

2025

Report on Climate, Environment and Biodiversity

User Needs and Requirements

#EUSpace 



EXECUTIVE SUMMARY

The Climate, Environment, and Biodiversity segment of the EU Space Programme is supported through the User Consultation Platform (UCP), a continuous process that captures evolving user needs and requirements for PNT and Earth Observation. This report consolidates insights from desk research, stakeholder consultations, and annual UCP events to provide an up-to-date reference for end users, service providers, and the EO/GNSS community.

It identifies market trends, key actors, regulatory drivers, and operational applications, highlighting user expectations, gaps, and limitations across climate, environmental, and biodiversity domains. The methodology combines systematic analysis of existing reports, expert knowledge, and direct validation with stakeholders, ensuring transparency and responsiveness to technological and market evolution. While this report informs planning and system development (including Copernicus, Galileo, EGNOS, and future initiatives), it does not constitute a commitment to deliver all identified needs. The outcomes feed into the EUSPA User Requirements Database, supporting decision-making, service design, and strategic evolution of EU space capabilities.

Copernicus provides open, multi-source Earth Observation data that underpins climate, environmental, and biodiversity monitoring at scale. Its datasets, from optical, radar, thermal, and altimetry satellites, enable repeatable, high-resolution tracking of ecosystems, carbon stocks, water resources, wetlands, pollution, and urban flood risk. EO supports evidence-based policymaking, sustainable resource management, and verification of biodiversity and carbon credits, often integrated with UAV/LiDAR, in-situ networks, and advanced analytics. The upcoming Sentinel Expansion missions will further enhance capabilities, including hyperspectral land imaging, CO₂ monitoring, soil moisture, and polar observations.

By 2026, demand for environmental monitoring is increasingly shaped by regulation, climate-risk management, and operational decision-making rather than ESG reporting alone. EO adoption is accelerating, driven by high-resolution, multi-sensor satellites, AI-enabled analytics, and hybrid integration with in-situ data, enabling actionable intelligence on biodiversity, carbon, wetlands, water resources, and urban climate risks. Copernicus and commercial constellations provide repeatable, science-grade observations, while Sentinel Expansion missions enhance coverage for CO₂, hyperspectral land imaging, and thermal monitoring.

EO users are broad and central, including authorities, water managers, city resilience teams, finance/credit platforms, and NGOs, relying on satellite time series for actionable, policy-grade intelligence on habitats, water resources, urban risks, and ecosystem condition.

EGNSS, primarily Galileo and EGNOS, plays a complementary role, anchoring EO data to precise geospatial references. Its high-accuracy positioning is valuable in niche applications such as marine buoy monitoring, coastal change detection, and vertical motion studies, ensuring data confidence and traceability. GNSS strengthens EO-based indicators and enables specialized scientific and infrastructure use cases.

GNSS users remain niche but critical: oceanographers, hydrographic agencies, coastal engineers, and research institutions deploy GNSS on buoys and tide gauges for absolute sea-level, coastal dynamics, and hazard assessments.

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1 SCOPE AND METHODOLOGY

1.1 Scope

The User Consultation

The User Consultation Platform (UCP) is a process developed at the European Union Agency for the Space Programme (EUSPA) to collect user needs and requirements and take them as inputs for the provision of user driven space data-based services by the EU Space Programme.

The objective of this report is to provide a reference for the EU Space Programme and for the Climate, Environment, and Biodiversity segment community, reporting the most up-to-date user needs and requirements in the Climate, Environment, and Biodiversity market segment for the use of Position, Navigation and Timing (PNT) and Earth Observation (EO) technologies. Its scope is to cover needs and requirements from the user perspective, considering the market conditions, regulations, and standards that influence them. The report serves as a reference for end users, service providers and the whole EO community in planning and decision-making activities for those concerned. The report is also intended to serve as an input to more technical discussions on systems engineering and to shape the evolution of the European Union's satellite navigation systems, Galileo and EGNOS and the EO system, Copernicus,

The UCP process starts with interviews in which users from different market segments share their needs and application-level requirements related to PNT and EO. These interview results are then discussed during a regular multi-stakeholder event, where participants collectively discuss and refine the identified needs. This document provides a consolidated summary of those discussions and conclusions and is maintained as a living report by EUSPA, regularly updated to reflect evolving user needs, markets, and technologies. It serves as a key input to the continuous UCP process but does not constitute any commitment by the EU Space Programme to implement or satisfy the listed needs or requirements in current or future services and data.

This report is organized as follows:

- Section 2.1 addresses the prospective use of EO and GNSS in the Climate, Environment, and Biodiversity segment, with identified trends, and innovations
- Section 2.2 presents the market evolution and key trends in the Climate, Environment, & Biodiversity segment, together with definitions of main user groups and actors in the value chain,
- Section 2.3, that describes the market drivers (regulations, standards etc.)
- Section 2.4 describes applications and operational scenarios relevant for EO and GNSS, presenting main user needs and expectations towards services and data to serve operational scenarios, together with limitations and gaps identified by end users. Some applications are more detailed as they have been assessed specifically during the 2025 UCP.
- Section 2.5 summarizes the main User Requirements for the Climate, Environment, and Biodiversity segment in the applications domains analysed in this report.

1.2 Methodology

The UCP process follows systematic steps that are implemented in a continuous, repetitive manner. The logical steps allow transparency and continuous updates of the results, considering the new market developments and evolving user needs and requirements.

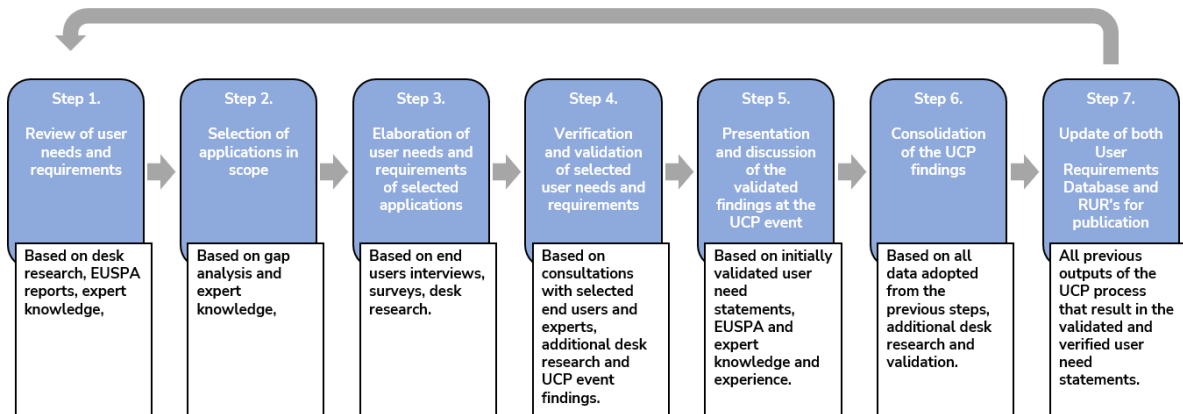


Figure 1 - Climate, Environment, and Biodiversity segment user requirements analysis methodology

Each Market Segment has its peculiar evolution due to the changes in legislation, standards, technological trends and so forth, therefore the update of the Report on User Need and Requirements can occur with a time distance of at least two years.

UCP user needs and requirements collection and analysis is based on one hand side on desk research and on the other, on stakeholders' consultations and experts' knowledge.

The UCP process starts with review and analysis of the most up-to-date sources related to the user needs and requirements in selected market segments. This step leverages on the previous UCP Reports on User Requirements, latest EUSPA EO and GNSS Market Report, Technology Reports and other expert publications and knowledge. The selection of relevant applications in each market segment is made based on the market analysis, the gap analysis from the earlier editions of the UCP and EUSPA, as well as external experts' know-how.

After the initial desk research, in order to validate the findings and collect missing information, the stakeholders' consultations are carried out, both representing end users and intermediate users (service providers) (Step 3). Validation of user needs requires additional feedback from relevant users' representatives that review the draft version of the Report on User Needs and Requirements, prepared in advance of the UCP event.

The UCP event is organized by EUSPA on an annual basis and offers a forum to present and discuss the findings, being additional layer of updates and gaps filling in the process. All the information and data gathered during the previous steps are consolidated in the segment-specific, presented here Report on User Needs and Requirements (RUR) and later in the EUSPA User Requirements Database (Step 7).

2 CLIMATE, ENVIRONMENT, & BIODIVERSITY

2.1 The role of the European Space Programme to meet the evolving user needs

The role of EUSPA

EUSPA (European Union Agency for the Space Programme) plays a pivotal role in the context of the EU Space Programme, acting as a key operational agency that is user-oriented and focused on promoting and maximizing the uptake of satellite-based services across various sectors, through the following activities:

1. User-Centric Approach

- EUSPA adopts strategies that prioritize the needs and requirements of users. It aims to enhance the accessibility and integration of satellite services, ensuring that a broad spectrum of users, including governmental bodies, businesses, and citizens, can benefit from services related to Earth Observation, Satellite Navigation, and Connectivity.

2. Service Provisioning

EUSPA is responsible for providing state-of-the-art services in areas such as:

- Positioning, Navigation, and Timing: Through the Galileo and EGNOS systems.
- Satellite imagery: Copernicus is the EO component of the European Union's Space Programme, providing free and open-access satellite data services.
- Satellite Communications: It facilitates communication services for governmental applications through GOVSATCOM and is working on the new IRIS2 initiative.
- Space Surveillance: EUSPA manages Front Desk services for the EU Space Surveillance and Tracking program, ensuring safety and security in space operations.

3. Enhancing the European Space Ecosystem

EUSPA works to foster a robust European space ecosystem by:

- Providing market intelligence and technical expertise to innovators, SMEs, and academia.
- Leveraging EU funding programmes such as Horizon Europe to stimulate innovation and research in space-related technologies.
- Supporting startups and developing partnerships that enhance technological advancements.

4. Ensuring Security

- EUSPA plays a critical role in the security of the EU Space Programme. By operating the Galileo Security Monitoring Centre (GSMC), it implements and monitors the security of satellite services, thereby bolstering the overall security framework for EU Member States.

5. Stakeholder Engagement

- EUSPA actively engages stakeholders from the entire space value chain, including industry leaders, academic institutions, and end-users. It facilitates feedback mechanisms where users can express

their needs and satisfaction levels regarding EU satellite services. This engagement is crucial for the continuous evolution of the EU Space Programme.

EUSPA conducts various essential activities which include:

- **User Consultation Processes:** These are designed to gather insights and perceptions from users to improve service delivery.
- **Market and Technology Monitoring:** EUSPA analyses trends and forecasts in the space industry to inform strategic decisions.
- **Research and Development Funding:** The agency identifies funding needs for R&D initiatives and ensures their implementation.
- **Pilot Programmes:** EUSPA supports the testing and piloting of innovative applications to explore new possibilities in space services.
- **Commercial Acceleration Programmes:** Through the CASSINI Programme, EUSPA promotes innovative commercial ideas and facilitates their growth in the marketplace.

In summary, EUSPA serves as a cornerstone of the EU Space Programme, bridging the gap between technological advancements and user needs. By providing innovative satellite services, fostering a collaborative space ecosystem, ensuring security, and engaging with a wide array of stakeholders, EUSPA is crucial in advancing the EU's strategic interests in space and enhancing the overall benefit of space technologies for society.

The role of COPERNICUS

Copernicus is the Earth Observation component of the European Union's space programme, looking at our planet to support the management of the environment, climate mitigation actions and civil security across Europe. Copernicus delivers its data and services with a free and open policy. It consists of three main components:

Space Component, which delivers data from a fleet of dedicated observation satellites (the 'Sentinels') and other Copernicus Contribution Missions (CCM). Six Sentinel satellites families are designed to serve a wide range of users and are provided with a free and open access globally. They ensure an independent and autonomous Earth Observation capacity for Europe with global coverage. The satellites provide observations which serve a wide range of users for a multitude of applications in the areas of climate, land and ocean services, emergency management, atmosphere and air quality, among others.

- Sentinel-1A, -1C, and -1D provide all-weather, day and night radar imagery for land and ocean services. Sentinel 1-B was retired in 2022.
- Sentinel-2A, -2B, -2C provide optical imagery for land and emergency services.
- Sentinel-3A & -3B provide optical, radar and altimetry data for marine and land services.
- Sentinel-5P provides atmospheric data, bridging the gap between ENVISAT and future Sentinel-5 data.
- Sentinel-4 & Sentinel-5 launched in 2025 monitor air quality, trace gases and aerosols over Europe at high spatial resolution and very high frequency.
- Sentinel-6 provides radar data to measure global sea surface height observations for climate monitoring and ocean and seasonal forecasts. It continues a time series of mean sea level rise measurements dating back to 1992.

CCMs complement the data portfolio in the Sentinel satellites missions with another layer of value to meet user needs, providing data from commercial data providers. There are around 30 existing or contributing missions, encompassing various technologies like SAR, optical sensors, spectrometers and altimetry systems.

The In-Situ Component collects data acquired by a multitude of sensors at air-, sea- and ground-level, and includes geospatial reference data.

The Service Component of Copernicus programme transforms the various data into timely and actionable information products. The Copernicus Services deliver value-added information products in six thematic areas:



Figure 2: Copernicus services

Copernicus provides open access to hundreds of scientifically validated datasets that support climate, environmental, and biodiversity monitoring. These datasets include both multi-year archives, near-real-time products and future projections, developed from satellite observations, in-situ measurements, and numerical models. They enable large-scale, high-resolution monitoring of ecosystems, carbon stocks, water resources, and pollution, supporting evidence-based policymaking, climate accounting, and sustainable management of natural resources.

EO data from Copernicus like CLMS and C3S is increasingly used for **EO-Based Validation of Biodiversity Credits**, allowing large companies to invest in conservation projects with measurable impacts. The following are employed to monitor habitat quality, tree species, and canopy structure in areas ranging from tens to thousands of hectares, with monthly updates supporting yearly verification.:

- High-resolution optical imagery
- Normalized Difference Vegetation Index (NDVI)
- Leaf Area Index (LAI)
- Fraction of Absorbed Photosynthetically Active Radiation (fAPAR)
- Plant Phenology Index (PPI)
- hyperspectral data (to be made available with the inception of CHIME)
- SAR

Similarly, **Carbon Stock Change Detection in Peatlands** (CLMS, C3S) is assessed through a combination of InSAR for hydrological dynamics, SAR for surface properties, and optical satellites for vegetation indices, moisture mapping, and thermal sensors for land surface temperature. This approach allows to assess carbon stored or released in restored peatlands.

Flood-Induced and Retention Wetland Dynamics are monitored through CEMS and CLMS for their role in flood regulation and carbon storage. Multi-temporal SAR, optical imagery, altimetry, and digital elevation models track seasonal expansion and contraction, providing monthly updates and weekly monitoring during flood events for active restoration projects. **Monitoring Reservoir Water Levels, Sedimentation, and Evaporation Loss** (CLMS) are carried out using optical, SAR, altimetry, and high-resolution commercial products to assess storage levels, sediment accumulation, and evaporation losses, ensuring sustainable water management and supporting drought monitoring. **Water Pollution Monitoring from Industrial and Agricultural Runoff** detects eutrophication zones and pollution hotspots

using high-resolution multispectral imagery and integrated in-situ data across agricultural basins and industrial discharge areas (CAMS, CLMS, CEMS).

Monitoring Urban Flash Flood Risk via Impervious Surface Expansion tracks urban growth to inform flash flood susceptibility assessments and climate-resilient infrastructure planning. Sentinel imagery using CLMS and CEMS, high-resolution DEMs, and urban mapping datasets provide detailed updates on growth patterns, hydrological flow, and areas vulnerable to extreme rainfall events.

Copernicus data is increasingly integrated with commercial EO products and advanced machine learning algorithms to improve monitoring of biodiversity, carbon dynamics, water resources, and pollution. EUMETSAT satellites complement this by providing continuous atmospheric, oceanic, and climate-relevant measurements. METEOSAT satellites monitor atmospheric conditions, METOP satellites deliver high-resolution climate and atmospheric data, and Sentinel-3, S-4, S-5 and S-6 provide critical observations for land, ocean, and climate studies. Jason-3 contributes precise sea surface height data, which feeds into hydrological and ecosystem analyses.

By combining optical, radar, altimetry, and thermal data with in-situ networks, Copernicus and associated EO systems provide a comprehensive environmental intelligence platform. This enables scalable, timely, and science-based monitoring of **biodiversity credits, carbon stocks, wetlands, water resources, and urban climate risks**, supporting effective climate action and sustainable ecosystem management.

In 2024, ESA and the EU confirmed full funding to complete all six “[Sentinel Expansion](#)” missions, largely enabled by the UK’s decision to rejoin Copernicus, which closed previous budget gaps. The missions are now in advanced development phases (Phase C/D), with industrial prime contracts in place and launch readiness targeted progressively from the late 2020s onward, extending Copernicus into greenhouse-gas monitoring, hyperspectral land imaging, polar and Arctic services, and L-band radar:

- CO2M (Copernicus Anthropogenic CO₂ Monitoring) – Measures atmospheric CO₂ from human activities at high resolution to support the EU Green Deal, Paris Agreement monitoring, and national emission inventories.
- CHIME (Copernicus Hyperspectral Imaging Mission for the Environment) – Provides hyperspectral imaging of land surfaces for agriculture, soils, minerals and vegetation health, enabling detailed crop and nutrient monitoring.
- CIMR (Copernicus Imaging Microwave Radiometer) – Focuses on sea-ice concentration, sea-surface temperature and salinity, and other marine variables in high latitudes, supporting Arctic operations, climate and weather services.
- CRISTAL (Copernicus Polar Ice and Snow Topography Altimeter) – Monitors sea-ice thickness and land-ice elevation with a dual-frequency altimeter, improving sea-level rise and cryosphere change assessments.
- LSTM (Land Surface Temperature Monitoring) – Delivers high-resolution land-surface temperature data for agriculture water use, drought monitoring, and urban-heat analysis.
- ROSE-L (Radar Observing System for Europe in L-band) – An L-band SAR mission providing all-weather observations of soil moisture, biomass, geohazards, and land-use change, complementing C-band Sentinel-1.

As described above, this market segment focuses on the following EO operational scenarios and respective applications. Please note that some applications might be covered in the 2024 edition and not included in this version.

Application	Code	Operational scenario
Ecosystems monitoring	EO 1	Nature credits: EO-Based Validation of Biodiversity Credits
Environmental auditing	EO 2	Carbon Stock Change Detection in Peatlands for Climate Accounting

Environmental auditing	EO 3	Flood-Induced and Retention Wetland Dynamics
Climate change mitigation and adaptation	EO 4	Monitoring Reservoir Water Levels, Sedimentation, and Evaporation Loss for Water Security
Climate change mitigation and adaptation	EO 5	Monitoring Urban Flash Flood Risk via Impervious Surface Expansion
Environmental auditing	EO 6	Water Pollution Monitoring from Industrial and Agricultural Runoff
Ecosystems monitoring	EO 7	Habitat Robustness: Monitoring for Biodiversity Change

Table 1: EO applications and codes in Climate, Biodiversity, & Environment

Takeaways for EO from the 2025 UCP in Climate, Biodiversity, & Environment	
Need to monitor large and hard-to-access areas consistently over time: Users require scalable and repeatable observations to establish baselines and detect change.	
Need for credible, transparent, and verifiable evidence: Users must rely on independent and auditable measurements to support biodiversity, carbon, and water accounting as well as regulatory reporting.	
Need to combine heterogeneous data sources into decision-grade indicators: Users need integrated information rather than isolated datasets.	
Need for early warning and risk mitigation: Users require timely detection of environmental pressures such as drainage, fires, floods, or urban expansion to support adaptive management.	
Need to comply with policy requirements and support market mechanisms: Users must meet EU reporting obligations, corporate sustainability targets, and participate in emerging markets such as biodiversity and carbon credits.	

Table 2: Takeaways for EO from the 2025 UCP in Climate, Biodiversity, & Environment

The role of European Global Navigation Satellite System (EGNSS)

EGNSS is the European satellite navigation programme designed to provide highly accurate and reliable positioning, navigation, and timing services on a global scale and ensuring Europe's technological autonomy. EGNSS offers high-precision and multi-constellation capability. There is a free positioning service available to the public, as well as encrypted services for government and commercial use, like the Public Regulated Service (PRS) for government-authorized users. EGNSS includes two main systems:

- **Galileo** is the European satellite navigation system that provides highly accurate global positioning and timing information. It offers several unique features, including higher accuracy (especially in urban areas), improved availability, and an authentication service to prevent signal spoofing. Numerous EU economic sectors rely on Galileo, from transport and agriculture to border management and search and rescue. HAS and its 20cm accuracy makes Galileo a game changer for autonomous driving and commercial drones. Already more than 3.5 billion smartphones are Galileo-enabled.
- **EGNOS** (European Geostationary Navigation Overlay Service) is a satellite-based augmentation system (SBAS) that improves the accuracy, integrity, and reliability of the navigation services to aviation, maritime and land-based users in over 30+ countries.

For the Climate, Biodiversity, and Environment segment, Galileo remains a niche service. However, it has a role in **sea-level monitoring through GNSS-integrated buoys** amongst others.

This market segment focuses on the following GNSS applications. Please note that some applications might be covered in the 2024 edition and not included in this version.

Code	Application
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GNSS 1	GNSS-Based Climate Modelling
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Table 3: GNSS applications and codes in Climate, Biodiversity, & Environment

Takeaways for GNSS from the 2025 UCP in Climate, Biodiversity, & Environment Need to measure absolute sea level, not distorted by land motion: Users require sea-level trends that are geodetically referenced and decoupled from subsidence or uplift. GNSS enables ocean buoys and co-located coastal stations to provide absolute sea-surface height and vertical land motion, transforming relative tide-gauge records into climate-quality indicators. Need for reliable calibration and validation of satellite altimetry, especially near the coast: Users depend on stable, independent references to verify satellite sea-surface height and detect drift. GNSS-equipped buoys can be deployed directly on or near altimeter ground tracks, delivering traceable, high-frequency measurements that strengthen Sentinel-6, Sentinel-3 and Jason cal/val, particularly where coastal corrections are most challenging.

Table 4: Takeaways for GNSS from UCP 2025 in Climate, Biodiversity, & Environment

2.2 Market overview & trends

While public attention may have shifted in recent months due to rising geopolitical tensions, concerns about climate change remain. These challenges continue to drive the need to collect robust environmental data and to better assess the changes ahead. In this context, satellite data and particularly EO play a key role, offering the ability to monitor the planet continuously and at a global scale.

2.2.1 Market Evolution and Key Trends

In 2026, concerns about climate tipping points, biodiversity loss, and environmental degradation remain acute, even as political attention has shifted toward geopolitics, energy security, and economic resilience. In this context, advances in EO, GNSS, AI, and emerging sensing technologies are driving sustained demand for high-resolution, continuous environmental monitoring. While ESG reporting was a major catalyst in the early 2020s, demand is now increasingly shaped by hard regulation, climate-risk management, and operational needs across public authorities and critical economic sectors.

The role of AI-enabled analytics continues to expand, but with a shift in focus. Companies are moving beyond ESG dashboards toward decision-grade environmental intelligence, supporting regulators, insurers, infrastructure operators, and commodity supply chains. Demand is strongest where EO directly informs risk pricing, permitting, compliance enforcement, and crisis response, rather than narrative sustainability reporting.

Regulatory drivers remain important, but they are more targeted and sector-specific than in 2024. Climate and nature requirements increasingly focus on verifiable asset-level data, including Scope 3 emissions hotspots, deforestation exposure, and ecosystem condition in high-risk regions. Wetlands and peatlands have emerged as a priority domain, driven by climate mitigation, restoration mandates and methane-reduction strategies.

Biodiversity monitoring is also evolving from experimental metrics to policy-grade indicators, supporting EU nature legislation and international commitments. Wildlife tracking, habitat connectivity analysis, and ecosystem-condition monitoring increasingly rely on integrated space data, supported by AI models that assess climate stress and disruption risks.

Overall, by 2026 the EO market has matured beyond its ESG-led expansion phase. Growth is now anchored in regulations and directives such as the [EU Corporate Sustainability Reporting Directive \(CSRD\)](#) or the [EU Habitats Directive](#), climate resilience, security of supply, and operational decision-making, with specialised EO processors playing a central role in transforming raw satellite data into trusted, actionable intelligence for public authorities and strategic industries.

2.2.1.1 GNSS Key Market Trends

GNSS-based applications remain comparatively niche within this market. While GNSS plays a critical enabling role for positioning, timing, and synchronization, particularly in aviation, maritime operations, precision agriculture, and asset tracking, its direct contribution to climate, environment, and biodiversity monitoring remains limited. In most use cases, GNSS acts as a supporting technology, enhancing the value of EO and in-situ observations rather than driving demand on its own.

GNSS plays a small but critical enabling role, mainly in sea-level and coastal monitoring. It can be used for monitoring vertical land motion in peatlands and wetlands. GNSS deployed on buoys and at tide-gauge sites provides absolutely referenced sea-surface height and vertical land-motion measurements, complementing satellite altimetry where coastal accuracy is most challenging. These data are used by oceanographic agencies and researchers to calibrate and validate altimeter missions, separate ocean change from land subsidence, and support coastal risk management and engineering.

In addition, GNSS tags are also used on selected animal species to track movement and habitat use, supporting biodiversity research and conservation efforts.

Finally, Galileo OSNMA currently plays a limited role in this market. Environmental and scientific applications typically operate in low-threat environments, where intentional jamming or spoofing is uncommon, and data are primarily used for monitoring and analysis rather than safety-critical operations. While these services may add robustness against unintentional interference and support more autonomous deployments in the future, they are not yet a key driver of demand in climate, environmental, and biodiversity monitoring applications. Galileo HAS is also limited in use for sea-level monitoring as centimetre-level is required.

2.2.1.2 EO Key Market Trends

Rising climate and biodiversity concerns, combined with advances in EO technology and AI, alongside tightening environmental regulations, are accelerating the adoption of satellite data for consistent, high-resolution Earth monitoring.

- Private satellite operators increasingly complement public systems, particularly where precision and revisit frequency are critical. Methane-monitoring constellations, including GHGSat and Copernicus Contributing Missions like Sentinel-5P (TROPOMI), now enable point-source detection at sub-100-metre resolution.
- [Copernicus](#) services are scaling up with enhanced capabilities. The launch of Sentinel-1C in December 2024 restored full C-band InSAR capacity by March 2025, stabilising operational services for flood mapping, wetland dynamics, forestry disturbance, and ground-deformation monitoring. At the same time, CLMS HR-VPP2 is expanding with new layers on Gross Primary Productivity and tree-cover disturbance, with an Operational Readiness Review planned for winter 2025/26.
- [Copernicus Expansion](#) missions like CO2M, CHIME and LSTM secured full funding in 2024. At the same time, CAMS, C3S, and CLMS evolution streams are channelling significant EU and national investments.
- New hyperspectral and commercial SAR systems support near-daily global observations, allowing robust tracking of biomass dynamics, soil carbon proxies, and peatland emissions, capabilities increasingly essential for Article 6 mechanisms, EU climate policies, and national Digital Monitoring, Reporting and Verification (DMRV) frameworks, beyond voluntary ESG reporting.
- There is a consistent emphasis on the integration of EO data with ground-based observations. This hybrid approach enhances the accuracy and reliability of monitoring efforts, whether it's for biodiversity credits, carbon stock changes in peatlands, or water quality assessments.
- The use of advanced EO technologies, including radar, optical sensors, and machine learning algorithms, is prevalent. These technologies enhance the ability to monitor complex environmental variables and improve the precision of assessments.
- Climate reanalysis datasets are becoming more powerful and more detailed. [C3S ERA6](#) production started in early 2025 at around 14 km resolution, integrating coupled land-ocean models and uncertainty estimates.
- The involvement of various stakeholders, including governmental agencies, NGOs, and private companies, is a common theme. Collaborative efforts are essential for successful project implementation and achieving environmental goals.
- Despite the advancements in EO, challenges remain regarding data accessibility, quality, training, awareness and the need for robust validation methods. Ensuring that EO data is usable and meets the needs of diverse users is critical for effective environmental management.

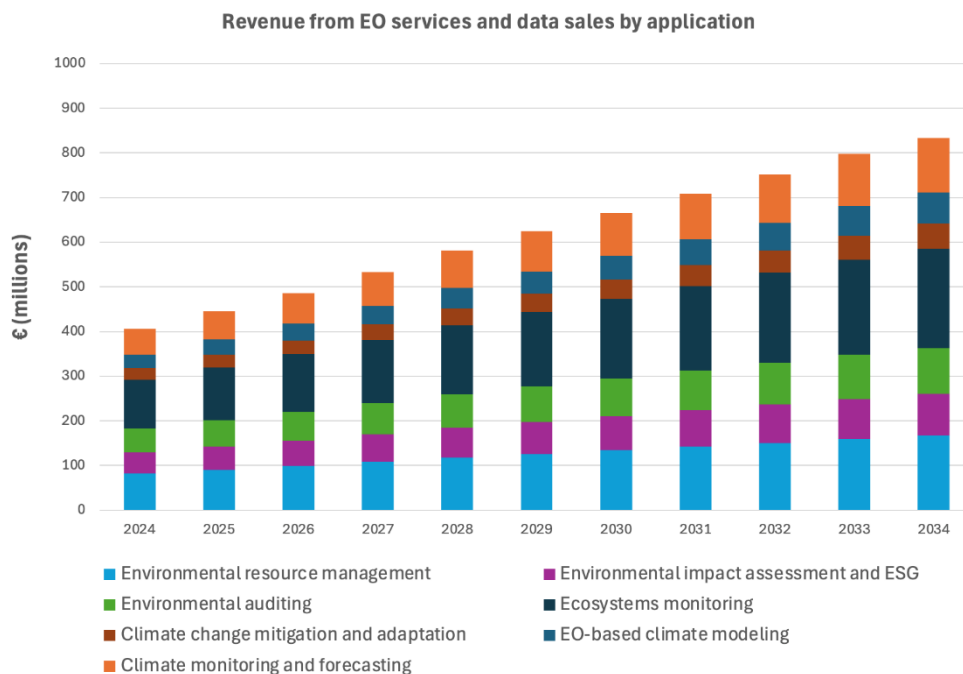


Figure 3: EO data and service revenues for Climate, Biodiversity & Environment by application

2.2.2 Main User Communities

The Climate, Environment and Biodiversity user community can be divided into five main categories:

- Institutions, Environmental Agencies
- NGOs and conservation groups
- Research organisations and laboratories
- Corporations
- General public

For environmental monitoring, the principal users are national and international public bodies together with their agencies and institutes. They are also the main users of climate services, as they need information to plan and trigger adaptation and mitigation measures. As lead actors in nature conservation, they likewise depend on data for biodiversity and ecosystem monitoring. This group includes governmental organisations and specialised agencies responsible for land, forests and biodiversity. NGOs and conservation organisations are making broader use of satellite-derived information to understand the state of the environment and to support their policies and programmes. The conservation community has even produced practical guidance to help teams apply remote sensing in their work.

Research organisations and the scientific community have historically been the primary users of both EO and tracking data to observe the environment, wildlife and the climate. The advent of large-scale processing has enabled more sophisticated climate models that assimilate growing volumes of data. These models are now more accurate than in the past, are continuously refined, and are used to forecast climate evolution and provide evidence to policy makers.

Corporations are comparatively new users of EO within environmental monitoring, climate services and biodiversity monitoring. In practice, they often act as indirect users: companies needing to deliver ESG reporting or demonstrate compliance on environmental impacts typically rely on specialised providers that use EO to produce indicators, assessments and reports. At present, this mainly concerns larger firms under recent regulations in Europe and the United States, but it is likely that smaller companies and additional jurisdictions will follow, further increasing demand for EO-based information.

Finally, as extreme events become more visible, large wildfires, unusual heatwaves or sustained drought, the general public is increasingly aware of climate risks and impacts. Copernicus imagery helps make the scale and effects of such events clear, while the different Copernicus services (atmosphere, marine, land, climate change, security, emergency) transform raw data into targeted insights for many applications. This has made climate-related information more accessible to a wide audience, and Copernicus content frequently reaches very high levels of public engagement on social media.

2.2.2.1 GNSS Key Users

In this segment, the use of GNSS is currently limited and mainly supports specialised sea-level and coastal monitoring. Uptake is gaining traction via GNSS-integrated buoys and co-located tide-gauge stations.

Key users for Climate, Environment & Biodiversity are mainly the following:

- Oceanographers & climate scientists: They mount GNSS on buoys to track sea-surface height and waves, and co-locate GNSS at coastal sites to measure vertical land motion. Together these data help calibrate/validate satellite altimetry and sharpen long-term sea-level trends.
- Hydrographic/oceanographic agencies, tide-gauge operators & coastal authorities: By pairing GNSS with tide gauges, they separate land uplift/subsidence from ocean change, convert relative measurements to absolute sea-level, and support shoreline risk analyses (e.g., storm surge, flooding).
- Research institutions (e.g., IFREMER, NERC) running buoy campaigns: They deploy multi-constellation GNSS buoys, often on/near satellite ground tracks, to provide independent references for altimetry stability/drift and to observe near-shore dynamics that wide-swath sensors can miss.
- Coastal engineers & infrastructure planners (ports, offshore, protection): They use GNSS-derived sea-level, wave statistics and vertical land motion as inputs to design criteria and hazard assessments for coastal and offshore assets.
- European/international coordination bodies & climate networks (e.g., ESA, EUMETSAT, IPCC-relevant contributors): They integrate these GNSS coastal observations into long-term sea-level budgets and policy-relevant assessments, alongside altimetry and tide-gauge records.

2.2.2.2 EO Key Users

In this segment, EO is the primary enabler for Climate, Environment & Biodiversity monitoring. Users rely on satellite time series to plan actions, track outcomes and report with confidence.

Building on the applications covered in this report and recent UCP inputs, five groups consistently emerge as the main users of EO for Climate, Environment and Biodiversity purposes:

- Environmental and climate authorities/agencies: They use Copernicus and related services to map and monitor protected areas, restoration sites and climate risks (e.g., floods, droughts), and to produce policy-grade reports with consistent, documented methods. Typical outputs include habitat and disturbance maps, seasonal indicators, and evidence for adaptation and mitigation plans.
- River-basin authorities and water utilities: They combine EO with in-situ data to track wetlands and flood retention, monitor reservoirs (levels, sedimentation, evaporation) and watch water quality hot spots. These insights support day-to-day operations and longer-term investment and drought planning.
- City resilience and civil protection teams: They use up-to-date EO land-cover and urban layers to follow impervious surface growth, assess flash-flood susceptibility, and inform green/blue infrastructure and heat-mitigation measures, turning satellite images into practical maps for drainage upgrades and emergency preparedness.

- Digital Monitoring, Reporting, and Verification (DMRV) platforms, certifiers and finance (banks/insurers): For emerging nature- and carbon-credit use cases, they need clear, locally credible indicators (e.g., habitat condition, wetness, disturbance) with transparent uncertainty to support verification and investment decisions; they also ask for benchmarks and simple “how-to” materials to avoid the “data trap” of global layers that are not fit for site-level action.
- Research organisations, conservation NGOs and observatories: They develop methods, validate indicators and provide public transparency, turning EO archives into trusted evidence for agencies and communities; they also highlight the need for stable time series and harmonised products so non-specialists can reuse results with confidence.

2.3 Key market drivers – Policies, Regulations, Standards

Regulations and policies are key market drivers for the Climate, Environment and Biodiversity segment. They drive usage of EU Space systems, R&D and technological innovation, development of new applications. While the emergence of nature credits after carbon credits is supposed to create private markets to supplement government driven climate and environment markets, these voluntary markets are slow to emerge and require regulatory pushes as well as standards to support their growth.

2.3.1 Relevant organizations

There are several organizations relevant to climate and biodiversity. The European Commission is playing a major role here in the frame of its green deal, establishing significant regulations to protect the environment and fight climate change, as listed in the next section. In particular, the [EU's Biodiversity Strategy for 2030](#) is a comprehensive, ambitious and long-term plan to protect nature and reverse the degradation of ecosystems.

Part of the EU, the role of the [EEA](#) (European Environment Agency) is key to achieve sustainability.

The [IUCN](#) (International Union for Conservation of Nature) is an international organization providing authoritative information on the status of the natural world and the measures needed to safeguard it.

The [IPCC](#) (Intergovernmental Panel on Climate Change) produces the massive "Assessment Reports" every few years that summarize the state of global warming. They provide the scientific basis for the UNFCCC negotiations.

The [IPBES](#) (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services) produce reports on extinction rates, invasive species, and the value of nature (vital for the biodiversity credits market).

The [GCF](#) (Green Climate Fund) is the world's largest dedicated climate fund. It finances projects in developing countries to reduce emissions (mitigation) and cope with climate impacts (adaptation).

The [GEF](#) (Global Environment Facility) is another financial mechanism for multiple treaties, supporting various biodiversity or environment related projects.

The [IAPB](#) is an international initiative launched to create a global rulebook for biodiversity credits. Its goal is to prevent the market from becoming an area of greenwashing (as happened with early carbon markets) and instead ensure that credits actually help nature and local communities.

The [TNFD](#) (Taskforce on Nature-related Financial Disclosures) provides a global framework for organisations to report and act on evolving nature-related risks and opportunities, bridging financial markets with biodiversity and ecosystem protection.

To support carbon and biodiversity credits, several organizations play a key role, acting as certification bodies. These organizations establish their own standards that are used to verify the project targets.

Verra, Gold standard, Climate Action Reserve, Plan Vivo, Ceqarbo are some of the verifiers active in the biodiversity markets.

2.3.2 Selection of applicable regulations, treaties and conventions

This chapter presents regulations and standards that are relevant to this market segment. As awareness of the impact of climate change is growing as well as more data is available on the loss of biodiversity and habitat, governments around the world have put in place new regulations to fight climate change and better protect the environment.

EU regulations and laws

The **EU Corporate Sustainability Reporting Directive (CSRD)** entered in force in 2024. Companies doing business in the EU will need to report on how they affect the environment and people, and how environmental matters affect their financial performance. CSRD improves existing reporting obligations to include more comprehensive information, including GHG emissions, climate risk, pollution, water and marine resources, biodiversity and ecosystems, resources and circular economy for the Environment related part. CSRD currently concerns companies over 1000 employees as a 2025 EU directive postponed the obligation for smaller companies.

- Most applications provide audit-ready satellite-derived indicators on GHGs, water, biodiversity, pollution and physical climate risk to support CSRD disclosures and risk management. EO-Based Validation of Biodiversity Credits, Carbon Stock Change Detection in Peatlands, and Habitat Robustness provide auditable indicators for biodiversity, carbon and land-use. Water Pollution Monitoring adds pollution metrics for CSRD disclosures.

The **Nature Restoration law** was formally adopted in June 2024, and it transposes the Montreal biodiversity agreement into EU law. The law includes targets to restore at least 30 % of the EU's land and sea areas by 2030 and 90% by 2050. This law improves the existing regulations, the EU Habitats Directive and the EU Birds Directive. Member states are currently in the final stages of drafting their individual "National Restoration Plans." This includes restoration measures for drained peatlands under agricultural use by 2030 with at least a quarter being rewetted and with a target of 50% by 2050.

- Carbon Stock Change Detection in Peatlands, Flood-Induced and Retention Wetland Dynamics, and Habitat Robustness enable tracking of rewetting, wetland recovery, and habitat extent/condition.
- Water Pollution Monitoring captures key pressures

EU Habitats Directive has been in place since 1992 and has implemented a set of preventive measures to conserve Europe's wild flora and fauna. The directive aims to protect over a thousand species, including mammals, reptiles, amphibians, fish invertebrates, and plants, and to make sure that habitat types are maintained, or restored, to a favourable conservation status within the EU.

- Carbon Stock Change Detection in Peatlands, Flood-Induced and Retention Wetland Dynamics, and Habitat Robustness enable tracking of rewetting, wetland recovery, and habitat extent/condition.
- Water Pollution Monitoring captures key pressures.

EU Birds Directive is the oldest piece of EU environmental legislation as it was adopted in 1979. It provides a legal framework for the protection, management, and control of all 500+ wild bird species naturally occurring in the European Union. While the Habitats Directive (1992) covers a broad range of animals and plants, the Birds Directive specifically addresses the unique threats facing avian species, particularly habitat loss and illegal hunting/capture.

- Wetland Dynamics, Water Pollution Monitoring, and Habitat Robustness deliver SPA-relevant indicators on hydrology, water quality and habitat change for managing breeding/feeding areas and fragmentation risks.

The **EU Soil directive** was adopted in December 2025 and is part of the EU Soil Strategy for 2030 that provides the framework towards protecting and restoring soils and ensuring that they are used sustainably. The primary ambition of the law is to ensure that all EU soils are in healthy condition by 2050. Currently, it is estimated that 60–70% of EU soils are unhealthy due to erosion, compaction, contamination, and loss of biodiversity.

- Carbon Stock Change Detection in Peatlands and Wetland Dynamics provide soil-moisture/rewetting signals.
- Urban Flash-Flood/Impervious Surface and Reservoir Sedimentation add sealing and erosion/sedimentation evidence for soil-health objectives.

The **EUDR** (EU Deforestation Regulation) was adopted in 2023 to establish strict measures to prevent companies from placing products on the EU that are linked to deforestation or forest degradation. The EU parliament voted in late 2025 a simplification of the law with new rules to establish and postponed its entry into force to early 2027.

- Habitat Robustness and EO-Based Validation of Biodiversity Credits verify land-use/land-cover change for due diligence, with Peatland Carbon highlighting high-risk conversions in supply chains.

The **LULUCF Regulation** (Land Use, Land-Use Change and Forestry) establishes binding national net removal targets for 2026-2030 (310 MtCO_{2e} EU-wide), shifting from "no debit" rules to track emissions/removals across forests, croplands, grasslands, and wetlands—requiring Member States to report carbon stocks in biomass, soils, and dead matter while enabling flexibilities for natural disturbances.

- Peatland Carbon and Wetland Dynamics apps directly support LULUCF compliance through soil carbon, rewetting, and land-use change monitoring.

The **CRCF** (Carbon Removals Certification Framework) creates EU-wide standards to certify permanent carbon removals (e.g., peatland restoration, BECCS) for credits, ensuring additionality, durability (>5-100+ years), and quantification via digital MRV—including satellite verification benchmarks for scalability.

- Biodiversity Credits and Peatland Carbon apps provide EO-derived baselines and change detection aligned with CRCF certification metrics.

Finally, the **Nature Credits Roadmap** (IP/25/1679) is the Commission blueprint scaling biodiversity credits by 2030, integrating with CSRD/TNFD disclosures and leveraging Copernicus EO for verifiable restoration outcomes in National Restoration Plans.

International treaties

The **Paris Agreement** is a legally binding international treaty on climate change. It was adopted by 196 Parties at the UN Climate Change Conference (COP21) in Paris, France, in December 2015 and entered into force in November 2016. Its overarching goal is to hold “the increase in the global average temperature to well below 2°C above pre-industrial levels” and pursue efforts “to limit the temperature increase to 1.5°C above pre-industrial levels.”. Since 2020, signatories have been submitting their national climate action plans, known as nationally determined contributions (NDCs).

- Peatland Carbon, Wetland Dynamics, and Reservoir Water Security quantify mitigation/adaptation.
- Urban Flash-Flood and Habitat Robustness add exposure and ecosystem resilience, with GNSS-Galileo Buoy data informing coastal sea-level risk.

The **Kunming-Montreal Global Biodiversity Framework** (GBF) was signed in December 2022 by 196 nations to “take urgent action to halt and reverse biodiversity loss” by 2030 and to protect 30 percent of land and sea area by 2030. It is a non-binding agreement, but it provides hopes for building a new relationship between people, the economy and nature. Signatories have committed to demonstrate progress in areas such as nature-related disclosure & data, harmonized taxonomies and standards,

biodiversity targets and risk management and nature-based sustainable finance. The GBF is supported by the UNEP and targets in particular financial policy and regulation.

- Habitat Robustness and Biodiversity-Credit Validation underpin 30x30 and restoration tracking, while Wetland Dynamics and Water Pollution Monitoring quantify pressures/outcomes for GBF reporting and finance.

The **Convention on Wetlands**, commonly known as the Ramsar Convention, is an intergovernmental treaty dedicated to the conservation and "wise use" of wetlands. Adopted in 1971 by 88 countries, it is the oldest modern global environmental agreement and provides the framework for national action and international cooperation regarding the protection of wetland habitats.

- Wetland Dynamics provides core condition/extent metrics.
- Peatland Carbon and Water Pollution Monitoring address peat/water-quality drivers, with GNSS-Galileo Buoy data adding sea-level context for coastal sites.

2.3.3 Other standards, practices and guidelines

All nature projects supported by biodiversity of carbon credits follow a strict standard to ensure the positive results on the environment. These standards, usually called **MRV (Monitoring, Reporting and Verification)** are designed to ensure replicability and transparency to guarantee the outcomes of the projects. There are number of different standards and methodologies that have been developed by private certifiers such as Verra or by public organizations such as REDD+ supported by the UNFCCC (United Nations Framework Convention on Climate Change). Verra has developed a number of methodologies and standards, including the [SD VISta Nature Framework](#) in 2024 that it expects to become widely used for nature credit projects. To support its various standards, Verra also has developed specific tools to monitor specific parameters; for example, the "VT0014 Estimating Organic Carbon Stocks Using Digital Soil Mapping" tool includes specifically the use of satellite EO with other tools to estimate carbon above ground.

For clarity, it is important to define a nature credit. The definition given by [BCA](#) (Biodiversity Credit Alliance) is "*a certificate that represents a measured and evidence-based unit of positive biodiversity outcome that is durable and additional to what would have otherwise occurred*".

As of the production of this report, there are no regulations to mandate nature credits. In some countries such as France or the UK, new laws implement voluntary biodiversity credits and natural sites to support restoration. In addition, some companies propose their own biodiversity credits that companies or individuals can purchase to support restoration efforts. For example, [Terrasos](#) in Colombia developed TEBU, a voluntary biodiversity credit based on blockchain technology that can be purchased for \$27 and that guarantees the protection of 10 m² of ecosystems for 30 years.

The European Commission presented in August 2025 its **nature credits roadmap** to reward nature-positive action and boost private finance. This initiative aims to create a market-based system where companies, financial institutions, and individuals can invest in certified, nature-positive projects, such as restoring wetlands or expanding forests. In return for their investment, these entities receive "nature credits," which can enhance their reputation and reduce business risks associated with nature degradation.

The key objectives of the roadmap are to address the Funding Gap estimated at €65 billion annually, to create new revenue streams for farmers, foresters, and other landowners, who undertake nature restoration and conservation activities to establish credibility and avoid greenwashing and to support economic resilience as over 75% of European area businesses depend on nature.

A main goal of this roadmap is to develop clear standards and a reliable certification process to ensure that nature credits are trustworthy and effective, which is an area that can be supported by the EU space system.

Without a leading regulation nor standard, a lot of work needs to be done to create a nature credit market similar to the carbon credit market. Notably, tools and methodologies to compare different credits and measure biodiversity need to be established.

The Paris Agreement (article 6) also addresses explicitly funding for Nature-Based solutions, highlighting five priorities:

- Set rigorous and scientific certifications with reliable verification methods;
- Establish a market infrastructure and a robust monitoring system to avoid greenwashing;
- Test and deploy the mechanism on a large scale;
- Leverage existing international work on nature credits;
- Establish a framework adapted to local realities, limiting administrative burdens as much as possible.

These guidelines pave the way for the use of EU Space system as reliable and trustable methods to monitor and verify certifications.

2.4 User Needs and Requirements

2.4.1 EO 1 - Nature credits: EO-Based Validation of Biodiversity

Nature credits are a financial instrument designed to put a price on the preservation or restoration of nature, much like carbon credits do for greenhouse gases. The European Commission is implementing its Roadmap towards Nature Credits to bring additional funding to meet the targets of the EU Nature Restoration Law (which requires restoring 20% of EU land and seas by 2030).

A nature credit is a tradeable certificate that represents a measurable "unit" of nature that has been restored or preserved, and it works like this:

- A project developer (e.g., a landowner, indigenous community, or conservation group) protects a specific area or restores a damaged ecosystem. They measure the improvement (e.g., "1 hectare of restored rainforest" or "10% increase in pollinator species").
- Companies or governments buy these credits. Unlike carbon markets, where the main goal is often to offset pollution, nature credits are increasingly pitched as a way to make "Nature Positive" contributions (investing in nature to meet Corporate Social Responsibility (CSR) goals) rather than strictly cancelling out damage done elsewhere.

The value of these credits is attached to certain goals to reach that all depend on the project: it can be reforestation, protection of an animal species, etc. To assess these goals and ascertain the value of the credits, dedicated organizations establish standards and deliver certification. The leader remains Verra followed by Plan Vivo, Gold, Equitable Earth, Cercabono and others. These organizations play a key role as they provide a methodology to be applied and deliver certificates. A key challenge is transparency of the certificates: the methodology used must be replicable and verifiable to avoid greenwashing and unreliable results. Remote monitoring systems can play a key role as they provide scientific data that is checkable, that can be repeated and that is scalable.

At this moment, most biodiversity credits are voluntary: unlike carbon credits, there is no obligation or incentive for a company to buy such credits, except in some countries like the UK with the [UK's Biodiversity Net Gain scheme](#). The upcoming EU roadmap towards credits as well as increased confidence in certificates may speed up the development of this market.

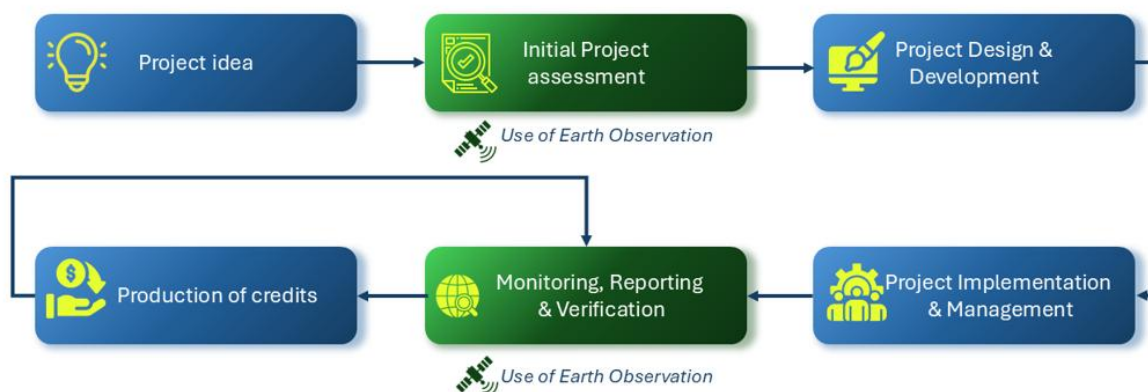


Figure 4: Steps of a nature credit project (credit FDC)

While few methodologies impose the use of EO, its benefits make it a solution used at many steps of a nature project:

- A nature project starts with a detailed and accurate **baseline of the existing ecosystem**. EO is used for mapping land cover, estimating biomass, and assessing habitat fragmentation. This baseline is the crucial starting point against which all future changes and improvements are measured.
- During the project, EO is used to **monitor change and prove additionality**, the principle that positive environmental outcomes would not have occurred without the project. Satellites track changes in vegetation cover, forest density, and land use over time. For example, satellite data can show the rate of reforestation in a project area compared to a similar, unprotected area.
- A key aspect is that EO enhances **transparency and reduces risks**: By providing independent and verifiable data, EO increases the transparency and credibility of nature credit projects, thus reducing the risk of "greenwashing" and increasing confidence among investors.
- Beyond carbon sequestration, satellite data can help to quantify other important "co-benefits" of nature-based projects, such as improved water quality and enhanced biodiversity. For instance, hyperspectral imagery can be used to assess the health of different plant species.

There are few EU funded projects that are relevant to biodiversity credits. One relevant project is Europabon which designed a structure for monitoring biodiversity and ecosystem services through modelling essential variables from diverse data sources and monitoring strategies. While the project does not address directly nature credits, it provides a large set of variables that are needed to assess credits. Europabon identified that 25% of the EBV (Essential Biodiversity Variables) applicable to nature credits could be measured with Earth Observation, making it part of the toolbox of the certifiers. EO is relevant mainly for variables categorized in ecosystem functioning and ecosystem structure.

The biodiversity credit market is not as mature as the carbon credit market as it is significantly more challenging: lack of fungibility (e.g. equivalence of one credit with another), complex metrics with many indicators and limited legal framework... However, this is evolving under the impulsion of the EU commission and Copernicus has an important role to play to support a rigorous methodology for nature credits assessment.

ID	EUSPA-EO-UR-CLIMA-0001
Operational scenario	EO-Based Validation of nature credits
Users	Users are certifiers which are companies that validate the credits following some methodology (like Verra, Gold Standard, etc...) and project developers which are the organizations that have a biodiversity project (it

	can be an NGOs or private companies). Other stakeholders include the companies that pay the credits, usually large corporations in agribusiness (indirect users). In some cases, specialized EO service providers act to validate data for certifiers
Operational scenario description	Nature credit projects are similar to carbon credit projects: a project developer plans to improve biodiversity in a specific area. To finance the project, he will issue nature credits that will be purchased by a large company. A third party, usually a certification company, will verify the change in biodiversity based on a specific methodology that depends on the project focus. Verification usually takes place at the project design (for eligibility), at the start of the project and afterwards every year for the duration of the project (up to several decades).
Size of area of interest	10Ha to 10000Ha
Frequency of information needed	Verification needs to be performed on a yearly basis
Type of service (continuous, forecasting, one-off?)	Continuous
Satellite EO Data Requirements	
Spatial resolution	1m (for small projects) to 10m (for whole ecosystems)
Temporal resolution	Monthly
Spectral resolution	Many indicators that can be measured with EO are relevant to biodiversity credits (but this depends on the project). Optical imagery like Sentinel-2 is used for habitat classification, forest type, soil moisture, vegetation health and habitat connectivity (vegetation corridors). NDVI is widely used to assess the change in vegetation, a key biodiversity indicator. Hyperspectral imagery from Prisma, Enmap or Pixxel is used for tree species Identification, plant health & stress monitoring as well as aquatic biodiversity. SAR like Sentinel-1 is used to estimate canopy height, estimate above ground biomass and monitor wetlands.
Data supplements	In situ data is still required for many observations: public data sets like gbif (https://www.gbif.org/) provide open access to massive data sets collected from participants citizen observations or citizen science where ordinary people provide information on nature. This often translates into pictures of animal and is particularly effective for birds' observation. Data quality is variable and should be interpreted with caution.

	photo traps are used to collect automated data on terrestrial fauna eDNA (environmental DNA) is DNA that is collected from a variety of environmental samples such as soil, sediment, freshwater, seawater, snow or air and that reveal the presence of the species in an ecosystem GNSS tags on specific animal species to monitor their habitat drones with diverse sensors (LIDAR, cameras) to collect images of the vegetation and monitor biodiversity-related indicators digital or smart microphones monitor biodiversity in natural environments. These devices autonomously record sounds from wildlife, such as birds, mammals, insects, and amphibians, and identify the species using AI to assess the health and diversity of ecosystems,
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Table 5: User needs and requirements - EO-Based Validation of Nature Credits

Case Study / User Story
Rabobank is a key European player in nature restoration. They support restoration projects, mostly in agroforestry, through credits (CRU) that they issue. These credits are bought by banks or technology companies and finance the projects. Rabobank follows and monitors the projects that are certified by Plan Vivo. Rabobank has set up an internal team of 25 professionals in remote sensing to monitor the projects. Rabobank uses data from the EU Copernicus satellites to monitor land use, water extent and other parameters. LIDAR data from drones is used in the field to complement remote sensing. As an example, a project in Tanzania for coffee producers covered around 100000Ha and was financed via 60000 credits. The goal was to transform the farmers activity into agroforestry to restore the environment and increase revenues and resilience of the activity. The project planted 3M trees, captured 60000t of carbon and is expected to save some declining animal species. Satellite data is extensively used to assess the change of land use towards sustainable agroforestry practices.

Table 6: Case study - EO-Based Validation of Nature Credits

2.4.2 EO 2 - Carbon Stock Change Detection in Peatlands for Climate Accounting

Peatlands are a critical, yet often overlooked, component of the Earth's climate system. While their geographical footprint is small, their influence on the global carbon cycle is immense. Understanding the formation, scale, and vulnerability of their vast carbon stores is fundamental to addressing the challenges of global climate change. These unique ecosystems represent a legacy of millennia of carbon sequestration, a legacy that is now under threat from both climatic shifts and direct human pressures.

The global significance of peatlands lies in their extraordinary carbon density. Despite covering only about 3% of the Earth's total land surface, they are the largest and most concentrated terrestrial reservoir of organic carbon. Globally, peatlands are estimated to store between 550 and 600 Gigatonnes (Gt) of carbon. This is more than twice the carbon stored in the entire biomass of the world's forests and constitutes approximately 30% of all global soil carbon. Per unit area, a functioning peatland can store up to 30 times more carbon than a healthy tropical rainforest, making these ecosystems the most space-effective natural carbon stores on the planet.

These critical ecosystems are found in over 180 countries, spanning all continents and climates. The largest stocks are concentrated in the vast boreal and subarctic regions of Russia and Canada, the tropical peat swamp forests of Indonesia and the Congo Basin, and high-altitude mountain ranges like the Andes. In Europe, most peatlands are found in the UK, Germany, Poland and the Baltic states and account for

12% of the global peatlands. This wide distribution underscores the global nature of their importance and the widespread risk posed by their degradation.

Damaged peatlands are a major source of greenhouse gas emissions, responsible for almost 5% of global anthropogenic CO₂ emissions. Peatland restoration can reduce emissions significantly. While 88% of the world peatlands are in the original state, the situation is much different in Europe where 46% are degraded. This degradation is caused by artificial drainage, most often for agriculture, forestry or peat extraction. The situation is worse in Germany, the Netherlands, Denmark, Poland, and Ireland where more than 80% of the peatlands have been drained. Degraded peatlands in Europe cause the emission of 600 Mt CO₂e per year.

Impacted European countries have established national programs regarding peatlands. Austria, England, Germany, Finland, Ireland, Northern Ireland, Scotland, and Wales have adopted national strategies to promote the conservation, restoration, and sustainable use of peatlands. For example, the National Peatland Protection Strategy in Germany implements preservation goals as well as emission reduction targets and it includes regular reporting and monitoring of peatlands. Scotland has emerged as a leader in the effort to restore these habitats, which cover more than 20% of the country. The government has set ambitious goals to restore 400000 Ha by 2040 along

Measuring carbon stock in peatlands is fundamentally different from measuring carbon in a forest: in peatlands, carbon must be assessed below ground with the assessment of the volume, the density and the carbon content. Typically, the depth of the peatland must be measured at several spots and samples must be collected at various depths to measure in laboratory the density and carbon concentration as the peat is stratified and varies depending upon the depth. Once this is done, the area of the peatland is measured to estimate the carbon stock, and this task can be supported by EO as peatlands are difficult to map when they are remote and difficult to access. Thus, a combination of EO and in-situ measurements can support the measurement of peatland carbon stock. However, the belowground peat is often hidden by different land cover types and cannot be directly observed by satellites. For this reason, the use of Earth Observation has to be conducted in conjunction with field campaigns or 'ground truthing'.

For example, low biomass, open canopied peatlands are best monitored by the shorter wavelength radar systems (C-band) and optical-IR data. In contrast, higher biomass forest canopies from boreal bogs to tropical palm swamp peatlands need longer wavelength radar systems (L-band), which have greater capability to penetrate through the forest canopy and interact with the soil layers, allowing retrieval of hydrologic information from forested peatlands. Optical and Multispectral Imaging: Satellites and aircraft equipped with optical and multispectral sensors are also used to capture images of peatlands in different wavelengths of light. These images can be used to map vegetation cover, assess vegetation health, and detect changes in land use, such as deforestation or drainage, which are major drivers of carbon stock changes

In addition, for credit projects, it is essential to know if the peatland is emitting or sequestering carbon. This is difficult as peatlands emit CO₂ when dry but also methane when wet, making the net assessment a challenge. Thus, some key indicators are used to approximate the carbon flux and make possible an assessment:

- **Peat drainage** for agriculture, forestry, or infrastructure development is a major cause of carbon loss,
- **Peat fires** can release large amounts of carbon and occur above and below ground,
- **Land Use Change** to palm oil plantations or deforestation can lead to significant carbon losses,
- **Climate Change** can affect the water balance of peatlands, potentially leading to drying and increased carbon emissions,
- Finally, the **rewetting and restoration** of degraded peatlands can help to reduce carbon emissions

Leading carbon standards, such as Verra (VM0036 for temperate/boreal peatlands) and the UK's Peatland Code, have developed rigorous protocols for peatland projects. These methodologies mandate the use of advanced monitoring techniques—combining field data, remote sensing, and modelling—to establish baselines, quantify emission reductions, and monitor the project's performance over its lifetime.

These methodologies are also applicable for non-credit projects and while data from the ground remains essential to assess the status of peatlands, this method is not scalable. On the other hand, remote sensing technologies offer the means to monitor vast, often inaccessible peatland landscapes repeatedly and cost-effectively. These technologies do not measure carbon directly but provide crucial proxies for peatland condition, hydrology, and vegetation dynamics, which can be used to infer changes in carbon stocks and are thus an ideal complementary technique to ground truth.



Figure 5: Wet peatland in Scotland (credit Alasdair MacDonald / Wet peat land / CC BY-SA 2.0)

ID	EUSPA-EO-UR-CLIMA-0002
Operational scenario	Carbon Stock Change Detection in Peatlands for Climate Accounting
Users	Users include environmental and climate authorities, governmental agencies implementing peatland restoration programs and certification organizations for carbon credits. Carbon assessment is provided by specialized companies or scientific bodies.
Operational description	A governmental agency oversees a program for peatland restoration. One of the outcomes is carbon stored below ground. The agency mandates another organization to assess on a yearly basis the state of the peatland and the amount of carbon stored (or released).
Size of area of interest	From 10Ha to 100000Ha

Frequency of information needed	Assessments need to be made on a yearly basis as peatlands are subject to seasonal effects (the peat bog).
Type of service (continuous, forecasting, one-off?)	Continuous
Satellite EO Data Requirements	
Spatial resolution	1-10m
Temporal resolution	Monthly
Spectral resolution	InSAR is used to map peatland condition and to detect rapid hydrological response to restoration, providing early validation long before ecological changes are visible. SAR is sensitive to the physical properties of the surface, including roughness and moisture content. This makes SAR a useful tool for assessing the extent of waterlogging and monitoring changes in the water table depth over large areas. Optical satellites like Sentinel-2 are used to provide vegetation index (NDVI) and land cover classes used as reliable proxies for vegetation health, density, and photosynthetic capacity. The Normalized Difference Water Index (NDWI) is sensitive to the moisture content of vegetation and soil. This allows for the inference of soil moisture conditions and, indirectly, the water table depth (WTD)—a key determinant of greenhouse gas emissions. Thermal sensors measure the Land Surface Temperature (LST) which serves as a critical input for models that estimate Ecosystem Respiration (ER),
Data supplements	EO data is supplement with ground data: Peat depth is measured using Peat Coring or Ground Penetrating Radar (GPR) Ground samples are collected at different depths for analysis (density and carbon %) Eddy covariance flux towers and wireless Internet of Things (IoT) sensor networks are used to measure and report greenhouse gas emissions For finer-scale measurements, static or automated chambers are placed directly on the peat surface to capture the gases being emitted from a small, defined area, In peatlands, LiDAR data from aerial surveys is used to measure the height of vegetation, which can be correlated with above-ground biomass and carbon stocks. By comparing LiDAR data from different time periods, changes in vegetation structure and, by extension, carbon stocks can be detected. Drones equipped with various sensors, including high-resolution cameras, multispectral sensors, and even LiDAR, are increasingly being used for

	detailed, localized monitoring of peatlands. UAVs can provide data at a much higher resolution than satellites, allowing for more precise measurements of vegetation structure and changes in the peatland surface
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Table 7: User needs and requirements - Carbon Stock Change Detection in Peatlands for Climate Accounting

Case Study / User Story
The Scottish Peatland ACTION is the national programme in Scotland dedicated to the restoration of damaged peatlands. It was launched in 2012 and is funded by the Scottish Government. Its primary mission is to help Scotland reach its "Net Zero" climate targets by turning damaged peatlands (which emit carbon) back into healthy peatlands (which store carbon). The program has a specific target to restore 250 000 Ha of degraded peatland by the end of the decade (90 000 Ha have been restored since 1990) and 400 000 Ha by 2040. The program has set strict evaluation and monitoring procedures based on various techniques. The impact of Peatland ACTION is measured by deploying a national-scale monitoring system and integrating with complementary initiatives such as LiDAR. InSAR based on Sentinel-1 data has been used at scale to map 680000Ha of peatlands. InSAR is used to estimate subsidence of the peatland and classify it in three categories: degrading (sustained subsidence), good (multi annual stability with annual swelling) and stiff (continuously stable, typical at the end of the peat degradation). InSAR data has been used to monitor peatland response to restoration and infrastructure, potentially leading to better restoration design in future projects and to prioritise areas for restoration or monitor how peatlands are responding to climate change.

Table 8: Case study - Carbon Stock Change Detection in Peatlands for Environmental Auditing

2.4.3 EO 3 - Flood-Induced and Retention Wetland Dynamics

Wetlands represent one of the most productive and ecologically significant ecosystems on Earth, providing critical services that extend far beyond their immediate boundaries. While they occupy only about 6% of the global land surface, their influence on hydrological cycles, biodiversity conservation, and climate regulation is disproportionately large. Understanding the temporal dynamics of wetland expansion and contraction is fundamental to managing water resources, protecting biodiversity, and addressing the challenges of climate change adaptation. These transitional zones between terrestrial and aquatic environments function as natural infrastructure, absorbing excess water during floods and gradually releasing it during dry periods, thereby moderating downstream flow regimes and reducing flood peaks that threaten human communities and agricultural lands.

The hydrological significance of wetlands lies in their extraordinary capacity to store and regulate water flows. Floodplain wetlands in particular serve as natural retention basins, temporarily storing floodwaters that would otherwise contribute to downstream inundation and property damage. A single hectare of wetland can store between 1000 and 15000 cubic meters of water depending on its depth and vegetation structure, effectively reducing flood peaks by 20 to 40% in some river basins. This retention capacity translates directly into avoided infrastructure damage and human displacement during extreme precipitation events, which are becoming more frequent and intense under changing climate conditions. Beyond flood regulation, wetlands play essential roles in groundwater recharge, water quality improvement through nutrient and sediment filtration, and maintenance of baseflow in rivers during drought periods.

These critical ecosystems are found across all continents and climatic zones, from the vast peatlands of boreal regions to tropical mangrove swamps, temperate freshwater marshes, and high-altitude wetlands in mountain valleys. The largest wetland complexes include the Pantanal in South America covering over 150000 square kilometres, the Okavango Delta in Africa, and the extensive floodplains of major river

systems like the Danube, Amazon, Mekong, and Mississippi. In Europe, significant wetland areas persist in the Netherlands' polder systems, Poland's river valleys, Romania's Danube Delta, Spain's Doñana marshes, and the extensive mire complexes of Finland and Sweden. However, historical drainage for agriculture has reduced European wetland area by over 50% since the beginning of the 20th century, with some countries losing more than 80% of their original wetland extent. This wide distribution underscores both the global importance of wetland conservation and the universal challenges posed by competing land use pressures that prioritize short-term agricultural or urban expansion over long-term ecosystem resilience.



Figure 6: Danube Delta view. Photo © Mircea Bezergheanu

Degraded and drained wetlands represent a significant source of greenhouse gas emissions and lost ecosystem services. When wetlands are drained for agriculture or development, the exposed organic soils undergo rapid oxidation, releasing stored carbon as carbon dioxide at rates that can exceed 20 tonnes per hectare per year. Simultaneously, the loss of water storage capacity increases downstream flood risk, while reduced filtration capacity leads to nutrient and sediment pollution of surface waters. The ecological consequences are equally severe, with drainage eliminating habitat for specialized wetland species including migratory waterfowl, amphibians, and invertebrates that cannot survive in drier conditions. The situation is particularly acute in Europe where intensive drainage for agriculture has converted vast wetland areas into cropland over the past two centuries. Countries like the Netherlands, Germany, and Poland have lost more than 80% of their original wetland area, with corresponding increases in flood vulnerability, water quality degradation, and biodiversity loss. In contrast, intact floodplain wetlands continue to provide multiple benefits simultaneously. A comprehensive study of the [Danube floodplains](#) found that each hectare of restored wetland reduces downstream flood damage by approximately 3000 euros per major flood event while simultaneously supporting populations of endangered species like the European pond turtle, white-tailed eagle, and numerous fish species that depend on seasonal flooding for spawning.

Recognizing these values, numerous European countries and international organizations have established programs to protect and restore wetlands as nature-based solutions for climate adaptation and

biodiversity conservation. The [Ramsar](#) Convention on Wetlands, signed by 172 countries, provides an international framework for wetland conservation and wise use, with over 2400 designated sites of international importance covering more than 250 million hectares worldwide. At the national level, countries including the Netherlands, Poland, Romania, and Spain have adopted wetland restoration strategies as components of integrated river basin management under the EU [Water Framework Directive](#), which requires member states to achieve good ecological status for all water bodies. Scotland has set particularly ambitious targets to restore 250000 hectares of degraded peatlands by 2030, recognizing both their carbon storage and flood regulation functions. The European Commission's [Biodiversity Strategy](#) for 2030 includes explicit targets for wetland restoration as part of a broader commitment to restore degraded ecosystems, with wetlands prioritized due to their multiple co-benefits for climate, water, and biodiversity. International programs like the [Global Wetland Center](#) focus specifically on the role of wetlands in regulating greenhouse gas emissions, developing methodologies to quantify carbon sequestration and emissions from these dynamic ecosystems that can alternate between carbon sinks and sources depending on their hydrological condition.

Monitoring wetland dynamics presents unique challenges that distinguish it from mapping other land cover types. Unlike forests where biomass changes occur gradually over years or decades, wetlands can expand or contract dramatically within days or weeks in response to precipitation events, snowmelt, or river stage fluctuations. A floodplain wetland may be completely dry during summer months and then inundated to depths of several meters following spring snowmelt or intense rainfall associated with atmospheric rivers or tropical storms. This temporal variability requires monitoring systems capable of detecting rapid changes at frequent intervals throughout the year. Furthermore, water presence beneath dense vegetation canopies is invisible to optical sensors that detect reflected sunlight, necessitating the use of radar systems that penetrate vegetation to detect underlying water surfaces. The combination of temporal variability and optical complexity means that no single sensor or observation frequency can adequately characterize wetland dynamics across all ecosystem types and climatic settings, requiring instead an integrated approach that combines multiple data sources with complementary strengths and limitations.

Measuring the hydrological buffer function of wetlands requires more than simply mapping their extent at a given moment. To quantify flood retention capacity, which determines the value of wetlands as natural infrastructure for flood risk reduction, managers need estimates of water depth and volume, not just inundated area visible from above. A wetland covering 100 hectares but only 10 centimetres deep stores 100000 cubic meters of water, while the same area with an average depth of 1 meter stores 1 million cubic meters, a tenfold difference that is invisible in simple presence-absence maps. Similarly, understanding the connectivity between wetlands and river channels is essential for assessing their effectiveness in moderating flood peaks. A wetland that fills only after river levels exceed bankfull stage provides less flood attenuation than one that begins filling at lower flow levels and can intercept a greater proportion of the flood wave. These hydrological details require integration of satellite observations — including surface deformation maps derived from InSAR that reveal subtle ground subsidence linked to waterlogging dynamics — with meteorological data capturing precipitation variability and evapotranspiration demand, high-resolution digital elevation models, and hydrodynamic modelling. Together these inputs transform simple presence-absence maps into quantitative assessments of ecosystem function that can support cost-benefit analyses and infrastructure planning decisions.

Current operational wetland monitoring services leverage multiple Earth Observation data sources to address these multifaceted challenges. Sentinel-1 synthetic aperture radar provides all-weather capability to detect water presence beneath moderate vegetation canopies, with C-band frequencies at approximately 5.5 centimetres wavelength penetrating grasses and shrubs but attenuating significantly in dense forest. For forested wetlands, including tropical peat swamp forests and boreal bogs where tree canopies obscure the ground surface, L-band radar from missions like ALOS PALSAR offers deeper canopy penetration due to its longer wavelength of approximately 23 centimetres. Optical data from Sentinel-2 complements radar observations by providing information on vegetation health and phenology through indices like the Normalized Difference Vegetation Index, which quantifies photosynthetic activity, and the Normalized Difference Water Index, which enhances the contrast

between water and land surfaces. Water exhibits characteristic low reflectance in near-infrared wavelengths due to strong absorption, enabling reliable water detection in open areas free of overhanging vegetation. The combination of radar and optical data, with different sensors capturing complementary information about surface conditions and vegetation structure, enables more complete characterization than either sensor type alone, particularly in heterogeneous landscapes where wetlands are intermixed with agriculture and forest.

The processing chain for operational wetland monitoring begins with multi-temporal image acquisition to capture seasonal and interannual variability in hydrological conditions. Monthly composites are commonly generated to reduce the influence of individual cloud-contaminated observations, which are particularly problematic in humid tropical regions where wetlands may be cloud-covered 70% of the time, while preserving temporal resolution sufficient to detect seasonal flooding patterns associated with monsoons or snowmelt. These composites are then subjected to classification algorithms that distinguish water, emergent vegetation, and upland cover types based on their spectral or backscatter signatures. Increasingly, machine learning approaches including random forests and deep neural networks are employed to integrate multiple data sources and extract patterns that traditional rule-based classifiers miss, such as the subtle spectral signatures of water beneath dense emergent vegetation. However, these algorithms require substantial training data consisting of ground reference observations paired with satellite measurements collected at the same time. The scarcity of high-quality training data constrains the accuracy and transferability of automated classification systems, particularly for rare wetland types like seepage wetlands or regions where field access is difficult due to remoteness or security concerns.

Altimetry missions including Sentinel-3 and the recently launched Surface Water and Ocean Topography mission offer additional capabilities for monitoring water levels in larger wetlands. These radar altimeters measure the distance between the satellite and the water surface with centimetre-scale precision by analysing the return time and shape of radar pulses, enabling detection of subtle water level changes that correlate with flood storage and release dynamics. However, altimetry has fundamental limitations in spatial coverage, providing measurements only along narrow ground tracks separated by tens to hundreds of kilometres rather than wall-to-wall mapping. For wetlands larger than 1 square kilometre that are intersected by satellite ground tracks, altimetry can complement optical and SAR observations by adding a vertical dimension to horizontal extent mapping, enabling estimation of volume changes that are critical for quantifying flood retention services. The integration of these three observation types—optical for vegetation mapping, SAR for water detection beneath canopy, and altimetry for water level monitoring—represents the current state of the art in comprehensive wetland characterization and supports applications ranging from national inventory updates to real-time flood forecasting.

The integration of wetland monitoring into carbon markets and climate finance mechanisms represents an emerging application with growing policy relevance and potential to mobilize private investment in restoration. Restored wetlands sequester atmospheric carbon as plant material accumulates in waterlogged soils where decomposition is inhibited by lack of oxygen, with accumulation rates ranging from 0.5 to 5 tonnes of carbon per hectare per year depending on climate, vegetation type, and hydrological regime. Conversely, drained wetlands emit carbon as exposed organic soils oxidize upon contact with atmospheric oxygen, releasing carbon dioxide at rates that can exceed 20 tonnes per hectare per year and represent a significant contribution to national greenhouse gas inventories. Quantifying these carbon fluxes for carbon credit generation or national inventory reporting requires estimates not only of wetland extent but also of vegetation type, water permanence, and land use history. A permanent marsh dominated by cattails that remains flooded year-round exhibits different carbon dynamics than a seasonally flooded wet meadow with grasses and sedges that experience periodic drying. Similarly, recently restored wetlands go through successional stages with changing vegetation composition and carbon accumulation rates as pioneer species are replaced by more stable communities. Current monitoring approaches do not routinely distinguish these functional types or track vegetation succession at the temporal frequency needed for carbon accounting under protocols like [Verra's VM0036 methodology](#) or the [UK Peatland Code](#). The data exist within Copernicus archives spanning back to 2015 for Sentinel-2 and 2014 for Sentinel-1, but operational processing chains to generate integrated carbon-

ready products do not yet exist outside of research contexts, limiting the ability of restoration projects to access carbon finance that could accelerate implementation.

ID	EUSPA-EO-UR-CLIMA-00013
Operational scenario	Flood-Induced and Retention Wetland Dynamics Monitoring
Users	National wetland authorities, environmental consultants, carbon credit verifiers, international organizations (UN RAMSAR, ministries), restoration project managers, research institutions (universities), and industry stakeholders (e.g. DHI).
Description	Mapping and monitoring seasonal flood wetlands for GHG emission modelling, biodiversity tracking, and restoration verification using Earth Observation data.
Size of area of interest	Restoration projects > 100 ha
Frequency of information needed	Monthly composites (current); target bi-weekly during flood season; weekly for active restoration monitoring.
Type of service (continuous, forecasting, one-off?)	Continuous
Satellite EO Data Requirements	
Spatial resolution	≤10 m (current); target 3–5 m for small wetlands (<1 ha detection); 30 m acceptable for national inventories.
Temporal resolution	Monthly for operational wetland monitoring. Weekly for quantifying carbon fluxes.
Spectral resolution	Spectral/SAR for wetland detection and multitemporal changes monitoring: SAR (C-band + L-band for vegetation penetration); optical NDVI, NDWI for vegetation health; water permanence indices. Altimetry: Sentinel 3/SWOT mission data for water level changes in larger wetlands (>1 km ²)
Data supplements	flood depth estimates, GHG emission proxies (vegetation type, water permanence), carbon storage indicators. Labelled training data for machine learning

Table 9: User needs and requirements - Flood-Induced and Retention Wetland Dynamics Monitoring

Case Study / User Story

[DHI](#) (Danish Hydraulic Institute) is a global, independent research and consultancy organization specializing in water environments. In collaboration with the Global Wetland Centre, they have conducted wetland mapping projects across Uganda, South Africa, Colombia, and Australia to develop operational monitoring frameworks that support national reporting obligations under the Ramsar Convention and national climate commitments. The initiative included stakeholder workshops with around 60 participants representing environment ministries, water management agencies, private sector restoration companies, and international conservation organizations. These workshops identified key operational requirements including annual map updates to track restoration progress, monthly monitoring during flood season for adaptive management, and integration with national greenhouse gas inventory systems to quantify emission reductions from restoration.

Torsten Bondo from DHI explained during consultations that "labelled data for machine learning is limited—technological capacity is strong, but data annotation remains a bottleneck." Instead, the project relied on a combination of limited field surveys, interpretation of high-resolution commercial imagery, and transfer learning from existing datasets in similar ecological settings.

The project generates annual wetland maps with 10-meter resolution, using monthly Sentinel-1 and Sentinel-2 composites, DEM models, ALOS PALSAR (L-band SAR), and the Surface Water and Ocean Topography (SWOT, altimetry mission), providing national coverage at reasonable computational cost. However, validation against high-resolution airborne imagery revealed that small wetlands smaller than 1 hectare, which constitute approximately 40% of total wetland area in the pilot regions, are systematically missed. This omission is particularly problematic for biodiversity assessments because many endemic species depend on small, isolated wetlands that serve as refugia during droughts.

Bondo noted that ensuring data utilization and policy impact remains an ongoing challenge: "Data is expected to support decision-making and policy development at national levels." To address this, DHI is working through programs like UN RAMSAR to ensure national-level reporting and compliance, embedding wetland monitoring into existing governance structures rather than creating parallel systems. The project demonstrates the critical need for continuous updates with yearly maps updated monthly during flood season and improved stakeholder engagement to ensure data leads to meaningful policy and conservation impact rather than remaining in scientific repositories unused by decision-makers.

Table 10: Case study - Flood-Induced and Retention Wetland Dynamics Monitoring

2.4.4 EO 4 - Monitoring Reservoir Water Levels, Sedimentation, and Evaporation Loss for Water Security

Reservoirs are critical infrastructure for water supply, hydropower generation, irrigation, and flood control, storing water during wet periods for use during dry seasons when natural streamflow cannot meet demand. Effective reservoir management requires continuous monitoring of water levels, storage capacity changes due to sedimentation, and evaporation losses that reduce available water supply. Understanding the current state and trends in reservoir storage is fundamental to ensuring water security for growing populations under increasingly variable climate conditions. These artificial lakes represent humanity's principal adaptation to the natural variability of river flows, enabling agricultural development in semi-arid regions and reliable electricity generation from hydropower that supplies over 16% of global electricity production.

Globally, large reservoirs store approximately 8000 cubic kilometres of water, equivalent to three times the annual flow of all the world's rivers. This storage buffers against drought by ensuring water availability during dry years when rainfall and snowmelt are below average. It enables irrigation of over 300 million hectares of cropland worldwide, producing food for billions of people in regions where rainfed agriculture alone would be insufficient. It generates clean, renewable electricity through hydropower with lower greenhouse gas emissions per kilowatt-hour than fossil fuel alternatives. Additionally, reservoirs provide flood control by temporarily storing peak flows during storms and releasing water gradually after flood risk has passed, protecting downstream communities and infrastructure from inundation.

These critical water storage facilities are found on every inhabited continent, with particularly high concentrations in regions where natural water availability is insufficient to meet demand or highly seasonal. Large reservoir systems include the Three Gorges Dam in China with a storage capacity of 39 cubic kilometres, Lake Kariba between Zambia and Zimbabwe storing 185 cubic kilometres, Lake Nasser behind Egypt's Aswan High Dam, and major reservoir systems in the western United States, southern Europe, and central Asia. In Europe, significant reservoir capacity exists in the Alpine regions of Switzerland, Austria, and Italy for hydropower generation, in Spain and Portugal for irrigation and urban water supply in the semi-arid Mediterranean climate, and in Scandinavia for hydropower and flood control. Spain alone operates over 1200 large reservoirs with combined storage exceeding 56 cubic kilometres, providing water security for agriculture that accounts for nearly 3% of the country's GDP. This widespread distribution underscores the universal importance of reliable reservoir monitoring for water resource management and the shared challenges posed by sedimentation that gradually reduces storage capacity and climate change that alters inflow patterns and evaporation rates.



Figure 7: [Aldeadávila Dam](#), located on the Douro River on the border between Spain and Portugal.

Poorly managed reservoirs or those lacking accurate storage information represent risks to water security and public safety. When reservoir levels are overestimated due to undetected sedimentation, water allocations to agriculture or urban users may exceed actual available supply, leading to shortages that impact food production or drinking water availability. When evaporation losses are not accurately quantified, water budgets become unbalanced and planning decisions may be based on inflated availability estimates. Conversely, when reservoir levels are underestimated, opportunities to store additional water may be missed, or unnecessary releases may reduce storage heading into dry seasons. The consequences of poor reservoir management extend beyond water supply to include safety risks when reservoir operations do not account for actual storage capacity, potentially leading to uncontrolled overflow during extreme flood events. Sedimentation reduces storage capacity gradually, with some reservoirs losing 1 to 2% of their capacity per year in regions with high erosion rates. Over the decades-long lifespan of reservoir infrastructure, this cumulative loss can amount to 30 to 50% of original capacity, yet many reservoir operators lack regular bathymetric surveys to quantify this loss and adjust operations accordingly.

Recognizing these challenges, water utilities, hydropower companies, and public water management authorities increasingly rely on integrated monitoring systems that combine satellite imagery, altimetry, meteorological reanalysis, and hydrological models to track reservoir conditions continuously. The European Commission's [Common Implementation Strategy](#) for the Water Framework Directive provides

guidance on reservoir monitoring to support ecological status assessment, while national programs in countries including Spain, Italy, and Portugal mandate regular reporting of reservoir storage to inform drought declarations and water allocation decisions. International initiatives like the [Global Reservoir and Dam Database](#) compile information on reservoir locations, capacities, and operational purposes to support global water security assessments and climate impact studies. The [International Commission on Large Dams](#) provides technical standards for reservoir monitoring and safety assessment that increasingly reference remote sensing as a cost-effective complement to traditional ground-based measurements.

Monitoring reservoir dynamics presents distinct technical challenges compared to natural water bodies. Unlike lakes where bathymetry remains relatively stable over time, reservoirs experience continuous sedimentation that alters depth distribution and storage capacity, requiring periodic remapping that is expensive using traditional boat-based acoustic surveys. Unlike rivers where flow is the primary variable of interest, reservoirs require monitoring of both horizontal extent and vertical water level to accurately determine storage volume using area-elevation curves that relate water surface area to depth and total volume. Unlike wetlands where vegetation obscures water surfaces, most reservoirs have minimal aquatic vegetation due to water level fluctuations that prevent establishment, simplifying optical detection but creating different challenges related to water quality and submerged features that affect remote sensing algorithms. The combination of changing bathymetry, need for volumetric rather than areal measurements, and clear water surfaces with variable bottom reflectance means that operational reservoir monitoring requires integration of multiple satellite observation types with complementary information content.

Quantifying reservoir storage requires moving beyond simple water surface mapping to estimate both area and level, which together determine volume through area-elevation relationships. A reservoir may have the same water surface area at two different times but store vastly different volumes if water levels differ due to filling or drawdown. For example, a reservoir with steeply sloping sides changes levels dramatically with small volume changes, while a reservoir with flat, broad bottom changes levels minimally even with large volume changes. Understanding these relationships requires either detailed bathymetric maps showing underwater topography or empirical calibration against in-situ gauge measurements over many years to empirically derive area-elevation curves. Furthermore, evaporation from reservoir surfaces can represent a major water loss pathway, particularly in arid and semi-arid regions where annual evaporation may exceed 2 meters of water depth. A reservoir with 10 square kilometres of surface area losing 2 meters per year to evaporation loses 20 million cubic meters of water, enough to supply a city of 100000 people. Quantifying this loss requires estimates of water surface temperature, air temperature, humidity, wind speed, and solar radiation, demanding integration of satellite observations with meteorological data in energy balance models that are complex and require careful calibration.

Current operational reservoir monitoring services leverage multiple Earth Observation data sources to address these interconnected challenges. Sentinel-2 optical imagery with 10-meter resolution provides water surface extent through spectral water indices that exploit the low near-infrared reflectance of water compared to land. By tracking changes in water surface area over time and relating these to water level through area-elevation curves, operators can estimate volumetric storage changes without requiring direct level measurements. However, this approach requires either pre-existing bathymetric surveys to establish area-elevation relationships or long time series of simultaneous satellite and in-situ measurements to empirically derive these relationships, neither of which is available for many smaller reservoirs or those in developing countries where gauge networks are sparse. Sentinel-3 altimetry provides direct water level measurements for larger reservoirs intersected by satellite ground tracks, with vertical precision of approximately 30 centimetres under favourable conditions. For reservoirs larger than 10 hectares that are regularly overflowed, altimetry offers an independent measurement of water level changes that can validate and complement area-based estimates. Sentinel-3 also provides water surface temperature at 300-meter resolution, enabling estimation of evaporation rates when combined with meteorological data on air temperature, humidity, and wind speed from reanalysis products like ERA5-Land.

Commercial very high-resolution optical imagery from satellites like WorldView, Pléiades, and SkySat offers sub-meter resolution that enables detailed bathymetric mapping in shallow areas through spectral analysis of bottom reflectance in clear water. Light penetration in blue and green wavelengths allows detection of depth variations up to 10 to 15 meters in clear waters, providing partial bathymetric information that can complement sparse acoustic surveys. However, satellite-derived bathymetry remains experimental for most inland reservoirs, with accuracy degrading rapidly in turbid water where suspended sediments scatter and absorb light, in vegetated areas where aquatic plants obscure bottom features, and at depths greater than two to three times the Secchi depth where light penetration is insufficient. Most operational bathymetric mapping still relies on boat-based acoustic surveys that are expensive, time-consuming, and conducted infrequently, often at intervals of 5 to 10 years, during which substantial sedimentation may occur undetected.

The processing chain for operational reservoir monitoring typically begins with water surface extraction from Sentinel-2 imagery using spectral indices like the Normalized Difference Water Index or machine learning classifiers trained on local reference data. Time series of water surface area are then converted to water level using area-elevation curves, which may be derived from digital elevation models, historical bathymetric surveys, or statistical relationships calibrated against gauge data. For reservoirs with Sentinel-3 altimetry coverage, direct water level measurements provide an independent estimate that can validate area-based retrievals and improve accuracy. Water surface temperature from Sentinel-3 is combined with meteorological variables from ERA5-Land, including air temperature, relative humidity, wind speed, and incoming solar radiation, to calculate evaporation using the Penman-Monteith equation or similar energy balance approaches. The resulting estimates of storage volume and evaporation loss are integrated into water balance models that account for inflows from upstream catchments, outflows through dam releases, and abstractions for water supply, providing a complete picture of reservoir water availability for operational decision-making.

ID	EUSPA-EO-UR-CLIMA-0004
Operational scenario	Monitoring Reservoir Water Levels, Sedimentation, and Evaporation Loss for Water Security
Users	Water utilities (integrated water services), hydropower companies, public water management authorities, irrigation district managers, drought monitoring agencies, reservoir operators.
Description	Operational monitoring of reservoir water levels, bathymetry changes due to sedimentation, and evaporation losses to support water supply planning, hydropower management, and drought preparedness.
Size of area of interest	Reservoirs > 10 ha
Frequency of information needed	Weekly
Type of service (continuous, forecasting, one-off?)	Continuous
Satellite EO Data Requirements	
Spatial resolution	10 m for water reservoirs and <10m for rivers.
Temporal resolution	Weekly.

Spectral resolution	Sentinel-2 (optical VIS-NIR), Sentinel-3 (surface water temperature and altimetry).
Data supplements	• DEM • Water level time series • bathymetry maps • evaporation rates • fractional water cover • reservoir inflow/outflow estimates

Table 11: User needs and requirements - Monitoring Reservoir Water Levels, Sedimentation, and Evaporation Loss for Water Security

Case Study / User Story
Waterjade, an Italian SME, provides decision support systems to municipalities, hydropower companies, and integrated water services across southern Europe. "Our mission is to help utilities monitor and predict water availability in rivers, reservoirs, and springs," explains Matteo Dall'Amico, co-founder of Waterjade. The company develops physically-based hydrological models that integrate in-situ gauge data with EO-derived parameters to forecast water availability days to weeks in advance, enabling utilities to optimize operations and plan for drought or flood conditions. For reservoir monitoring specifically, Waterjade uses Sentinel-2 optical imagery at 10-meter resolution to map water surface area, which is then converted to water level and storage volume using area-elevation curves derived from digital elevation models and calibrated against available gauge data. The company serves both small and large utilities with different levels of technical capacity. To serve this diverse client base, Waterjade delivers processed products rather than raw imagery, including time series of reservoir water level, inflow forecasts based on upstream snowpack and weather predictions, and water availability assessments that translate hydrological conditions into decision-relevant information like "current storage is 70% of normal for this date" or "predicted inflows over the next two weeks will be 40% below average." Looking to emerging capabilities, Waterjade is "currently exploring how to include underwater monitoring," recognizing that bathymetric changes due to sedimentation affect reservoir storage capacity over time and should be incorporated into long-term planning models.

Table 12: Case study - Monitoring Reservoir Water Levels, Sedimentation, and Evaporation Loss for Water Security

2.4.5 EO 5 - Monitoring Urban Flash Flood Risk via Impervious Surface Expansion

Rapid urbanization increases impervious surface coverage through construction of roads, buildings, parking lots, and other infrastructure that prevents water infiltration into the soil. While agricultural land and forests allow 50 to 90% of precipitation to infiltrate and recharge groundwater, impervious surfaces allow only 5 to 15% infiltration, with the remainder becoming immediate runoff that flows overland to drainage systems. This fundamental change in hydrological response elevates flash flood risk, particularly in areas with inadequate drainage infrastructure that cannot accommodate the increased runoff volumes and peak flow rates. Understanding the spatial patterns and temporal trends of impervious surface expansion is fundamental to managing urban flood risk, prioritizing infrastructure investments, and implementing nature-based solutions for stormwater management. These land cover changes represent one of the most pervasive human modifications to the environment, affecting not only flood risk but also water quality, urban heat islands, and aquatic habitat connectivity in urban streams.

The hydrological significance of impervious surface expansion lies in its dramatic impact on the timing and magnitude of urban flood response. Urbanization can increase peak runoff rates by factors of 2 to 10 compared to pre-development conditions, depending on the extent of impervious coverage and the capacity of drainage infrastructure. Furthermore, the time to peak runoff decreases substantially as water flows rapidly across impervious surfaces rather than moving slowly through soil. This combination of higher peaks and faster response creates flash flood conditions where water depths can reach dangerous levels within minutes, particularly in low-lying areas, underpasses, and channels constricted by bridges or culverts.

These critical urbanization processes are occurring worldwide, with urban populations growing by approximately 200,000 people per day and urban land area expanding even faster due to decreasing population density in sprawling development patterns. Regions experiencing particularly rapid urbanization include rapidly growing cities in Southern and Eastern Europe, peri-urban areas surrounding major metropolitan centres, and coastal zones where population concentration and flood risk both run high. In Europe, countries including Spain, Portugal, Italy, and Greece have experienced extensive urban expansion in recent decades, often in coastal areas attractive to tourism and retirement communities. Northern Europe, while more slowly growing, faces challenges from intensification of land use in already-developed areas through infill development and redevelopment of industrial sites. This widespread spatial distribution underscores the universal nature of urban flood challenges and the need for systematic monitoring systems that can track land use changes and inform adaptive management across diverse geographic and climatic contexts.



Figure 8: River-based [flooding](#) in European city. Photo by Rich Ekaterina Pokrovsky, Shutterstock

Beyond direct flood damages, increased runoff from impervious surfaces degrades water quality through transport of pollutants including oils, heavy metals, nutrients, and bacteria that accumulate on streets and parking lots between storms and are washed into streams during rainfall. Urban streams receiving this runoff experience elevated erosion, habitat degradation, and biological impairment that reduces biodiversity and ecosystem services.

Recognizing these challenges, municipalities, drainage authorities, and urban planning agencies increasingly implement green infrastructure and low-impact development practices to mitigate the

hydrological impacts of urbanization. The [European Commission's Floods Directive](#) requires member states to assess flood risk, map flood hazards and risks, and develop flood risk management plans that prioritize prevention and protection measures. At national and local levels, cities including [Copenhagen](#) and [Rotterdam](#) have implemented comprehensive stormwater management programs that combine grey infrastructure like enlargement of drainage pipes and construction of detention basins with green infrastructure including permeable pavements, rain gardens, green roofs, and urban wetlands that restore some degree of infiltration and detention in developed areas. Germany's [national strategy](#) on climate adaptation specifically addresses urban flooding and calls for increased use of data to monitor land use changes and assess vulnerability. Spain has developed [flood risk maps](#) for urban areas throughout the country following devastating floods in recent years that caused billions of euros in damages and multiple fatalities.

Current operational approaches to urban flood risk assessment leverage multiple Earth Observation and ancillary data sources in integrated modelling frameworks. Sentinel-2 optical imagery provides land cover classification at 10-meter resolution, enabling mapping of broad impervious surface categories including dense urban, medium density urban, and low density urban, as well as pervious surfaces like parks, forests, and agricultural land within and surrounding cities. The [Copernicus Urban Atlas](#), produced by the European Environment Agency for functional urban areas across Europe, provides higher thematic detail including road networks, building footprints, industrial areas, and green spaces at 5-meter resolution for large cities and 10-meter resolution for smaller cities. This product, updated approximately every 6 years, provides a reference dataset for urban land cover that can be used to train classification algorithms and validate satellite-derived products. For rapidly growing cities or areas where more frequent updates are needed, Sentinel-2 time series analysis enables annual or more frequent change detection to identify areas where new development has occurred.

Commercial very high-resolution imagery from satellites like WorldView, Pléiades, and SkySat offers 30-centimeter to 2-meter resolution that enables detection of individual buildings and narrow roads, supporting detailed impervious surface mapping at the parcel scale. However, these data are not freely available, and their cost limits routine use to targeted campaigns covering limited areas rather than comprehensive city-wide or regional monitoring.

Digital elevation models derived from airborne LiDAR surveys provide the topographic detail essential for urban hydrological modelling. LiDAR measures surface elevation using laser pulses with vertical accuracy of 10 to 15 centimetres and horizontal resolution of 0.5 to 2 meters, enabling identification of subtle topographic features like curbs, swales, and localized depressions where water ponds during storms. This level of detail matters because hydrological models relying on coarser satellite-derived DEMs and impervious surface mapping frequently underestimate localized flooding, failing to resolve small-scale features such as clogged drainage inlets, street-level depressions, or minor topographic variations that nonetheless exert a disproportionate influence on flow routing and ponding. These fine-scale features are critical for accurate flood modelling because they control flow directions and ponding locations that determine which properties are inundated for a given rainfall intensity, and their omission can only be addressed through higher-resolution data and careful calibration against observed flood events. However, LiDAR surveys are expensive, typically costing thousands of euros per square kilometre, and are conducted infrequently due to budget constraints. Many European cities lack comprehensive recent LiDAR coverage, particularly in rapidly growing peri-urban areas where development is active but municipal budgets are limited.

The processing chain for urban flood risk assessment typically begins with impervious surface mapping using supervised classification of Sentinel-2 imagery or higher resolution commercial imagery where available. Algorithms ranging from simple threshold-based approaches on spectral indices to complex machine learning classifiers like random forests or convolutional neural networks are trained on reference data from the Urban Atlas or manually digitized samples. The resulting impervious surface maps are then updated by detecting changes through multi-temporal analysis that flags areas where spectral signatures have transitioned from pervious to impervious classes, indicating new development. These updated impervious surface maps are integrated with high-resolution DEMs, drainage network datasets showing pipe locations and capacities, and hydrological models that simulate rainfall-runoff generation and

routing. Because each of these inputs carries its own error characteristics and spatial resolution, data fusion techniques and data assimilation approaches — which combine multiple data streams in a statistically principled way — are increasingly advocated to reduce error propagation across the processing chain and improve the overall accuracy of the resulting flood models. The models are forced with design storms representing specific recurrence intervals like the 10-year or 100-year storm, producing maps of predicted inundation extent and depth that identify vulnerable areas and properties.

ID	EUSPA-EO-UR-CLIMA-0005
Operational scenario	Monitoring Urban Flash Flood Risk via Impervious Surface Expansion
Users	Municipal flood risk managers, urban planners, environmental consulting firms, civil protection authorities, insurance companies, drainage infrastructure operators.
Description	Tracking urban sprawl and impervious surface expansion to update flash flood susceptibility models and inform municipal drainage planning.
Size of area of interest	Urban areas > 50 k inhabitants
Frequency of information needed	Quarterly
Type of service (continuous, forecasting, one-off?)	One-off and forecasting.
Satellite EO Data Requirements	
Spatial resolution	5-10 m
Temporal resolution	Weekly.
Spectral resolution	Sentinel-2 (optical VIS-NIR).
Data supplements	• Copernicus Urban Atlas. • CORINE Land Cover. • Weather radar. • Building footprints and heights. • Drainage infrastructure proxies. • Urban morphology indicators. • Precipitation estimates (radar integration). • Reservoir inflow/outflow estimates.

Table 13: User needs and requirements - Monitoring Urban Flash Flood Risk via Impervious Surface Expansion

Case Study / User Story
Waterjade provides flash flood susceptibility mapping to municipalities and integrated water services across Italy, a country where urban flash floods have caused billions of euros in damages and multiple fatalities in recent decades. "We work on urban flash floods, pluvial and fluvial events," explains Matteo

Dall'Amico, co-founder. The company develops decision support systems that combine high-resolution digital elevation models, impervious surface maps derived from satellite imagery and urban atlas data, and hydraulic models to identify areas at risk for different storm intensities.

"Urban areas require 1–2-meter DEMs from LiDAR, often municipal or government owned," notes Dall'Amico, explaining that these data are essential for accurate flow routing in urban environments where subtle elevation differences of tens of centimetres determine whether water flows to drainage inlets or ponds in low spots. "Rural areas can work with 30-meter DEMs from Copernicus, but cities need meter-level resolution for accurate inundation mapping." Waterjade typically obtains these high-resolution DEMs directly from municipalities who have commissioned LiDAR surveys, but data access is inconsistent and many smaller municipalities lack recent coverage.

The fundamental challenge for flash flood early warning is the temporal mismatch between satellite revisit times and flood evolution. "Floods may last only hours; satellites often miss maximum expansion. Current EO temporal resolution is insufficient," explains Dall'Amico, referring to public open datasets. While private datasets are not always affordable for small government.

Instead of attempting real-time mapping, Waterjade uses EO-derived impervious surface products to build susceptibility models that identify which neighbourhoods and streets are vulnerable based on topography, land cover, and drainage capacity. These models simulate numerous design storms representing 10-year, 50-year, and 100-year rainfall intensities, generating maps that show predicted inundation extent and depth for each scenario. Municipalities use these risk maps to prioritize drainage improvements, establish building codes that require minimum floor elevations in flood-prone areas, and plan emergency response including identification of evacuation routes and shelters.

Table 14: Case study - Monitoring Urban Flash Flood Risk via Impervious Surface Expansion

2.4.6 EO 6 - Water Pollution Monitoring from Industrial and Agricultural Runoff

Water quality degradation from industrial point sources and agricultural diffuse pollution threatens ecosystem health, drinking water safety, and compliance with environmental regulations including the EU Water Framework Directive and national water quality standards. Detecting and monitoring pollution plumes, eutrophication zones characterized by excessive algal growth, and harmful algal blooms that produce toxins dangerous to humans and wildlife using Earth Observation enables regulatory agencies to enforce compliance, prioritize remediation efforts, and issue public health warnings that protect recreational users and drinking water consumers. Understanding the spatial extent, temporal dynamics, and sources of water pollution is fundamental to managing water resources sustainably and ensuring that surface waters meet ecological and human health objectives. These monitoring requirements represent one of the fastest growing applications for Earth Observation in the water sector, driven by tightening environmental regulations, growing public awareness of pollution impacts, and the limitations of traditional monitoring approaches based on sparse point sampling that miss spatially and temporally variable pollution events.

The significance of water pollution for public health and ecosystems lies in the diverse impacts of different pollutant types. Nutrients including nitrogen and phosphorus from agricultural fertilizers and wastewater discharges stimulate excessive growth of algae and aquatic plants, a process called eutrophication that depletes oxygen when this biomass decomposes, creating dead zones where fish and other aquatic life cannot survive. In severe cases, eutrophication leads to harmful algal blooms that produce toxins called microcystins and anatoxins that can cause liver damage, neurological effects, and skin irritation in humans who swim in or consume contaminated water, and that kill livestock and pets. The economic consequences of water pollution include billions of euros annually in treatment costs for drinking water utilities that must remove pollutants to meet safety standards, lost recreation and tourism revenue when beaches are closed due to algal blooms or bacterial contamination, and reduced property values near polluted water bodies.

These water quality challenges are widespread across Europe and globally, affecting rivers, lakes, estuaries, and coastal waters. Regions with particularly acute pollution problems include intensive agricultural areas in the Netherlands, Denmark, Germany, northern France, and the Po Valley of Italy where decades of fertilizer application have created chronic nutrient enrichment. Industrial regions including the Rhine and Danube river basins have legacies of heavy metal and organic chemical contamination from decades of unregulated discharges, though point source controls implemented under [EU directives](#) have substantially reduced loads in recent decades. Mediterranean coastal areas experience seasonal eutrophication problems as tourist populations surge in summer, overwhelming wastewater treatment capacity and discharging nutrients that stimulate algal growth in warm waters with long residence times. Lakes throughout Europe experience harmful algal blooms with increasing frequency, attributed to combination of nutrient enrichment and warming water temperatures that favour bloom-forming cyanobacteria. This widespread spatial distribution underscores the universal nature of water pollution challenges and the need for monitoring systems that can systematically track water quality across diverse water body types, pollution sources, and climatic settings.



Figure 9: [Po River](#) in the Po Valley of Italy.

Traditional water quality monitoring based on manual sampling at fixed stations provides valuable information but has fundamental limitations in spatial and temporal coverage. A typical river monitoring program might sample 10 to 20 locations monthly, missing pollution events that occur between sampling dates and missing pollution hotspots that occur between sampling locations. For large lakes and reservoirs, boat-based sampling is expensive and time-consuming, limiting frequency and spatial coverage. For coastal waters, traditional monitoring may cover only high-priority beaches and shellfish harvesting areas, leaving vast areas unmonitored.

Recognizing these limitations and the opportunities provided by Earth Observation to complement traditional monitoring, environmental protection agencies, river basin authorities, and research institutions increasingly integrate satellite-based water quality products into operational monitoring programs. The [EU Water Framework Directive](#) requires member states to assess ecological status of all surface waters based on biological, chemical, and hydro morphological indicators, with assessments updated every 6 years. Earth Observation can support this directive by providing synoptic spatial coverage and frequent temporal sampling that fills gaps between in-situ monitoring sites. At national levels, countries including

the [Netherlands](#) and [Germany](#) have established programs to integrate EO-derived water quality indicators into routine monitoring and reporting. The [Copernicus Marine Service](#) provides operational water quality products for European coastal and marine waters including chlorophyll-a concentration, turbidity, and total suspended matter derived from Sentinel-3 ocean colour imagery. These products are validated against in-situ measurements and delivered with documented accuracy that enables their use in regulatory assessments. However, comparable operational products for inland waters remain under development, with most applications still in research or pilot phases rather than routine operational use.

Monitoring water pollution using Earth Observation presents distinct challenges compared to coastal marine applications where algorithms and products are more mature. Inland waters are optically complex, meaning their optical properties are influenced not only by phytoplankton chlorophyll that is the primary target for eutrophication monitoring, but also by suspended sediments that scatter light, dissolved organic matter that absorbs light, and bottom reflectance in shallow areas that contributes to the signal detected by satellites. This optical complexity means that standard algorithms developed for clear ocean waters perform poorly when applied to turbid rivers, shallow lakes, or humic-rich waters with high concentrations of dissolved organic carbon. Algorithm calibration requires extensive datasets of simultaneous satellite imagery and in-situ measurements of chlorophyll, suspended sediments, and coloured dissolved organic matter, collected across the range of optical conditions present in a region. Such datasets are expensive to collect and available for only a limited number of well-studied water bodies, constraining algorithm development and validation.

Attributing observed pollution to specific sources requires integration of water quality observations with spatial data on pollution sources and hydrological connectivity. A satellite image showing high chlorophyll concentration in a lake indicates eutrophication but does not identify whether nutrients are coming from agricultural runoff, urban stormwater, wastewater treatment plant discharges, or internal loading from sediments. Distinguishing among these sources requires combining satellite observations with land use maps showing agricultural intensity and urban development, infrastructure datasets locating wastewater treatment plants and industrial facilities, hydrological models that trace water movement from sources to water bodies, and in-situ monitoring that provides ground truth and nutrients speciation to fingerprint sources. This integration of multiple datasets and modelling tools requires expertise in remote sensing, geographic information systems, hydrology, and water chemistry that may exceed the capacity of small environmental agencies, limiting operational adoption to larger jurisdictions or specialized consulting firms.

Current operational water quality monitoring services leverage optical multispectral imagery from Sentinel-2 and Sentinel-3 as primary data sources. Sentinel-2 with 10 to 20-meter resolution across visible and near-infrared bands provides the spatial detail needed to resolve pollution plumes in rivers and small lakes, though its 5-day revisit is compromised by cloud cover that reduces effective temporal resolution in many regions. Sentinel-3 with 300-meter resolution provides daily global coverage at coarser spatial resolution suitable for large lakes and coastal waters. Both sensors measure water-leaving radiance, the light reflected upward from the water surface after removing the contribution from atmospheric scattering, which depends on the concentrations and optical properties of water constituents. Algorithms ranging from simple band ratios to complex radiative transfer inversions are applied to retrieve chlorophyll-a concentration as an indicator of phytoplankton biomass, total suspended matter as an indicator of sediment load and turbidity, and coloured dissolved organic matter as an indicator of dissolved organic carbon. Additional algorithms detect floating algae and vegetation that indicates eutrophic conditions, identify oil slicks and industrial discharges based on their spectral signatures, and classify water types to support ecological status assessment. However, each of these data sources and retrieval algorithms carries inherent uncertainties, and the integration of satellite-derived products with in-situ measurements and ancillary environmental data — such as meteorological forcing or hydrological inputs — increasingly calls for data fusion and data assimilation frameworks that combine multiple streams in a statistically consistent manner, reducing error propagation and improving the accuracy and reliability of operational water quality assessments.

Ancillary datasets play essential roles in interpreting satellite observations and attributing pollution to sources. The [Copernicus Land Monitoring Service](#) provides land cover maps including agricultural land

use that identifies intensive crop production areas likely to contribute nutrient runoff, and impervious surface products that identify urban areas contributing stormwater runoff with elevated nutrients, bacteria, and toxic pollutants. These land cover products are used to delineate watersheds draining to each water body and quantify the intensity of potential pollution sources. Infrastructure datasets from OpenStreetMap and national spatial data infrastructures provide locations of wastewater treatment plants, industrial facilities, and combined sewer overflows that may discharge during storms. Digital elevation models from Copernicus enable delineation of drainage networks and hydrological connectivity, tracing pathways from pollution sources on land through streams and rivers to downstream lakes, reservoirs, and coastal waters. Integration of these datasets into geographic information systems enables spatial analyses that correlate satellite-observed water quality with upstream land use and infrastructure, supporting source identification and prioritization of control measures.

The processing chain for operational water quality monitoring typically begins with atmospheric correction of satellite imagery to remove the effects of aerosols, water vapor, and Rayleigh scattering that dominate the signal at the top of atmosphere, isolating the water-leaving radiance that contains information about water constituents. For Sentinel-2, several atmospheric correction algorithms are available including Sen2Cor distributed with standard Copernicus products, ACOLITE optimized for aquatic applications, and Polymer that handles sun glint and thin clouds. Each algorithm has strengths and limitations, with performance depending on atmospheric conditions and water optical properties. After atmospheric correction, water quality retrieval algorithms are applied to estimate chlorophyll-a and other parameters. For optically complex waters, machine learning algorithms trained on local in-situ datasets often outperform standard algorithms by learning the specific optical relationships in a region. The resulting water quality maps are then integrated with in-situ monitoring data through geostatistical interpolation methods that optimally combine point measurements with satellite-derived spatial fields, producing best estimates that leverage the complementary strengths of both data sources.

ID	EUSPA-EO-UR-CLIMA-0006
Operational scenario	Water Pollution Monitoring from Industrial and Agricultural Runoff
Users	Environmental protection agencies, water quality regulators, river basin authorities, industrial facility compliance officers, agricultural extension services, environmental consulting firms, public health authorities (HAB monitoring), fishing and aquaculture operators.
Description	Detecting and monitoring water quality degradation from industrial point sources and agricultural diffuse pollution using Earth Observation to support regulatory compliance, ecosystem health assessment, and early warning systems.
Size of area of interest	Agricultural basins 10–100 km ²
Frequency of information needed	<24 hours for acute pollution events; 3–7 days acceptable for routine monitoring
Type of service (continuous, forecasting, one-off?)	Continuous.
Satellite EO Data Requirements	

Spatial resolution	10–30 m for industrial plume detection and large-scale nutrient mapping; 5 m for agricultural pollution source attribution and riparian buffer monitoring.
Temporal resolution	Sub-Weekly.
Spectral resolution	Sentinel-2 (optical VIS-NIR) and Sentinel-3 (Ocean Colour)
Data supplements	• Copernicus Land Monitoring Service. • DEM. • commercial VHR optical (1–5 m). • agricultural land use intensity. • impervious surfaces. • riparian buffer zones. • hydrological connectivity (surface water network, drainage pathways). • pollution source maps (industrial facilities, wastewater treatment plants).

Table 15: User needs and requirements - Water Pollution Monitoring from Industrial and Agricultural Runoff

Case Study / User Story	
EOMAP, a German SME recently acquired by FUGRO based in Munich and leading provider in aquatic Earth Observation, has pioneered operational water quality monitoring services through its cloud-based platform eoapp AQUA, which delivers the motto "Water quality at your fingertips." The company, which grew from an ESA Business Incubation Centre startup to win multiple awards including the 2023 EUSPA CASSINI Maritime Prize and recognition as a top-3 finalist for the German Innovation Prize 2025, serves authorities and industry worldwide with physics-based water quality analytics powered by satellite data. The eoapp AQUA platform, developed in collaboration with major industry partners including Xylem and Fugro who helped shape the application based on real customer needs. "The new app offers a pro-active approach to water management. Clients can, for example, detect potentially harmful algae blooms, and take early actions or inform the public," explains Karin Schenk, Head of Water Quality at EOMAP. The platform represents EOMAP's third online solution following SDB-Online for hydrographic applications and HYPOS for hydropower stakeholders, all sharing the common goal of providing decision support through fast and simple access to satellite-based information. The operational workflow begins when users define their area of interest, select water quality parameters of concern including chlorophyll-a concentration indicating algae abundance, turbidity showing particle concentrations, and total suspended matter affecting light penetration and habitat quality, choose their observation period and temporal resolution, and specify satellite data sources from a range including Copernicus Sentinel-2 and Sentinel-3 providing free global coverage, and commercial high-resolution missions like Planet SuperDoves enabling finer spatial detail where needed. The system then automatically processes data using standardized, physics-based algorithms that have been validated across diverse water types globally, generating water quality maps delivered through an intuitive web interface within 3 to 12 hours after satellite data acquisition. A long-term analysis tool enables users to examine up to 40 years of historical satellite records, revealing trends and patterns that inform understanding of how water bodies respond to climate variability, land use changes, and management interventions. The monitoring feature tracks both current status and recent developments, automatically flagging changes that may indicate emerging problems like algal	

bloom initiation or pollution discharge events. An alert function based on user-defined thresholds sends notifications when water quality parameters exceed critical values, enabling rapid response before conditions deteriorate to levels threatening public health or aquatic ecosystems.

A critical feature for operational adoption is the ability to integrate satellite-derived water quality data with in-situ measurements from conventional monitoring programs. Once uploaded to eoapp AQUA, in-situ observations are incorporated into analyses, enabling users to validate satellite retrievals, calibrate algorithms for their specific water bodies, and fill temporal gaps between satellite overpasses with continuous sensor measurements. This integration addresses a fundamental requirement identified across user consultations: operational water management demands fusion of complementary data sources rather than reliance on any single observation type.

User feedback and operational adoption demonstrate the platform's success in meeting real operational needs. Authorities across Europe use eoapp AQUA for bathing water monitoring, with case examples including the Mecklenburgische Seenplatte lake district in northern Germany where the system provides comprehensive chlorophyll-a status across a large region with many water bodies, and the Massower See reservoir where time series show how chlorophyll-a developed through summer 2022, enabling retrospective analysis of bloom dynamics and planning of prevention strategies for future seasons. In Africa, the system monitors large drinking water reservoirs, providing baseline assessments and ongoing surveillance that informs treatment operations and water allocation decisions in regions where field monitoring capacity is limited. The platform has expanded to serve coastal and inland waters worldwide, with users spanning developed countries with mature monitoring programs seeking to enhance cost-effectiveness and spatial coverage and developing regions where satellite-based approaches provide water quality information that would otherwise be unavailable due to limited in-situ infrastructure.

Table 16: Case study - Water Pollution Monitoring from Industrial and Agricultural Runoff

2.4.7 EO 7 - Habitat Robustness: Monitoring for Biodiversity Change

Meeting the ambitions of the EU Biodiversity Strategy 2030 and the Nature Restoration Law requires a consistent, decision-grade view of how habitats are changing, where they are being lost or fragmented, where condition is improving or degrading, and how well ecological networks are functioning across landscapes and protected areas. Habitat Robustness – Monitoring for Biodiversity Change provides that view. It combines Copernicus observations with in-situ evidence and administrative datasets to produce comparable, policy-ready indicators of habitat extent, condition and connectivity across Natura 2000 sites, protected landscapes and surrounding matrices, making trends visible early enough to guide restoration, enforcement and spatial planning. The service is offered by specialized environmental monitoring providers and research consortia, targeting national and regional environmental agencies, protected-area managers, conservation NGOs and observatories (including EuropaBON partners), land managers (farmers, foresters, wetland custodians), river-basin authorities, and public bodies responsible for reporting under EU and global frameworks, including the Kunming–Montreal Global Biodiversity Framework. Explicit documentation of data provenance and processing ensures that outputs are reproducible and auditable, meeting the accountability requirements of policy and regulatory reporting.

Operationally, the service addresses four recurring management problems: (i) habitat fragmentation and loss (e.g., conversion of semi-natural grassland, heathland or wetlands into crops or urban land); (ii) degradation of wetlands, riparian zones and coastal habitats; (iii) expansion or intensification of agriculture and forestry into high-value habitats and corridors; and (iv) systematic monitoring of the condition and connectivity of Natura 2000 and other protected areas, including early detection of pressures such as drainage, encroachment and infrastructure. Each problem is expressed as a measurable question, where, how fast and with what ecological consequences, so that the outputs can be traced to specific interventions (designation, restoration, buffer expansion, or enforcement). The auditable workflow ensures that each output can be linked back to source datasets, processing steps, and decision-making context, supporting transparency for authorities and stakeholders.

The measurement stack draws first on Sentinel-2 MSI (10–20 m) to derive land-cover/habitat maps, vegetation indices (NDVI, EVI), phenology and productivity/stress indicators; Sentinel-1 C-band SAR (10 m) adds all-weather sensitivity to vegetation structure, surface moisture and inundation, crucial for floodplains, wetlands and riparian corridors; and Sentinel-3 products provide regional context on productivity and surface temperature to interpret local dynamics. These data are complemented by Copernicus Land Monitoring Service (CLMS) products: long-term change from CLC and global layers, and High-Resolution Layers (HRLs) (Forest, Grassland, Wetness & Water, Imperviousness, Cropland, etc.) that expose pressures and habitat attributes at 10 m. In many deployments, S1+S2 fusion and HRL evolution underpin robust habitat mapping and change detection, including for riparian and coastal zones.

Non-space inputs improve credibility and local relevance. In situ habitat and species datasets from national schemes and research plots, field-based condition assessments (e.g., structure, grazing intensity, invasive species), and UAV/LiDAR for fine-scale features (hedgerows, micro-wetlands) provide calibration and validation. Administrative and planning layers, Natura 2000 boundaries, other designations, zoning, restoration projects, allow outputs to be interpreted directly in the policy context. Framing indicators within the Essential Biodiversity Variables (EBVs) architecture increases comparability and scientific uptake, while aligning the service with ongoing European efforts to standardise biodiversity monitoring across data sources and geographies.

The processing workflow is reproducible and auditable. First, multi-temporal S2 and S1 scenes are ingested and pre-processed (radiometric/BRDF corrections, speckle filtering, co-registration), then composited to mitigate cloud and seasonality effects. Supervised and hybrid ML approaches, implemented in standard GIS/EO toolchains (e.g., ArcGIS, QGIS) and Python/R environments, generate land-cover/habitat classes and condition metrics; network and landscape ecology methods quantify connectivity, fragmentation and edge effects. These outputs are validated against in situ/UAV references with documented accuracy metrics and then packaged into indicators and dashboards targeted to the relevant authority or site management unit. Auditable documentation of workflows, assumptions, and validation steps ensures that results can be independently reviewed, supporting trust and accountability for policy and regulatory decisions.

Data flows to environmental agencies, conservation organisations, researchers, land managers, and policy makers are structured to match their operational and strategic decision cycles: near-real-time to monthly delivery supports rapid response to abrupt pressures such as drainage, clear-cutting, flooding, or fire, enabled by the S2/S1 revisit schedule and cloud-free compositing; seasonal updates address phenology-driven habitats like grasslands, wetlands, and floodplains, informing management actions and seasonal planning; and annual to multi-annual trend analyses provide robust insights into habitat condition, fragmentation, and restoration progress, supporting policy reporting, long-term monitoring, and evaluation of conservation interventions. This ensures that each user group receives actionable information at the cadence they require to make timely and evidence-based decisions.

The core of the application's impact lies in its KPIs, which provide actionable insights for diverse stakeholders. Net habitats gain or loss and conversion rates by class give environmental agencies and policymakers direct measures of land-use change, informing restoration and conservation strategies. Fragmentation metrics such as mean patch size, edge density, and corridor integrity enable protected-area managers and conservation NGOs to assess ecological connectivity and prioritize corridor protection. The proportion of Natura 2000 and other protected sites with up-to-date condition assessments supports reporting bodies and national authorities in fulfilling obligations under EU legislation and global frameworks. Wetland extent, inundation dynamics, and riparian continuity KPIs guide river-basin authorities and land managers in identifying hydrological pressures and making informed decisions on floodplain management and restoration.

Phenological anomalies and productivity deviations allow researchers and seasonal managers to adapt conservation strategies and detect early ecosystem stress. Finally, detection lead-time for new pressures, aiming for weeks rather than seasons, empowers rapid-response teams and on-the-ground managers to address threats such as encroachment, drainage, or fire promptly. Where relevant, vegetation phenology

and productivity metrics are derived from CLMS, ensuring consistent EU-wide comparisons and minimizing methodological differences across member states.

Adoption is accelerating but uneven. CLMS launched Protected Areas coverage for all 24,298 Natura 2000 sites in 2024, yet uptake lags due to limited agency/NGO capacity in GIS/ML for S1/S2 fusion and workflow silos blocking API integration.¹

Addressing these limitations is crucial for generating policy-grade indicators. Formulating indicators in alignment with Essential Biodiversity Variables (EBVs), clearly documenting sources of uncertainty, and sustaining investment in validation networks and reference datasets can increase confidence and usability. Continued development and adaptation of CLMS products, such as high-resolution land cover layers tuned to habitat condition and corridor continuity, would directly support EU reporting obligations. By embedding these improvements into operational workflows, CLMS can reduce the technical and financial burden on smaller authorities, increase interoperability across national systems, and enable more timely, robust monitoring of habitat change and ecological pressures.

ID	EUSPA-EO-UR-CLIMA-0007
Operational scenario	Habitat Robustness - Monitoring for Biodiversity Change
Users	National and regional environmental agencies, park and protected-area managers, conservation NGOs and biodiversity observatories (e.g. EuropaBON partners), land managers (farmers, foresters, wetland managers) and river-basin authorities, policy makers and reporting authorities for EU Biodiversity Strategy 2030, Nature Restoration Law and the Kunming–Montreal Global Biodiversity Framework.
Description	Habitat fragmentation and loss (e.g. conversion of semi-natural grassland, heathland, wetlands to agriculture or urban land). Degradation of wetlands, riparian zones and coastal habitats. Expansion or intensification of agricultural and forestry activities into high-value habitats or ecological corridors. Monitoring the condition and connectivity of Natura 2000 sites and other protected areas, including early detection of pressures (drainage, encroachment, infrastructure).
What (space and non-space) data is used by the application	Space inputs: Sentinel-2 MSI (optical, 10–20 m): Multispectral time series in visible, NIR and SWIR used to derive land-cover/habitat maps, vegetation indices (NDVI, EVI), phenology metrics, and indicators of productivity and stress. Sentinel-1 SAR (C-band, 10 m): Provides all-weather information on vegetation structure, surface moisture and inundation, crucial for wetlands, riparian zones and floodplains. Copernicus projects and CLMS use S1+S2 fusion for habitat mapping and change detection. Sentinel-3 OLCI/SLSTR (300 m–1 km): Regional indicators of productivity, phenology and surface temperature to contextualise local habitat changes and climate drivers.

¹ <https://land.copernicus.eu/en/news/the-clms-contract-for-the-protected-areas-product-has-kicked-off>

	Copernicus Land Monitoring Service (CLMS) products: Corine Land Cover (CLC) and CGLS / WorldCover-type global land-cover layers to track long-term land-cover change and major habitat conversions; High Resolution Layers (HRLs) (Forest, Grassland, Wetness & Water, Imperviousness, Cropland, etc.) providing 10 m EU-wide information on key habitat characteristics and pressures. Non-space inputs: In situ habitat and species data from national monitoring schemes, protected-area inventories and research plots. Field-based habitat condition assessments (e.g. vegetation structure, grazing intensity, invasive species) used to calibrate and validate Copernicus-derived indicators. Drone (UAV) imagery and LiDAR for high-resolution mapping of fine-scale habitat features (micro-habitats, hedgerows, small wetlands). Administrative and planning data: Natura 2000 boundaries, protected-area designations, zoning and land-use plans, restoration projects.
How the data is processed or analysed	software programmes (ArcGIS, QGIS), coding programmes (python, R2), data storage programmes, processing technologies (radiometric correction), machine learning for pattern recognition, commercial machine learning or in-house machine learning technologies etc. The use of Essential Biodiversity Variables (EBVs) frameworks promotes consistency and comparability in monitoring outputs critical for scientific and policy uptake.
To whom the data is transmitted	Environmental agencies, conservation organizations, researchers, land managers, and policy makers.
When data is processed and/or transmitted	Near-real-time to monthly for detecting abrupt or short-term changes (drainage, clear-cutting, flooding, fire), enabled by the 5-day S2 and 6-day S1 revisit plus cloud-free compositing. eSeasonal monitoring to capture phenological changes, productivity and seasonal habitat dynamics (grasslands, wetlands, floodplains). Annual to multi-annual trend analysis to assess habitat robustness, long-term fragmentation and progress against restoration targets.
For what purpose data is processed and/or transmitted	Assess the condition, extent and robustness of habitats and ecological networks over time, including Natura 2000 and other protected sites. Support strategic spatial planning for protected-area designation, ecological corridors and green infrastructure. Underpin reporting and policy evaluation for the EU Biodiversity Strategy 2030, Nature Restoration Law, Birds and Habitats Directives, and Kunming–Montreal Global Biodiversity Framework. Provide evidence for restoration and management decisions (e.g. where to restore wetlands, reconnect riparian corridors, or reduce fragmentation).
List of identified user needs	See below

Table 17: User needs and requirements - Habitat Robustness - Monitoring for Biodiversity Change

Case Study / User Story
The Copernicus for Natura 2000 (COP4N2K) project developed the EU Grassland Watch service to support monitoring and management of grassland-dominated Natura 2000 protected sites across the EU using Copernicus Earth Observation data. It combines long time-series optical (Sentinel-2, Landsat) and SAR (Sentinel-1) imagery with reference datasets (e.g., CLMS N2K, CORINE) to produce annual land-cover/land-use maps and habitat change indicators that reveal status and trends in grassland extent, quality, and dynamics. The results are made accessible through a user-friendly webtool for site managers, authorities, and the public, helping track conservation status, detect degradation or improvement, and inform policy and management decisions at site, national, and EU scales. The prototype is being upgraded to a fully operational service with broader coverage, richer thematic detail, and stronger stakeholder engagement.²

Table 18: Case study - Habitat Robustness - Monitoring for Biodiversity Change

2.4.8 GNSS 1 - GNSS-Based Climate Modelling

Rising seas and increasingly energetic coastal conditions demand measurements that are both absolutely referenced and operationally actionable. This application uses multi-constellation GNSS, enhanced by Galileo, on surface buoys and at coastal reference stations to generate precise sea-surface height, vertical land motion, and wave parameters that close critical gaps in climate monitoring, satellite altimetry calibration/validation, and coastal risk management. In practical terms, it complements and strengthens satellite altimetry and tide-gauge records by delivering high-frequency, geodetically consistent observations at and near the shoreline, where societal exposure is highest.

The primary users span the scientific and operational continuum: oceanographers and climate scientists (including altimetry cal/val³ teams and sea-level research groups), national hydrographic and oceanographic agencies, tide-gauge operators and coastal authorities, research institutions running GNSS sea-level experiments, and coastal engineers and infrastructure planners responsible for ports, offshore platforms, and flood defences. International coordination bodies and climate reporting communities also benefit as these observations contribute to long-term sea-level budgets and uncertainty reduction for policy-relevant assessments.

Buoy operators (e.g., research institutions like NOC or Ifremer) deploy multi-constellation receivers on buoys, quality-screen raw data, and compute sea-surface height (SSH) plus wave parameters (Hs, Tp) by detrending trajectories. Tide-gauge agencies (e.g., national hydro services) co-locate GNSS for land motion, applying corrections to relative sea-level records.

The application directly addresses user needs by producing precise sea-level trends (ocean change decoupled from land motion), verifying satellite-derived sea-surface height stability, capturing near-shore dynamics unresolved by wide-swath altimetry alone, and characterising waves and extremes that drive design criteria.

The system supports:

- 1) long-term monitoring of absolute sea-level change at coastal and open-ocean sites;

² <https://cop4n2k.eu/>

³ Cal/Val stands for Calibration/Validation – the essential process in satellite remote sensing to ensure data accuracy. Calibration adjusts raw sensor measurements against known reference standards (like GNSS buoys or tide gauges) to correct systematic biases. Validation independently verifies that the calibrated products accurately reflect real-world conditions through cross-checks with ground truth data.

<https://os.copernicus.org/articles/19/1277/2023/>

- 2) calibration/validation of satellite altimeters (e.g., Jason series, Sentinel-3 and related missions) using GNSS buoys deployed on or close to ground tracks;
- 3) monitoring of vertical land motion at tide-gauge sites via co-located GNSS, allowing separation of subsidence/uplift from oceanic signals;
- 4) high-frequency wave and sea-surface variability sensing through kinematic GNSS at ≥ 1 Hz; and
- 5) inputs to coastal engineering, hazard assessment and management (storm surge, flooding, subsidence hotspots).

Where Sentinel-6 altimetry provides the global climate backbone for sea-surface height, GNSS buoys supply independent, traceable references at selected sites to test stability and drift, especially in the coastal zone where retracking and geophysical corrections are most challenging.

On-buoy receivers track multi-constellation GNSS (Galileo, GPS, others) and compute precise kinematic positions, typically using PPP or tightly constrained solutions, to estimate sea-surface height and derive wave parameters by removing the mean sea level. Co-located coastal GNSS stations at tide gauges contribute vertical land motion estimates critical for converting relative tide-gauge records to absolute sea-level trends.

HAS is not relevant in this context, as this application requires centimetre to sub-centimetre accuracy levels. OSNMA has limited applicability because environmental and scientific applications typically operate in low-threat environments, where intentional jamming or spoofing is uncommon, and data are primarily used for monitoring and analysis rather than safety-critical operations. While these services may enhance robustness against unintentional interference and support more autonomous deployments in the future, they are not currently a key driver of demand in climate, environmental, and biodiversity monitoring applications.

For climate monitoring, absolute sea-level trends are measured with corrections for local land movement and reliability metrics are provided. For hazards and coastal engineering, significant wave heights, wave patterns, extreme events, and combined storm-surge risks are assessed, alongside site-specific vertical land motion to inform design standards. Performance is evaluated through real-time accuracy, data stability, system uptime, comparison with Sentinel-6 and Sentinel-3, and latency to operational dashboards. For wide-area context and independent comparison, the system incorporates satellite altimetry (Jason, Sentinel-3, Sentinel-6), while met-ocean sensors and models (pressure, winds, currents, density) supply dynamic corrections. Reference-frame consistency and geophysical models (tides, loading) ensure compatibility across instruments and platforms, supporting reliable, high-accuracy measurements for environmental monitoring and engineering applications.

The workflow begins with robust receiver configuration, antenna calibration and buoy attitude characterisation (often with IMUs for sensor fusion). Raw observables are quality-screened, cycle slips repaired, and precise orbits/clocks applied. Multi-constellation PPP solutions yield buoy trajectories from which sea-surface height and wave metrics (e.g., significant wave height, peak period) are extracted; extreme events are flagged through thresholding and spectral diagnostics. At tide-gauge sites, continuous GNSS time series are analysed for vertical land motion, and corresponding corrections are applied to gauge records. For cal/val, buoy data are collocated temporally/spatially with overpasses on altimeter ground tracks, and differences are analysed to quantify biases, drifts and coastal performance. All steps are versioned, with uncertainty budgets reported to users alongside the core products.

Telemetry supports real-time streams for situational awareness and hazard response (e.g., storm surge, extreme waves), while periodic reprocessing produces stable, long-term time series for climate assessment and reporting. Data are disseminated to research institutions, oceanographic agencies, policy makers and international climate monitoring networks through standard formats and APIs aligned with community practices.

GNSS buoys are already used in multiple cal/val and feasibility campaigns, demonstrating tide-gauge-like precision and unique flexibility, deployment directly on ground tracks and in energetic coastal zones. Remaining challenges include power and endurance for long deployments; mooring stability in

high-energy seas; rigorous, standardised uncertainty reporting⁴; and harmonised reference-frame management across GNSS, altimetry and tide-gauge networks.

GNSS Requirements		
ID	EUSPA-GN-UR-ENV-0201	
Application	GNSS-Based Climate Modelling	
Accuracy	Horizontal	Metre-level
	Vertical	Instantaneous SSH / buoy height: ~cm-level precision (a few centimetres) from kinematic PPP or differential processing, consistent with GNSS buoy cal/val results. Long-term vertical trends (VLM): stability on the order of ≤ 0.5 mm/yr, ideally approaching 0.2–0.3 mm/yr, to match climate-quality sea-level trend requirements. Hydrographic data providers need only 1 to 2-metre accuracy for standardised climate monitoring.
Availability	Urban canyon	Not applicable
	Natural canyon	Not applicable
	Canopy	Not applicable
	Indoor	Not applicable
	Better than 95%	Yes
	Better than 99%	Yes
Robustness		High - receivers must maintain performance under temperature extremes, vibrations and motion, and in the presence of multipath from waves and structures. Robust performance in high sea states is critical (SWH limits depend on buoy design).
Integrity and reliability		Medium - stable, well-characterised error budgets; clear integrity flags and quality indicators (number of satellites, PDOP, HAS status, OSNMA status) should be available to data centres and climate services. Detection of gross errors or GNSS anomalies would be a plus.
Size, weight, autonomy	Relevance	Yes – receivers and antennas must be compact, low-power and marine-grade to integrate into small buoys or shared payloads.

⁴ Standardised uncertainty reporting quantifies data reliability consistently using GUM/ISO 5725 standards for error propagation, enabling dataset comparability and regulatory compliance (CSRD, Article 6 DMRV).

https://www.iso.org/sites/JCGM/GUM/JCGM100/C045315e-html/C045315e_FILES/MAIN_C045315e/07_e.html

	Time a device can run	Months to years of operation on buoy power systems, with minimal maintenance
TTFaF	In hot start	For stationary buoys and long-term monitoring, initial TTFaF of a few minutes is acceptable; what matters more is rapid reconvergence (for PPP / HAS) after outages and continuous tracking thereafter.
Service area	Geographical coverage	Oceans and coastal areas

Table 19: User needs and requirements - GNSS-Galileo Enhanced Marine Buoy Modelling for Climate Monitoring

Case Study / User Story
A study presents a new cal/val site in the Nouméa lagoon (New Caledonia) to improve the accuracy of satellite altimetry measurements of SSH in coastal regions, where local sea level dynamics and signal contamination can introduce significant errors. Researchers deployed in-situ instruments, including a GNSS-equipped buoy and tide gauges, and developed a method to link tide-gauge data with altimeter tracks from Jason and Sentinel-3 satellites. By comparing these measurements, they derived absolute altimeter bias time series and assessed long-term sea level trends with centimetre-level precision. The results highlight the value of integrated in-situ and satellite observations for reducing uncertainties in coastal sea level estimates and supporting future wide-swath altimetry missions.⁵

Table 20: Case study - GNSS-Galileo Enhanced Marine Buoy Modelling for Climate Monitoring

⁵ <https://os.copernicus.org/articles/19/1277/2023/>

2.5 User Requirements Specifications

ID	Description	Type	Source
EUSPA-GN-UR-ENV-020101	The PNT solution shall provide horizontal positioning accuracy at the metre level. The PNT solution shall provide vertical positioning accuracy commensurate with the intended use case: For instantaneous sea surface height or buoy height estimation, the vertical accuracy shall be at the centimetre level (on the order of a few centimetres), achievable through kinematic PPP or differential GNSS processing. For long-term vertical land motion monitoring, the solution shall ensure vertical stability on the order of ≤ 0.5 mm/year, ideally approaching 0.2–0.3 mm/year, in line with climate-quality sea-level trend requirements. For standardised climate monitoring applications, hydrographic data providers shall be supported with vertical accuracy on the order of 1–2 metres.	Performance	[RD50]
EUSPA-GN-UR-ENV-020102	The availability of the location information provided by the PNT solution fulfilling its performance requirements shall be High	Performance	[RD50]
EUSPA-GN-UR-ENV-020103	The PNT solution shall provide robustness against temperature extremes, vibrations, and dynamic motion, and shall maintain performance in the presence of multipath effects caused by waves and surrounding structures. The PNT solution shall maintain robust performance in high sea states, with supported significant wave height limits dependent on buoy design.	Functional	[RD50]
EUSPA-GN-UR-ENV-020104	The PNT solution shall provide a stable and well-characterised error budget.	Functional	[RD50]

ID	Description	Type	Source
	The PNT solution shall provide clear integrity indicators and quality flags, including information such as the number of satellites, PDOP, HAS status, and OSNMA status, made available to data centres and climate services. The PNT solution shall support the detection of gross errors or GNSS anomalies.		
EUSPA-GN-UR-ENV-020105	The PNT solution shall be compact, low-power, and marine-grade, enabling integration into small buoys or shared payload configurations.	Feature	[RD50]
EUSPA-GN-UR-ENV-020106	The PNT solution shall support an initial Time to First Fix and Time to First Ambiguity Fix on the order of a few minutes under hot-start conditions for stationary buoys and long-term monitoring applications. The PNT solution shall prioritise rapid reconvergence following signal outages, particularly for PPP or HAS-based positioning, and shall support continuous tracking thereafter.	Performance	[RD50]

Table 21: Synthesis of Requirements Relevant to GNSS

ID	Application	Abstract of the Need & Requirement	Size of the area of interest	Frequency of information needed	Spatial resolution	Temporal resolution	Type of EO data
EUSPA-EO-UR-CLIMA-0001	EO-Based Validation of Biodiversity Credits	Purchase of nature credits by large companies to finance the improvement of biodiversity for specific areas. Those nature projects need to be	10Ha to 10000Ha areas.	Yearly verification during the entire lifetime of the project.	1m (for small projects) to 10m (for whole ecosystems)	Monthly.	Visible imagery for habitat classification, tree identification, etc. NDVI to assess

ID	Application	Abstract of the Need & Requirement	Size of the area of interest	Frequency of information needed	Spatial resolution	Temporal resolution	Type of EO data
		monitored and validated thoroughly.					the change in vegetation. Hyperspectral imagery for tree species Identification, etc. SAR to measure canopy height, etc.
EUSPA-EO-UR-CLIMA-0002	Carbon Stock Change Detection in Peatlands for Climate Accounting	Yearly assessment of peatland restoration programme aiming at analysing the amount of carbon stored or released.	Areas ranging from 10Ha to 100000Ha.	Yearly assessment since peatland are subject to seasonal effects (the peat bog).	1m-10m.	Monthly.	InSAR to map peatland condition and to detect rapid hydrological response to restoration. SAR for the physical properties of the surface. Optical satellites (Sentinel-2) to provide vegetation index (NDVI). Normalized

ID	Application	Abstract of the Need & Requirement	Size of the area of interest	Frequency of information needed	Spatial resolution	Temporal resolution	Type of EO data
							Difference Water Index (NDWI) for moisture content of vegetation and soil. Thermal sensors for Land Surface Temperature (LST).
EUSPA-EO-UR-CLIMA-0003	Flood-Induced and Retention Wetland Dynamics	Monitor temporal expansion/contraction of wetlands for flood regulation, GHG modelling, and restoration verification. Integrate vegetation type, water permanence, and carbon storage indicators.	Restoration projects >100 ha; National inventories (basin to country scale)	Monthly composites for annual maps; Weekly during flood season for active restoration monitoring	10 m (Sentinel-1/2). 3–5 m for small wetlands (<1 ha detection)	Monthly composites. Bi-weekly during flood season; Weekly for restoration monitoring	Multi-temporal SAR (C-band: Sentinel-1; L-band: ALOS PALSAR); Optical (Sentinel-2: NDVI, NDWI); Altimetry (Sentinel-3, SWOT) for water levels >1 km ² ; DEM for topographic context
EUSPA-EO-UR-CLIMA-0004	Monitoring Reservoir Water Levels,	Track seasonal storage changes, sediment accumulation, and	Reservoirs >10 ha; Regional	Weekly to bi-weekly. Daily for operational	10 m for large reservoirs. ~1 m for narrow rivers	2–5 days (cloud-dependent). Daily for	Optical (Sentinel-2) for surface area;

ID	Application	Abstract of the Need & Requirement	Size of the area of interest	Frequency of information needed	Spatial resolution	Temporal resolution	Type of EO data
	Sedimentation, and Evaporation Loss	evaporation losses to ensure sustainable water availability. Provide bathymetry (± 30 cm accuracy) and integrated optical + SAR + altimetry products.	water supply systems	drought monitoring.	(<10 m width) and detailed bathymetry.	drought/snow monitoring	Altimetry (Sentinel-3) for water levels; Surface temperature (Sentinel-3) for evaporation; SAR for all-weather monitoring; Commercial VHR (1–3 m) for bathymetry
EUSPA-EO-UR-CLIMA-0005	Monitoring Urban Flash Flood Risk via Impervious Surface Expansion	Track impervious surface growth to update flash flood susceptibility models and inform infrastructure planning.	Urban areas >50k inhabitants; Municipal drainage basins	Bi-annual to annual. Quarterly for fast-growing areas	10 m (Sentinel-2). 1–3 m for detailed urban land cover DEM: 30 m (Copernicus), 1–2 m LiDAR for hydrological modeling	Quarterly for fast-growing areas; Bi-annual minimum for stable areas	Optical (Sentinel-2, commercial VHR) for impervious surface mapping; High-resolution DEM (1–2 m LiDAR) for flow routing; Copernicus Urban Atlas for reference data

ID	Application	Abstract of the Need & Requirement	Size of the area of interest	Frequency of information needed	Spatial resolution	Temporal resolution	Type of EO data
EUSPA-EO-UR-CLIMA-0006	Water Pollution Monitoring from Industrial and Agricultural Runoff	Detect eutrophication zones and pollution hotspots in inland and coastal waters. Provide 5 m resolution, bi-weekly revisit, and integration with in-situ networks for validation.	Agricultural basins 10–100 km ² ; Industrial discharge zones	Monthly during growing season. Daily for illegal discharge detection; Weekly for operational surveillance	10–30 m for large-scale mapping. 5 m for agricultural pollution source attribution and riparian buffer monitoring	5 days (Sentinel-2). Daily for acute events; Weekly for routine monitoring	Optical multispectral (Sentinel-2, Sentinel-3) for water quality parameters (Chl-a, turbidity, TSM); Commercial VHR (1–5 m) for detailed plume tracking; Land cover data for pollution source identification
EUSPA-EO-UR-CLIMA-0007	Habitat Robustness: Monitoring for Biodiversity Change	Monitoring the condition and connectivity of Natura 2000 sites and other protected areas, including early detection of pressures by environmental agencies, conservation organisations, researchers, land managers, and policy makers.	From 10ha to national scale areas.	Weekly to monthly for early warning and condition changes in dynamic systems.	10m.	Weekly or more frequently if needed (during key phenological periods).	Copernicus EO (Sentinel 1/2/3, CLMS products).

Table 22: Synthesis of Requirements Relevant to EO

3 ANNEX

A.1 Definition of key EO performance parameters

This annex provides a definition of the most used EO performance parameters and includes additional details which are relevant for Climate, Biodiversity & Environment community.

Spatial resolution refers to the level of detail and clarity in the images, specifically the size of the smallest discernible ground features. It is determined by the pixel size, which is the smallest unit in the image that represents a spatial area on the Earth's surface. Spatial resolution is usually measured in terms of meters per pixel. Thus, a spatial resolution of 1 meter means that each pixel represents a 1 by 1 meter area on the ground.

Spectral resolution refers to the ability of a sensor to differentiate electromagnetic radiation of different wavelengths. In other words, it refers to the number and “size” of wavelength intervals that the sensor is able to measure. The finer the spectral resolution, the narrower the wavelength range for a particular channel or band. In remote sensing, features (e.g. water, vegetation) can be characterised by comparing their “response” in different spectral bands.

Radiometric resolution expresses the sensitivity of the sensor, that is to say its ability to differentiate between different magnitudes of the electromagnetic energy. The finer the radiometric resolution, the more sensitive it is to small differences in the energy emitted or reflected by an object. The radiometric resolution is generally expressed in bit, e.g. an 8-bit image has a scale of $2^8=256$ nuances.

Temporal resolution relates to the time elapsed between two consecutive observations of the same area on the ground. The higher the temporal resolution, the shorter the time between the acquisitions of two consecutive observations of the same area. In absolute terms, the temporal resolution of a remote sensing system corresponds to the time elapsed between two consecutive passes of the satellite over the exact same point on the ground (generally referred to as “revisit time” or “orbit cycle”). However, several parameters like the overlap between the swaths of adjacent passes, the agility of the satellites and in case of a constellation, the number of satellites mean that some areas of the Earth can be reimaged more frequently. For a given system, the temporal resolution can therefore be better than the revisit time of the satellite(s).

Geolocation accuracy refers to the ability of an EO remote sensing platform to assign an accurate geographic position on the ground to the features captured in a scene. An accurate geolocation makes easier the combination of several images (e.g. combination of a Synthetic Aperture Radar image with a cadastral map and a vegetation map).

Spectral range refers to the wavelength range of a particular channel or band over in which remote sensing data must be collected.

Latency is the difference between the reference time of the satellite measurement and the time the final product is made available to the user (here the service provider).

A.2 Additional EO definitions

Ground deformation monitoring is the process which consists in tracking the vertical and horizontal movements of the land surface and their dynamics, whatever these movements are caused by natural phenomena (e.g. volcanic activity) or by human activities (e.g. aquifer exploitation).

Change detection is the process which aims at identifying difference in the state of “objects” (e.g. bridges, constructions, urban areas) or of a phenomenon (e.g. deforestation, soil sealing) by comparing snapshots of the situation at different times. In Earth Observation, change detection is extensively based on satellite imagery obtained through a wide variety of sensors (e.g. optical, radar, infrared, microwave, etc).

Geodesy (see [RD3]) is the earth science of accurately measuring and understanding three of Earth's fundamental properties: its geometric shape, orientation in space, and gravitational field. The field also studies of how these properties change over time. Today, geodesy goes beyond that, being the geoscience that deals among other with the monitoring the solid Earth (which includes the monitoring of displacement, subsidence or deformation of the ground and structures due to tectonic, volcanic, and other natural phenomena as well as human activity).

Interferometric Synthetic Aperture Radar (InSAR) is a technique enabling to generate surface deformation maps based on the processing of SAR images captured at different moments in time. The processing uses the fact that if the ground has moved between the times of two SAR images of the same area, a slightly different portion of the wavelength is reflected to the satellite resulting in a measurable phase shift that is proportional to displacement. The processing therefore consists in obtaining information about the vertical movements of the ground surface by calculating the phase difference between the emitted radar signal and the signal backscattered by the surface for successive images. InSAR can potentially measure deformations of millimetre-scale during periods ranging from days to years.

Near-Real-Time (NRT) refers, when used in the context of EO applications, to applications/services/products for which the time delay between the occurrence of a given event and the availability of the outcomes of the processing of the Earth observation data corresponding to that event is considered as being not significant from a user perspective. The notion of "near real-time" is therefore depending on user requirements. For Earth observation, the corresponding time delays may range from a few hours to a few days depending on the application/service/product.

A.3 Definition of key GNSS performance parameters

This annex provides a definition of the most commonly used GNSS performance parameters, taken from Climate, Biodiversity, & Environment.

Availability: the percentage of time the position, navigation or timing solution can be computed by the user. Values vary greatly according to the specific application and services used but typically range from 95-99.9%. There are two classes of availability:

- System availability: the percentage of time the system allows the user to compute a position - this is what GNSS Interface Control Documents (ICDs) refer to.
- Overall availability: considers the receiver performance and the user's environment. Values vary greatly according to the specific use cases and services used.

Accuracy is the difference between true and computed solution (position or time). This is expressed as the value within which a specified proportion – usually 95% – of samples would fall if measured. This report refers to positioning accuracy using the following convention: centimetre-level: 0-10cm; decimetre level: 10-100cm; metre-level: 1-10 metres.

Continuity is the ability of a system to perform its function (deliver PNT services with the required performance levels) without interruption once the operation has started. It is usually expressed as the risk of discontinuity and depends entirely on the timeframe of the application. A typical value is around 1×10^{-4} over the course of the procedure where the system is in use.

Indoor penetration is the ability of a signal to penetrate inside buildings (e.g. through windows). Indoor penetration does not have an agreed or typical means for expression. In GNSS this parameter is dictated by the sensitivity of the receiver, whereas for other positioning technologies there are vastly different factors that determine performance (for example, availability of Wi-Fi base stations for Wi-Fi-based positioning).

Integrity is a term used to express the ability of the system to provide warnings to users when it should not be used. It is the probability of a user being exposed to an error larger than the alert limits without timely warning. The way integrity is ensured and assessed, and the means of delivering integrity-related information to users are highly application dependent. Throughout this report, the “integrity concept” is to be understood at large, i.e. not restricted to safety-critical or civil aviation definitions but also encompassing concepts of quality assurance/quality control as used in other applications and sectors.

Latency is the difference between the reference time of the solution and the time this solution is made available to the end user or application (i.e. including all delays). Latency is typically accounted for in a receiver but presents a potential problem for integration (fusion) of multiple positioning solutions, or for high dynamics mobile devices.

Robustness relates to spoofing and jamming and how the system can cope with these issues. It is a more qualitative than quantitative parameter and depends on the type of attack or interference the receiver is capable of mitigating. Robustness can be improved by authentication information and services.

Authentication gives a level of assurance that the data provided by a positioning system has been derived from real signals. Radio frequency spoofing may affect the positioning system, resulting in false data as output of the system itself.

Power consumption is the amount of power a device uses to provide a position. It will vary depending on the available signals and data. For example, GNSS chips will use more power when scanning to identify signals (cold start) than when computing a position. Typical values are in the order of tens of milliwatts (for smartphone chipsets).

Probability of false alarm refers to the likelihood of the receiver to indicate the presence of a signal when no signal is present.

Probability of detection refers to the likelihood of a receiver to detect the presence of a GNSS signal when a signal is indeed present.

Time To First Fix (TTFF) is a measure of time between activation of a receiver and the availability of a solution, including any power on self-test, acquisition of satellite signals and navigation data and computation of the solution. It mainly depends on data that the receiver has access to before activation: cold start (the receiver has no knowledge of the current situation and must thus systematically search for and identify signals before processing them – a process that can take up to several minutes.); warm start (the receiver has estimates of the current situation – typically taking tens of seconds) or hot start (the receiver understands the current situation – typically taking a few seconds).

Time To First accurate Fix (TTFaF) is a measure of a receiver's/solution's performance covering the time between activation and output of a position within the required accuracy bounds.

A.4 Other performance parameters

EO

Agility corresponds to the ability of a satellite to modify its attitude and to point rapidly in any direction to observe areas of interest outside its ground trace. High agility can improve the temporal resolution compared with the revisit time of the satellite.

Swath corresponds to width of the portion of the ground that the satellite “sees” at each pass. The larger the swath, the bigger the observed area at each pass.

Off-nadir angle corresponds to the angle at which images are acquired compared with the “nadir”, i.e. looking straight down at the target. In practice, objects located directly below the sensor only have their tops visible, thus making it impossible to represent the three-dimensional surface of the Earth. High resolution images are therefore generally not collected at nadir but at an angle. A large off-nadir angle enables a wider ground coverage at each pass and the identification of features not visible at nadir, but it reduces the spatial resolution. For optical imagery, typical off-nadir angles are in the range of 25-30 degrees.

Sun-elevation angle corresponds to the angle of the sun above the horizon at the time an image is collected. High elevation angles can lead to bright spots on the imagery while low elevation angles lead to darker images and longer shadows. The most appropriate angle depends on the type of application: a high sun elevation is appropriate for spectral analysis since the objects to be observed are well illuminated while a lower elevation angle is better suited to interpretation of surface morphology (e.g. the projected shadows can enable a better image interpretation).

GNSS

Size, weight, autonomy, and power consumption. Power consumption and size are not strictly GNSS performance parameters, however they are also considered in this analysis, especially for GIS and Mapping-related applications.

- **Autonomy.** Power consumption is the amount of power a device uses to provide a position. The power consumption of the positioning technology will vary depending on the available signals and data. For example, GNSS chips will use more power when scanning to identify signals (cold start) than when computing a position. Typical values are in the order of tens of Mw (for smartphone chipsets). GNSS is considered one of the heaviest drains on smartphones batteries
- **Size, weight.** Most GIS devices used by NGOs are handheld or rugged tablets/phones, which implies that they must remain small and lightweight.

Resiliency is the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions; including the ability to recover from deliberate attacks, accidents, or naturally occurring threats or incidents. A resilient system will change its way of operations while continuing to function under stress, while a robust (but non-resilient) system will reach a failure state at the end, without being able to recover.

Connectivity refers to the need for a communication and/or connectivity link of an application to be able to receive and communicate data to third parties. Connectivity relies on the integration with both satellite and terrestrial networks, such as 5G, LEO satellites, or LPWANs.

Interoperability refers to the characteristic of a product or system, whose interfaces are completely understood, to work with other products or systems, in either implementation or access, without any restrictions (e.g. ability of GNSS devices to be combined with other technologies and the possibility to merge the GNSS output with the output coming from different sources).

Traceability is the ability to relate a measurement to national or international standards using an unbroken chain of measurements, each of which has a stated uncertainty. For Finance applications,

knowledge of the traceability of the time signal to UTC is essential to ensure regulatory compliance of the timestamp.

A.5 List of Acronyms

Acronym	Definition
ACOLITE	Aquatic Colour processing of Landsat & Sentinel-2 (water-focused atmospheric correction toolkit).
AI	Artificial Intelligence.
ALOS	Advanced Land Observing Satellite (platform carrying PALSAR L-band SAR).
AQUA (eoapp AQUA)	EOMAP's cloud platform for satellite-based water-quality analytics.
BRDF	Bidirectional Reflectance Distribution Function (radiometric/illumination normalisation).
BY-SA	Creative Commons Attribution–ShareAlike licence indicator.
C3S	Copernicus Climate Change Service.
CAMS	Copernicus Atmosphere Monitoring Service.
CASSINI	EU space entrepreneurship/acceleration programme.
CC	Creative Commons (appears in image credit context).
CCM / CCMs	Copernicus Contributing Mission(s) (partner/commercial missions complementing Sentinels).
CEMS	Copernicus Emergency Management Service.
CGLS	Copernicus Global Land Service.
CLC	CORINE Land Cover (pan-EU land-cover maps within CLMS).
CLMS	Copernicus Land Monitoring Service.
CMEMS	Copernicus Marine Environment Monitoring Service.
COM	European Commission services (context: cover page to be agreed with COM).
CORINE	Coordination of Information on the Environment (basis of CLC).
CO2M	Copernicus Anthropogenic CO ₂ Monitoring mission.
CRCF	Carbon Removals Certification Framework
CRU	Carbon Removal Unit (credit unit used in nature/climate finance context).
CSR	Corporate Social Responsibility.
CSRD	Corporate Sustainability Reporting Directive (EU).
CSS	Copernicus Security Service.
DEM	Digital Elevation Model.
DHI	Danish Hydraulic Institute (water & environmental consultancy).
DMRV	Digital Monitoring, Reporting, and Verification

Acronym	Definition
DNA	Deoxyribonucleic Acid (appears within “eDNA”).
EBV / EBVs	Essential Biodiversity Variable(s) (indicator framework).
EEA	European Environment Agency (implements EU component of CLMS).
EGNOS	European Geostationary Navigation Overlay Service (SBAS).
EGNSS	European Global Navigation Satellite System (Galileo + EGNOS).
ENVISAT	ESA Earth-observing mission (heritage context).
EO	Earth Observation.
EOMAP	Aquatic Earth Observation company (Munich).
ER	Ecosystem Respiration (used in peatland carbon context).
ESA	European Space Agency.
EU	European Union.
EUDR	EU Deforestation Regulation.
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites.
EUSPA	European Union Agency for the Space Programme.
EVI	Enhanced Vegetation Index.
fAPAR	Fraction of Absorbed Photosynthetically Active Radiation
FDC	(FDC) Company referenced as partner/author in context.
GCF	Green Climate Fund.
GDP	Gross Domestic Product.
GEF	Global Environment Facility.
GFZ-TIGA	GFZ's TIGA GNSS tide-gauge network/project.
GHG	Greenhouse Gas.
GIS	Geographic Information System.
GNSS	Global Navigation Satellite System.
GOVSATCOM	EU secure satellite communications initiative.
GPP	Gross Primary Productivity (CLMS HR-VPP revamp).
GPR	Ground Penetrating Radar.
GSMC	Galileo Security Monitoring Centre.
HAS	High Accuracy Service (Galileo).
HRLs	High Resolution Layers (CLMS thematic 10 m layers).
HR-VLC	High-Resolution Vegetated Land-Cover characteristics (CLMS).

Acronym	Definition
HR-VPP / HR-VPP2	High-Resolution Vegetation Phenology & Productivity (revamp noted as HR-VPP2).
Hs	Significant wave height (wave metric).
HY-2A	Chinese ocean/altimetry mission (HY-2 series).
IFREMER	French Research Institute for Exploitation of the Sea.
IMU	Inertial Measurement Unit (buoy attitude/sensor fusion).
InSAR	Interferometric Synthetic Aperture Radar (surface deformation).
IoT	Internet of Things (in-situ sensor networks).
IPBES	Intergovernmental Science-Policy Platform on Biodiversity & Ecosystem Services.
IPCC	Intergovernmental Panel on Climate Change.
IOC-GLOSS	IOC Global Sea Level Observing System.
JASON-3	Ocean altimetry mission (Jason series; sea-level reference).
JNCC	Joint Nature Conservation Committee (UK).
KPI	Key Performance Indicator.
LiDAR	Light Detection and Ranging (laser scanning).
LAI	Leaf Area Index
LST	Land Surface Temperature.
LSTM	Land Surface Temperature Monitoring (Copernicus mission).
LULUCF	Land Use, Land-Use Change and Forestry
Metop-SG	Meteorological Operational satellite – Second Generation.
MSI	MultiSpectral Instrument (Sentinel-2).
MTG-S	Meteosat Third Generation – Sounder.
NDCs	Nationally Determined Contributions (Paris Agreement).
NDVI	Normalized Difference Vegetation Index.
NDWI	Normalized Difference Water Index.
NERC	Natural Environment Research Council (UK).
NRT	Near-Real-Time.
OLCI	Ocean and Land Colour Instrument (Sentinel-3).
OSNMA	Open Service Navigation Message Authentication (Galileo).
PALSAR	Phased Array type L-band Synthetic Aperture Radar (on ALOS).
PDOP	Position Dilution of Precision (GNSS geometry quality).

Acronym	Definition
PNT	Positioning, Navigation and Timing.
PPI	Plant Phenology Index
PPP	Precise Point Positioning (GNSS processing method).
PRS	Public Regulated Service (encrypted Galileo service).
RUR	Report on User Needs and Requirements.
SAR	Synthetic Aperture Radar.
SATCOM	Satellite Communications.
SBAS	Satellite-Based Augmentation System (e.g., EGNOS).
SD VISta	Sustainable Development Verified Impact Standard (Verra) – Nature Framework.
S-1 / S-2 / S-3	Sentinel-1 / Sentinel-2 / Sentinel-3 missions (Copernicus).
Sentinel-6	Radar altimetry mission for global sea level (Jason continuity).
SONEL	Système d'Observation du Niveau des Eaux Littorales (coastal GNSS/sea-level network).
SSH	Sea-Surface Height (absolute sea level).
SWH	Significant Wave Height (same concept as H _s ; used for sea-state limits).
SWOT	Surface Water and Ocean Topography mission (wide-swath altimetry).
TFND	Taskforce on Nature-related Financial Disclosures
T _p	Peak wave period.
TTFF	Time To First Fix (GNSS).
TTFaF	Time To First accurate Fix (GNSS; accuracy-bounded TTFF).
UAV	Unmanned Aerial Vehicle (drone).
UCP	User Consultation Platform (EUSPA process/event).
UNFCCC	United Nations Framework Convention on Climate Change.
UTC	Coordinated Universal Time (time standard).
VHR	Very High Resolution (imagery, ~0.3–2 m).
VLM	Vertical Land Motion (GNSS-derived at tide gauges/coasts).

Table 23: Acronyms

A.6 Reference Documents

Id.	Reference	Title	Date
[RD1]	EUSPA Market Report	EUSPA EO and GNSS Market Report (Issue 2)	2024
[RD2]	https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Copernicus_Sentinel_Expansion_missions	Copernicus Sentinel Expansion missions	
[RD3]	https://dataspace.copernicus.eu/copernicus-services	Copernicus Services	
[RD4]	https://land.copernicus.eu/en/news/the-clms-contract-for-the-protected-areas-product-has-kicked-off	The CLMS contract for the Protected Areas product has kicked off	20/06/2024
[RD5]	https://cop4n2k.eu/	Copernicus for Natura 2000 EU Grassland Watch	
[RD6]	https://os.copernicus.org/articles/19/1277/2023/	Nouméa: a new multi-mission calibration and validation site for past and future altimetry missions?	22/08/2023
[RD7]	https://www.iso.org/sites/JCGM/GUM/JCGM100/C045315e-htm/C045315e_FILES/MAIN_C045315e/07_e.html	Section 7: Reporting uncertainty	
[RD8]	Communication from the commission to the European Parliament, the council, the european economic and social Committee and the committee of the regions	Roadmap towards Nature Credits	07/07/2025
[RD9]	Finance for Biodiversity Foundation	Biodiversity measurement approaches - A practitioner's guide for financial institutions	March 2025
[RD10]	CREDIBLE EU carbon farming DOI 10.5281	EO for monitoring, reporting and verification (MRV) of Carbon Farming (CF) – Uncertainty and Benchmarking	
[RD11]	Biodiversity Credit Alliance	Definition of a Biodiversity Credit	May 2024
[RD12]	CDC Biodiversité	Crédits Biodiversité : Vers un nouveau marché de la nature en europe ?	July 2024
[RD13]	EUROPABON Project	D3.2 Report on gaps and important new areas for monitoring in Europe D4.2 Novel technologies for biodiversity monitoring	
[RD14]	IAPB	High-Level Principles to Guide the Biodiversity Credit Market	July 2025
[RD15]	Carbone 4	Towards biodiversity certificates: proposal for a methodological framework	
[RD16]	Verra	Sustainable Development Verified Impact Standard	2019

Id.	Reference	Title	Date
[RD17]	IUCN National Committee United Kingdom	UK Peatland strategy – Progress Report 2024	2024
[RD18]	Federal Ministry of the Environment	National Peatland Protection Strategy	2022
[RD19]	Department of Agriculture, environment and rural affairs	Northern Ireland Peatland Strategy to 2024	
[RD20]	UN – Global Peatlands Initiative	Global Peatlands Assessment: The State of the World's Peatland	2022
[RD21]	Scottish Government	Peatland ACTION Five Year Partnership Plan 2025-2030	2025
[RD22]	Nottingham Trent University	Remote sensing of Peatlands – A technical review	
[RD23]	Nature - Centre for Climate Research, Warsaw University of Life Sciences	Towards a remote sensing-based assessment of carbon emissions from peatlands	2025
[RD24]	NatureScot Research Report 1308	Analysis of an InSAR “bog breathing” based classification of peatland condition relative to field observations in Cairnsmore of Fleet National Nature Reserve	2025
[RD25]	https://romaniatourism.com/danube-delta.html	Danube Delta	2026
[RD26]	https://climate-adapt.eea.europa.eu/en/metadata/case-studies/lower-danube-green-corridor-floodplain-restoration-for-flood-protection	Lower Danube green corridor: floodplain restoration for flood protection	2020
[RD27]	https://www.ramsar.org/	Ramsar Convention on Wetlands	1971
[RD28]	https://eur-lex.europa.eu/eli/dir/2000/60/oj	EU Water Framework Directive	2000
[RD29]	https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/actions-being-taken-eu/eu-biodiversity-strategy-2030_en	European Commission's Biodiversity Strategy for 2030	2020
[RD30]	https://globalwetlandwatch.org/	Global Wetland Center	2026
[RD31]	https://verra.org/methodologies/vm0036-methodology-for-rewetting-drained-temperate-peatlands/	Verra's VM0036 methodology	2017
[RD32]	https://www.iucn-uk-peatlandprogramme.org/peatland-code	UK Peatland Code	2015
[RD33]	https://www.iberdrolaespasa.com/sustainability/environment/spain-reservoirs	How reservoirs promote sustainable water use and help mitigate the effects of drought in Spain	2026
[RD34]	https://op.europa.eu/en/publication-detail/-/publication/5811a721-8326-11e9-9f05-01aa75ed71a1	Common Implementation Strategy for the Water Framework Directive	2000
[RD35]	https://www.globaldamwatch.org/	Global Reservoir and Dam Database	2026
[RD36]	https://www.icold-cigb.org/	International Commission on Large Dams	2026

Id.	Reference	Title	Date
[RD37]	https://environment.ec.europa.eu/news/new-analysis-indicates-european-cities-and-countries-highest-expected-losses-future-flooding-2023-06-21_en	New analysis indicates European cities and countries with highest expected losses from future flooding	2023
[RD38]	https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32007L0060	European Commission's Floods Directive	2007
[RD39]	https://www.c40.org/case-studies/cities100-copenhagen-green-infrastructure-prevents-flooding/	Cities100: Copenhagen - Green Infrastructure Prevents Flooding	2015
[RD40]	https://www.c40.org/case-studies/c40-good-practice-guides-rotterdam-climate-change-adaptation-strategy/	C40 Good Practice Guides: Rotterdam - Climate Change Adaptation Strategy	2016
[RD41]	https://www.bundesumweltministerium.de/en/download/2024-german-climate-adaptation-strategy	German Climate Adaptation Strategy	2024
[RD42]	https://www.waternewseurope.com/new-maps-double-flood-risks-of-spanish-homes/#:~:text=In%20recent%20decades%2C%20hundreds%20of,in%20urban%20underpasses%2C%20are%20excluded.	New maps double flood risks of Spanish homes	2025
[RD43]	https://land.copernicus.eu/local/urban-atlas	Copernicus Urban Atlas	
[RD44]	https://eur-lex.europa.eu/eli/dir/2000/60/oj/eng	EC Directive for Community action in the field of water policy	2000
[RD45]	https://www.landsrl.com/en/work/renaturation-of-po-river/	Renaturation of Po River	2026
[RD46]	https://earsc.org/sebs/wp-content/uploads/2024/02/Water-quality-management-in-the-Netherlands-vFinal.pdf	A Case Study: Water quality management in the Netherlands	2023
[RD47]	https://earsc.org/sebs/wp-content/uploads/2021/06/Water-Quality-Management-in-Germany-final-1.pdf	A Case Study: Lake Water Quality Management in Germany	2021
[RD48]	https://marine.copernicus.eu/news/may-2021-product-release-sentinel-2-and-3-improve-water-quality-monitoring	May 2021 product release: Sentinels 2 and 3 improve water quality monitoring	2021
[RD49]	https://land.copernicus.eu/en/products/global-dynamic-land-cover	Global Dynamic Land Cover	2026
[RD50]	Interviews	Interviews	2025-2026

Table 24: Reference documents

EUSPA Mission Statement

The mission of the Agency is defined by the EU Space Programme Regulation.

EUSPA's mission is to be the user-oriented operational Agency of the EU Space Programme, contributing to sustainable growth, security and safety of the EU. In the execution of its mission, EUSPA counts on strong partnerships with the European Commission, European Parliament, Member States, European Space Agency, and private actors across the EU.

EUSPA:

- Provides state-of-the-art, safe and secure positioning, navigation and timing services based on Galileo and EGNOS, cost-effective satellite communications services for EU GOVSATCOM and soon IRIS² and Front Desk services of the EU Space Surveillance Tracking whilst ensuring the systems' service continuity and robustness.
- Promotes and maximises the use of data and services offered by Galileo, EGNOS, Copernicus, EU GOVSATCOM and soon IRIS² across a broad range of domains.
- Fosters the development of a vibrant European space ecosystem by providing market intelligence, and technical know-how to innovators, academia, start-ups, and SMEs. The Agency leverages Horizon Europe, other EU funding, and innovative procurement mechanisms.
- Implements and monitors the security of the EU Space Programme components in space and on the ground with the aim to enhance the security of the Union and its Member States. To do so, EUSPA operates the Galileo Security Monitoring Centre (GSMC).
- The EU Space Programme Security Accreditation Board is established within the Agency, representing the security accreditation authority for all of the EU Space Programme's components.

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