 6) scientific papers, and 7) peer reviews, etc. .
Innovations	<ul style="list-style-type: none"> <li>• Structured and interlinked metadata for ESS resources produced in NFDI4Earth or relevant for the NFDI4Earth. These ESS resources can be any research product listed above, but also an article of the Living Handbook, or an educational material from the EduTrain. We use RDF (Resource Description Framework) as an encoding format.</li> <li>• Structured and interlinked metadata for ESS resources hosted by NFDI4Earth partners.</li> </ul>

	<ul style="list-style-type: none"> <li>NFDI4Earth label - compiled based on the available metadata - as an indicator of the extent to which services are FAIR, and in particular, the degree of interoperability of the services.</li> </ul>
Users	<ul style="list-style-type: none"> <li><b>Consumers:</b> people who have skills in programmatic data access (i.e., they are able to program a short snippet of code in a programming language to retrieve data).</li> <li><b>Producers:</b> these create/edit metadata for the Knowledge Hub. They may have programming skills (in which case they create/edit metadata, e.g., harvest, via the API of the Knowledge Hub) or have no programming skills (in which case they do the creation/editing via a user interface).</li> </ul>
Interface(s)	SPARQL API
Unit of adoption	Individuals

The Knowledge Hub is available at: <https://knowledgehub.nfdi4earth.de/>

### Blackbox OneStop4All

*This blackbox description is based on OneStop4All concept one-pager (<https://doi.org/10.5281/zenodo.7583596>).*

The NFDI4Earth OneStop4All is the primary visual and user-friendly NFDI4Earth access point.

Challenges	<p>Research products from the ESS community are diverse and increasingly difficult to find. There is thus a need for platforms that efficiently organize the access to ESS resources, in particular quality-assured resources. These platforms should be:</p> <ul style="list-style-type: none"> <li>User-friendly and easy-to-use, taking specific user characteristics and needs into account</li> <li>Flexible enough to integrate future RDM services (e.g., address multidisciplinary use cases with other NFDIs, link to EOSC services).</li> </ul>
Innovations	<ul style="list-style-type: none"> <li>Central search on NFDI4Earth resources and distributed sources, including relevant governmental, research and other open data sources</li> <li>Innovative user interfaces to explore the linked ESS resources that adapt to the needs of different user groups</li> </ul>



	<ul style="list-style-type: none"> <li>• Intelligent functionality to connect Living Handbook information for registered resources</li> <li>• Seamless transition from machine-based to human-based support</li> <li>• A community tool fostering the sharing of high-quality information and resources</li> </ul>
Users	<p>We envision the following types of primary users:</p> <ul style="list-style-type: none"> <li>• Users, who are looking for ESS research and ESS RDM information, e.g., events, networks</li> <li>• Users, who are looking for support, e.g., on NFDI4Earth tools or on how to use NFDI4Earth services</li> <li>• Users, who want to offer information/research products</li> <li>• Users, who want to provide feedback on the content</li> </ul>
Interface(s)	User interface
Unit of adoption	Individuals

The NFDI4Earth OneStop4All is available at: <https://onestop4all.nfdi4earth.de/>

### Blackbox EduTrain

*This blackbox description is based on the EduTrain concept one-pager (<https://doi.org/10.5281/zenodo.7583596>).*

The EduTrain provides a comprehensive overview on existing education and training material and provides FAIR, open, ready-to-use modular course material that are developed by the EduTrain team based on the community's needs.

Problem	<p>A lack of FAIR and open educational resources is one of the biggest obstacles to scientific activities. Although substantial effort has already been put into developing Open Educational Resources (OERs), many issues still exist, e.g., peer-reviewing the content, maintenance responsibility, quality control, management, and lack of funding for the development and maintenance. Another major problem is that most existing FAIR principles and Open Science materials are generic. At the same time, ESS-specific materials that outline adapting the FAIR principles and Open Science concepts are highly needed but mainly missing<sup>5</sup>.</p>
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<sup>5</sup> Peter Pelz et al., Working Group Charter Training Infrastructures, <https://doi.org/10.5281/zenodo.6478698>, 2022.

Innovations	<ul style="list-style-type: none"> <li>• Development and maintenance of OERs and curriculum based on regular educational needs assessment of the ESS community</li> <li>• Continuous collection and evaluation of existing OERs in research data management tailored for ESS, spatio-temporal data literacy, and spatio-temporal data science</li> <li>• Funding the development of new open-licensed materials to meet the educational needs of the ESS community by publishing calls for educational pilots</li> <li>• Development of target group-specific curricula</li> </ul>
Users	<ul style="list-style-type: none"> <li>• Scientists, ranging from early-career researchers (Ph.D. students, Post-Docs) to experienced senior scientists and professors</li> <li>• Master students</li> <li>• Bachelor students</li> <li>• Educators and training professionals (e.g., professors, lecturers, teaching assistants)</li> </ul>
Interface(s)	User interface
Unit of adoption	<ul style="list-style-type: none"> <li>• Individuals</li> <li>• Higher education institutions</li> <li>• Research centres</li> </ul>

The EduTrain Service is available at: <https://edutrain.nfdi4earth.de/>

## Whitebox NFDI4Earth-developed Services

Here, we describe the implementation solutions for the NFDI4Earth-developed services and the NFDI4Earth-funded Community Software.

### Whitebox Knowledge Hub

The NFDI4Earth Knowledge Hub consists of three building blocks to harvest, process and provide metadata.

The ***pre-processing scripts*** mainly provide pipelines to harvest data sources or populate manually collected metadata, map metadata to the NFDI4Earth schemas and add/update the harmonised metadata in the data management system.

These scripts are written in Python and provided as open-source in the NFDI4Earth GitLab.

Through the use of a **data management system** that stores all manually-created and harvested metadata, the NFDI4Earth software architecture supports the management and provision of FAIR digital objects.

The **triple store** stores all metadata as semantically-enriched metadata in RDF (Resource Description Framework) and is accessible through a SPARQL API.

The implementation of the data management system and the triple store happens in NFDI4Earth through open-source software.

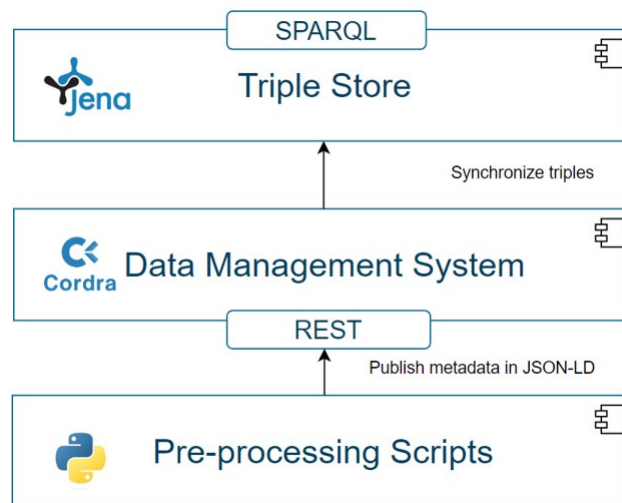


Figure 3: Whitebox Knowledge Hub

The NFDI4Earth Ontology is available at: <https://nfdi4earth.de/ontology>. The Ontology is iteratively developed in the open Knowledge Hub working group.

The Knowledge Hub source code is managed in the NFDI4Earth GitLab: <https://git.rwth-aachen.de/nfdi4earth/knowledgehub>. Developments, e.g., harvester implementations, are coordinated across the products in the NFDI4Earth developer meeting: <https://www.nfdi4earth.de/2coordinate/software-developer-team>

### Whitebox OneStop4All

The OneStop4All provides the Web frame for all NFDI4Earth user interface (UI) services. Thus, the OneStop4All links or embeds the EduTrain learn management system and the Living Handbook user interfaces with respect to a user-friendly navigation and a common look-and-feel for all NFDI4Earth UI services and provides access to the User Support Network via Web form. By doing so, the OneStop4All does not provide the exclusive, but an additional access point for all other NFDI4Earth services with user interfaces. The central search on all NFDI4Earth resources provides the core functionality of the OneStop4All.

The OneStop4All is implemented as a custom solution.

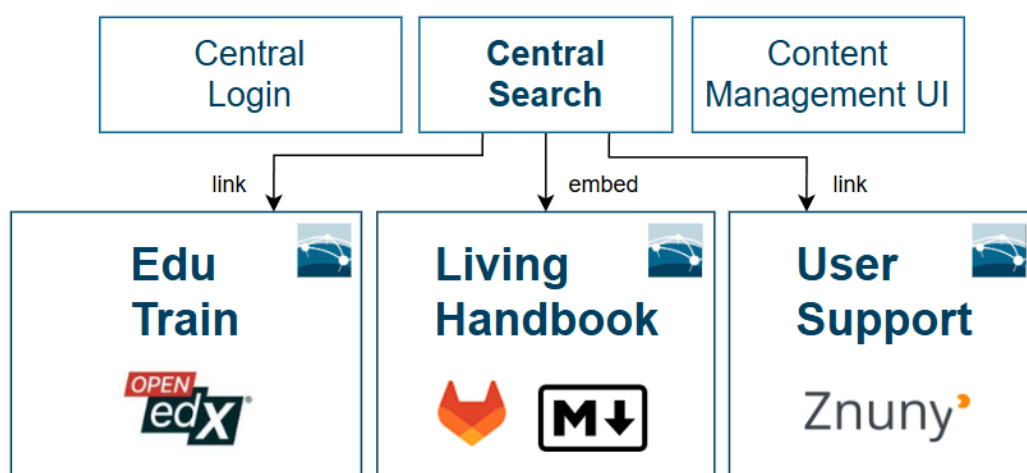


Figure 4: Whitebox OneStop4All with linked and embedded services

The design and implementation strategy are described here: <https://doi.org/10.5281/zenodo.10351658>, <https://doi.org/10.5281/zenodo.13629130>. OneStop4All source code is managed in the NFDI4Earth GitLab: <https://git.rwth-aachen.de/nfdi4earth/onestop4all>. Developments are coordinated across the products in the NFDI4Earth developer meeting: <https://www.nfdi4earth.de/2coordinate/software-developer-team>

#### *Blackbox Living Handbook*

*This blackbox description is based on the Living Handbook concept one-pager (<https://doi.org/10.5281/zenodo.7583596>).*

The Living Handbook provides an interactive Web-based documentation for all aspects related to the NFDI4Earth, its services and outcomes.

Problem	Many researchers, societies, funding agencies, companies, authorities, or the interested public are not familiar with each aspect of the NFDI4Earth, its services, or ESS research data in general. A core service with overview documents of such topics is, hence, required. The various user needs, and prior knowledges must be reflected in these documents, i.e., these must provide a flexible granularity, from being brief and informal to being comprehensive and detailed.
Innovations	<ul style="list-style-type: none"> <li>Structuring and harmonizing all aspects of NFDI4Earth as well as ESS related information from different, also previously unpublished, sources.</li> <li>Curate and present information about the NFDI4Earth as a collection of edited, inter-linked, human-readable</li> </ul>

	<p>documents of various types (documentation, report, article, manual, tutorial, ed-op, etc.) that are externally linked with general ESS resources.</p> <ul style="list-style-type: none"> <li>• Compilation of documents tailored to the different proficiency levels and backgrounds of readers by a combination of automatic re-combination and re-arrangement of the document's elements.</li> </ul>
Users	<ul style="list-style-type: none"> <li>• <b>Consumers:</b> Users with interest in NFDI4Earth, NFDI or else ESS related information, data, services, concepts, software etc. We expect users with a high variety in their backgrounds and prior knowledge.</li> <li>• <b>Editors/authors:</b> Persons that provide and regularly quality check the LHB contents.</li> </ul>
Interface(s)	User interface
Unit of adoption	<p>The LHB is beneficial to, e.g.:</p> <ul style="list-style-type: none"> <li>• Researchers as a manual how to use NFDI4Earth and related external products and to learn what the scope of the NFDI4Earth and its services are.</li> <li>• Scientific and professional societies as a place to refer their members as a resource for ESS data related topics.</li> <li>• Funding agencies to understand how researchers are using and providing ESS data</li> <li>• Authorities to get and provide information about ESS data</li> <li>• The interested public as the first stop to find ESS related information</li> </ul>

The Living Handbook is managed here: <https://git.rwth-aachen.de/nfdi4earth/livinghandbook/livinghandbook>

#### *Blackbox User Support*

*This blackbox description is based on the User Support Network concept one-pager (<https://doi.org/10.5281/zenodo.7583596>).*

The User Support Network provides distributed, cross-institutional user support based on the services of the existing partner institutions' services and the upcoming NFDI4Earth innovations.

Challenges	<p>Research data services from the Earth system sciences community are diverse and until now mainly directed to a smaller community, e.g., an institute. We work on a structure in the USN that allows to map the different resources and to access them. The</p>
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	USN will also evaluate if an open community support system (like Stack Overflow) will be of value next to the institutional RDM support of the USN team. To work on that evaluation, we need a solid idea of what kind of user questions are asking, which we expect to get by running the ticketing system.
Innovations	<ul style="list-style-type: none"> <li>• Single point of access to a national expert pool offering individual support for ESS RDM problems for all phases of the data lifecycle</li> <li>• Collection, harmonization and provision of expert knowledge based on institutional experience, e.g., via Living Handbook</li> <li>• Creation of standard operation procedures (SOPs) for user support</li> </ul>
Users	<p>We envision the following types of primary users:</p> <ul style="list-style-type: none"> <li>• Users, who are looking for general information, e.g., on NFDI4Earth tools or on how to use NFDI4Earth services</li> <li>• Users, who are looking for support in ESS research data management (RDM)</li> </ul>
Interface(s)	User interface
Unit of adoption	<ul style="list-style-type: none"> <li>• Individuals</li> <li>• Research institutions</li> </ul>

The User Support Network can be contacted via: <https://onestop4all.nfdi4earth.de/?support>

### Whitebox NFDI4Earth-funded Community Software

The NFDI4Earth-funded community software includes NFDI4Earth Pilots and Incubators.

### Blackbox NFDI4Earth Pilots

*The blackbox description is based on the Pilots concept one-pager (<https://doi.org/10.5281/zenodo.7583596>).*

The NFDI4Earth Earth System Science (ESS) Pilots are small projects from various disciplines of the ESS community usually lasting for one year. Pilots are used to assess and define requirements in other task areas and promising results will be integrated into the NFDI4Earth infrastructure.

Problem	To achieve acceptance and adoption of the community as well as a cultural change, NFDI4Earth must not implement top-down solutions but involve ideas and existing tools from the research community. Different domains of ESS face different challenges in interoperability, standardization of data, methods and workflows. Expertise and technologies are existent but need further development to meet domain specific requirements and often lack transferability for usage beyond a small user group.
Innovations	<ul style="list-style-type: none"> <li>• Agile projects that directly reflect researchers' needs in data management and implement novel solutions for research data management</li> <li>• Bottom-up innovation scouts for other Task Areas of NFDI4Earth</li> <li>• Focus on transferability of results and enhancement of technologies to make use of existing resources and foster community driven design of NFDI4Earth</li> </ul>
Users	The target community are researchers from the ESS community working on tools that enhance research data management. The solutions implemented from the pilots are targeted to the respective scientific community.
Interface(s)	Depending on the individual pilot proposals
Unit of adoption	<ul style="list-style-type: none"> <li>• NFDI4Earth includes pilots' results into their infrastructure</li> <li>• User communities of different domains that adopt the newly developed tools by pilots</li> </ul>

As the pilots provide individual solutions, we don't include the whitebox description here.

NFDI4Earth Pilots are available at: <https://git.rwth-aachen.de/nfdi4earth/pilotsincubatorlab/pilots>

### Blackbox NFDI4Earth Incubators

NFDI4Earth Incubators are documented here: <https://nfdi4earth.de/2participate/incubator-lab>

## Deployment View

Information about the deployment view is available at: <https://nfdi4earth.pages.rwth-aachen.de/architecture/architecture-docs/#deployment-view>

# Architecture Decisions

## Decision Process

As described in the NFDI4Earth proposal, the Measure 4.3 *Central Support Services for the federated NFDI4Earth Community* is responsible for the *Support and Coordination of Software Developments* (Action 5). One major goal of this action is to ensure a coherent software development within and for NFDI4Earth.

Software decisions concern the use and purpose of software solutions (what and how) that are parts of the emerging NFDI4Earth software components and whose use affects the NFDI4Earth community directly or prospectively. The software decisions are made by the NFDI4Earth Architecture Team on the proposal of and in consultation with the measure leads responsible in each case. This ensures that the chosen tools and systems fit into the overall software ecosystem and the NFDI4Earth software architecture concept.

The software solutions selected for NFDI4Earth software products should meet essential functional and non-functional requirements of the respective software component or be the best available basis for further development. Moreover, it should meet the software constraints 2 and 7-11 (see Section Architecture Constraints).

Software solutions chosen for an NFDI4Earth software component can be changed at any time - again in consultation with the NFDI4Earth Architecture Team - if there are appropriate reasons for doing so (e.g., better solutions on the market or changes in requirements). Decisions on software solutions are made by the NFDI4Earth Architecture Team within 14 days. The request for a software decision to the NFDI4Earth Architecture Team is usually made by a measure lead.

In the case of unresolvable conflicts or diverging ideas on software decisions between the measure leads and the NFDI4Earth Architecture Team, the NFDI4Earth Architecture Team prepares a decision proposal for the steering group, which then acts as the decision-making authority.

Software decisions are documented by the initiating measure leads including the time of the decision, the NFDI4Earth related software products and a short explanation taking into account the above-mentioned criteria for software selection and the made decision. This documentation is edited by the NFDI4Earth Architecture Team and published in the form of a management version in the software architecture project of the NFDI4Earth GitLab.

*The NFDI4Earth Architecture Team consists of Auriol Degbelo, Christin Henzen, Carsten Keßler, Ralf Klammer, Daniel Nüst, Claus Weiland and can be contacted via [nfdi4earth-architecture@tu-dresden.de](mailto:nfdi4earth-architecture@tu-dresden.de)*



## Decisions

The following decisions have already been taken:

1. Fuseki<sup>6</sup> as the *triple store* for the **Knowledge Hub**
2. CORDRA<sup>7</sup> as *middleware* for metadata and data management for the **Knowledge Hub**
3. MkDocs<sup>8</sup> as a *static site generator* for the **Living Handbook**
4. Znuny<sup>9</sup> as *ticketing system* for the **User Support Network**
5. OPENedX<sup>10</sup> as **EduTrain** learn management system
6. A custom solution based on React<sup>11</sup> is implemented for the **OneStop4All**

## Acknowledgements

### About NFDI4Earth

This specification and guides are developed by the members of the project NFDI4Earth – <https://nfdi4earth.de>. This work has been funded by the German Research Foundation (DFG) through the project NFDI4Earth (TA4 M4.3, DFG project no. 460036893) within the German National Research Data Infrastructure (NFDI, <https://www.nfdi.de/>).

### About arc42

arc42, the Template for documentation of software and system architecture. For this documentation, we use an adapted Template Version 8.2 EN. January 2023 Created, maintained and © by Dr. Peter Hruschka, Dr. Gernot Starke and contributors. See <https://arc42.org>.

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<sup>6</sup> We expect this decision to change as Fuseki might not be able to scale as the number of managed triples grows rapidly.

<sup>7</sup> <https://www.cordra.org>

<sup>8</sup> <https://www.mkdocs.org>

<sup>9</sup> <https://www.znuny.org>

<sup>10</sup> <https://openedx.org>

<sup>11</sup> <https://react.dev>