GEOSS Platform Plus

D3.6

The GPP Vision for GEOSS Evolution

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Abstract:

The current document describes the GPP Vision for GEOSS evolution, considering the existing context and ecosystem, inputs from the GEOSS 2.0-related efforts, the Data Provider Workshops feedback, the Expert Advisory Group (EAG) recommendations, the Mid-Term Evaluation report and the ongoing discussions in the GEOSS Infrastructure Development Task Team (GIDTT). The resulting overarching architecture is an input to the GEOSS Vision post 2025 agenda. It identifies necessary components and existing component evolutions, corresponding role, the links between them and links with external entities, along with the identification of actors involved.

The current document is provided in two copies as it incorporates the contribution of the current deliverable (D3.6) and also the contribution to GEO Governance Challenges identification (D5.6).

Document Log

Date	Author	Changes	Version	Status
30/09/2024	GPP Team	First version	1.0	Delivered

EXECUTIVE SUMMARY

The document outlines the GPP vision for the evolution of the Global Earth Observation System of Systems (GEOSS) into a Digital Ecosystem (DE) to better address the needs of decision-makers and other stakeholders. It highlights the importance of adapting to continuous changes in the GEO context, as well as in science/policy and technological contexts.

- **GEOSS Evolution Vision**: The document presents the GPP high-level vision for the future GEOSS, focusing on transitioning from a data-sharing paradigm to a knowledge generation and sharing model to support decision-making processes.
- **Digital Ecosystem Concept**: GEOSS as a Digital Ecosystem aims to create a flexible, adaptive environment where diverse and autonomous entities interact and evolve, providing valuable ecosystem services without imposing predefined behaviors.
- **Core Digital Ecosystem Enablers**: The GEOSS Digital Ecosystem must be supported by a minimal set of logical components, including data source registries, mediators, and interfaces, which enable the digital environment.
- **Governance Challenges**: The governance of the GEOSS Digital Ecosystem must address several challenges, such as determining eligibility for participation, balancing autonomy and belonging, managing core enablers, and ensuring sustainability.
- **Implementation Challenges**: Specific challenges are identified for implementing the GEOSS Digital Ecosystem, including satellite data replication, in-situ data management, remote processing systems, and knowledge formalization.
- **Role of GPP**: The GEOSS Platform Plus (GPP) project contributes to the vision by operating and enhancing current GEOSS Platform components, developing use cases, and prototyping new components to enrich the ecosystem.
- **GPP Use Cases**: GPP use cases, such as SDG 15.3.1 Land Degradation and Nutrient Pollution in European Inland and Coastal Waters, demonstrate how the GEOSS Digital Ecosystem can provide tailored information and actionable knowledge for end users.
- **Technological Integration**: The GEOSS Digital Ecosystem can integrate various technological advancements, such as cloud computing, data cubes, IoT, edge computing, and AI, to enhance EO data processing and knowledge generation.
- **Future Directions**: The GEOSS Digital Ecosystem must be designed to adapt to continuous changes in the GEO context, science/policy context, and technological context, ensuring long-term sustainability and relevance.

In summary, the GEOSS Digital Ecosystem is a forward-looking approach that aims to create a flexible, adaptive environment for knowledge generation and sharing, supported by a robust governance framework and technological integration.

1 Introduction

1.1 Purpose and Scope

This document (*D3.6 – The GPP Vision for GEOSS Evolution*) has been generated in the context of WP3 - GEOSS Evolution design, development, integration, and deployment within the GPP (short for GEOSS Platform Plus) project, Grant Agreement no. 101039118.

The present document provides a high-level vision for the future GEO Infrastructure (formerly GEOSS) and, also, a proposal for possible GPP contributions. This document is the result of several years of discussions on how GEOSS and the GEOSS Platform can bring benefit to the GEO Communities (Activities, Initiatives, Flagships, Focus Areas, etc.). To achieve this goal, during the last years several events, workshops and meetings took place: the Data Provider Workshops, the Mid Term Evaluation, and the Expert Advisory Group reporting. During these events, feedback, requirements, and recommendations have been noted and analysed and included in the scope of the GPP project in order to fill the weakness points identified: what is missing in GEOSS, the need to move towards a user centric approach, the improvement for discoverability and accessibility of in-situ data, and which are the future directions that GEOSS should look at for the post-2025 agenda.

The present document is the second release of the GPP vision for GEOSS evolution. The main updates to the document include inputs from GEO Post 2025 Strategy, GIDTT, Common European Data Spaces (in particular, the Green Deal Data Space), and EuroGEOSec. Besides, we analyse the role of GPP and its use cases to demonstrate how the GPP Vision of a GEOSS Digital Ecosystem can move forward, allowing different actors to contribute to the GEOSS Digital Ecosystem, by providing new tools, services, applications, middleware and other third-party components which exploit and enrich the GEOSS Digital Ecosystem.

Besides D3.6, it has been decided that current document integrates as well the content for the deliverable D5.6 - *Contribution to GEO,* identifying Governance challenges identified by the GPP team. The main reason is that the overarching architecture and governance challenges are narrowly related and thus they should be presented in a same frame (i.e. document).

1.2 Document Organisation

The document is organised as it follows:

- Section 1 describes the purpose and scope of the document and its organization.
- Section 2 contextualizes the origin of GEO and GEOSS and the GEOSS Platform.
- Section 3 describes the current status and architecture of the GEOSS Platform, and the challenges identified towards the 2025 Agenda.
- Section 4 describes the proposed GEOSS Overarching Architecture, based on the Digital Ecosystem concept.
- Section 5 describes how the GEOSS Platform Plus project can contribute to the vision of a GEOSS Digital Ecosystem.
- Section 6 provides conclusions.

2 The Past: A Short History of GEO, GEOSS and the GEOSS Platform

2.1 GEO and GEOSS

Back in 2005, exploitation of Earth Observations suffered from difficulties deriving from insufficient coordination among Earth observation system owners (mostly governments), the lack of cross-discipline data sharing as well as from technological barriers due to data volume, heterogeneity, scattering, inadequate integration, accessibility and interoperability. Also, the price tag that often came with the data, hindered the exploitation and benefit from their potential to the full extent at least until 2008, when the Landsat policy changed.

The Group on Earth Observations (GEO) was established in response to these challenges, being an intergovernmental voluntary partnership with the aim to improve the availability, access and use of Earth observations for a sustainable planet. It promotes open, coordinated, and sustained data sharing and infrastructure for better research, policy making, decisions and action across many disciplines. The GEO community focuses on three global priority engagement areas:

- Sustainable Development Goals,
- Climate Action
- Disaster Risk Reduction
- Resilient Cities & Human Settlements

A central part of its Mission is to build the **Global Earth Observation System of Systems (GEOSS),** which is a set of coordinated, independent Earth observation, information and processing systems that interact and provide access to diverse information for a broad range of users in both public and private sectors.

This 'system of systems', through its **GEOSS Platform (formerly GEOSS Common Infrastructure - GCI),** proactively links together existing and planned observing systems around the world and supports the need for the development of new systems where gaps currently exist. It promotes common technical standards so that data from the thousands of different instruments can be combined into coherent data sets.

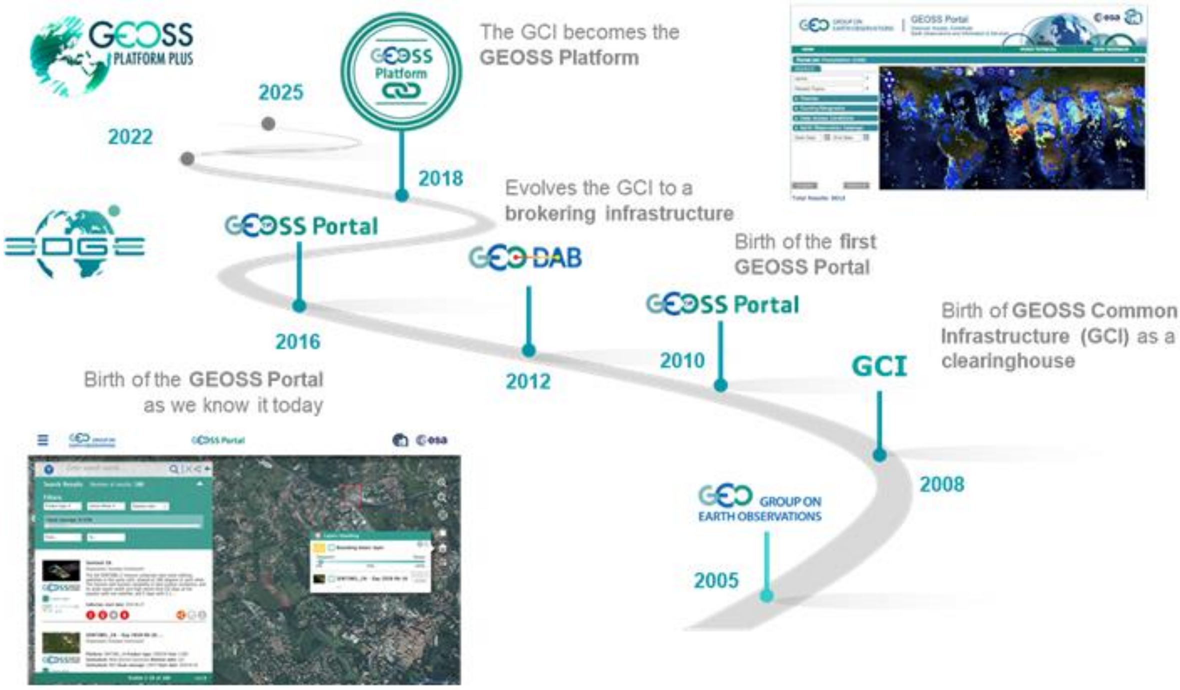

Figure 1 – The History of GEOSS

The GEOSS journey, started with the establishment of GEO in 2005, continued with the birth, in 2008, of the GEOSS Common Infrastructure (GCI) as a clearinghouse catalogue, which included the core components for data source registration, mediation and, in 2010, with the first version of the GEOSS Portal for human-to-machine interaction.

Two years later, the GCI evolved into a brokering framework, able to connect to multiple data sources exposing different interfaces. In 2016, a complete refurbishment of the Portal was undertaken to improve the user experience by enhancing the discovery, access and visualization functionalities, leading to the GEOSS Portal, as we know it today.

The ESA-led, EC H2020 co-funded project EDGE[1] (short for European Direction in GCI Enhancements), that started in 2017, as a response to the need to move from a more data-oriented to a more user-focused approach, contributed to the enhancement of the core components of the GCI, which, in 2018, officially became the **GEOSS Platform** opening the core functionalities through a dedicated Application Programming Interface (API).

The GEOSS Platform Plus (GPP) Project continues the journey started with EDGE towards a more user-centric GEOSS.

2.2 The GEOSS Platform

The GEOSS Platform acts as a bridge between the data providers and the users, mostly "intermediate users" such as technical personnel supporting decision-makers including developers and research scientists, who access and process the Earth Observations to turn them into actionable information for end users (e.g., decision makers).

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[1] Grant Agreement number 776136

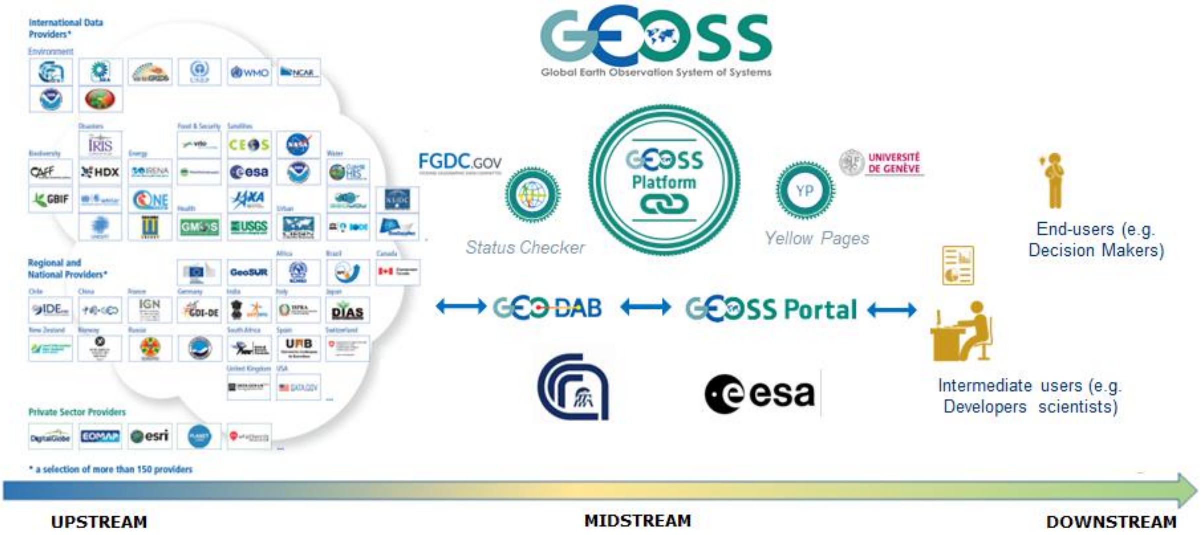

Figure 2 – High-level Overview of GEOSS Platform

The main components of the GEOSS Platform today are the GEOSS Portal operated by the European Space Agency (ESA), the GEO DAB operated by the Italian National Research Council, Institute of Atmospheric Pollution (CNR IIA), the Status Checker operated by the United States Geological Survey (USGS-FGDC) and the Yellow Pages operated by the University of Geneva (UNIGE).

2.2.1 The GEO Discovery and Access Broker

The **GEO Discovery and Access Broker (GEO DAB)** is the primary mechanism by which all data and information is discovered and accessed. The GEO DAB implements the necessary mediation and harmonization services through Application Program Interfaces (APIs). These APIs allow data providers to share resources without having to make major changes to their technology or standards.

Presently the GEO DAB brokers more than 190 autonomous data catalogues and information systems, useful for the different GEO Societal Benefit Areas, including data from: CAFF, Data.gov, Data.uk, EEA, GBIF, Iris, JRC Open Data catalog, NASA, NCAR, NOAA, OCHA HDX, RCMRD, UNEP, UNOSAT, USGS, Web Energy Services, WMO WIS and many more. Data providers are constantly being added and brokered, according to user needs, thematic and geographic balance of the data and relevance of resources shared. The types of data are very varied and includes space-sensed, aerial, in-situ as well as other types of data.

2.2.2 The GEOSS Portal

The **GEOSS Portal** (link: Welcome - GEOSS (geoportal.org)) is built on top of the GEO DAB and uses its APIs to offer a single Internet access point to Earth observation data, information and knowledge from all over the world for users with different backgrounds and from different disciplines. The Portal has an intuitive, easy-to-use interface to discover, access and use the ever-growing quantities of GEO resources. Through the Portal, the GEOSS Platform connects users to the wealth of heterogeneous collections of databases and other portals and provides reliable, up-to-date and user friendly (current and historical) information – vital for the work of decision/policy makers, planners and emergency managers. Both the public and private sector but as well citizens are served.

Users can discover data considering temporal, thematic and geographic search criteria, and apply progressive filtering to retrieve, quickly and accurately, the resources they need. Information regarding the data can be inspected either via an information window or visually on different background maps if enabled before download.

The GEOSS Portal can be now easily accessed and explored thanks to a newly developed landing page. This landing page serves as a structured entry point, offering users a clear and intuitive interface that highlights the key features and benefits of the GEOSS platform, increasing user awareness and foster engagement with the GEOSS Portal. Through the landing page, the user is guided towards the most important areas of the portal (e.g., Thematic Areas, Catalogs, Community Portals, Use Cases...), enhancing the overall user experience. Moreover, the user interaction with the page is monitored through analytics, providing valuable insights into user behaviour and engagement.

2.2.3 The GEOSS Yellow Pages

The **GEOSS Yellow pages** service implements the simplified registration process for new Data Providers.

2.2.4 The GEOSS Service Status Checker

The **GEOSS Service Status Checker** is the component, developed by USGS FGDC and integrated into the GEO DAB, which aims at improving the user experience by providing information on Reliability of Services. The Status Checker is an automatic mechanism to monitor, diagnose and alert data providers and users on the Health status of the web services provided by the GEOSS Platform.

2.2.5 The GEOSS Reuse Components

In addition to the above-described main components of the Platform, GEOSS offers the so-called **Reuse Components** to serve the specificities of the various user communities. This means that user communities, which might have their own data, portals and corresponding specific needs, can reuse some of the GEOSS Platform components customized and tailored to their specific requirements.

The Reuse Components are:

- The *GEOSS View*, which provides access to a subset of specifically defined GEOSS resources using temporal, thematic and spatial criteria;
- The *GEOSS APIs*, which expose the discovery and access functionalities of the GEO DAB and as such can be exploited by user communities' client applications or portals;
- The *GEOSS Mirror* is a GEOSS Portal site customization for Flagships, Initiatives, Focus Areas and Communities. The customization better serves the specific community interests by filtering catalogues and search results by a specific theme or GEO DAB view, location of interest, etc.
- The *GEOSS Widget* is a freely available instantiation of selected GEOSS Portal functionality made available for possible customization in various areas of application (e.g. Initiatives, Focus Areas etc.). This is accomplished by publishing portal code parts (widgets) wrapped up in API.
- The *GEOSS Self Creation Tool* is a feature dedicated to all of the communities that want to host their version of GEOSS Portal. Community can now download fully customizable GEOSS Portal and develop it on its premises, with their own brand, configurations and settings. Code is open and unlimited. This tool lets separate communities event to create their own sub-community sites, letting their users to discover and process data even more precise.
- The *GEOSS Dashboards* feature lets registered users to create and share new resources based the results of their own service calculations. This tool, in a simple way, provides the possibility to build enhanced knowledge entries with map of the data, chart plots and rich descriptions. Resources are published and discoverable by anyone within GEOSS Portal.

3 The Present: Beyond the GEOSS Platform

In the latest years, the GEO Secretariat, members, participants, and the entire Earth observation community started a deep reflection about the role of GEO and GEOSS in the EO landscape. The changes in the global context and the different visions in the GEO community suggested rethinking the scope and objectives of GEO and consequently whether the original GEOSS concept is still valid. Such reflections took place in the context of different GEOSS Data Providers Workshops organized between 2016 and 2018, an evaluation performed mid-term the implementation period of GEOSS 2016-2025, and as part of an evaluation performed by an Expert Advisory Group as presented during the GEO Plenary XVIII that took place in Ghana.

3.1 The GEOSS Data Providers Workshops

Data Providers and, more generally, resource providers, play a fundamental role in the effective and efficient realization of GEOSS, and in the success of GEO. In 2016, the 1st GEO Data Providers Workshop was held as a side event of the GEO XIII Plenary in St. Petersburg, with the goals of establishing a two-way dialogue with data providers to improve the discoverability, accessibility, and usability of GEOSS resources. Data providers already contributing to GEOSS, and new data providers, flagships and initiatives and users were invited and encouraged to participate to strengthen the dialogue with Data Providers and to improve the discoverability, accessibility, and usability of GEOSS resources.

Given the high level of interest and success of the initial workshop, a more comprehensive two-day event was organized and hosted by the Italian National Research Council (CNR) in Florence, Italy, from 20th to 21st of April 2017, in collaboration with the European Space Agency (ESA). This second event **highlighted the depth and breadth of the GEOSS ecosystem and how it was continuously developing and improving**. Specifically, it focused on and discussed both the Technology Ecosystem, built around the GCI, and the Community Ecosystem, focusing on GEOSS Data.

A 3rd GEO Data Providers Workshop was held at ESRIN, the establishment of the European Space Agency (ESA) in Frascati (Italy) from the 2nd to the 4th of May 2018. The event was co-organized by the GEO Secretariat, ESA, CNR-IIA (Italy), United States Geological Survey (USGS) and the University of Geneva (Switzerland). The Joint Research Centre of the European Commission contributed to the event report. The workshop brought together more than 200 data providers and users from more than 130 organizations from 33 countries and 5 continents and provided a space to share experiences and knowledge that can improve the ways in which Earth observations are managed, communicated, disseminated and used to enhance the Global Earth Observation System of Systems (GEOSS) The Workshop agenda included 97 presentations and was organized according to: 26 scientific sessions, 11 training sessions, one Hackathon and one arduino sensors do-it-yourself session for citizen science.

The workshop showed that user needs had become a priority for the GEOSS Platform and were an essential driver for the GEOSS evolvement (GEO, 2018). In particular, **it highlighted the importance of knowledge generation, management, and sharing for evidence-based science and policymaking**.

The transition from data to knowledge was indeed one of the main topics raised by several presentations and by the discussion, requiring a specific attention on the design and implementation of the GEOSS Platform interaction with knowledge generation systems and services. The main outcome was that **the GEOSS Platform Ecosystem must continue its evolution in response to evolving user requirements and to include the most recent innovative technologies for data analytics to generate knowledge from data.**

3.2 The Mid-term Evaluation

As part of the self-assessment process of GEO, an evaluation took place midway in the implementation of the GEO Strategic Plan 2016-2025 covering the period from 2016 to 2020 (GEO, 2021).

The report provides some findings with potential impact on the GEOSS evolution.

FOCUS AREA #1: GEO Organizational Model

KEY FINDING #1-Mission: "*GEO is making good progress on working towards becoming a world leading organization in coordinating availability, access and use of Earth observations […}"*

KEY FINDING #4-Re-evaluating GEOSS: "*GEO needs to reassess the concept of GEOSS, what the main goals are, and whether the original concept of GEOSS remains relevant to the organization without modifications. Specifically,* ***GEO should evaluate and decide what it wants or needs to pursue in terms of data infrastructure, producing data products, and user services****, how GEOSS can integrate and execute the Knowledge Hub, and whether GEO has the capacity to carry this out.*"

FOCUS AREA 2: Policy and Users' Interface

KEY FINDING #5-Relations with the UN and other stakeholders: "S*trengthening such engagement [with the UN and multilateral environmental agreements] would contribute to the establishment of a comprehensive ecosystem approach to the role of GEO in coordinating availability, access and use of Earth observations. Lastly, even though there has been progress in the engagement with the private sector and member states, better results can be achieved through a clearer definition of GEO value proposition*".

FOCUS AREA 3: Interoperability

KEY FINDING #8-External and technical interoperability: "[…} *the GEOSS Implementation Plan needs to be reviewed.* ***The GEOSS portal, as described, is unable to meet user expectations*** *in terms of its low technical capability, low performance compared with other global and regional systems, and the lack of good integration of in situ data. […]* ***Technology advances have significantly changed the original concept for the GEOSS*** *and GEO no longer has the tools, right partners or resources to meet the project GEO had intended in the early years (2005 – 2010) to build a system of systems. GEO would benefit from improved external connectivity with major Earth observation data portals, at all levels.* ***Attention should be paid to links with global, regional and national data systems****.* ***Particular attention should be made to improving the availability and integration of in situ observations*** *within the GEO Portal, working with in situ terrestrial, freshwater, coastal, ocean and atmospheric observation systems and new in situ initiatives such as GBON and others. It is believed that* ***the new GEO Knowledge Hub could provide more support to the Earth observation value chain and, although still at an early stage of development, should become part of the GEOSS infrastructure****. However****, this development needs to be balanced against GEO's other priorities****. Recently, the early development of the Knowledge Hub has required a high level of support from GEO Secretariat staff, and this heavy burden is not sustainable in light of other GEO priorities.*"

FOCUS AREA 4: Regional GEOs

KEY FINDING #9-Role of Regional GEOs: Interviews with key informants highlighted that Regional GEOs need to become more integrated into the functions of the GEO Work Programme and the overarching structure of GEO itself.

FOCUS AREA 5: The Private Sector

KEY FINDING #11-Engagement with the Private and Commercial Sectors: "*key informants highlighted that lack of the private sectors' involvement or views in GEO's activities such as in designing of GEO tasks or Work Programme*"

3.3 The Expert Advisory Group outcomes

Amongst the key recommendations of the mid-term evaluation (MTE) of GEO was to review whether the concept of the GEO System of Systems (GEOSS) remains relevant to the objectives of GEO into the future. In April 2022, a 26-member Expert Advisory Group on GEOSS (EAG) comprised of internationally acknowledged EO experts across the geospatial sector was convened to assess two main questions:

- whether the concept of GEOSS continues to be relevant to the GEO Mission and, if so, how this concept should be defined in the context of GEO's current understanding of its value proposition, and
- whether GEO should continue to serve as a provider of geospatial information and services infrastructure and, if so, what main function the said infrastructure should provide.

The final report of the EAG was presented at the last GEO Plenary (GEO-18), held in Accra (Ghana). The full EAG report is available online (GEO, 2022b).

The EAG conducted a survey of GEO community, receiving 155 responses containing perspectives on the use and functionality of GEOSS, and with recommendations for improving its ease of use and impact in future. The survey provided some interesting insights on the GEOSS Platform usefulness and capabilities (the complete outcomes of the survey are available in the EAG report (GEO, 2022b)):

1. Utilization of GEOSS platform: "***The majority of respondents (68%) stated GEOSS infrastructure provides benefits to the GEO community due to its support in accessing EO data****, capacity building, support for research and other uses.* ***However, 19% of the respondents do not see benefits for the community****, […]"*
2. Improvement of GEOSS Platform: Consistent with the limiting factors identified above, **the majority of respondents suggests improving user-friendliness including the search functionality** (46%) […]
3. Engagement and Capacity Development: **51% responded that they are already engaged or see no need to be engaged**, while 32% of respondents prefer stronger engagement in co-development. **Most respondents (62%) express their wish to be more engaged in the process of developing GEOSS infrastructure and tools** […]
4. Coverage of GEOSS and further development: **A regional GEOSS would be more beneficial to most respondents (46%) while a global one would be preferred by 36%**. […] **Fifty-nine percent of respondents indicated added value from smaller and geographically or thematically targeted GEOSS subsets, however 27% of the respondents disagree**. […] **The majority of respondents (77%) indicated that data access, management and quality control are the major challenges for the future GEOSS**. […] **access to cloud platform to support data processing** (64), **access to thematic EO data products** (62) and **direct access to the raw EO data** (53).

Based on inputs from the survey, and the perspective and experience of members of the EAG, this report considers the technical, user and governance implications of three broad options for the future GEOSS:

1. Discontinue investment in current GEOSS Platform
2. Pivot investments from the current GEOSS platform toward end-user needs
3. Continue investing in the GEO-hosted GEOSS Platform and enhance its functionality to support GEO impact areas

While the options are presented as distinct, the report clarifies that these are not mutually exclusive and components of each could be implemented in a GEOSS of the future, depending on the resources available and the direction GEO decides to take with regard to the platform.

The report included some specific recommendations:

1. **Discontinuing the use of the term and rebrand everything as GEO**. Replace the name "GEOSS" with the name "GEO." The GEOSS term is confusing. This includes removing all references to GEOSS on the GEO website.
2. **Ensure that all GEO-endorsed datasets, including metadata, follow open, industry standards**. Open standards facilitate interoperability and data exchange among different products and services and enable widespread use.
3. **Consider improving in-situ data support**. GEO is in a unique position globally to identify standards for in-situ data metadata and storage requirements. Providing in- situ data hosting facilities would provide a point of difference with existing geospatial compute and storage offerings and could provide additional functionality for the calibration and validation of geospatial datasets, and to support modelling.

3.4 GEO Post 2025 Strategy

The latest GEO Plenary (Cape Town, 2023) formally approved the GEO Post 2025 Strategy document (GEO, 2023). The document introduces the concept of "Earth Intelligence" to "*emphasize the need for GEO to provide targeted and actionable insights, based on Earth Observation data, that is co-created with users and enables them to make better informed decisions for a more sustainable world*". Earth Intelligence "*comprises integrated Earth and social science derived knowledge and insights that inform strategic decisions, build capacities and empower society to address environmental, societal, and economic challenges*" (GEO, 2023).

Building on GEO past achievements, the Post 2025 Strategy document refines GEO vision and mission to move towards the provisioning of trusted Earth Intelligence:

- **GEO Vision**: A world where trusted Earth intelligence is universally accessible and empowers society to achieve a sustainable future.
- **GEO Mission**: GEO co-produces user-driven Earth intelligence solutions that inform decisions and accelerate action on global, societal, and environmental challenges, leveraging its unique position as an established intergovernmental body with a strong and inclusive partnership.

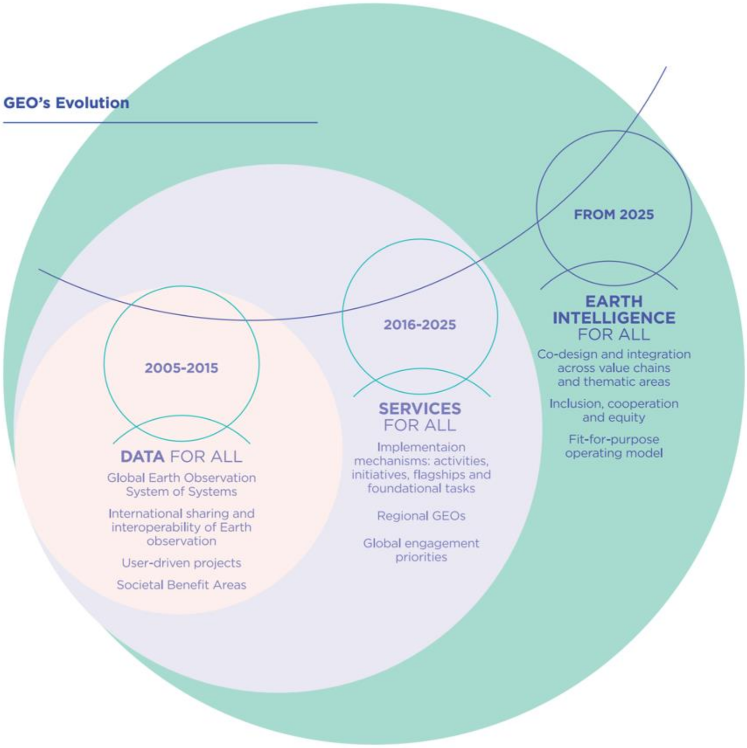

Figure 3 - GEO's Evolution, source: (GEO, 2023)

The Post 2025 Strategy identifies the following main activities to achieve its mission:

- Make Earth intelligence a fundamental pillar of knowledge-based decision-making for sustainable development, building an inclusive, sustainable and resilient future for people and the planet.
- Facilitate a shift from a focus on the development of services to a focus on provision of needs-based services to all, in order to bridge global knowledge and information gaps.
- Co-design user-orientated services by identifying policy and decision-making needs, designing the services needed to support these needs, creating the products to enable the services, and identifying affordable and trusted Earth observation components — from across the value chain — required to sustain these products.
- Integrate Earth observations, models, and innovative new technologies (including artificial intelligence, machine learning, digital twins, cloud computing) into the design of services that provide Earth intelligence.
- Enhance inclusivity and adaptability in the GEO community by leveraging expertise and resources from across the scientific community, indigenous peoples and local communities, private sector, civil society and international finance institutions, and by fostering open data and knowledge and building capacities

3.5 GIDTT Technical Assessment of the GEO Infrastructure

At its 60th meeting, GEO Executive Committee endorsed the direction for the evolution of the GEO Infrastructure, as proposed by the GEO Secretariat in response to the Expert Advisory Group on GEOSS (EAG) report (see section 3.3). The decision includes re-establishing the GEO Infrastructure Task Team (GIDTT) to assess the technical feasibility and the requirements (institutional and financial resources, and governance model) for the implementation of the endorsed direction.

In April 2024, the GIDTT submitted to the GEO Executive Committee its Technical Assessment of the GEO Infrastructure. Recognizing that the GEO Infrastructure plays a pivotal role in advancing GEO's role within the international community and demonstrates the importance and impact that Earth Observations have in the decision-making process, the GIDTT is working to design a User's friendly, impactful GEO Infrastructure.

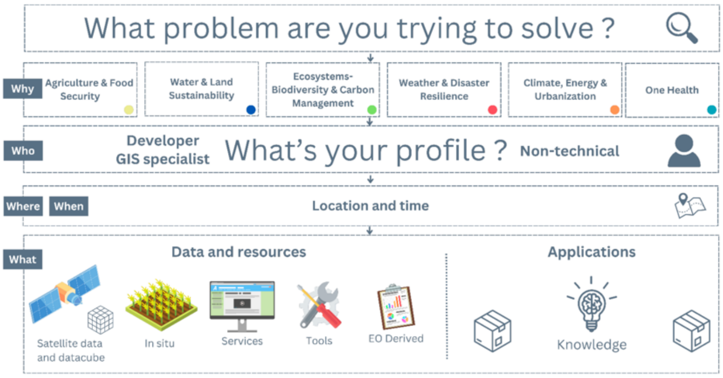

Figure 4 - Simplified schema of the user-oriented GEO Infrastructure, source: Technical Assessment of the GEO Infrastructure

The document focuses on the requirements for building a simplified, user-friendly GEO Infrastructure with enhanced functionalities to support the GEO community in the usage of EO for the decision-making as presented in Figure 4.

The Technical Assessment document also clarified the relations and the high-level organization of the GEO Infrastructure. Figure 5 highlights the links between the GEO Infrastructure and other components and partners, such as cloud provider, Regional GEOs, etc.

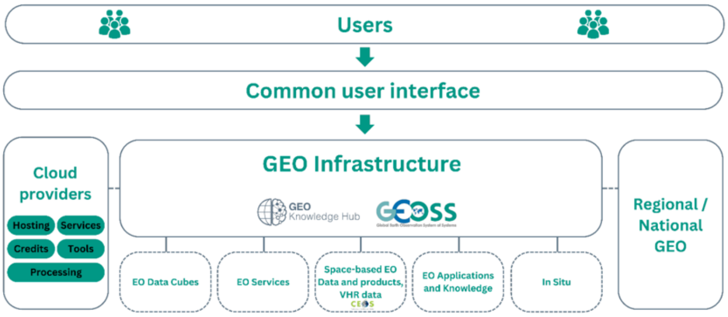

Figure 5 - Links between the GEO Infrastructure and other components and partners, source: Technical Assessment of the GEO Infrastructure

The GIDTT work was organized in the following three subgroups, each of which identified requirements and functionalities for the enhancement of the GEO Infrastructure:

- Space based data, Data Cubes, Cloud Providers and Very High-Resolution Data
- In situ Data and Regional GEOs
- Quality check of non-space-based data in the GEOSS Platform/Integration GKH and GEOSS Platform

3.6 EuroGEOSec

In December 2023, the Horizon Europe project EuroGEOSec kicked off. The overarching goal of the EuroGEOSec project is to support the coordination of the EuroGEO initiative and develop a sustainability plan guiding its long-term operation. This will be achieved by establishing the EuroGEO Secretariat with the mission to:

- strengthen GEO-related coordination mechanisms at European and national levels;
- support increased innovation, space application development and reinforcement of the European space data ecosystem concept;
- foster international cooperation to help stimulate the market and promote European technology and services;
- contribute to the European Green Deal objectives and the European strategy for data (EU Data Spaces) by further deploying and exploiting the use of EO towards a strengthened Global Earth Observation System of Systems (GEOSS).

GPP organized a meeting in March 2024 with the coordinator of the EuroGEOSec project to discuss potential collaboration in the context of the EuroGEO framework.

3.7 Green Deal Data Space

On February 2020, the European Commission (EC) published a Communication introducing “A European strategy for data” (ESD) for the creation of “*a single European data space – a genuine single market for data, open to data from across the world*”. The development of Common European data spaces in strategic sectors and domains of public interest is one of the four pillars of the strategy. According to the ESD, data spaces should foster an ecosystem (of companies, civil society, and individuals) creating new products and services based on more accessible data. In addition, what distinguishes the Common European data spaces from other data sharing initiatives is its focus on preserving European values, balancing the flow and wide use of data, while preserving high privacy, security, safety, and ethical standards.

One of the proposed sectorial European data spaces is the Green Deal Data Space (GDDS), which is particularly relevant for the GEO/EuroGEO context. A preparatory project (GREAT) for the GDDS was funded under the Digital Europe Programme with the task of developing an implementation roadmap, including a technical blueprint, governance scheme and a list of priority datasets. The GREAT project completed its activities in April 2024. Among the outputs of the project, the technical blueprint (Santoro et al., 2024) describes the design of the GDDS reference architecture. The deployment phase of the

GDDS will be carried out by the upcoming project SAGE (The Data Space for a Sustainable Green Europe), funded under the Digital Europe Programme, which is currently under negotiation.

As one of the key enablers for the green and digital transitions envisioned by the European Commission, the GDDS must be designed with a long-term perspective in mind. This means that the GDDS must be able to react and adapt to changes (e.g., the new functionalities and requirements stemming from such changes), particularly in the science/policy and technology contexts.

The design of the GDDS is based on the concept of Digital Ecosystem (DE) and a 'soft' infrastructure comprised of a set of logical components that enable the ecosystem's digital environment.

4 The future: Towards a GEOSS Digital Ecosystem

4.1 A history of changes

Limiting the scope to the second decade of GEO (2016-2025) several changes occurred greatly affecting the GEOSS context. They include changes in the GEO landscape, more general changes in the Science/Policy context, and, finally, changes related to the technological innovation.

4.1.1 Changes in the GEO context

Regional GEOs

The GEO Strategic Plan 2016-2025 encouraged to promote regional cooperation through national and regional GEO mechanisms (GEO, 2015). However, it did not identify a specific role or implementation instrument for regional activities, although it did highlight several areas where regional activities were needed, including: stakeholder engagement, identifying user needs, capacity building, fostering partnerships, and implementing regional services. Regional GEOSS Initiatives were included in the 2016 transitional GEO Work Programme as GEO Initiatives as a temporary arrangement. Later, the Regional GEOSS based on GEO caucus regions – initially named AfriGEOSS, AmeriGEOSS, Asia-Oceania GEOSS, and EuroGEOSS – were changed to Regional GEOs Initiatives (GEO, 2019) – AfriGEO, AmeriGEO, Asia-Oceania GEO, and EuroGEO.

The advent of Regional Initiatives impacted on GEOSS in terms of service governance and implementation. Beside the positive effect of better addressing local and regional needs, the potential implementation of regional services poses interoperability and reusability issues at a global level. There is also the risk of a Regional GEO competition which would go against the global and inclusive vision of GEO and GEOSS. The transformation of Regional GEOSS in Regional GEOs was beneficial focusing Regional Initiatives on stakeholder engagement, user requirements, capacity building, etc. instead of infrastructure implementation. However, the four Regional GEOs are still heterogeneous and, at least in some cases vague, in terms of what they provide at global level making difficult to include them in a full picture.

Engagement priorities

The GEO Strategic Plan 2016-2025 focused the scope of GEO and GEOSS on targeting societal challenges, highlighting that "Earth observations are an indispensable component to measure and monitor our progress towards addressing societal challenges" (GEO, 2015). To this aim, the GEO XIII Plenary in 2016 approved an Engagement Strategy (GEO, 2016) and selected three key policy priorities to guide GEO's efforts over the medium term:

- United Nations 2030 Agenda for Sustainable Development;
- Climate Change, with specific emphasis on the Paris Agreement; and

- Sendai Framework for Disaster Risk Reduction.

At its 18th meeting in September 2020, the GEO Programme Board reviewed and endorsed a proposal from the Urban Resilience Subgroup recommending that Urban Resilience be recognized as a fourth GEO engagement priority (GEO, 2020).

The identification of engagement priorities and their change over time impacted on the GEOSS evolution shifting focus from data sharing to the generation of knowledge from EO, for example to compute indicators, such as the UN Sustainable Development Goals indicators. They also highlighted the role of decision-makers and policy-makers as end-users of GEOSS.

GEO Knowledge Hub

The first decade of GEO activities in implementing GEOSS was mostly focused on data and information sharing. The original implementation plan did not consider knowledge explicitly, just mentioning the general idea that "t*he vision for GEOSS is to realize a future wherein decisions and actions for the benefit of humankind are informed by coordinated, comprehensive and sustained Earth observations and information*" (GEO, 2005). Instead, the GEO Strategic Plan 2016-2025 focused the scope of GEO and GEOSS on targeting societal challenges, explicitly encouraging to "improve technical means that provide access to global Earth observation systems, so that the data, information, knowledge, products and services needed for scientific understanding and sound decision-making are increasingly easy to access, integrate, and use" (GEO, 2015).

The problem of generating and sharing knowledge from EO data was then addressed in GEO related projects and initiatives. For example:

- The H2020 ERA-PLANET project (2016-2022) establishing "The European network for observing our changing planet", specifically in the GEOEssential Transnational Project, developed a general framework for Data to Knowledge transition highlighting the role of Essential Variables as high value intermediate products to generate knowledge as indicators and indices (Mazzetti et al., 2018; Giuliani et al., 2020; Lehmann et al., 2019; Mazzetti et al., 2022).
- The H2020 EDGE project (2017-2020) aiming at providing "European Direction in GEOSS Common Infrastructure Enhancements" experimented knowledge generation from EO in the GEOSS context (EDGE Consortium, 2020) based on the ERA-PLANET framework and tools as the Virtual Earth Laboratory (VLab) which was enhanced in several GEO related European Projects such as ECOPOTENTIAL, ENERGIC-OD, ERA-PLANET.
- (Craglia & Nativi, 2018) introduced the importance of Open Knowledge for reproducibility explicitly considering GEOSS as a case study where Big (Earth) Data can be shared and used for knowledge generation.

On September 2018, as an initiative of the newly appointed GEO Secretariat Director Dr. Gilberto Camara, a GEO Expert Advisory Board (EAB) was established. The Terms of Reference of the EAB mentioned knowledge as one of the main targets of GEOSS with the explicit intention to "t*ransform the GEOSS Platform from a discovery and access facility to a knowledge hub*". The GEO Secretariat then put substantial effort in building the GEO Knowledge Hub (GKH) "*An open-source digital repository of open, authoritative and reproducible knowledge created by the Group on Earth Observations*" (*GEO Knowledge Hub*, n.d.).

These and other initiatives and reflections on the role of EO-based knowledge for enabling and support environmental policy and decision-making contributed to the activities of the GEOSS Evolve Initiative first and the GEOSS Infrastructure Development Task Team (GIDTT) later in envisioning the future of GEOSS. They culminated with the release of the "Concept Paper for the Next Phase of the GEOSS Infrastructure" which advocated the need for a "*shift from the traditional data sharing paradigm to the* *more effective geospatial digital ecosystem model to generate and share knowledge, virtually can be applied to the GEO value-chain framework*” (GEO GIDTT, 2021).

4.1.2 Changes in Science/Policy context

The focus on Societal Challenges made GEO exposed to changes in the Science/Policy context. This is reflected in the initial choice of Engagement Priorities (Paris Agreement on Climate Change, Sendai Framework on Disaster Risk Reduction, United Nations Agenda for Sustainable Development), with the later proposal of a fourth Engagement Priority (Urban Resilience) and uprising challenges suggested by occurring events such as the environmental impact on health following the pandemic of 2020.

These changes affect the GEOSS design and development due to different requirements concerning data (spatial-temporal resolution and coverage, uncertainty, etc.) and modelling.

4.1.3 Changes in the technological context

As a system of systems for data sharing, GEOSS must deal with technological innovations. In the last decades, several technologies have affected - or had the potential to affect - the landscape of EO data sharing and processing. Just to mention a few of them:

- *Cloud technologies* enable storing and remote processing of big satellite data. Cloud-based platforms were developed specifically for accessing, visualizing, and processing EO data (Google Earth Engine, Copernicus DIAS, etc.). They demonstrated how remote processing of data can improve performance, thus suggesting a *mobile code* approach instead of the traditional *search and download* approach.
- *Data cubes*, by pre-processing datasets during the ingestion phase, it is possible to access the so-called Analysis Ready Data (ARD), potentially reducing the data preparation phase, and making processing for knowledge generation more efficient.
- The *Internet-of-Things* (IoT), enabling the networking of sensors and actuators promise a new era of in-situ data acquisition but also potentially a new data deluge with new challenges on storing, accessing, and processing these new datasets.
- *Edge computing*, moving data (pre-)processing close to the sensors can help to address IoT challenges, reducing the required bandwidth, and envisioning a Cloud Continuum supporting data processing.
- *Artificial Intelligence* (AI) boosted by the advancement of data-driven approaches based on Machine Learning (ML) and Deep Learning (DL) promise to deeply affect EO data processing as other fields.

Each of these recent technologies is a potential enabler for the desirable digital transformation of the process for evidence-based environmental decision-making. However, it is also a challenge for GEOSS on how to exploit such a technology, and for GEO on understanding how the resulting innovation affects positively or negatively the transparency, reproducibility, replicability, and reusability of generated knowledge.

4.1.4 An ever-changing world

The lesson learned from the past of GEOSS is that it must be able to react and adapt to changes in the GEO context, science/policy context and technological context. If these changes would happen once - or in a predictable cyclic way - it would be easy to cope with them with periodical revisions of GEOSS and releases of the enabling infrastructure. But the reality is that changes happen continuously. For example: GEO is now considering a new focus on in-situ as a consequence of an increased accessibility of satellite data through cloud platforms and the increasing need of ground truth from communities for validating theory-driven models and training of data-driven models; the geopolitical situation may suggest a new focus on applications of EO to energy and raw materials; new technologies like blockchain and quantum computing are emerging with potential impact on EO data sharing and processing. Therefore, the real lesson learned from the past is that **change is unpredictable but not unexpected**. We do not know which changes will occur, but we know that some changes will do. Therefore, **the process of change must be part of the design and implementation of GEOSS**.

4.2 The concept of (geospatial) Digital Ecosystem

A Geoscience Digital Ecosystem (GDE) can be defined as a "*system of systems that applies the digital ecosystem paradigm to model the complex collaborative and competitive social domain dealing with the generation of knowledge on the Earth plane*"(Nativi & Mazzetti, 2020).

The Digital Ecosystem (DE) paradigm stems from the concept of natural ecosystems (Blew 1996). DEs focus on a holistic view of diverse and autonomous entities (i.e., the many heterogeneous and autonomous online systems, infrastructures, and platforms that constitute the bedrock of a digitally transformed society) which share a common environment. In search of their own benefit, such entities interact and evolve, developing new competitive or collaborative strategies, and, in the meantime, modifying the environment (Nativi et al., 2021). In the geosciences domain, DEs are called to enable the coevolution (i.e. the complex interplay between competitive and cooperative business strategies) of geosciences public and private organizations around the new opportunities and capacities offered by the digital transformation of society – Internet, big data, and computing virtualization processes represent some of the main engines of innovation, rising an entirely new type of geosciences ecosystems (Nativi & Mazzetti, 2020).

A Natural Ecosystem can be characterized through its Ecosystem Functions and Services. Ecosystem Functions include the physicochemical and biological processes that occur within the ecosystem to maintain terrestrial life. Ecosystem services are the set of ecosystem functions that are directly linked to benefit human well-being.

While the interaction among the species and with the environment can vary making the ecosystem adapt to external and internal changes, some of these changes can affect the Ecosystem Services and become disruptive. This is the reason Natural Ecosystems need management and protection.

As depicted in Figure 6, the same paradigm can be applied to the digital domain. In a Digital Ecosystem, diverse and autonomous entities – i.e., digital 'species' – share a common digital environment, and in search of their own benefit, they interact and evolve, developing new competitive or collaborative strategies, and, in the meantime, modifying the environment. Also, in the Digital Ecosystem it is possible to identify Ecosystem Functions, that are informational processes, and Ecosystem Services that are those functions of value for the Society.

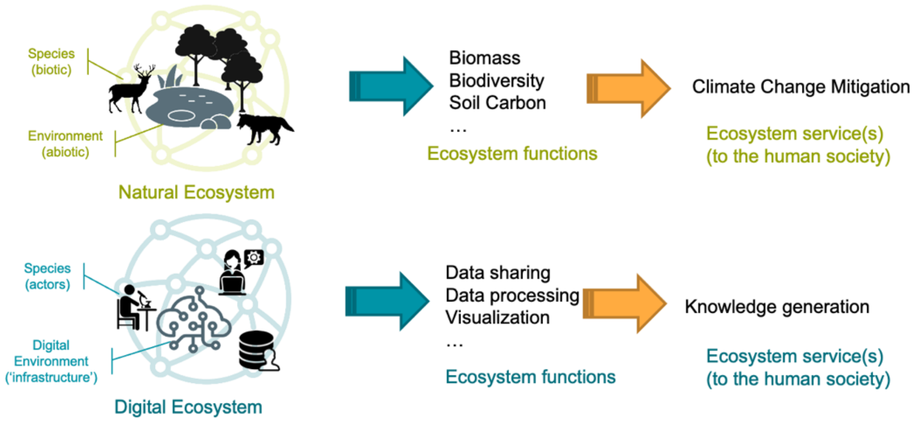

Figure 6 - Natural and Digital Ecosystems

What makes the ecosystem paradigm so powerful for adaptation to changes is that it focuses on the overarching values – through the provision of ecosystem services – not imposing any predefined behavior to the belonging species. Indeed, the inner structure of the digital ecosystem is free to vary over time adapting to contextual changes to preserve and enhance the ecosystem services. The digital ecosystem does not expect that species work for the ecosystem, but that they work for their own benefit and in doing so they contribute to the ecosystem's functions and services. This works as far as species gain benefit from belonging to the ecosystem. Each species must find its own compromise between the desire of Autonomy (to be free to pursue its own benefit without any constraint) and the advantages of Belonging (to contribute to the ecosystem to gain an indirect benefit).

4.2.1 Types of Digital Ecosystems

Adapting to contextual changes while preserving and enhancing the ecosystem services is a key characteristic of digital ecosystems, which must be free to evolve to cope with such changes. However, during this evolutionary process, values and services of the digital ecosystem must be maintained and protected. To this aim, it is expected that the ecosystem services are associated to a set of essential characteristics of the ecosystem that must be preserved. Those characteristics should be identified and considered as the real invariants, the immutable core that cannot change under penalty of the destruction of the ecosystem – i.e., the loss of any ecosystem service. Preserving the invariants requires a cybernetic mechanism of control and communication that is part of the digital ecosystem governance. Besides, governance should address possible conflicts such as belonging vs. autonomy – i.e., the possibility of conflict between participating system values and of overall ecosystem values.

Three main types of governance styles can be recognized for digital ecosystems:

- **Acknowledged**: there is a central management organization without coercive power to run the digital ecosystem, but constituent systems interact to fulfil agreed-upon central purposes.
- **Directed**: an integrated ecosystem is built to fulfil specific purposes, the ecosystem is centrally managed to ensure the long-term fulfilment of those purposes, as well as any new ones the system owners might wish to address.
- **Collaborative**: like in the directed ecosystems, there are recognized objectives, a designated ecosystem management, and resources allocated for its operation. However, like in the acknowledged ecosystem, the normal operational mode of the constituent systems (species) is not subordinated to the central managed purpose, and they retain their independent ownership, objectives, funding, and development and sustainment approaches.

4.3 An example of Digital Ecosystem: the World Wide Web

To evaluate the feasibility of an information sharing system as a (Geospatial) Digital Ecosystem it is first interesting to search for successful examples of Digital Ecosystems.

A first clear example is the World Wide Web: it is built around a set of architectural principles – Identification, Interaction and Representation – and related technical specifications – mainly URL, HTTP, HTML, and their descendants. Currently the WWW is an ecosystem hosting a diversity of species, including institutions, organizations, companies, citizens. They have their own interests and values, but all of them limit their Autonomy using the WWW to publish and access information. They find that Belonging to the Web – i.e., accepting its governance and technological constraints – is acceptable because they get something in return – i.e., access to resources, visibility – that help them to achieve their objectives – i.e., business opportunity, social interactions, etc. On their own point-of-view belonging to the Web is better than being fully autonomous.

The WWW has many distinct functions, but it is valuable as an ecosystem supporting (unstructured) information sharing. Species have their own interest to pursue, but all of them contribute to the information sharing which can be considered as its ecosystem service.

The WWW underwent deep changes since its birth in mid-90s. It was able to support new devices – e.g., mobile phones, web sensors –, new applications – e.g., search engines, social networks, e-commerce, e-governments -, new users - e.g., companies, public administrations, citizens. It is worth noting that none of them was anticipated in the creation of the WWW which was designed as a ‘simple’ system for hypertext sharing.

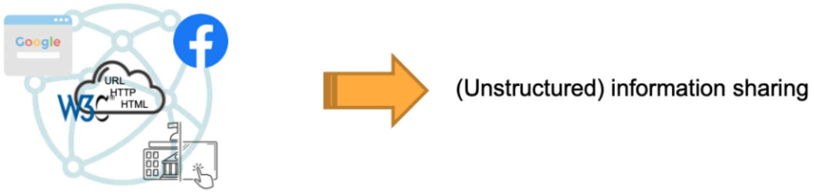

Figure 7 - The Web Ecosystem

There are other valuable examples of Digital Ecosystems. In recent years, Software Ecosystems evolved as Business Ecosystems built around one or more core (software) technologies. Google, with Android, and Apple, with iOS, built examples of successful Ecosystems. Developing the Android operating system and opening it to external developers, Google created an ecosystem hosting several species. It also started a virtuous cycle with an increasing number of applications: more apps are available and more devices the producers sell; more Android devices exist, and more developers are encouraged to create Android apps.

Of course, there is a fundamental difference between the WWW and the Android (or Apple) ecosystems. The WWW is not controlled by a single organization: its governance is distributed among different organizations, i.e., it is an acknowledged ecosystem. On the other hand, typical software ecosystems like Google’s Android or Apple’s iOS are controlled by a single organization, the one that controls the core technologies, i.e., it is a directed ecosystem.

4.4 The design of a digital ecosystem

The Web's success can help highlight recommendations for the design of a digital ecosystem. As discussed in the previous section, the Web did not even contemplate applications that are now considered essential and often qualifying it for users: e.g., search engines and social networks. How was it possible to create a system that was later able to accommodate such heterogeneous applications?

The answer is that the Web was not designed based on a set of specific use-cases and scenarios; it was built around a generic service of (unstructured) information sharing. As far as an application contributes to sharing – e.g., facilitating it as a search engine or focusing on specific interactions like social networks – it can be supported. Also, the Web did not try to optimize the information sharing to a specific kind of application, it just supports a basic (and often inefficient) synchronous request/response interaction. If an application needs more – e.g., asynchronous interaction, information streaming - then it is up to the application itself to provide such additional functionalities.

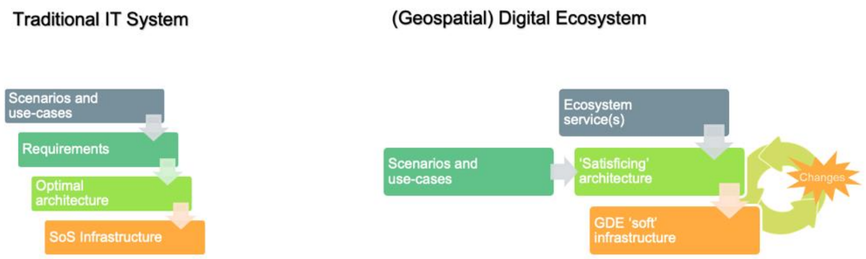

Figure 8 - Design of a Digital Ecosystem

This suggests that a digital ecosystem design is different from traditional system design. Traditional system design considers a well-defined set of use-cases (user requirements collection). Then designers elicit functional and non-functional requirements from the use-cases. Finally, they provide the best architecture to meet the requirements. The resulting system is optimal for the identified requirements, but there is no guarantee that it will remain optimal – or even acceptable – after any change. New applications, new technologies, new users can easily make the system obsolete or under-performing.

Instead, the outline of a digital ecosystem should first identify the (high-level) ecosystem service to provide and then design a *satisficing*[2] architecture. Scenarios and use-cases are important but just to validate the architecture and they should be identified to cover a spectrum of potential applications as wide as possible. Changes have a minor impact in digital ecosystems than in traditional systems, because: a) they can introduce new use-cases and scenarios as far as they do not disrupt the ecosystem service; b) a satisficing architecture can easily accommodate changes remaining a satisficing architecture, while an optimal architecture can easily become suboptimal.

Another important lesson learned from the Web, is that the core architecture is made of agreements including technical standards. The Web is developed around three pillars – Identification, Interaction, Representation – with their three specifications: URL, HTTP and HTML. Although there were some improvements and ancillary specifications, the Web is still built around these three specifications. There are many Web Server implementations, many browser implementations, many other clients, but they are not part of the core. You do not need to use Apache Web Server, or Google Chrome browsers, etc. In every technology there is competition and collaboration, but the Web is still just an agreement on using URL, HTTP and HTML. The Web is what is also called a 'soft' infrastructure in contrast with 'hard' infrastructure based on specific technologies. Of course, 'soft' infrastructures are much more flexible and adaptable to technology changes.

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[2] 'satisficing' is a term coined by the economist Herbert Simon to better model the behaviour of the 'rational agent' who typically does not search for an optimal decision which would require too much time and effort, but just stop their search at the first occurrence of a satisfying and sufficing solution.

4.5 GEOSS as a (Geospatial) Digital Ecosystem

4.5.1 GEOSS Digital Ecosystem Service

As outlined in the previous section, the definition of the ecosystem service(s) is of paramount importance in the design phase of a digital ecosystem. Therefore, designing GEOSS as a digital ecosystem requires, first, the identification of such a service. To this aim it is useful to recall the vision for the future of GEOSS formulated in the "Concept Paper for the Next Phase of the GEOSS Infrastructure" released by GEOSS Infrastructure Development Task Team (GIDTT) which advocated the need for a "*shift from the traditional data sharing paradigm to the more effective geospatial digital ecosystem model to generate and share knowledge, virtually can be applied to the GEO value-chain framework*" (GEO GIDTT, 2021). The role of EO-based knowledge for enabling and supporting environmental policy and decision-making is also recognized as a key area for the future of GEO by Post-2025 Working Group, which in its "Interim Report of the Post-2025 Working Group", presented at the GEO Plenary in Ghana, states "*… the abundance of information and information sources in the marketplace has not necessarily led to greater access to, and wider and effective use of, Earth observation information. Accelerating equitable access to, and making the use of, science-based earth observations for critically important decisions at the local, regional and global level remains a challenge. Against this context, the GEO partnership must evolve to remain relevant.*" (GEO, 2022a). This vision was consolidated in the approved GEO Post 2025 Strategy document, with its main focus on the provisioning of Earth Intelligence defined as "*integrated Earth and social science derived knowledge and insights that inform strategic decisions, build capacities and empower society to address environmental, societal, and economic challenges*" (GEO, 2023).

Therefore, we can identify the GEOSS Ecosystem Service as it follows:

Provisioning of trusted EO-based knowledge for decision-making

If such an ecosystem service is provided by GEOSS, a virtuous cycle can be initiated. End-users will utilize tools and services of the ecosystem because they find what they need; intermediate users (e.g., developers, scientists, etc.) will build new tools on top of (and contributing to) the ecosystem to attract end users; providers will have more interest in participating (belonging) to the ecosystem to spread the use of their resources.

Besides the ecosystem service (the 'what'), it is necessary to recognize the high-level values the ecosystem should adhere to (the 'how'). These can be expressed through a set of general principles acting as requirements and constraints and part of the essential characteristics of the ecosystem. It is possible to identify a set of basic principles:

- **Inclusiveness**: a high level of heterogeneity (of data systems in terms of supported metadata content and formats, data encoding, coordinate reference systems, ontologies, etc.) has always characterized the GEOSS environment, mainly for its multidisciplinary nature. At least part of this heterogeneity is justified by the specificity of the communities that generate and use those data. Since a knowledge generation ecosystem is intrinsically dependent on the sharing of valuable datasets, data systems cannot be excluded only due to their diversity. This principle is related to other principles such as Transparency and Openness. Potential conflicts (e.g., for some private actors) should be addressed at governance level.
- **Fairness**: GEOSS is also characterized by high heterogeneity in terms of involved actors ('species') including big companies, SMEs, public administrations, research and academic

organizations, intergovernmental institutions, etc. The GEOSS ecosystem should be the common ground where collaboration and competition take place for the benefit of the 'species' but, overall, for the ecosystem to provide the ecosystem service. Therefore, no privileged access should be granted to anyone at the risk of changing the fairness of the ecosystem itself.

- **Autonomy**: GEOSS was conceived to build on systems that are already part of other SoS or ecosystems with their own mandate and governance. It is necessary to respect such autonomy without imposing, de-iure or de-facto, the exclusive participation in the GEOSS ecosystem. This is strictly related to the autonomy vs. belonging conflict that has already been described. In the GEOSS ecosystem, belonging should be encouraged through soft means mostly based on the overall value of the ecosystem itself.

4.5.2 GEOSS Digital Ecosystem Actors

Another important aspect in the design of GEOSS as a digital ecosystem is the identification of the involved Actors (the ecosystem 'species'), focusing in particular on their roles and interest in becoming part of the ecosystem. The identification of the actors (along with their roles and interest in participating) is crucial to formulate a valid strategy to promote the GEOSS ecosystem, triggering the virtuous cycle of utilization/contribution which underpins the success of the ecosystem.

At least three roles can be identified for actors in the GEOSS ecosystem:

- **End users**: they benefit from the ecosystem service provided by the GEOSS ecosystem, which they can exploit through dedicated tools (e.g., desktop/web applications) developed on top of the GEOSS ecosystem; decision and policy makers are primary examples of actors with end user role. It is worth noting that, in general, also researchers and professionals can be considered in this category. However, GEO is mainly a policy-oriented initiative, i.e., it aims at exploiting research results for policy. Thus, the main beneficiaries as end-users (i.e., user that do not directly interact with the system) are decision and policy makers while researchers and professionals (who contribute to creating added-value products) are more intermediate users (see below).
- **Providers**: they contribute resources (e.g., data, processing platforms, scientific models, etc.) to the GEOSS ecosystem; their interest in participating (belonging) is widening the possible user-base of their resources and gaining more visibility which can help them to achieve their objectives (e.g., funding sustainability, new business opportunities, etc.); examples of actors with this role include space agencies distributing their EO products, in-situ/IoT networks, cloud computing providers, etc.
- **Intermediate users**: they develop components (applications, tools, services, etc.) leveraging the GEOSS ecosystem resources and generating added-value content, which in turn enriches the ecosystem itself; the generic term *component* is utilized because of the wide range possible added-value artifacts developed by intermediate users, including middleware services (e.g., mediation/harmonization), scientific models, web/desktop applications for end users, etc.; intermediate users benefit from participating by: (i) exploiting the amount of available resources which they use to generate their added-value content, and (ii) offering their content to the rest of the ecosystem actors; examples of intermediate user actors include developers (implementing applications for end users or middleware services which provide added-value functionalities), scientists (developing models which extract knowledge from existing data). It is worth noting that the private sector can play a significant role here through the development

of added-value components (applications, services, intermediaries, etc.) exploiting GEOSS ecosystem resources.

4.5.3 GEOSS Digital Ecosystem Soft Infrastructure

The previously mentioned principles define the essential traits of the ecosystem, highlighting what remains constant. During the design phase, it is crucial to identify the minimal set of logical components that sustain the ecosystem. These components make up the digital environment that enables the formation and growth of the ecosystem, and they are expected to form a constant part of its logical structure, even though they can be updated with innovative technologies.

The Inclusiveness principle states that the GEOSS Digital Ecosystem is a collection of various resource providers that offer their resources to diverse consumers, which mirrors the current state of (geospatial) data sharing globally. Rather than assuming this situation will change, the digital ecosystem approach acknowledges and supports it, driven by the principles of inclusiveness, fairness, and autonomy.

As a result, the GEOSS Digital Ecosystem must be established as a 'soft' infrastructure, a loosely federated system based on minimal agreement for openness - i.e., the description and documentation of adopted specifications. Establishing a single "common format" is not possible in a multidisciplinary and global context like GEOSS. Just to make some examples: data models for climatological studies require multidimensional time while data models for biodiversity applications require species taxonomies; arctic datasets need a different Coordinate Reference System than those on Africa, etc.

The challenge is how to transform a collection of disparate systems that use different technical standards into a digital ecosystem. The solution is not to eliminate fragmentation, but to build on top of it facilitating as much as possible the use of available resources. This requires a minimal set of logical components that enable the ecosystem's digital environment.

Thus, the GEOSS Digital Ecosystem soft infrastructure is comprised of the following two elements:

1. Agreements (including technical standards)
2. Minimal set of (logical) components creating the digital environment

4.6 Implementing the GEOSS Digital Ecosystem

Conceptually, the GEOSS Digital Ecosystem can be represented as in Figure 9. GEOSS Resources are contributed to the GEOSS DE by GEOSS providers utilizing the APIs which are exposed by their systems. To allow the exploitation of this set of heterogeneous resources, as recognized in previous section, the GEOSS Digital Ecosystem must be empowered by a set of (logical) components which enable the digital environment: the *GEOSS Digital Ecosystem Core Enablers*. These can be further extended/enriched by GEOSS Third-party Enablers, developed by intermediate users that aim to use GEOSS DE content for providing added-value services. GEOSS Applications are dedicated tools (e.g., desktop/web applications) developed for end users on top of the GEOSS DE content.

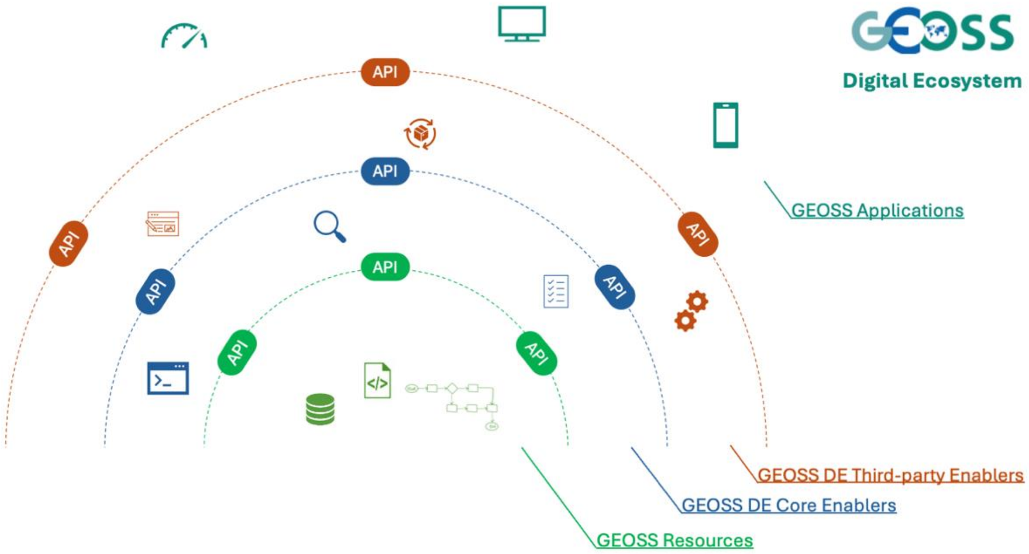

Figure 9 - Conceptual Representation of GEOSS Digital Ecosystem

Based on previous experiences in building SoS for geospatial data sharing, a preliminary set of such Enablers for the GEOSS Digital Ecosystem can be identified:

- **Data source registry**: it is necessary to know which data sources are 'officially' part of the ecosystem – e.g., for security and policy reasons - and they must be located for discovering and accessing datasets. It is worth noting that this technical component should be strictly associated with a well-defined governance process to identify the systems to be included in the GEOSS Digital Ecosystem (see section 4.8.1) in accordance with a user-driven approach.
- **Mediators**: these components provide mediation and harmonization functionalities to see heterogeneous and fragmented resources as a unique virtual set of harmonized resources.
- **Interfaces**: these are logical components providing tailored interfaces to the other components. We can expect at least three realizations of interfaces: a human-computer-interface which enables human users' interaction (typically through the Web); a machine-to-machine interface for system integration (typically based on de-iure/de-facto standard services) and a machine-to-machine interface for application developers (typically based on a set of Application Programming Interfaces or APIs).

In addition to the above ones, enabling basic data sharing, it is likely that new components will have to be identified to enhance the capabilities of the GEOSS DE and, in turn, contribute to the GEOSS DE service, i.e., the provisioning of trusted EO-based knowledge for decision-making. Of course, this strictly depends on what 'knowledge' means in the GEO context. Assuming a 'scientific' knowledge, that is knowledge acquired according to the agreed scientific method, knowledge generation and sharing require high-quality observations and scientifically sound computational models supporting transparency and reproducibility. This suggests that new resources, specifically algorithms for scientific models and policy indicators computations, are shared in the GEOSS DE. Moreover, every resource – i.e., data, models – should be addressable, accessible and well documented in terms of quality and uncertainty for transparency, and reproducibility. Potential GEOSS DE components include:

- **Persistent identifier**: to unambiguously refer to a resource – dataset or algorithm – it must have a persistent identifier that the other DE components can use for documenting a scientific business process for transparency and reproducibility.

- **Model registry**: a model registry collects scientific models that are ‘officially’ part of the ecosystem. It is necessary only if finding a model is the entry point of a supported use-case. (E.g., an intermediate user who wants to know if there is any model available to calculate some air pollution index).
- **Model harmonizer**: scientific models are encoded with heterogeneous software environment (programming or simulation frameworks, cloud environments,…). A harmonizer could facilitate the reusability of models allowing them to execute on different running environments. (The CNR-IIA VLab is an example of model environment harmonizer supporting a virtual cloud).
- **Knowledge base**: a knowledge base collects best practices concerning the generation of knowledge from EO for replicability and reusability. (The GEO Knowledge Hub is an example of knowledge base).
- **Marketplace**: a marketplace provides access to the applications available for generating (or supporting the generation of) knowledge from EO. (The CNR-IIA GOS4M simulator is an example of potential GEO app).

It will be necessary to identify which of these and other additional components will be part of the Core Digital Ecosystem Enablers, i.e., provided by the GEOSS DE itself. This is in line with the high-level diagram provided by the GIDTT Technical Assessment of the GEO Infrastructure, Figure 5, highlighting the links between the GEO Infrastructure and other components and partners (such as cloud provider, Regional GEOs, etc.) providing resources to GEOSS.

Figure 10 depicts the mapping between the concepts of the GEOSS DE and the high-level diagram provided by the GIDTT Technical Assessment of the GEO Infrastructure.

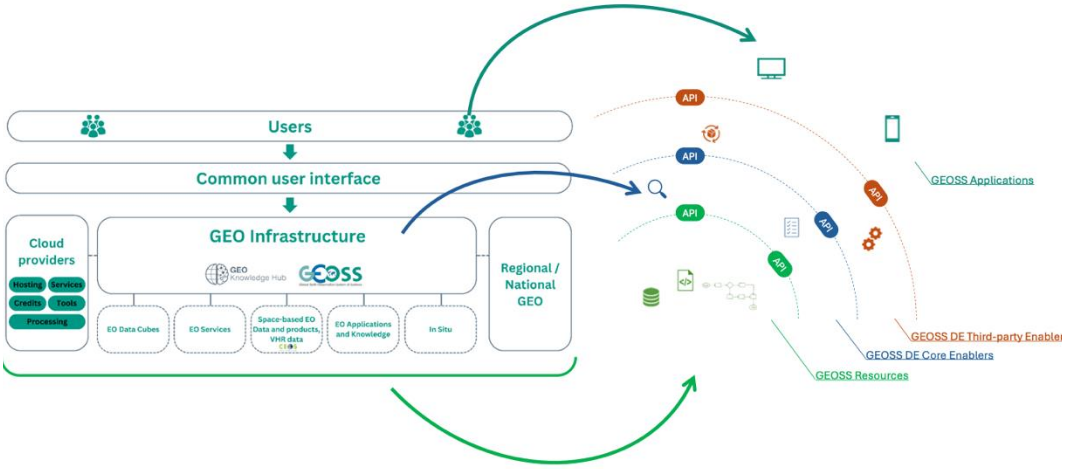

Figure 10 – Mapping of GEOSS DE to GIDTT Technical Assessment of the GEO Infrastructure

The process for identifying which components are part of Core Digital Ecosystem Enablers (as well as high-level operational governance of each enabler) should be part of the GEOSS DE governance framework, as outlined in section 4.8.

4.7 Specific challenges for the GEOSS Digital Ecosystem

Based on the analysis from sections 2 and 3, some specific challenges emerge for enabling the GEOSS DE.

4.7.1 Satellite data discovery and access

Satellite data replication:

Satellite datasets are often replicated on several clouds. For example, Sentinel datasets are available not only through the Copernicus Open Access Hub, which is the full and authoritative source, but also on the Amazon cloud, Copernicus DIAS, Copernicus Data Space Ecosystem, and on different local and regional datacubes. This situation poses multiple challenges on GEO and GEOSS.

Should GEOSS point only to the original and authoritative source or also to alternative sources? Of course, providing information about all the available copies would be important for supporting relevant use-cases, e.g., selecting the best platform for data processing. However, it poses significant challenges related to: synchronization (what if the copy is not up-to-date or partial?), authoritativeness (what if the copies are not exactly the same of the original?), etc.

Satellite data hubs:

CEOS provides a single point of access to satellite EO datasets through its Federated EO Gateway (FedEO). FedEO is a source already brokered by the current GEOSS Platform. However, GEOSS currently brokers EO data sources directly. This can be considered a duplication of effort, although it allows supporting more use-cases (see the previous point).

4.7.2 In-situ data discovery and access

Successful experiments with open in-situ data sources, and with other systems adopting the same technology of GEOSS (e.g., WMO WHOS) shows that the discovery and access to in-situ datasets is not a technological challenge even for the current GEOSS Platform. Instead, there exist relevant policy and governance challenges related to the access policies, to the long-term sustainability of in-situ data sources, to the availability of open repositories and archives for in-situ datasets. Another relevant aspect is if in-situ datasets should be flagged or otherwise categorized in the metadata.

A dedicated logical component implementing an open in-situ archive potentially managed by an international regional or global organization (e.g., EEA in Europe, the GEO Secretariat itself, Regional GEOs, etc) and brokered by the GEOSS Platform could be a viable solution.

4.7.3 Remote processing systems

The advent of cloud systems providing Infrastructure-as-a-Service (IaaS), Platform-as-a-Service (PaaS) and Software-as-Service (SaaS) capabilities has changed the EO data processing landscape. Remote run of mobile code has replaced the traditional download & process scenario enabling handling and processing of Big Earth Data.

Datacubes serving the so-called Analysis Ready Data (ARD) as multidimensional arrays through homogeneous pre-processing of heterogeneous datasets facilitate the processing and computation of EO-based indicators.

Both systems, although widening the set of supported use-cases and allowing to overcome Big Earth Data Volume and Velocity challenges, pose significant challenges to be incorporated in a GEOSS architecture. For example, there is the need of a description of processing system capabilities (e.g., supported software environments) and terms of use/policy (e.g., cost model[3], authentication and authorization), also in relationship with data policy (e.g., for transferring datasets from the original data source to a cloud).

4.7.4 Knowledge Formalization and Sharing

Since the GEOSS DE aims at "*Provisioning of trusted EO-based knowledge for decision-making*", it is crucial to be able to formalize, collect and share EO-based knowledge. The present GEO Knowledge Hub (GKH) provides discovery and access of a collection of best practices concerning the generation of knowledge from EO.

However, current implementation of the GKH does not provide an actual formalization (and sharing) of the knowledge generation process. A general framework to address this issue would enable a wide set of use cases, including: the replicability/reproducibility/reusability of scientific processes and related workflows, the possibility to generate inferences on many aspects: data/models gap analysis ("which datasets or models are missing to better generate an indicator?"), EO value ("how many and which indicators benefit from a particular dataset?"), etc.

The development of such a framework will require addressing several challenges, e.g., the user-friendliness of the knowledge provision and formalization (i.e., to facilitate the knowledge provision by expert), and to the governance of the process. In fact, if, as expected, the knowledge provision is a distributed process, including the possibility of different stakeholders annotating the same resource, a quality assurance methodology is necessary.

The use of Large-Language-Models (LLM) could help to support semantic queries.

4.8 Governance of GEOSS Digital Ecosystem

The GEOSS Digital Ecosystem aims to build on existing systems, encouraging the development of new elements to fill any gaps, and creating a complex digital environment. The participating systems in the GEOSS context are highly diverse and managed by various organizations, ranging from legacy systems with differing objectives and technological characteristics to systems with diverse content. As a result, the success of the GEOSS Digital Ecosystem largely relies on proper governance of the ecosystem as a whole. This governance must establish a set of rules and principles to guide the evolution and effectiveness of the ecosystem ensuring to continue delivering the defined ecosystem service, as it navigates through the various changes in the political, social, scientific, and technological environment in which it operates.

While it is out of the scope of this document to detail the specific governance mechanisms which will have to be applied to the GEOSS digital ecosystem, it is noteworthy to underline that, with respect to the different governance styles of digital ecosystems introduced in section 4.2.1), a context like GEOSS will require a mixed approach (although probably leaning towards the acknowledged style). It is instead useful to recognize that the governance of a complex digital ecosystem like GEOSS faces several challenges, stemming from its global, heterogeneous, and voluntary-based nature. The following sections briefly introduce and describe some of the main governance challenges recognized for the GEOSS digital ecosystem.

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[3] Remote processing tools are currently often based on cloud platforms, where they can exploit the high level of flexibility and scalability in the utilization of the required computational resources. To cover the costs associated with the computational resources, such remote processing tools might utilize different cost models, e.g., pay-per-use, subscription, allow to use users' own cloud credits, etc.

4.8.1 Who is Part of the Digital Ecosystem

The governance framework's main concern is determining which systems are suitable for inclusion in the GEOSS Digital Ecosystem. It is important to note that eligibility should focus on the organization's requirements operating the system and users' needs (i.e., what are the necessary data and resources to address their use cases), rather than technical aspects.

It is worth noting that the governance framework must not necessarily impose limitations on eligibility and may instead decide that any system from any organization can be part of the GEOSS Digital Ecosystem. However, this decision falls within the purview of the governance framework and an appropriate process should be clearly defined.

Example: Research Projects as System Providers

Should the digital ecosystem accept participation requests by research projects? This is a typical governance decision since allowing such systems to be part of the digital ecosystem has both benefits and drawbacks. In fact, on one hand, such systems might be experimenting innovative technologies from which the digital ecosystem might benefit; on the other hand, research projects usually have a limited lifespan after which the systems can be dismissed, creating potential drawbacks at the digital ecosystem level.

Another important aspect is that the contributing system should also guarantee the preservation of the services/data/resources to minimize the broken links or unavailability of the services.

4.8.2 Balancing Belonging vs. Autonomy

The success of a digital ecosystem depends on the ability of participant systems to collaborate and achieve a common value (i.e., the ecosystem service), while also pursuing their own enterprise goals. Thus, it is crucial for the governance to establish and manage acceptable behaviors (including the level of openness and transparency), time evolution, and communication and interoperability levels of participating systems. The digital ecosystem must be flexible enough to accommodate distinct levels of participation and autonomy, which are determined by each system, and guarantee equal accessibility for all stakeholders.

These compromises have a significant impact on the technological solutions supporting the digital ecosystem and should be carefully regulated by the governance framework.

Example: Sharing Metadata Only

A typical example of governing the balance between belonging and autonomy is the case of a data provider system which shares metadata only, without the possibility to automatically retrieve data as well. The clear benefit of belonging for the data provider is the increased visibility of its content, while keeping the autonomy of not to allow data to be retrieved from the digital ecosystem, but "forcing" users to use the data provider's own system. The digital ecosystem governance must decide if such a participatory arrangement is acceptable (what if all the providers give access to metadata only?) and/or how that should be dealt with (e.g., giving a low ranking to such metadata in search results). It is important to note that these kinds of decisions are part of the governance realm, not the technological one.

4.8.3 Core Digital Ecosystem Enablers

As recognized in previous sections, the GEOSS digital ecosystem requires a minimal set of logical components (the Core Digital Ecosystem Enablers) which enable the digital environment where all participating systems can interact. The governance framework should establish a clear process to identify such components; in fact, as part of the adaptation to science/policy/technology changing contexts, there might be the need to add/dismiss such components.

Besides, for each component, high-level operational governance should be laid out. This includes at least two items: (i) high-level functionalities provided by the component, and (ii) life-cycle process(es) operated by the component. Finally, in accordance with a user-centric approach, the adoption of metrics on the usage of the platforms, bug tracker (and wish list), benchmarks, helpdesk, etc., will help better addressing users' needs.

Example: In-situ Repository

It was recently discussed if GEOSS should provide a specific repository for in-situ data, dedicated to the collection of multiple in-situ observations, which would otherwise be dispersed. This can be considered as an example of a new component that the governance framework is requested to evaluate as part of the Digital Ecosystem Enablers or not. To answer this question there is the need for a well-defined process and a set of criteria for establishing which components are part of Digital Ecosystem Enablers.

It is important to note here that the recognition of a new Core Digital Ecosystem Enabler should not specify any particular technology or implementation; at this level it is important to recognize the need of a new Digital Ecosystem Enabler and to define its high-level functionalities (e.g., in case of the in-situ repository, the possibility to store and share in-situ observations) and its life-cycle process(es) (e.g., in case of the in-situ repository, who can add observations, should any quality check be executed and when, etc.).

4.8.4 Sustainability

Digital ecosystems must be sustainable over the long term, which requires careful planning and management. Governance must ensure that the ecosystem remains financially viable and continues to provide value to its participants.

In the case of GEOSS digital ecosystem, specific sustainability solutions must be identified to support the minimal set of enablers; thus, ensuring that the GEOSS Digital Ecosystem functions are interoperable with other infrastructures and/or Digital Ecosystems. Besides, a sustainability plan should as well as to ensure that participants, in particular providers and intermediate users, are motivated to contribute to (and thus enrich) the digital ecosystem. This will guarantee that the ecosystem resources (from providers) and innovative services (from intermediate users) remain sustainable.

5 The Role of GPP

In this section, we analyze how the GEOSS Platform Plus project contributes to the vision of a GEOSS Digital Ecosystem like what was described in section 4. In brief, at least three types of contributions can be recognized for GPP:

- Operation and enhancement of the current GEOSS Platform components, as candidate Core Digital Ecosystem Enablers of the GEOSS Digital Ecosystem.
- Development of use-cases to "validate" the proposed approach.
- Development and support of the integration of proof-of-concepts/prototypes of new components, which demonstrate how the digital ecosystem can be enriched by third-party actors (i.e., intermediate users).

In the implementation of the above activities, GPP also considered the specificity of the European context and relevant initiatives such as EuroGEO, Copernicus, European Strategy for Data (which includes activities on the Common European Data Spaces and Destination Earth) and others – e.g., data sovereignty as one of the European values will be proposed and discussed as a challenge also in GEOSS.

5.1 Operation and enhancement of the current GEOSS Platform components

The GEOSS Platform currently represents the midstream layer that enables access and exploitation of EO and non-EO data and other resources (upstream) made available by the providers, in a form that is easily exploitable by (downstream) applications, which are then utilized by the final users.

The GEOSS Platform Plus (GPP) project, in close collaboration with the GEO partners, is aimed at evolving the European GEOSS Platform components, i.e., the GEOSS Portal, the GEO Discovery and Access Broker and the GEOSS Yellow Pages. Looking at the Core Digital Ecosystem Enablers initially identified in section 4.6, it is easy to recognize that these are covered, at least partially, by the current GEOSS Platform components as depicted in Figure 11.

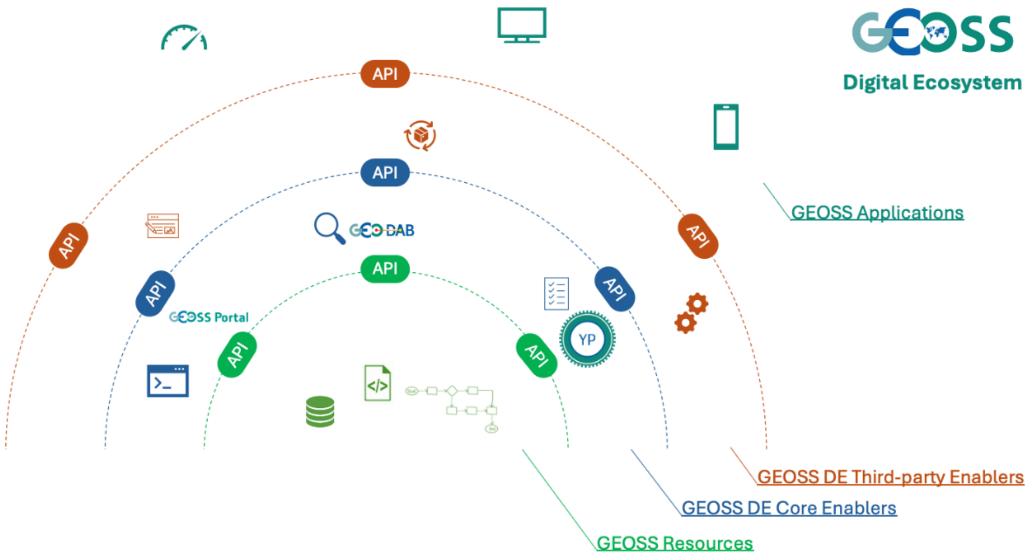

Figure 11 – European GEOSS Platform Components as GEOSS DE Enablers

Table 1 captures a high-level mapping of current European GEOSS Platform components to the identified GEOSS Digital Ecosystem Enablers.

Table 1 - Possible mapping of European GEOSS Platform Components to GEOSS Digital Ecosystem Enablers

	Data Source Registry	Mediators	Interfaces
GEOSS Yellow Pages	Organizations		M2M (under dev.)
GEO DAB	Web Services/APIs	Metadata and Data[*]	M2M
GEOSS Portal			H2M

Therefore, GPP can contribute to the GEOSS Digital Ecosystem vision by enhancing the existing European GEOSS Platform components towards potential implementations of GEOSS Digital Ecosystem Enablers. Of course, this will require a much more detailed definition of the GEOSS Digital Ecosystem Enablers at the governance level (as discussed in section 4.8.3). However, pending the governance framework of the GEOSS Digital Ecosystem, such developments can help demonstrate the value of the proposed vision and, in case, identify major issues in its implementation in the context of GEOSS.

It is worth noting that, in addition to the technological contribution, such contribution can help preserve the past efforts and investments in GEOSS Platform at the European level and to reinforce the European participation and leadership in GEOSS.

5.2 Use Cases

One of the main objectives of GPP is to enable access to tailor-made information and actionable knowledge in close collaboration with different GEO partners involved in the development of the GEOSS. GPP will focus on services to non-specialists in the domain of adaptation to extreme climatic events and to changes in climatic conditions. To this aim, GPP is developing a set of use cases which are built on the GEOSS Platform and its components.

Through the development of its use cases, GPP can provide a significant contribution in assessing the proposed vision of the GEOSS Digital Ecosystem. In fact, use cases build on top of existing European GEOSS Platform components (which, as observed in previous section, can be considered as first implementations of GEOSS Ecosystem Enablers) and, when needed, develop prototypes of the missing middleware components. Thus, on one hand, GPP use cases can be used to validate the use of European GEOSS Platform components as early implementations of Core Digital Ecosystem Enablers; on the other hand, GPP use cases can be used to prototype new components with the aim of demonstrating how the GEOSS digital ecosystem can be enriched by third-party actors (i.e., intermediate users) and how they could interface and interoperate with the Digital Ecosystem.

In the remainder of this section, we analyze a couple of GPP use cases to demonstrate how the GPP Vision of a GEOSS Digital Ecosystem can move forward, allowing different actors to contribute to the GEOSS Digital Ecosystem, by providing new tools, services, applications, middleware and other third-party components which exploit and enrich the GEOSS DE. The analyzed use cases are *SDG 15.3.1 Land degradation* and *Nutrient Pollution in European Inland and Coastal Waters*. For readers' convenience we report below a very brief description of each use case (the full description of GPP use cases is available in project deliverables).

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[*] GEO DAB supports all metadata formats and services utilized by current GEOSS data providers, while not all the data formats and services are currently supported.

SDG 15.3.1 Land Degradation

This use case focuses on addressing the Sustainable Development Goal (SDG) 15.3.1, which aims to monitor and combat land degradation. The goal is to enable users, particularly from national SDG-related agencies and environmental organizations, to calculate the related SDG indicator at the national scale. Users can access Earth observation data sources such as land cover, land productivity, and carbon stocks. The GEOSS platform offers tools to discover relevant data, select suitable indicators, and execute calculations based on climate change scenarios, providing actionable knowledge in the form of risk maps. This use case highlights the platform's role in supporting sustainable land management and SDG tracking.

Nutrient Pollution in European Inland and Coastal Waters

In Europe, intensive agricultural practices together with high population density represent important sources of nutrients for fresh and coastal waters. Nutrient pollution is one of the major pressures on European aquatic ecosystems altering their condition. Ambitious water policies are in place in the European Union for protecting and restoring aquatic ecosystems. In October 2022, the Commission revised the Urban Wastewater Treatment Directive, adapting it to the newest standards, on the basis of an extensive impact assessment.

The GREEN model, developed by the EC Joint Research Centre, was utilized in the impact assessment to quantify the current pressures of point and diffuse nitrogen and phosphorus emissions to European fresh and coastal waters and analyze the effects of different policy scenarios of different ambition level on nutrient pollution reduction.

This use case, developed in collaboration with JRC, aimed at enabling the replication of the GREEN model results of the impact assessment, contributing to a transparent and evidence-informed policy making process, according to the principles of the European Commission Better Regulation agenda.

It is important to outline that the high-level common goal of the proposed use cases (i.e., to provide end users with tailor-made information and actionable knowledge) is aligned with the proposed GEOSS Ecosystem Service (i.e., provisioning of trusted EO-based knowledge for decision making). To achieve their goal, each use case requires not only data, but also the possibility to utilize existing models which produce the desired output. To address such a requirement, the use cases utilize a new mediator component: the Virtual Earth Laboratory (VLab) – see next section. In brief, VLab allows to execute scientific models on different cloud platforms and publishes a set of Web APIs which can be used to exploit its functionalities.

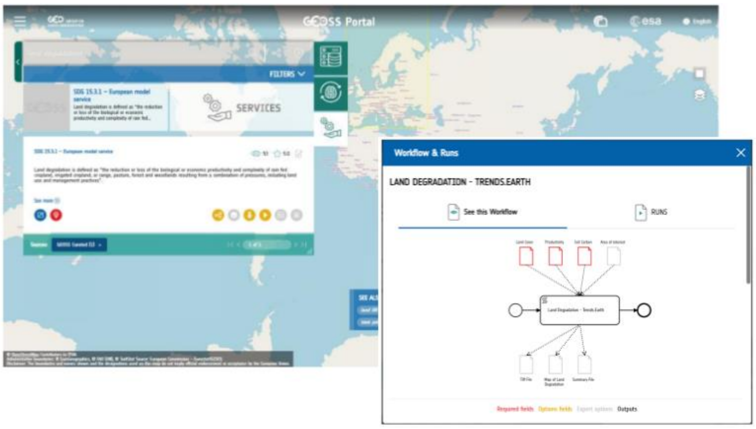
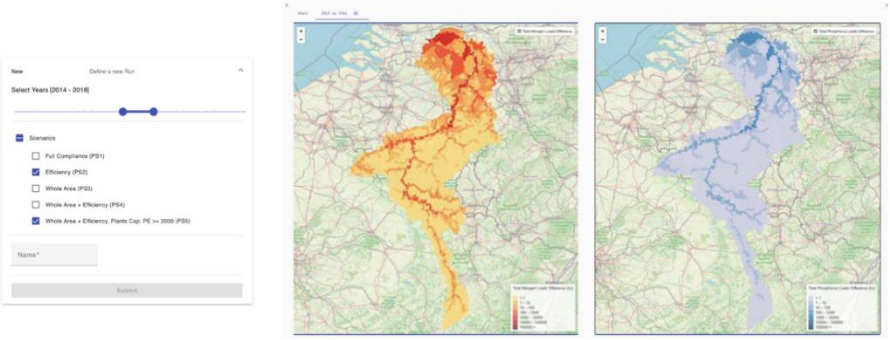


Figure 12 – Extension of the GEOSS Portal for SDG 15.3.1 Land Degradation use case

In keeping with the Digital Ecosystem approach, each of the above use cases developed a Graphical User Interface (GUI) to meet the needs of its end users. The *SDG 15.3.1 Land Degradation* GUI was developed as an extension of the general purpose GEOSS Portal (Figure 12).

This extension allows end users to discover the Trend.Earth model for SDG 15.3.1, select model input data utilizing the GEOSS Portal discovery interface, trigger the model execution and visualize its results in a user-friendly dashboard. On the other hand, the Nutrient Pollution in European Inland and Coastal Waters GUI was developed as a fully tailored dedicated Web App. The developed GUI is very simple and allows end users to easily select the region of interest and define the settings for the simulation (including different policy scenarios and the simulation years) and visualize results (Figure 13).



Select Years [2014 - 2018]

Scenarios
- ☐ Full Compliance (PS1)
- ☑ Efficiency (PS2)
- ☐ Whole Area (PS3)
- ☐ Whole Area + Efficiency (PS4)
- ☑ Whole Area + Efficiency, Plants Cap. PE >= 2000 (PS5)

Figure 13 – Web App of the Nutrient Pollution in European Inland and Coastal Waters use case

The implementations of these two use cases highlight the flexibility and openness which a Digital Ecosystem approach provides to a wide range of stakeholders and users. In fact, while both use cases are built on top of the capabilities provided by the DE enablers (i.e., GEO DAB for data and metadata harmonization, VLab for scientific models harmonization) they differ in how such capabilities are presented to end users. For *SDG 15.3.1 Land Degradation* use case, the GUI is a general-purpose portal (i.e., the GEOSS Portal with extensions for interacting with VLab). It allows users to search and discover the model, the input data and finally create a dashboard for results visualization. The second use case about *Nutrient Pollution in European Inland and Coastal Waters*, provides users with a very simplified Web App, which hides most of the underlaying details (which model to use, which data for which region of interest, etc.). This responds to the needs not only of end users, but of developers as well. In fact, in some cases developers want to be able to exploit the Digital Ecosystem content and functionalities utilizing their own technologies with minimal constraints (only Web APIs are necessary in this use case); as an example, a software company developing a tool for a Public Administration (PA) that uses GEOSS DE content but that must be integrated in the PA information system might require the use of specific technologies.

It is worth mentioning also other GPP use cases, which are in the finalization phase at the time of writing this document, that are implemented along the same lines as the two examples described above: the *SDG 11.7 - Monitoring the accessibility to urban green spaces*, *Above Ground Biomass* and *NewLif4DryLands Local Scale Indices*. The first one tackles the accessibility of urban green spaces (SDG11.7) using GEOSS. Users, including national SDG-related agencies and city planners, can calculate urban green space accessibility using various input data like NDVI, population grids, land cover, and more. The GEOSS platform offers tools for generating actionable information (through VLab) and visualizing the results as dashboards in the GEOSS Portal. The *Above Ground Biomass* use case deals with the estimation of forest above-ground biomass (AGB), which can be used as a proxy for the quantification of carbon stocks, particularly referring to Reduced Emissions from Deforestation and forest Degradation (REDD+) projects. The use case aims to exploit remote sensing data to generate maps of biomass utilizing, and comparing, different Machine Learning (ML) models. A dedicated Web GUI allows user to select the area and period of interest, trigger the map generation (through VLab) and visualize the results. Finally, the *NewLif4DryLands Local Scale Indices* builds on the outcomes of the NewLif4DryLands project[4] (funded from the LIFE financial instrument "LIFE Preparatory project – Programme for the Environment and Climate Action" of the European Commission) which extracted a set of remote sensing-based indices and indicators used as proxies to assess quantification and mapping of Land Degradation at local scale, trying to answer to the requests, by local institutional decision-makers, of increasingly more details difficult to reach by global/pan-European Union (EU) services (i.e., Copernicus). The modeling for the calculation of such indices were shared in VLab and a dedicated Web GUI was developed for the calculation, visualization and comparison of the local-scale indices.

Besides the examples described above, the Digital Ecosystem allows to address also other scenarios, e.g., the need to specialize the different components (enablers, GUI, etc.) for particular community needs. This was demonstrated in GPP with the development of community portals (based on GEOSS Portal), GEOSS views and GEO DAB community-driven extensions developed and utilized for the AfriGEOSS community portal, All-Atlantic community portal, the MAPS4GPP harmonized in-situ data for crop mapping use case, etc.

Figure 14 depicts the different components utilized by the described use cases and how they can enrich the GEOSS DE.

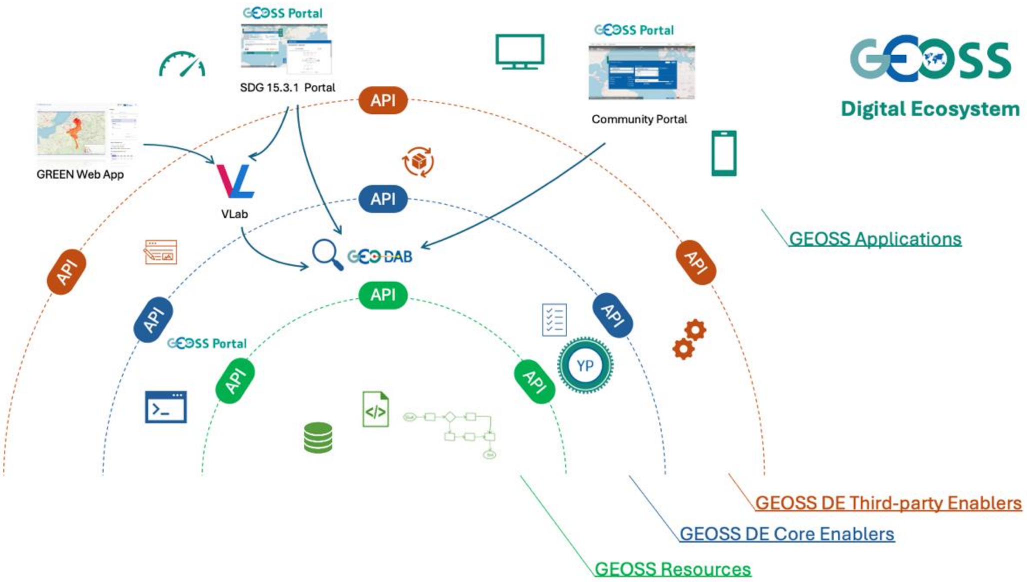


Figure 14 – GEOSS DE enriched with Components developed by the GPP use cases

Table 2 summarizes how the different use cases utilize the required GEOSS DE resources, through specific GEOSS DE enablers and different end users' GUI according to their needs.

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[4] https://www.newlife4drylands.eu/en/

Table 2 – Resources and Components utilized in GPP use cases

	Resources	Enablers	GUI
SDG 15.3.1 Land Degradation **SDG 11.7 - Monitoring the accessibility to urban green spaces**	Data Model Computation	GEO DAB VLab	General Purpose Portal (GEOSS Portal)
Nutrient Pollution in European Inland and Coastal Waters **Above Ground Biomass** **NewLif4DryLands Local Scale Indices**	Data Model Computation	GEO DAB (transparent for end users) VLab (transparent for end users)	Dedicated Web App (GREEN Web App)
AfriGEOSS **All-Atlantic** **MAPS4GPP**	Data	GEO DAB (with community extensions) GEOSS Views	Community Portal (tailored GEOSS Portal)

5.3 Proof-of-Concepts and Prototypes

One of the key characteristics of digital ecosystem is that it provides a digital environment where different actors interact, exploiting the digital ecosystem resources and providing new resources at the same time. This materializes, e.g., in third-party developers which build new services and tools on top of the digital ecosystem.

GPP can contribute to this process as well. In fact, as noted in the previous section, the development of GPP use cases requires the prototyping of new middleware components to provide missing functionalities required for the use case implementation. Such developments are to be considered as possible new components which demonstrate how, building on the GEOSS Digital Ecosystem Enablers, the GEOSS digital ecosystem can be enriched by third-party actors (i.e., intermediate users).

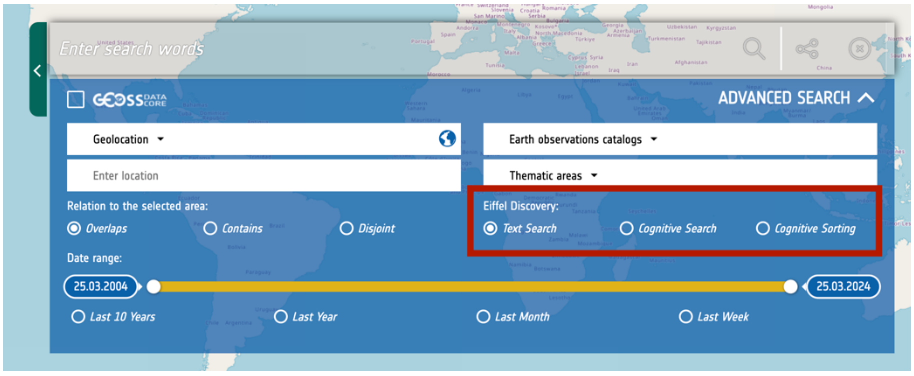
One example of such a development is the Virtual Earth Laboratory (VLab). In a nutshell, VLab is a framework which implements orchestration functionalities needed for executing a scientific model, i.e. retrieving the model source code, transferring it to a computing platform (AWS, DIAS, EOSC, etc.), ingesting the required input data, triggering the model execution, and finally collecting the generated output data. Besides, VLab publishes a set of Web APIs which can be used to discover its models and execute them on different cloud platforms. By connecting to the GEOSS Digital Ecosystem, VLab can leverage the available data to feed the scientific models which are currently available in the framework. At the same time, VLab can contribute to enrich the GEOSS Digital Ecosystem by sharing the model outputs, its models and allowing to execute them via its APIs.

The VLab example can clearly demonstrate how a third-party developer can benefit from the GEOSS Digital Ecosystem (retrieving in this case the input data necessary for the model execution) and at the same time contribute to the overall GEOSS Digital Ecosystem by sharing models for knowledge generation and outputs of these models.

Another example of how the Digital Ecosystem approach can facilitate the adoption of new technologies is the proof-of-concept that GPP developed in collaboration with EIFFEL project. Such a proof-of-concept aimed at demonstrating how to leverage AI-based LLM models to enhance the search capabilities provided by the GEO DAB. The EIFFEL project developed a system that comprises an AI language model optimized for Climate Change-related text and queries. To do this, GPP provided EIFFEL with a subset of the GEOSS resources metadata, that was utilized for training the AI language model.

To exploit this capability in the GEOSS Platform environment, GPP and EIFFEL projects collaborated to implement a set of specific APIs which enable the discovery of GEOSS content not only with traditional text-based searches, but also taking advantage of the EIFFEL cognitive search. Technical details of the implementation are provided in GPP deliverable D3.4. In brief, two integration approaches were implemented:

- Cognitive Search: in this approach text-based constraints of a query are executed by EIFFEL AI LLM, the result set is then processed by GEO DAB which applies the other query constraints (spatial, temporal, etc.);
- Cognitive Soring: in this approach, GEO DAB first applies the query constraints, the result set is then sorted according by EIFFEL AI LLM according to text-based query constraints.



Relation to the selected area: ● Overlaps ○ Contains ○ Disjoint

Eiffel Discovery: ● Text Search ○ Cognitive Search ○ Cognitive Sorting

Date range: 25.03.2004 25.03.2024

Figure 15 – The Test Version of the GEOSS Portal for AI-based LLM Search

For testing the developed functionalities, a test version of the GEOSS Portal was implemented (Figure 15) to allow users select: Text Search (traditional search, GEO DAB only), cognitive Search, Cognitive Sorting. The developed proof-of-concept was demonstrated at the EGU 2024, during the splinter session *Supporting the Earth Intelligence paradigm of GEO: The EIFFEL experience*[5].

Figure 16 depicts the enriched GEOSS DE with EIFEEL Cognitive Search component and its interaction with GEO DAB.

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[5] https://meetingorganizer.copernicus.org/EGU24/session/51031

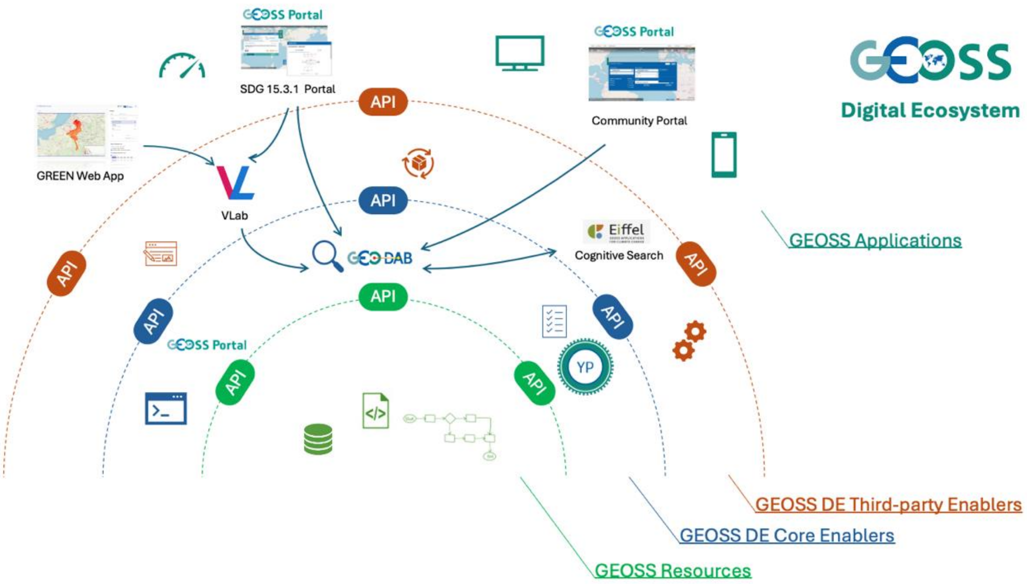

Figure 16 – GEOSS DE with EIFEEL Cognitive Search Component

6 Conclusions

In this document we described a high-level vision for the future GEOSS taking into account feedbacks, requirements, and recommendations provided throughout the last years in the context of several events, workshops and meetings, including: the Data Provider Workshops, the Mid Term Evaluation, the Expert Advisory Group reporting, the GEO Post-2025 strategy, the GIDTT Technical Assessment of the GEO Infrastructure, and the Common European Data Spaces (and in particular the Green Deal Data Space).

The document recognizes the main changes which affected GEOSS context in the last decade. They include changes in the GEO landscape, more general changes in the Science/Policy context, and, finally, changes related to the technological innovation. The concept of Digital Ecosystem is presented and acknowledged as a powerful paradigm to cope with such a rapidly changing context. Thus, we described GEOSS as a Digital Ecosystem for the provisioning of trusted EO-based knowledge for decision-making.

The GEOSS Digital Ecosystem (DE) is designed to adapt to continuous changes in the GEO context, science/policy context, and technological context. This adaptability is crucial for ensuring the long-term sustainability and relevance of GEOSS. The DE paradigm focuses on a holistic view of diverse and autonomous entities that interact and evolve within a common environment, providing valuable ecosystem services without imposing predefined behaviors. The GEOSS Digital Ecosystem aims to transition from a traditional data-sharing paradigm to a knowledge generation and sharing model. This shift is intended to support decision-making processes by providing trusted EO-based knowledge. The ecosystem's soft infrastructure, comprising agreements (including technical standards) and core enablers, is designed to address fragmentation and enable a flexible digital environment.

The governance of the GEOSS Digital Ecosystem faces several challenges, including determining eligibility for participation, balancing autonomy and belonging, managing core enablers, and ensuring sustainability.

The GEOSS Platform Plus (GPP) project plays a significant role in this vision by operating and enhancing current GEOSS Platform components, developing use cases, and prototyping new components to enrich the ecosystem.

In summary, the GEOSS Digital Ecosystem is a forward-looking approach that aims to create a flexible, adaptive environment for knowledge generation and sharing, supported by a robust governance framework and technological integration.

Finally, it is worth noticing that the Digital Ecosystem approach fits particularly well for the European context as well. The reference architecture of one of the proposed sectorial Common European data spaces, i.e., the Green Deal Data Space (GDDS) is based on the concept of Digital Ecosystem (DE). Besides, the EuroGEO initiative might take advantage of the DE concept to build upon the relevant European initiatives (including Coperncius, Destination Earth, etc.) and provide a flexible and adaptive environment where different stakeholders are able to seamlessly integrate and cooperate.

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Annex B. Figures and Tables

B.1 List of Figures

B.1 List of Tables

Annex C. Terminology

Acronym	Description
CEOS	Committee on Earth Observation Satellites
CNR	National Research Council
DAB	Discovery and Access Broker
DE	Digital Ecosystem
EAB	GEO Expert Advisory Board
EAG	Expert Advisory Group on GEOSS
EDGE	European Direction in GCI Enhancements
ESA	European Space Agency
GCI	GEOSS Common Infrastructure
GIDTT	GEOSS Infrastructure Development Task Team
GKH	GEO Knowledge Hub
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
GPP	GEOSS Platform Plus
MTE	Mid-term Evaluation
SoS	System of Systems