2023

Report on Agriculture and Forestry

User Needs and Requirements

#EUSpace

EUSPA European Union Agency for the Space Programme

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION AND CONTEXT OF THE REPORT

The Agriculture and Forestry sectors are tightly linked to today's complex environmental and regulatory challenges, from regulations involving environmental protection to the effects of climate change. Services enabled by Earth Observation (EO) and Global Navigation Satellite Systems (GNSS) aim at tackling part of these complexities and challenges faced by the two sectors. Consequently, EO and GNSS user requirements, strongly interlinked with the growing and evolving market trends, are affected by:

- Investments in sustainable solutions aiming at reducing the depletion of natural resources and the effects of climate change.
  - The health and wealth of land is greatly impacted by agricultural activities. Governments are committed to reduce the use of resources and the impact on the ecosystem of human intervention. The EU Green Deal and the agreement signed at COP15 are recent examples of the extensive commitment the EU has taken to protect the environment for the benefit of vegetation, wildlife and society.
  - EO and GNSS allow for unprecedented capacity to track, monitor and use accurate data to improve the management of agri-forestry activities as well as prevent illegal ones (like unauthorised logging). Several data-sharing systems have been established in the past years and these are expected to bring value not only to businesses and governments but also researchers, EU regulators and communities.
- The economic viability of digital solutions that optimise the cost-effectiveness of farming and forestry activities to the detriment of natural resources.
  - The satellite-based solutions integrated with other emerging technologies like AI, blockchain and advanced robotics have the occasion to solve the key challenge currently being addressed by farmers - to reduce both production costs and environmental impact while at the same time increasing the quality of crop, soil and biodiversity.
  - There is a trend towards achieving collection, analysis and prediction of data to optimise the use of resources (land fields, seeds, irrigation water, fertilisers, pesticides, etc.) and automatic machinery to maximise the quality of crops and health of the ecosystems.

In this framework, EO and GNSS solutions have a legacy of providing significant added value to the agriculture and forestry industry, and those technology are expected to continue doing so also in the future. The solutions used in agriculture and forestry relying on EO and GNSS are in fact meant to achieve better results in a more efficient way, with respect to traditional means. In order to support the evolution of those markets, is it of utmost importance to identify and monitor the user needs, to make sure the proposed solutions fit the requirements.

The European Union Agency for the Space Programme (EUSPA) answers to such challenge by organising the User Consultation Platform (UCP), a periodic forum where users from different market segments meet to discuss their needs and application-level requirements relevant for Position, Navigation and Timing (PNT), Earth Observation (EO) and secure telecommunications. The event involves end users, user associations and representatives of the value chain, such as receiver and chipset manufacturers and application developers. It also gathers organisations and institutions dealing directly, and indirectly, with the European Global Navigation Satellite System (EGNSS), encompassing Galileo and EGNOS. and newly since 2020, also with the EU Earth Observation system, Copernicus, Space Situational Awareness (SSA) as well as GOVSATCOM and IRIS[2], the upcoming system for EU Secure Satellite Constellation which offers enhanced communication capacities to governmental users and business. The UCP event is a part of the process developed at 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 document is to provide a reference, for the EU Space Programme, as well as for the Agriculture and Forestry sectors, of the most up-to-date user needs and requirements for the implementation of space data into everyday activities.

This report is a living and evolving document that will periodically be updated by EUSPA. It serves as a key input to the UCP, where it will be reviewed and subsequently updated and expanded to reflect the evolutions in the user needs, market and technology captured during the event.

The report aims to provide EUSPA with a clear and up-to-date view of the current and potential future user needs and requirements in order to serve as an input to the continuous improvement of the development of the space downstream applications and services provided by the EU Space Programme components. In line with the extended mandate of EUSPA, the Report on User needs and Requirements (RURs) previously focused on GNSS, have been revamped to include the needs of Earth Observation (EO) commercial users and is now organised according to the market segmentation of the EUSPA EO and GNSS Market Report.

Finally, as the report is publicly available, it also serves as a reference for users and industry, supporting planning and decision-making activities for those concerned with the use of PNT and of Earth observation technologies.

It must be noted that the listed user needs and requirements cannot usually be addressed by a single technological solution but rather by space downstream applications which combine several signals and sensors. Therefore, the report does not represent any commitment of the EU Space Programme to address or satisfy the listed needs and requirements in the current or future versions of the services and/or data delivered by its different components.

1.1 Methodology

The following figure details the methodology adopted for the analysis of the agriculture and forestry user requirements at application level.

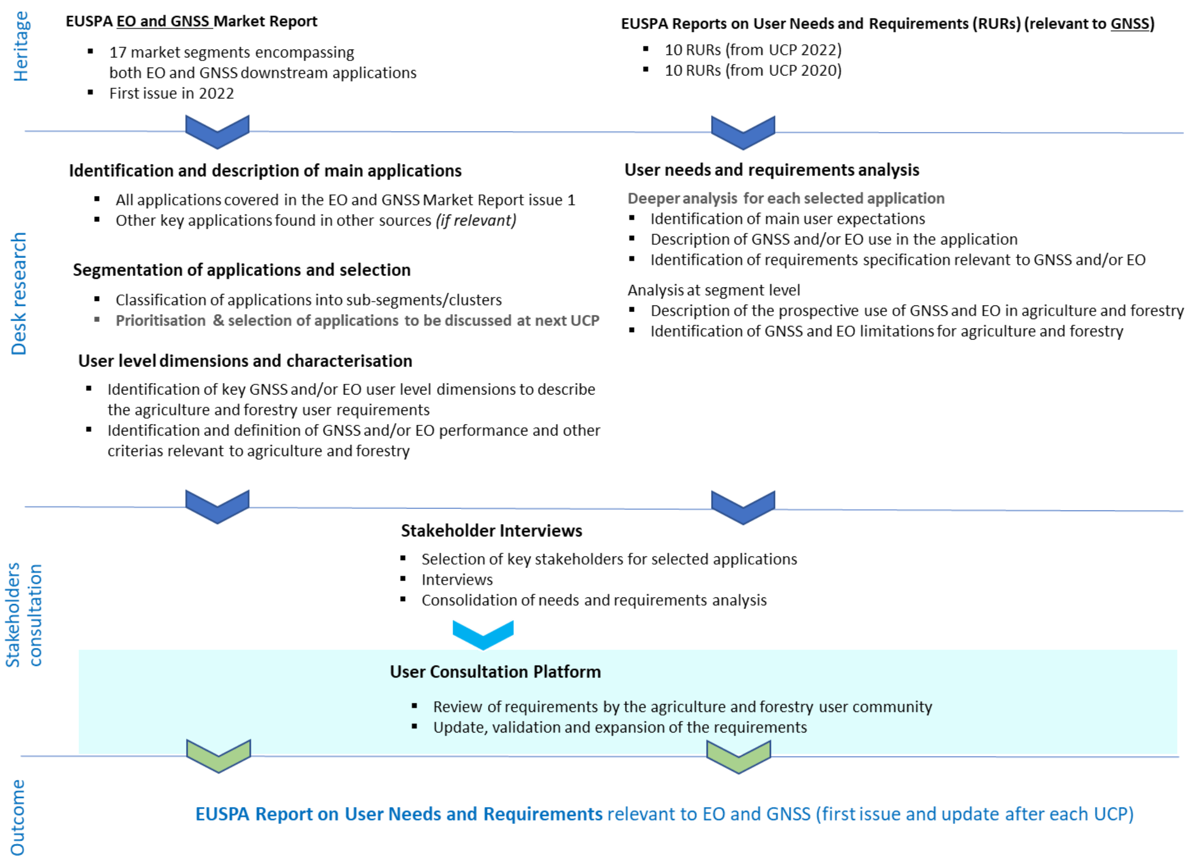

Figure 1 - Agriculture & Forestry user requirements analysis methodology

As presented in Figure 1, the work leverages on the latest EUSPA EO and GNSS Market Report, adopting as starting point the market segmentation for EO and GNSS downstream applications and takes on board the baseline of user needs and requirements relevant to GNSS compiled in the previous RURs published by the agency.

The analysis is split into two main steps, including a “desk research”, aiming at refining and extending the heritage inputs and at gathering main insights, and a “stakeholders’ consultation” to validate main outcomes.

More in details, the “desk research” was carried out to consolidate when required the list of applications and their classification, to identify the key parameters driving their performances or other relevant requirements together with the main requirements specification, etc. A deeper analysis was conducted for a set of applications prioritised for discussion at the last UCP event. The outcomes of this preliminary analysis were shared and consolidated prior to the UCP with a small group of key stakeholders, operating in the field of the selected applications.

These requirements analysis results were then presented and debated at the UCP with the Agriculture & Forestry user community. The outcomes of the Agriculture & Forestry forum discussions were finally examined to validate and fine-tune the study findings.

The steps described above have resulted in the outcomes that are presented in detail hereafter.

1.2 Scope

This document is part of the User Requirements documents issued by the European Union Agency for the Space Programme for the Market Segments where Position Navigation and Time (PNT) and Earth Observation (EO) data play a key role. Its scope is to cover requirements on PNT and Earth Observation-based solutions from the strict user perspective, while considering the market conditions, regulations, and standards that drive them.

The document is **split in two** parts: **Agriculture** and **Forestry.** For each section, it starts with a market overview, focusing on the market evolution and key trends applicable to the whole segment or more specific ones relevant to a group of applications or to the use of GNSS or EO. This section also presents the main market players and user communities. The report then provides a panorama of the applicable policies, regulations and standards. It then moves to the detailed analysis of user requirements. This section first presents an overview of the market segment downstream applications, and indicates for each application, the depth of information available in the current version of the report: i.e. broad specification of needs and requirements relevant to GNSS and EO, partial specification limited at this stage to needs and requirements relevant to GNSS, or limited to an introduction to the application and its main use cases at operational level. The content of this section will be expanded and completed in the next releases of the RUR.

Following its introduction, sections 2.4 and 3.4 are organised as follows:

- Sections 2.4.1 and 3.4.1 present current GNSS and/or EO use and requirements per application, starting with a description of the application, presenting main user expectations and describing the current use of GNSS and/or EO space services and data for the application and providing a detailed overview of the related requirements at application level. Three key applications have been addressed at the UCP and are more detailed for Agriculture and three for Forestry.
- Sections 2.4.2 and 3.4.2 describe the main limitations of GNSS and EO to fulfil user needs in the market segments.
- Prospective use of GNSS and EO in Agriculture & Forestry is addressed in sections 2.4.3 and 3.4.3.
- Sections 2.4.4 and 3.4.4 include a synthesis of the main drivers for the user requirements in Agriculture & Forestry.

Finally, sections 2.5 and 3.5 summarise the main User Requirements for Agriculture & Forestry in the applications domains analysed in this report.

The current version of the report will be expanded and completed through its future releases.

The RUR is 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 Earth Observation system, Copernicus, Space Situational Awareness, GovSatCom and IRIS2.

2 AGRICULTURE

2.1 Executive Summary

This report aims to enhance the understanding of market evolution, strongpoints, limitations, key technological trends and main drivers related to the uptake of GNSS and EO data and services across the different agriculture application domains. These elements are essential to frame the appropriate technology and service offering development against the requirements of the respective users.

Key trends and market evolution

The agriculture sector is undergoing a significant transformation, marked by the integration of EO and GNSS applications. These technologies have and continue to revolutionise farming practices, steering in an era of precision, efficiency, and sustainability.

Several influential factors are leading user needs and requirements in the agriculture sector, shaping the demand for GNSS and EO solutions. An overview of the agriculture market trends is presented in section 2.2. Key trends include:

- Food security
- Economic viability of digital solutions
- Agricultural sustainability and climate change considerations

The recent trends indicate that the market will focus on eco-schemes for sustainable farming, AI integration in farming tools and practices, and advanced robotics able to perform various tasks, improving the operational efficiency of agriculture activities.

Current and prospective use of GNSS and EO in the agriculture segment

The further integration of EO and GNSS technologies holds great promise for the agriculture sector. It fosters sustainability, enhances productivity, and bolsters resilience against global challenges. Policymakers, stakeholders, and farmers must embrace these innovations to secure a prosperous and environmentally responsible future for agriculture.

Drivers for users' requirements

In addition to the key market trends mentioned above, user requirements are driven by the policies, regulations and standards covered in section 0. The greatest policy-based driver at EU level is the Common Agriculture Policy (CAP).

2.2 Market Overview & Trends

2.2.1 Market Evolution and Key Trends

In the dynamic landscape of modern agriculture, the integration of various EO and GNSS applications has been revolutionizing farming practices, starting a new era of precision, efficiency, and sustainability.

Introduction to the Agriculture Segment

Spatial information is key for improving the management and health of cultivated land. EO and GNSS measurements are valuable at various levels, for different purposes and stakeholders.

EO data helps farmers address important challenges, like the pressure of reducing production costs and environmental impact, while maintaining or improving the quality of their yields. With EO sensors, they can monitor and use analytical models to make informed decisions based on agro-meteorological parameters (soil type and conditions, nutrient availability, crop type and height, control of pests and diseases, temperature, rainfall, radiation, etc.). These technologies enable insight-based farm management practices that improve, at the same time, the productivity, sustainability, and profitability of cultivated land.

At a macro-level, EO data feed accurate systems to generate reliable geospatial information on farming land, instead of less updated and accurate information collected via census or sampling methods. EO technologies allow for the collection of vast amounts and types of data, which can be used, among others, for optimising crop planning, food security monitoring, and large-scale mapping of farming terrain, both at regional and national levels. For these reasons, public authorities and economists can greatly benefit from the evidence produced by EO applications for their decisions and policy making.

Also, GNSS provides valuable data and applications for the agricultural sector. For instance, GNSS technology enables autonomous robots and drones for diverse agricultural tasks, including harvesting, weeding, planting, seeding, and even pesticide application. These technologies are increasingly adopted, especially in developed countries and the horticulture sector.

EO and GNSS are converging, and an increasing number of applications in the agriculture sector relies on the synergy of these two technologies.

Key Market Trends

The below market trends drive user needs and requirements in the agriculture sector.

- Food security in response to climate change, geopolitical developments and other crises
  - Satellite technology applications in agriculture play a pivotal role in addressing food security challenges by improving crop monitoring and forecasting, resource management, disaster preparedness, and supply chain efficiency. These capabilities are crucial for ensuring a stable and sufficient food supply to meet the needs of a growing global population.
  - By monitoring agricultural practices worldwide, satellites provide a comprehensive view of global food production trends. This data aids in identifying regions facing food shortages and enables international cooperation and aid efforts.
  - Satellites also contribute to developing early warning systems for extreme weather events like hurricanes, floods, and droughts. These systems allow for proactive disaster preparedness and response, safeguarding food supplies.
  - European Union funded projects, such as AgriAdapt, provide data for past climate conditions affecting agriculture and models for future climate indicators and crop health.

- Economic viability of digital solutions enabled by satellite-based solutions
    - The historical limitations in adopting space applications, driven by high expenses, poor resolution, and a lack of consumer confidence in the technology and awareness of the related advantages, are diminishing. EO and GNSS applications are becoming more affordable. The economic viability of digital solutions is a pivotal trend driving the adoption of satellite technology applications in agriculture. In an era where the agricultural sector faces increasing pressure to enhance productivity, **reduce costs, and ensure sustainability, solutions powered by satellite technology offer** several advantages.
    - Farmers and agriculture cooperatives can use an increasing number of space-based applications to obtain efficiency gains, cost reductions, risk mitigation and labour optimisation, thanks to EO and GNSS applications. For instance, autonomous robots and drones are becoming a much more common reality thanks to GNSS. Currently, these machines can perform various tasks like harvesting, weeding, planting and seeding.
    - Companies are also working to develop more sophisticated technologies embedding AI and machine learning to increase the efficiency of agricultural robots and drones.
- Agricultural sustainability and climate change considerations
    - Environmental sustainability is a crucial trend propelling the adoption of satellite technology applications in agriculture. It reflects a growing awareness of the need to minimize agriculture's environmental impact while fostering long-term soil health and productivity. EO and GNSS provide options to increase sustainability in agriculture by making agronomic practices, such as fertiliser application, irrigation, crop density, more efficient.
    - **The transition to Regenerative Agriculture is becoming increasingly popular.** It empowers farmers to implement practices that reduce environmental harm, promote soil health, conserve biodiversity, and enhance resilience to climate change, all essential for a sustainable and regenerative agricultural future. Data collection and data analysis are essential methods needed to foster the transition into regenerative agriculture, the availability of space data will support the process. Regenerative Agriculture uses several EO and GNSS applications that allow:
        1. Monitoring ecosystems and natural resources
        2. Assisting in biodiversity conservation efforts
        3. Enabling precision farming to reduce resource wastage
        4. Facilitating responsible water management
        5. Supporting soil health management and conservation practices
        6. Providing data for climate resilience and adaptation
        7. Assisting in land-use planning for conservation

Technology trends include:

- Advanced Imaging Sensors
- AI and machine learning
- IoT Integration
- Automated machines, robots and drones
- Small Satellites (CubeSats)
- New and advanced GNSS augmentation techniques
- Low Earth Orbit (LEO) Satellite Constellations

- Edge Computing
- Weather and climate modelling

Research gaps include:

- Agriculture data sharing platforms at very initial stage, examples include AgriDataSpace, FaST, demeter, FlexiGroBots and many other;
- Cybersecurity for data protection
- Blockchain for supply chain traceability

During the UCP several bottlenecks to the uptake of space services in the agriculture sector emerged. Firstly, farmers tend to have a limited capacity for innovation, which, combined with financial constraints, inhibit technological advancement within the farm. Moreover, the lack of uptake of space-based technologies by farmers is due to simply not being aware the technologies exist. Farmers are often not fully aware of satellite and space-based technologies and their capabilities in the agriculture sector, and if they are aware of them, they lack the knowledge to implement them is an obstacle to the adoption. In order to increase engagement of farmers as users the best approach would be to provide educational and training opportunities, with concrete case studies applicable to their area of agriculture.

GNSS Market Evolution

The GNSS market in agriculture has experienced a notable transformation in response to emerging trends. For instance, "swarm robotics" is gaining traction to streamline agricultural operations. GNSS technologies facilitate the coordination of multiple robots, ensuring precise and synchronized tasks such as planting, harvesting, and pest control. This results in increased operational efficiency and reduced labour costs.

The integration of AI into GNSS applications has been revolutionizing agriculture. AI algorithms analyse data collected from these systems to deliver real-time insights. This empowers farmers to make informed decisions, optimize crop health, and improve overall yields. In 2023 Galileo High Accuracy Service (HAS) was launched, pioneering a free of charge augmentation service provided free of charge. The corrections are provided through the Galileo signal and via terrestrial means (internet connection). HAS enhances position accuracy in real time, achieving accuracy down to decimetre lever under normal circumstances. HAS can serve the applications of VRA, farm machinery positioning, guidance and site-specific data analysis applications.

In the coming years, GNSS and AI technologies will be introduced in smaller and smarter machines (drones/UAVs or robots) that will perform various tasks in the fields as well as collect and analyse data for informed decision-making on crop management. Revenues from sales of GNSS devices and related services in the agriculture sector are expected to more than double in the coming decade, with **commercial augmentation services** being the source of the growth. Commercial augmentation service providers are able to provide high-accuracy services in the decimetre range.[1] Augmentation services improve accuracy across all precision agriculture applications, including farm machinery guidance, automatic steering, and are an incredibly useful tool for improved productivity. These technologies have been proven to improve yield and lower cost while increasing flexibility of farming techniques and are therefore particularly appealing to stakeholders in the agriculture sector. Figure 2 provides an evolution of the GNN revenues in agriculture in the upcoming decade.

[1] OmniSTAR (Fugro) & Starfire (John Deere)

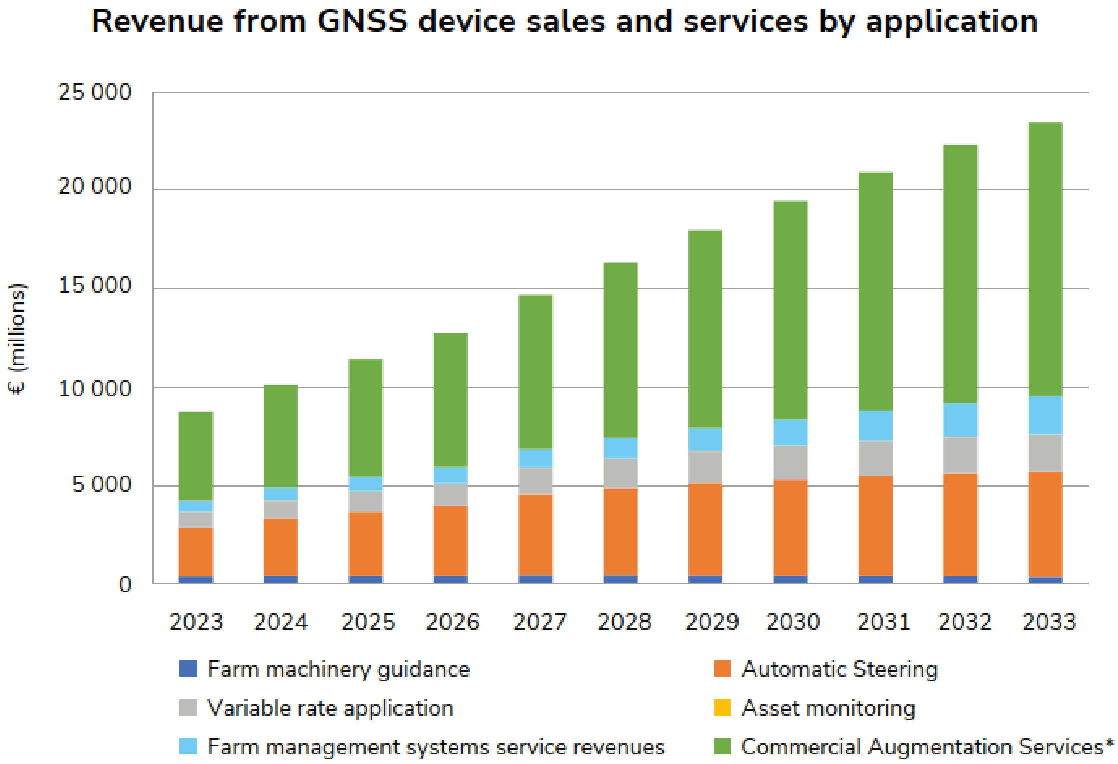

Figure 2 – Evolution of revenues from GNSS device sales and services in agriculture 2023-2033

Source: EUSPA EO and GNSS Market Report – Issue 2 2024

EO Market Evolution

Since EO technologies were first incorporated into agriculture, they have shaped global food production aiming at minimising the environmental impact while increasing productivity and ensuring the long-term viability of agriculture. Specialised information about growing conditions of vegetated land was the beginning of EO technologies in agriculture and remains invaluable information through to today.

The current unparalleled availability of high resolution (spatial, spectral and temporal) satellite images has promoted the use of earth observation in many precision applications, including crop yield forecasting, irrigation management, nutrient application, disease and pest management, and yield prediction. Since the adaptation of EO technologies agribusinesses have increased profit margins due to these precision agriculture applications which saves money through a greater application accuracy of pesticides, herbicides and nutritional needs of crops.

EO also plays a vital role in improving the transparency, accuracy, and efficiency of the agri-food systems. Eco-schemes, foreseen by the CAP and aimed at promoting sustainable farm and land management, have spurred significant innovation in this sector thanks to EO (and GNSS) technologies. It provides comprehensive solutions in the monitoring, reporting and verification of eco-schemes.

Currently, agriculture is undergoing a fourth revolution primarily driven by advancements in information and communication technologies. EO technologies coupled with, IoT, Big Data analysis, and artificial intelligence are promising tools deployed to optimize agricultural practices. The objective is to boost production while minimizing input usage and yield losses. Various IoT systems leveraging cloud computing, wireless sensor networks, and big data analysis have been devised for smart farming operations. These include automated wireless-controlled irrigation systems and intelligent systems for disease and pest monitoring and forecasting. The proliferation of agriculture date borne from EO enables machine learning and other AI techniques to be utilised for crop yield estimation, soil moisture, automated application of water and other agri-chemicals.

In 2023, the revenue from EO data and service sales in agriculture amounted to €450 million and is expected to reach over €670 million over the next decade. **Vegetation monitoring** holds the largest share of the market and is expected to continue to do so. Crop yield forecasting has the second largest share and is also expected to keep its position in the coming decade. Overall, the market shows steady growth for all applications, as shown in Figure 3.

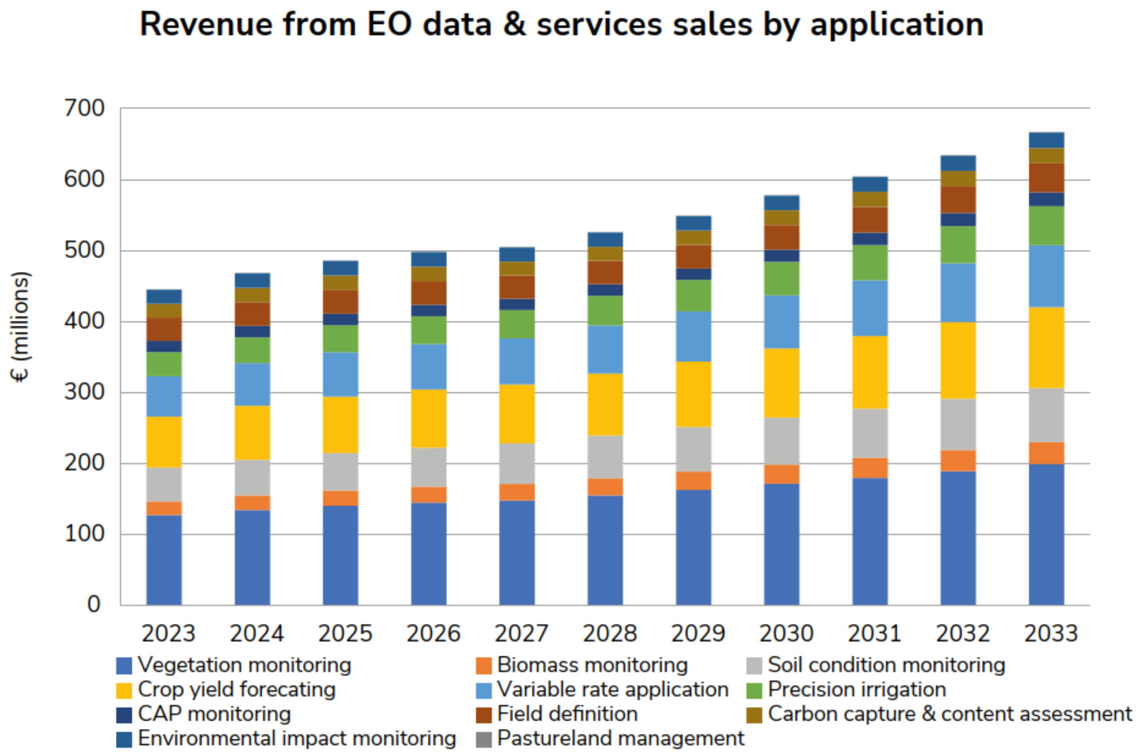

Figure 3 - Predicted evolution of the revenues for EO data and service sales in agriculture 2023-2033

Source: EUSPA EO and GNSS Market Report – Issue 2 2024

The targeted user communities for these products and services are intended to be far reaching and multidisciplinary, sometimes very different than the intended users. Some of the agriculture user communities are outlined in the following section.

2.2.2 Main User Communities

The main user communities are listed below, which partly shape the agriculture users' needs and requirements.

- **Governments, national and regional agricultural government agencies, environmental agencies** all use satellite technology for monitoring and managing agricultural activities, enforcing regulations, and providing data to support policy decisions and disaster management. Governments can also provide support and incentives for farmers to adopt precision agriculture practices. They offer subsidies for technologies like GNSS-guided machinery and irrigation systems, which enhance farming efficiency and reduce resource wastage.
- **International agencies and organisations advocating for food safety, human health and protection of the environment.** These entities use satellite data to monitor land-use changes, deforestation, and ecosystem health, and advocate for sustainable agriculture practices. Examples include the International Fund for Agricultural Development (IFAD) and the United Nations Conference on Trade and Development (UNCTAD).

- **Farmers, associations representing farmers and their cooperatives.** These are the most direct users of satellite technology applications in agriculture. They rely on satellite-derived data and technology for various purposes, including crop monitoring, precision agriculture, and decision-making to optimize their yields and resource management. These users are the group that would benefit the most from digital services as well as general awareness of the products and services provided for free by Copernicus and Galileo. For instance:
    - Small/medium to very large farms
    - The General Confederation of Agricultural Cooperatives in the European Union (COGECA) and the Committee of Professional Agricultural Organisations (COPA) which jointly form the umbrella organisation Copa Cogeca[2]
    - The World's Farmers' Organisation (WFO)
    - The International Farm Management Association (IFMA)
    - European Agricultural Machinery (CEMA)
- **Crop traders.** Investors and financial institutions may use satellite data to assess the financial viability of agricultural projects and make lending or investment decisions in the agricultural sector. Unlike conventional approaches that frequently depend on past or theoretical data, satellite imagery and analytics can significantly enhance the dependability and precision of future price forecasts by offering up-to-the-minute information on production, inventories, and supply chains.
- **Insurance companies.** Crop insurance providers rely on satellite data to assess crop health, yield predictions, and damage assessment for insurance claims, which helps manage risks for both farmers and insurers. Insurance companies gain extensive value from satellite applications. In addition to assessing risks, they leverage satellite imagery to get accurate data on soil quality, climate conditions, and other relevant variables when calculating premiums and coverage for farmers. They also use EO for fast and reliable assessment in case of damage.

2.2.3 Main Market Players

The main market players of the EO and GNSS market are highly variegated. These players range from enterprises providing services to end users, to satellite operators who are capturing and storing the data.

Some of the main players involved in EO and GNSS are depicted the value chains below.

[2] Copa Cogeca

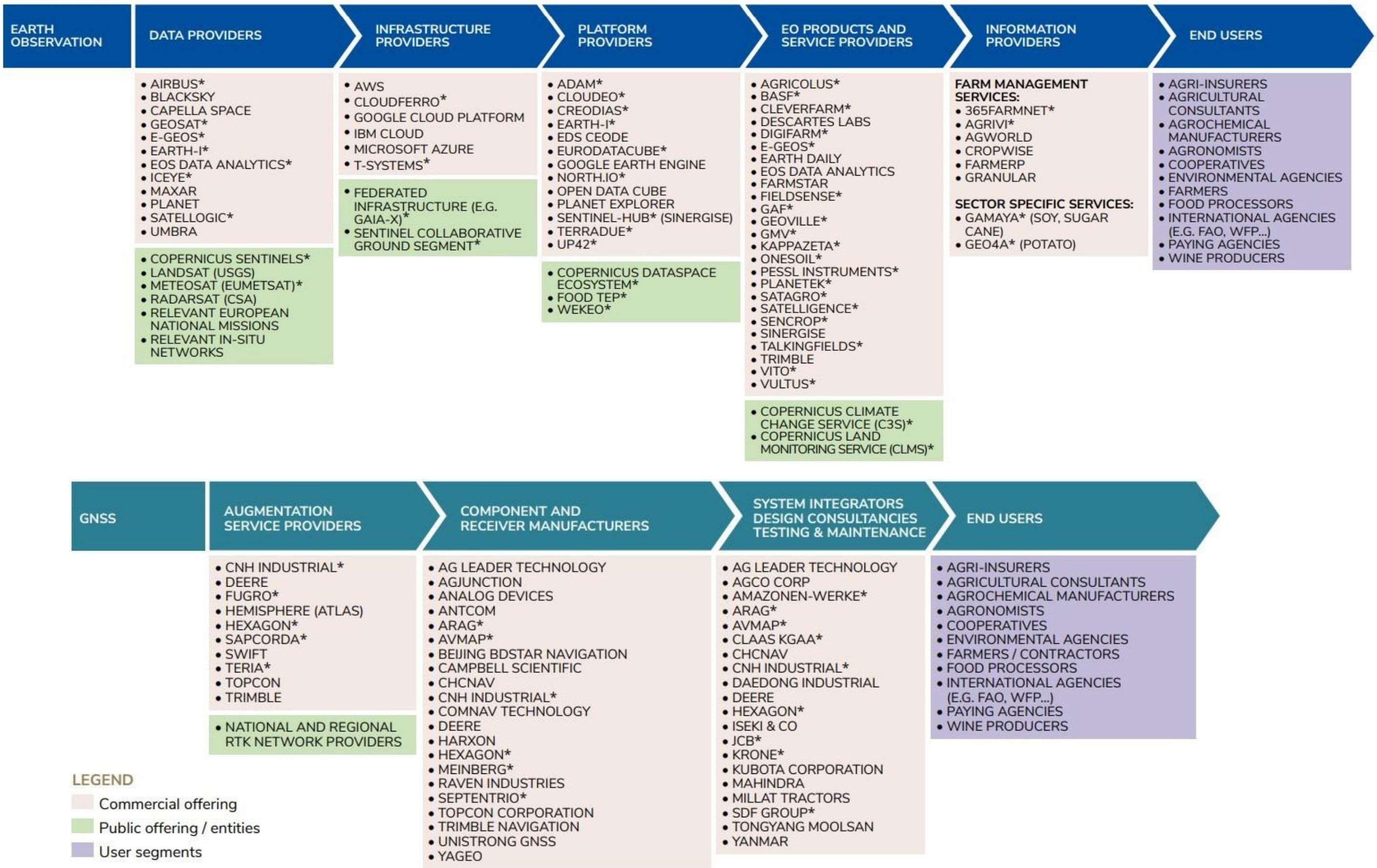

Figure 4: Earth Observation and GNSS Agriculture value chains.

Source: EUSPA EO and GNSS Market Report – Issue 2 2024

2.3 Policy, Regulations and Standard Standards

The below policies, regulations, and standards drive user needs and requirements in the agriculture sector. Both GNSS and EO provide the needed information to regulators or enforcers of the regulations. GNSS enables tracking and tracing as well as geolocation reference data. Certain regulations require, for instance, that agricultural cultivators keep the land in good agricultural and environmental condition or to comply with biodiversity standards. EO enables the monitoring of such conditions.

2.3.1 Policies

The Green Deal represents a comprehensive set of policy initiatives designed to guide the EU towards achieving carbon neutrality by 2050 through an integrated, cross-sectoral approach. Relevant initiatives for the agriculture sector include:

- **Farm to fork strategy.** At the heart of the EU's European Green Deal lies the Farm to Fork Strategy, a central pillar with the overarching aim of establishing fair, health-conscious, and environmentally sustainable food systems that ensure both robust food security and ecological responsibility. This strategy has the following among the key objectives:

    1. Ensuring sufficient, affordable, and nutritious food while respecting planetary limits.
    2. Reducing the use of pesticide and fertilizer by half, as well as the sales of antimicrobials.
    3. Expanding the extent of land dedicated to organic farming, fostering environmentally friendly agricultural practices.
    4. Encouraging more sustainable food consumption patterns and the adoption of healthier diets.
    5. Actively addressing the issue of food loss and waste along the entire supply chain.
    6. Combating food fraud, enhancing transparency, and bolstering the integrity of the food supply chain.
    7. Elevating standards of animal welfare within the agricultural sector.

    With these goals, the EU strives to create a more resilient and environmentally responsible food ecosystem.

- **EU biodiversity strategy for 2030.** It aims to help recover Europe's biodiversity by 2023, including in the agriculture sector, for the benefit of the climate and the planet. It is a roadmap designed to address the environmental challenges and safeguard biodiversity within the EU. This strategy, adopted in 2020, outlines objectives and targets aimed at reversing the decline in biodiversity and ecosystem health. This strategy contains commitments and actions to be delivered by 2030, which are constantly monitored, and the status of advancements is accessible through the dedicated *EU Biodiversity Strategy Actions Tracker* portal.
- **EU soil strategy for 2030.** It is a comprehensive and forward-looking initiative aimed at addressing the critical challenges associated with soil management and conservation within the EU. The key objectives of the strategy include promoting sustainable land uses, soil conservation, biodiversity in soil ecosystems, soil carbon storage and awareness of soil-related issues.

COP15 (global biodiversity conference) and the Kunming-Montreal Global Biodiversity Framework. The EU participated in the COP15 and adopted the framework containing goals and targets to protect and restore nature as well as remove pollution. Moreover, the EU joined initiatives during the conference, like increasing the resources for biodiversity and partnered up with countries to strengthen capacities and knowledge to deliver the Global Biodiversity Framework.

2.3.2 Applicable regulations

Policy: the Common Agricultural Policy (CAP)

The CAP (current period runs from 2023 to 2027) is the main EU policy governing the agri-food sector. The CAP regulates agricultural support, financing, and subsidies. It aims to promote sustainable and competitive agriculture meeting high safety and environmental standards and ensure a fair standard of living for farmers.

The CAP 2023-2027 is of critical importance given that the farming sector has the following distinctive factors

- It must ensure continued access to high-quality food for EU citizens (food security and affordability).
- Farmers typically earn approximately 40% less compared to those in non-agricultural professions.
- Adjusting farming output to demand is time-consuming and challenging.
- Agriculture is more susceptible to weather and climatic conditions than many other sectors.

Below are the novel aspects that the CAP 2023-2027 aims to address:

- Enhancement of the contribution to the EU environmental and climate goals, by setting environmental conditions to be met by farmers and additional voluntary measures. New obligations and incentives for farmers have been introduced, like preserving carbon-rich soils by protecting wetlands and peatlands and **eco-schemes** to incentivise farmers to apply agricultural practices beneficial for the climate and the environment;
- Introduction of annual reporting obligations based on performance, where Member States need to report their achievements yearly but have some flexibility in choosing specific interventions to respond to local conditions.

In this context, EO and GNSS technologies are instrumental to the fulfilment of the policy objectives to make EU agriculture fairer, greener and more results driven.

The CAP prescribes the utilization of the Area Monitoring System (AMS) across Member States. This is designed to monitor the performance and outcomes of beneficiaries participating in diverse land-based CAP interventions. Such an approach marks a significant shift in the management and control mechanisms of the CAP. AMS is defined as the systematic and consistent observation, monitoring, and evaluation of agricultural activities and practices on farmland using data from Copernicus Sentinel Satellites or other data sources possessing comparable value.

Other Regulations and Directives

Policies falling under the CAP or other directives are shaping the requirements for the use of EO and GNSS-enabled solutions by users (including farmers) trying to comply with the specific measures. Additional legislation applicable to agriculture that might be relevant for the applications of EO and GNSS exists:

- The Fertilizing Products Regulation (Regulation (EU) 2019/1009). It lays down common rules on safety, quality and labelling requirements for fertilising products.
- The Directive 2009/128/EC on the sustainable use of pesticides.
- Regulation (EC) No 1907/2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH).

- The Nitrates Directive (91/676/EEC).
- The Directive 2001/18/EC on Genetically Modified Organisms.

In addition, Natura 2000, a network of protected natural areas in Europe, designated under the Birds and Habitats Directive, established to conserve biodiversity and ensure the long-term survival of Europe's most valuable and threatened species and habitats, is primarily based on two EU directives: the Birds Directive (Directive 2009/147/EC) and the Habitats Directive (Council Directive 92/43/EEC). In particular, it requires Member States to take measures within Natura 2000 areas to maintain and restore the habitats and species in a favorable conservation status, avoiding activities that could significantly disturb these species, cause deterioration or damage of their habitats, impacting also on the conversion of natural land into agricultural land.

2.3.3 Other relevant standards and practices

The European Standardisation Organisations are active in the development of standards for the agriculture sector. The following ones are European harmonised standards, since they have been published in the Official Journal of the EU:

- EN 16590 Tractors and machinery for agriculture and forestry - Safety-related parts of control systems
- EN ISO 5674:2009 Tractors and machinery for agriculture and forestry - Guards for power take-off (PTO) drive-shafts - Strength and wear tests and acceptance criteria (ISO 5674:2004, corrected version 2005-07-01)
- EN 12965:2019 Tractors and machinery for agriculture and forestry - Power take-off (PTO) drive shafts and their guards - Safety
- EN ISO 16122 Agricultural and forestry machinery - Inspection of sprayers in use
- UNE EN ISO 22005:2008 Traceability in the feed and food chain - General principles and basic requirements for system design and implementation (ISO 22005:2007)

GNSS-enabled technologies have been applied to precision agricultural applications worldwide for decades. Since then, GNSS standards have played an important role in the consistency, quality and safety and security in the execution of agricultural applications, namely for precision agriculture applications. For example, the accurate guidance and automated steering features of GNSS-based systems enhance consistent seed placement, fertilizer application, and other field operations, leading to improved crop uniformity, optimized input utilization, and increased yields.

Standards are necessary to guarantee that the tools and techniques being developed across governmental, public, and private sectors translate into tangible benefits for people and the planet. The Geoscience and Remote Sensing Society has sponsored projects that are developing standards for Hyperspectral Imagers, SAR, GNSS Reflectometry, Calibration of Microwave radiometers and Protocols for Measuring Soil Spectroscopy. The Protocols for Measuring Soil Spectroscopy project aims to establish guidelines for generating, comparing, and applying soil spectral libraries derived from hyperspectral data. This initiative is poised to improve soil monitoring and mapping efforts on a global scale and will affect both agriculture and related forestry applications.

Overall GNSS and EO technologies aid in ‘digitising agriculture’ resulting in reduced costs and greater crop yield. Revenues from EO data and service sales across all agricultural applications are expected to increase from almost €450 million in 2023 to around €670 million in 2033, of which almost 14% generated in the EU[3]. Also GNSS boast a major uptake[4]:

- **97%** of new tractors in Europe using GNSS are equipped with EGNOS, the preferred low-cost entry technology for precision farming in Europe;
- **16%** is the yearly growth rate of revenues of Asset management in the period 2017-2029;
- **14%** is the yearly growth rate of revenues of VRT systems in the period 2017-2029;
- **69%** of new agriculture machinery is equipped with Galileo.

[3] EUSPA EO and GNSS Market Report 2024

[4] Agriculture | EU Agency for the Space Programme (europa.eu)

2.4 User Requirements Analysis

This chapter provides a detailed analysis of user needs and requirements pertaining to the agriculture segment applications to be covered, describing the different roles and needs covered by GNSS and EO and, ultimately, identifying the corresponding requirements from a user perspective.

Table 1 below depicts the main applications making use of GNSS and/or EO technologies in the agriculture segment. The list of applications is non-exhaustive and is expected to potentially grow and adapt according to the expected adoption of space technologies in the coming years and the innovations that should come with it. The current report being the first version of the agriculture report on User Needs and Requirements relevant to EO in addition to GNSS, of which user needs were gathered previously in addition to this year. It is a living and evolving document that will periodically be updated and expanded by EUSPA in its next releases.

While each one of the applications addressed in this document can benefit from GNSS and/or EO, the current issue the RUR does not cover in detail the needs and requirements of all applications. A categorisation was performed prioritising some applications based on their maturity level and relevance to the market trends and drivers. Other applications are foreseen to be covered in more detail in future versions of this RUR.

The following applications categorisation reflects the depth of information available in section 5:

● Application Type A: these applications correspond to those for which an in-depth investigation is presented, and for which needs and requirements relevant to GNSS and EO have been identified and validated with the agriculture user community at the UCP.

◐ Application Type B: these applications correspond to those not selected for in-depth investigation in the current version of the RUR, for which a partial specification of needs and requirements is provided, limited at this stage to the ones relevant to GNSS.

○ Application Type C: these applications correspond to EO-based applications, not selected for in-depth investigation in the current version of the document. A high-level description of the application is included considering that they will be further analysed and developed in next versions of the RURs.

The table below maps the agriculture-related applications to the three above-mentioned types. **The following** list of **applications and their** categorisation are **expected to evolve in the next versions of the document.**

Legend

EO only application ● ◐ ○

GNSS only application ● ◐ ○

Hybrid/synergetic application (combined use of EO and GNSS) ● ◐ ○

Table 1: Main applications of the agriculture segment and level of investigation.

Sub-segments	Applications	Types of Application/ Level of Investigation	
Environmental monitoring	Carbon capture & content assessment	C	○
	Environmental impact monitoring	C	○
Natural resources monitoring	Biomass monitoring	B	◐
	Crop yield forecasting	A	●

Sub-segments	Applications	Types of Application/ Level of Investigation	
	Soil condition monitoring	B	
	Vegetation monitoring	C	
Operations management	Asset monitoring	C	
	Automatic steering	A	
	CAP monitoring	B	
	Farm machinery guidance	B	
	Farm management systems	B	
	Field definition	B	
	Livestock wearables	B	
	Pastureland management	C	
	Precision irrigation	A	
	Variable rate application	A	
Weather services for agriculture	Climate services for agriculture	C	
	Weather forecasting for agriculture	C	

The next section 2.4.1 addresses first “type A” applications, then “type B” applications and finally “type C” applications, for which the level of provided information is currently the less developed.

Each EO-based “Type A” application will cover the needs and requirements for potentially several operational scenarios. For each scenario, a table summarises the EO related needs and requirements. The table template is illustrated below in Table 2 and explains the various inputs.

Table 2: Description of needs and requirements relevant to EO table[5]

ID	Identifier
Application	Application covered.
Users	Common users of the product/service.
User Needs	
Operational scenario	**Describes the operational scenario faced by the user, which requires a solution.**
Size of area of interest	Describes the area of interest of the user (e.g., a farmer is interested in the area of his fields, which can vary from a few to hundreds of hectares)
Scale	Describes the scale of interest of the user (e.g., a farmer is interested in portions of field of tens of m)
Frequency of information	How often the user requires the information.
Other (if applicable)	Other user needs such as contextual information (weather data) or file formatting requirements.

[5] See key EO performance parameters (detailed) definition in Annex

Service Provider Offer	
What the service does	Description of the service that satisfies the user's needs.
How does the service work	(Technical) description of how the service works.
Service Provider Satellite EO Requirements	
Spatial resolution	Spatial resolution of the satellite imagery/data required by the service provider to realise the service.
Temporal resolution	Frequency of satellite data (revisit time) over the area of interest.
Data type / Spectral range	Type of data (e.g., RGB, SAR) and spectral range (if relevant).
Other (if applicable)	Other data requirements.
Service Inputs	
Satellite data sources	Type of required data and examples of operational satellites that can provide these data.
Other data sources	Other sources of data that the service provider uses to realise the service.

Table 3 - Description of needs and requirements relevant to GNSS table[6]

GNSS user requirements for [Application]		
Accuracy	Horizontal	m/cm-level
	Vertical	m/cm-level
Availability	Canopy	Yes/no
		High/medium/low
Robustness		High/medium/low
Authentication		High/medium/low
Integrity and reliability		High/medium/low
Size, weight, autonomy	Relevance	Yes/no
	Autonomy	>h
TTFaF		Seconds/minutes

[6] See key GNSS performance parameters (detailed) definition in Annex

2.4.1 Current GNSS and EO use and requirements per application

2.4.1.1 Crop yield forecasting – Type A application

EO facilitates remote-monitoring and forecasting of harvest potentials, whilst GNSS allows in-situ positioning information of field sensors to feed forecast information.

Harvest or yield monitoring systems enable the collection of accurate yield/crop data at a GNSS receiver, a computer, a user interface and dedicated sensors that measure the amount and specific characteristics of crops harvested at the exact point where the harvester is located. Apart from accumulated grain weight, a readout of the harvested area and the corresponding yield rates, yield monitors may provide information such as soil moisture content and field elevation. The various yield data are stored and can be then plotted on maps via a GIS environment, allowing post-analyses and identification of crop performance trends. This is very beneficial for year-to-year farm management decisions on the application of inputs in different areas of a field.

The utilization of satellite spectral data for crop yield estimation is appealing due to its connection to crop vigour, which in turn, correlates with the spectral response of the crop as measured by satellite sensors. Crop yield forecasting is the process of predicting the amount that will be harvested from a specific area of crops in a given growing season, often using statistical models, remote sensing data, and historical trends to estimate future production levels. Accurate crop yield forecasting is crucial for agricultural planning, food security, and economic stability. The current EO/remote sensing technologies play a pivotal role in meeting the following user requirements outlined in the below operational scenarios, but the specific operational scenarios can vary significantly depending on factors such as location and crop species.

The main user needs identified during the 2023 Agriculture UCP for satellite data-based applications are reliable and repetitive satellite imagery, mainly for NDVI. Cloud coverage is a consistent issue and image repetition must be increased.

For the application of crop yield forecasting two operational scenarios were identified. The first operational scenario defines the user needs of EO data crop yield forecasting based on the crop species. Each species of plant will have its own set of operational scenarios when yield forecasting is performed with EO data therefore we have presented the operational scenarios of crop yield forecasting for three crops: rice, soybeans and cereal grains. The second operational scenario is the monitoring of soil health, as this is directly related to yield forecasting.

Table 4: Crop yield forecasting EO operational scenario 1.1 rice

ID	EUSPA-EO-UR-AGR-0001
Application	Crop yield forecasting
Users	Farmers, agricultural policy makers, insurance companies, commodity traders
User Needs	
Operational scenario	**Crop yield forecasting scenario: rice**
Size of area of interest	Area of rice fields (typically 150-300 ha)
Scale	30m
Frequency of information	Bi-weekly
Other (if applicable)	Data on precipitation, mean temperature
Service Provider Offer	
What the service does	Remote sensed estimation of rice yield throughout the 120-day growth period of the rice

How does the service work	Chlorophyll plays a crucial role in the photosynthetic activity of the rice plant, contributing to the production of carbohydrates for the formation of rice plant tissue and grains. It has a notable impact on the rice yield during harvesting. Consequently, there is a close association between the chlorophyll content of the biomass and rice yield. Digital image processing: NDVI and therefore crop yield forecasting is assessed via measurements of plant height and leaf greenness throughout the growth period of the rice.
Service Provider Satellite EO Requirements	
Spatial resolution	10-30m
Temporal resolution	Weekly
Data type / Spectral range	Multispectral, Enhanced thematic mapper plus (EMT+)
Other (if applicable)	n.a.
Service Inputs	
Satellite data sources	Sentinel-1 and 2, Scanning radiometer, AVHRR, multispectral bands, NDVI, RGB
Other data sources	Not satellite-based: field sensors, drones, airborne LiDAR and RADAR sensors

Table 5: Crop yield forecasting EO operational scenario 1.2 soybeans

ID	EUSPA-EO-UR-AGR-0002
Application	Crop yield forecasting
Users	Farmers, agricultural policy makers, insurance companies, commodity traders
User Needs	
Operational scenario	**Crop yield forecasting scenario: soybeans**
Size of area of interest	Area of soybeans fields (typically 150-300 ha)
Scale	10-30m
Frequency of information	Weekly
Other (if applicable)	Day-time land surface temperature and average precipitation
Service Provider Offer	
What the service does	To predict soybean yield utilizing vegetation indices like NDVI and EVI, along with independent variables such as land surface temperature and precipitation.
How does the service work	Crop yield is forecasted from data collected about the vegetation indexes, average land surface temperature and precipitation using machine learning algorithms.
Service Provider Satellite EO Requirements	
Spatial resolution	10m
Temporal resolution	Weekly
Data type / Spectral range	Multispectral
Other (if applicable)	n.a.
Service Inputs	
Satellite data sources	Sentinel-1 and 2, MODIS

Other data sources	Not satellite-based: field sensors, drones, airborne LiDAR and RADAR sensors, MODIS surface Reflectance products

Table 6: Crop yield forecasting operational scenario 1.3 cereal grains

ID	EUSPA-EO-UR-AGR-0003
Application	Crop yield forecasting
Users	Farmers, field suppliers insurance companies, commodity traders
User Needs	
Operational scenario	**Crop yield forecasting scenario:** cereal grains
Size of area of interest	Area of cereal grains fields (typically big farms, 100 ha and larger)
Scale	10m for centre of field and 5m for field boundaries
Frequency of information	Weekly Daily during harvest periods
Other (if applicable)	n.a.
Service Provider Offer	
What the service does	Crop monitoring software, builds field boundaries and estimates crop yields starting 2-3 months before harvest time
How does the service work	The service uses EO data to define fields and estimate the potential crop yield of certain cereal grains.
Service Provider Satellite EO Requirements	
Spatial resolution	5-10m
Temporal resolution	Weekly-daily
Data type / Spectral range	Multispectral,
Other (if applicable)	n.a.
Service Inputs	
Satellite data sources	Sentinel-1 &-2, Eumetsat, Planet
Other data sources	n.a.

Table 7: Crop yield forecasting EO operational scenario 2- Monitoring of soil health parameters for crop yield forecasting

ID	EUSPA-EO-UR-AGR-0004
Application	Crop yield forecasting
Users	Farmers, agricultural policy makers, insurance companies, commodity traders
User Needs	
Operational scenario	**Monitoring of soil health parameters for crop yield forecasting**
Size of area of interest	Sub-square-km level
Scale	10m
Frequency of information	Weekly/monthly
Other (if applicable)	n.a.

Service Provider Offer	
What the service does	Keeping track of soil health due to its impact on overall crop yield
How does the service work	Three soil health parameters, soil moisture, soil salinity and soil organic carbon, are utilized to estimate yield forecast in wheat crops. Soil moisture is estimated from optical, thermal, and microwave remote sensors, soil salinity is deduced from band rationing multispectral bands from multispectral measurements, high moisture content in soil is also related to higher organic matter.
Spatial resolution	10m
Temporal resolution	Weekly
Data type / Spectral range	Multispectral, SAR backscatter, thermal, microwave
Other (if applicable)	n.a.
Service Inputs	
Satellite data sources	Sentinel-1 and 2
Other data sources	Not satellite-based: field sensors, drones, airborne LiDAR and RADAR sensors

Table 8: GNSS user requirements for crop yield forecasting

GNSS user requirements for crop yield forecasting		
Accuracy	Horizontal (cm-level/sub-metre level/m-level)	m/cm-level
	Vertical	m-level
Availability	Canopy	Yes/no
	High/medium/low	Medium
Robustness	High/medium/low	High
Authentication	High/medium/low	Low
Integrity and reliability	High/medium/low	Medium
Size, weight, autonomy	Relevance (Yes/No)	n.a.
	Autonomy (>hour)	n.a.
TTFaF	Seconds/minutes/>20min	A few seconds

2.4.1.2 Precision irrigation – Type A application

Precision irrigation combines GNSS positioning with EO information to distribute the appropriate amount of water for irrigating crop. GNSS sensors enable the optimization of water distribution to crops by identifying specific areas within a field that require different levels of irrigation or reducing water waste by ensuring adequate water supply in certain areas.

Earth Observation (EO) plays a pivotal role in precision irrigation by providing valuable data to monitor soil moisture levels and plant health. Satellites equipped with remote sensing instruments capture multispectral and thermal imagery, enabling the assessment of crop conditions and the availability of water in the soil. These images reveal vital information about vegetation vigour and stress. By analysing spectral bands related to plant health, such as the Normalized Difference Vegetation Index (NDVI), and thermal infrared data to detect temperature variations, farmers and irrigation specialists can precisely gauge when and where irrigation is needed. EO data also aids in identifying areas of over- or under-irrigation, optimizing water usage, increasing crop yield, and conserving resources in agricultural practices. This approach to precision irrigation not only enhances the sustainability of farming but also helps address global water scarcity challenges.

Precision irrigation is increasingly vital for optimizing water resources in agriculture while ensuring crop health and productivity. Remote sensing technologies serve as a cornerstone in meeting user requirements for precision irrigation by enabling accurate crop health assessment and water stress detection. This introduction delves into the essential user requirements, emphasizing the need for remote sensing solutions that provide timely, high-resolution data, and advanced analytics to guide precise irrigation strategies, reduce water waste, and bolster crop resilience in the face of changing environmental conditions.

One operational scenario was chosen for further development, it is crop health assessment and water stress detection. Water stress, as well as soil moisture monitoring is easily observable with EO data. The observation of the health of the crops are also easily observable with EO.

Table 9: Precision irrigation EO operational scenario

ID	EUSPA-EO-UR-AGR-0005
Application	Precision irrigation
Users	Farmers
User Needs	
Operational scenario	**Crop health assessment and water stress detection**
Size of area of interest	30-50m^2
Scale	10m
Frequency of information	Daily-weekly
Other (if applicable)	n.a.
Service Provider Offer	
What the service does	Help water management in agriculture based on plant water stress
How does the service work	Water stress in crops diminishes both photosynthesis and transpiration in plants, which can be measured via earth observation. EO is used to collect water stress detection data, satellite imagery and vegetation indices, of crops focusing on geographical areas where water stress detection is most likely to occur. This is done by 'sampling' 30-50m^2 grids (depending on plant species) of crops within larger (10s of ha) agricultural areas.
Service Provider Satellite EO Requirements	

Spatial resolution	10m
Temporal resolution	Daily-weekly
Data type / Spectral range	Microwave/synthetic aperture RADAR (SAR) and optical multispectral
Other (if applicable)	n.a.
Service Inputs	
Satellite data sources	Sentinel-1 and -2
Other data sources	Not satellite-based: field sensors, drones

Table 10: GNSS user requirements for precision irrigation

GNSS user requirements for precision irrigation		
Accuracy	Horizontal (cm-level/sub-metre level/m-level)	Sub-m-level
	Vertical	m-level
Availability	Canopy	No
	High/medium/low	Medium
Robustness	High/medium/low	High
Authentication	High/medium/low	Low
Integrity and reliability	High/medium/low	Medium
Size, weight, autonomy	Relevance (Yes/No)	Yes
	Autonomy (>hour)	>8
TTFaF	Seconds/minutes/>20min	A few seconds

2.4.1.3 Variable rate application – Type A application

Variable rate application, similar to precision irrigation, combines GNSS positioning with EO information to distribute varying amounts of agrichemicals and seeds across a given area. Discrepancies in performance and areas of lower crop yields can be identified and specifically targeted with extra input treatments (fertilisers, pesticides) or seeds by farmers. This can help improve overall performance and reduce agricultural input usage.

Variable Rate Application (VRA) solutions enable farmers to perform site-specific management of field variability and apply the appropriate amounts of inputs at a precise time and/or location. This is achieved through the utilisation of a variable-rate control system that is linked to the application equipment. Following the accurate mapping and measurement of characteristics such as acidity levels, and phosphorous, nitrogen or potassium content, farmers use VRA to match the quantity of fertilisers to the need. The two types of VRA are **map-based** and **sensor-based.**

Certain plant species have distinct nutrient requirements at different stages of their life cycle, making precise timing of fertilizer application critical for optimal growth and yield. Earth Observation (EO) technologies, such as satellite imagery and aerial drones, are invaluable in addressing this need. EO sensors can capture multispectral data that reveal variations in vegetation health and nutrient status. By analysing this information, farmers and agronomists can identify the specific growth stages of crops and determine when they require fertilization. EO is instrumental in the identification of harvest-ready plants. Different crops have unique visual and spectral signatures when they reach maturity, such as changes in leaf colour or canopy structure. EO sensors can detect these subtle variations and provide real-time information on the readiness of crops for harvest.

Variable rate application is a critical component of modern agriculture, aiming to optimize the timing of fertilization and harvest for improved crop yields and resource efficiency. EO technologies play a central role in meeting these user requirements by providing essential data for precision farming. This introduction explores the essential needs of users in variable rate application, highlighting the demand for accurate and timely EO data to guide decisions on when and where to apply fertilizers and when to commence harvesting. By harnessing the power of EO, farmers and agronomists can make data-driven choices, enhance crop quality and yield, reduce environmental impacts, and ultimately contribute to more sustainable and productive agricultural practices.

One operational scenario, fertilization timing, was identified for the application of VRA, it was chosen due to the fact that it has the highest uptake of EO data when compared to other potential operational scenarios and is based on the life cycle of the plant which is easily observed via EO. The primary absorbent components of plant leaves in visible and infrared spectra are chlorophyll concentration and water content. Assessing the spectral properties of leaves involves examining the concentration of chlorophylls and pigments (such as carotenoids, xanthophylls, and anthocyanins), which play a role in absorbing biochemicals, such as fertilizer.

Table 11: Variable rate application operational scenario 1

ID	EUSPA-EO-UR-AGR-0006
Application	Variable rate application
Users	Farmers, other stakeholders in the agricultural industry
User Needs	
Operational scenario	**Fertilization timing**
Size of area of interest	Sub-square-km level
Scale	10m
Frequency of information	Monthly
Other (if applicable)	n.a.

Service Provider Offer	
What the service does	Assess when fertilization of a crop is needed based on chlorophyll content and other vegetation indexes such as nitrogen status
How does the service work	Data regarding nitrogen absorption by crops and the nitrogen nutrition index is available, enabling farmers to make informed decisions about precise nitrogen applications, geolocalised fertilizer spreaders can utilize Sentinel-2 sensed data to apply fertilizer in fields, ensuring a balanced application based on the specific needs of crops in each zone.
Service Provider Satellite EO Requirements	
Spatial resolution	10m
Temporal resolution	Weekly-monthly
Data type / Spectral range	Multispectral, NIR
Other (if applicable)	n.a.
Service Inputs	
Satellite data sources	Sentinel-2
Other data sources	Not satellite-based: Field work and drones

Table 12: GNSS requirements for variable rate application- Low (spraying, spreading, harvesting bulk crops

GNSS user requirements for VRA Low		
Accuracy	Horizontal (cm-level/sub-metre level/m-level)	2.5-10cm
	Vertical	m-level
Availability	Canopy	No
	High/medium/low	High
Robustness	High/medium/low	Low
Authentication	High/medium/low	Low
Integrity and reliability	High/medium/low	High
Size, weight, autonomy	Relevance (Yes/No)	n.a.
	Autonomy (>hour)	n.a.
TTFaF	Seconds/minutes/>20min	A few seconds

Table 13: GNSS requirements for variable rate application-High (seeding, planting)

GNSS user requirements for VRA High		
Accuracy	Horizontal (cm-level/sub-metre level/m-level)	2.5-10cm
	Vertical	m-level
Availability	Canopy	No
	High/medium/low	High

GNSS user requirements for VRA High		
Robustness	High/medium/low	Low
Authentication	High/medium/low	Low
Integrity and reliability	High/medium/low	High
Size, weight, autonomy	Relevance (Yes/No)	n.a.
	Autonomy (>hour)	n.a.
TTFaF	Seconds/minutes/>20min	A few seconds

2.4.1.4 Biomass monitoring – Type B application (GNSS only)

Biomass monitoring in agriculture involves utilizing remote sensing, sensors, and GNSS technology to measure vegetation changes across fields from planting to harvest. Various factors like temperature, sunlight, precipitation, soil quality, and farming practices influence vegetation growth. Remote sensing, particularly in the red and infrared spectrum, along with GNSS data, helps map these changes over time, enabling crop monitoring and development assessment. Low-resolution imagery is suitable for regional inventories, while high-resolution imagery from satellites like Copernicus Sentinel 1 and 2 provides detailed local insights. GNSS aids in crop health inspection and map validation, requiring sub-meter accuracy achieved through SBAS. Additionally, GNSS-Reflectometry is emerging as a promising technique for monitoring both moisture levels and vegetation structure in agriculture.

Table 14: GNSS user requirements for biomass monitoring

GNSS user requirements for biomass monitoring		
Accuracy	Horizontal (cm-level/sub-metre level/m-level)	Sub-metre-level
	Vertical	m-level
Availability	Canopy	No
	High/medium/low	Medium
Robustness	High/medium/low	Low
Authentication	High/medium/low	Low
Integrity and reliability	High/medium/low	Medium
Size, weight, autonomy	Relevance (Yes/No)	n.a.
	Autonomy (>hour)	n.a.
TTFaF	Seconds/minutes/>20min	A few seconds

2.4.1.5 Soil condition monitoring – Type B application (GNSS only)

Soil condition monitoring stands as a pivotal practice in crop management, as crop yield variability correlates strongly with diverse soil characteristics across different field locations. Precision soil condition monitoring facilitates the development of tailored farming strategies that account for this site-specific variability. By gathering precise, location-specific data on soil attributes like fertility, soilborne diseases, and contamination, farmers can prevent both the excessive and insufficient application of nutrients and chemicals across various zones within their fields. Consequently, this approach directly contributes to enhanced crop productivity and reduced environmental impact.

The main user needs identified during the 2023 Agriculture UCP for satellite-based soil conditions monitoring is consistent and repetitive satellite imagery. Cloud coverage is a consistent issue and image repetition must be increased.

Precision soil condition monitoring relies on GNSS technology for georeferencing soil samples based on their collection site. These samples are subsequently analysed in specialized laboratories to measure and characterize various soil parameters. GIS software tools are employed to process, assess, and visualize the georeferenced soil data in maps. Precision soil condition monitoring primarily employs two key methods: grid sampling and zone management.

Table 15: GNSS user requirements for soil condition monitoring

GNSS user requirements for soil condition monitoring		
Accuracy	Horizontal (cm-level/sub-metre level/m-level)	Sub-metre to metre-level
	Vertical	Metre-level
Availability	Canopy	No
	High/medium/low	Medium
Robustness	High/medium/low	Low
Authentication	High/medium/low	Low
Integrity and reliability	High/medium/low	Low
Size, weight, autonomy	Relevance (Yes/No)	Yes
	Autonomy (>hour)	>8
TTFaF	Seconds/minutes/>20min	A few seconds

2.4.1.6 Automatic steering – Type A application (GNSS only)

Automatic steering is an advanced form of guidance that allows a vehicle to steer itself without constant driver intervention. It employs integrated electro-hydraulic control systems or mechanical devices within the cab to achieve this. The driver may still oversee turns, but the auto-guidance system handles steering during field passes, freeing the operator to focus on other tasks.

These systems consist of components such as a GNSS receiver, controller, user interface module, sensors, and a steering actuator, with prices ranging from €10,000 to €40,000. Higher-end systems use RTK correction, offering improved compensation for terrain-related vehicle attitude variations and more advanced control algorithms. RTK-based auto-steer guidance achieves repeatable accuracy as precise as 2.5 cm and finds applications in planting, harvesting, drip irrigation installation, and controlled traffic farming (CTF).

When commenting on GNSS performance during the UCP 2023, the participants stressed the needs for integrity, availability and cm-accuracy. Concerning RTK augmentation systems, users identified the inability to uptake these technologies due to lack of internet connectivity in rural areas, stating that advancements in those kind of augmentation systems cannot be applied in areas lacking connectivity. Consistent and stable operations of GNSS networks are a necessity for automatic steering. Concerning EO higher revisit times was also identified as a user need for automatic steering and other precision agriculture applications.

Table 16: GNSS user requirements for automatic steering

GNSS user requirements for automatic steering		
Accuracy	Horizontal (cm-level/sub-metre level/m-level)	Down to 2.5cm (pass to pass)
	Vertical	m-level
Availability	Canopy	No
	High/medium/low	High
Robustness	High/medium/low	Medium
Authentication	High/medium/low	Low
Integrity and reliability	High/medium/low	High
Size, weight, autonomy	Relevance (Yes/No)	n.a.
	Autonomy (>hour)	n.a.
TTFaF	Seconds/minutes/>20min	A few minutes

2.4.1.7 Farm machinery guidance – Type B application (GNSS only)

Farm Machinery Guidance systems have significantly enhanced farm field operations such as spraying, fertilising, planting and harvesting. They utilise corrected GNSS signals for the precise determination of the deviations of the tractor from a reference line, thus aiding farmers in driving on the desired path. By reducing overlaps and skips between adjacent passes on the field, guidance systems enable increased driving accuracy, improve in-field efficiency, and allow working at night or under low-visibility conditions.

GNSS-based guidance systems offer two primary modes of operation: prior pass guidance and fixed-line guidance. In the prior pass guidance mode, the operator manually steers the machinery along the initial path across the field. Once this initial pass is recorded, all subsequent passes are executed at a consistent distance from the recorded prior pass. Typically, this distance corresponds to the equipment's swath width. The prior pass method provides flexibility, allowing for effective adaptation to the field's shape and contours. In contrast, fixed-line guidance entails the initial path along an AB line, connecting two predefined points on the field. Similar to prior pass guidance, all subsequent passes are defined by a specific offset distance, typically equivalent to the equipment's swath width, multiplied by an integer value. Unlike prior pass guidance, where each pass is related to its predecessor, fixed-line guidance links each pass to the AB line, the designated offset distance, and the respective integer value. This approach offers an alternative strategy for precision field navigation.

During the 2023 UCP it was noted that the needs for integrity, availability and accurate positioning are the same as those needed for the application Automatic Steering.

Table 17: GNSS user requirements for farm machinery guidance

GNSS user requirements for farm machinery guidance		
Accuracy	Horizontal (cm-level/sub-metre level/m-level)	10-30cm (pass to pass)
	Vertical	m-level
Availability	Canopy	No
	High/medium/low	High
Robustness	High/medium/low	Low
Authentication	High/medium/low	Low
Integrity and reliability	High/medium/low	High
Size, weight, autonomy	Relevance (Yes/No)	n.a.
	Autonomy (>hour)	n.a.
TTFaF	Seconds/minutes/>20min	A few minutes

2.4.1.8 Farm management systems – Type B application (GNSS only)

Both EO and GNSS can inform part of an overall farm management system, considering various types of practical, operational and financial data to help in the holistic management of a farm. It is enabled through the utilisation of telematics solutions. Telematics systems make combined use of electronic communication networks and GNSS receivers that are typically embedded in modern farm machinery to monitor and report key information on the status of farming equipment. This includes information on machine location, hours of operation, maintenance status, data related to the specific PA process carried out and trouble codes. Modern applications enable the simultaneous tracking of multiple machines. The accuracy required for this application is at the metre or sub-metre level and can be satisfied by SBAS.

The following table offers an overview of the user requirements only related to GNSS.

Table 18: GNSS user requirements for farm management systems

GNSS user requirements for farm management systems		
Accuracy	Horizontal (cm-level/sub-metre level/m-level)	Sub-metre to metre-level
	Vertical	Metre-level
Availability	Canopy	Yes
	High/medium/low	High
Robustness	High/medium/low	Medium
Authentication	High/medium/low	Medium
Integrity and reliability	High/medium/low	High
Size, weight, autonomy	Relevance (Yes/No)	n.a.
	Autonomy (>hour)	n.a.
TTFaF	Seconds/minutes/>20min	A few seconds

2.4.1.9 CAP monitoring – Type B application (GNSS only)

The Common Agricultural Policy (CAP) establishes the legislative framework around a system of subsidies and other support programmes for agricultural activities in the European Union. Since 1962, and throughout a series of reforms, the CAP has not only supported farmers in their efforts to supply EU citizens with good quality and safe food; it has also been guiding the implementation of sustainable agriculture across the EU. In particular, the enforcement of certain agricultural practices mandated by the CAP, such as the maintenance of permanent grassland or the diversification of crop species, can all be monitored and enforced using EO data or geotagged photos using GNSS.

Table 19: GNSS user requirements for CAP monitoring - Geotagged photos

GNSS user requirements for geo tagged photos		
Accuracy	Horizontal (cm-level/sub-metre level/m-level)	Metre-level
	Vertical	Metre-level
Availability	Canopy	Yes
	High/medium/low	High
Robustness	High/medium/low	Low
Authentication	High/medium/low	High
Integrity and reliability	High/medium/low	Medium
Size, weight, autonomy	Relevance (Yes/No)	n.a.
	Autonomy (>hour)	n.a.
TTFaF	Seconds/minutes/>20min	A few minutes

2.4.1.10 Field Definition – Type B application (GNSS only)

The utilization of Global Navigation Satellite Systems (GNSS) in agriculture has revolutionized field detection and management. GNSS technology, such as GPS and Galileo, provides precise location data that enables farmers to accurately identify and delineate field boundaries, monitor crop health, optimize resource usage, and enhance overall agricultural efficiency. This introduction explores the critical role of GNSS in field detection within the agricultural sector, emphasizing its impact on precision farming practices and sustainable agricultural development.

In the frame of the Common Agricultural Policy (CAP) budgetary support is provided to farmers that live up to strict standards relating to food safety, environmental protection and animal health and welfare. The size however of the support is directly related to the land parcels for which farmers request financial aid and the percentage/type of farmed areas within these parcels.

Table 20: GNSS user requirements for field definition

GNSS user requirements for field definition		
Accuracy	Horizontal (cm-level/sub-metre level/m-level)	Sub-metre-level
	Vertical	Metre-level
Availability	Canopy	Yes
	High/medium/low	Medium
Robustness	High/medium/low	Low
Authentication	High/medium/low	High
Integrity and reliability	High/medium/low	Low
Size, weight, autonomy	Relevance (Yes/No)	Yes
	Autonomy (>hour)	>5
TTFaF	Seconds/minutes/>20min	A few seconds

2.4.1.11 Livestock wearables – Type B application

Livestock tracking involves the use of GNSS-receivers embedded on the collars of individual animals (most commonly cows), that are used to track their behaviour regarding grazing habits, thus enabling optimised grassland and food resources utilisation. These innovative wearables are designed to address specific user requirements, such as real-time tracking of animal movement, health monitoring, and environmental conditions. In combination with other sensors (mortality sensor, thermometer, 3-axis accelerometer), GNSS receivers are also used to detect cow fertility or illness. This section explores the essential GNSS user requirements for livestock wearables, emphasizing the need for accurate location data, seamless connectivity, and actionable insights to enhance animal well-being, productivity, and overall farm management practices.

Table 21: GNSS user requirements for livestock wearables

GNSS user requirements for livestock wearables		
Accuracy	Horizontal (cm-level/sub-metre level/m-level)	Metre-level
	Vertical	Metre-level
Availability	Canopy	Yes

GNSS user requirements for livestock wearables		
	High/medium/low	High
Robustness	High/medium/low	Low
Authentication	High/medium/low	Low
Integrity and reliability	High/medium/low	Medium
Size, weight, autonomy	Relevance (Yes/No)	Yes
	Autonomy (>hour)	>24
TTFaF	Seconds/minutes/>20min	A few seconds

2.4.1.12 Type C applications

These applications correspond to those not selected for further investigations under SC1 and which were not addressed in the previous RURs. The content of the preceding section will be limited to a description of the application(s). These applications might be analysed, and corresponding sections developed in the next editions of the RURs. Please note that the following applications have overlapping use cases with the applications chosen for further investigation in this report and are covered in some aspect.

- **Carbon capture & content assessment**: The monitoring of agricultural vegetation and grassland cover through EO can help inform carbon sink capacity of different terrains. EO can also be used to monitor the maintenance of agricultural practices which pertain to CO_2 sequestration.
- **Environmental impact monitoring**: EO can be used to monitor greenhouse gas emissions associated with agricultural activities; evaluate the impact of fertilisation on the environment; explore the potential of carbon sequestration in agricultural land cover; and assess the level of biodiversity present in agricultural lands.
- **Vegetation monitoring**: EO enables the monitoring of vegetation coverage and health (through the generation of various indices such as NDVI). This information can be used to understand land cover statistics and provide inputs for efficient farm management practices.
- **Asset monitoring**: GNSS provides insightful telematics data from tractors and other farm vehicles/assets to help increase efficiency when conducting operations, monitor workforce activity and reduce costs.
- **Pastureland management**: EO can monitor the growth and maintenance of grasslands. Mowing and grazing activities on grassland can be detected and verified using EO.
- **Climate services for agriculture**: Long term forecasting and monitoring of climate variables relevant to agriculture using remotely sensed data. Air quality and land temperature can be understood through the use of EO, which in turn can help in understanding how our climate could affect future harvests and yields.
- **Weather forecasting for agriculture**: Short term weather forecasting. Air quality, land temperature and cloud cover can all be understood using EO, which in turn can help form weather forecasts relevant to precise locations. This allows farmers to plan operations such as irrigation or fertilizer scheduling.

2.4.2 Limitations of GNSS and EO

GNSS Limitations

GNSS serves as an enabling technology that facilitates the execution of precision agricultural practices as well as asset management and farm management practices. However, a number of limitations apply, which are typically overcome by employing the complementary technologies described in the previous section or by following best practices regarding the type of GNSS equipment used.

The primary limitations often stem from challenges posed by the agricultural operational environment. In areas with natural hindrances like tree canopies or artificial obstacles such as buildings or highly reflective surfaces, as well as regions characterized by intricate topographies, issues such as interference, multipath effects, and restricted GNSS signal availability need to be mitigated through the integration of complementary technologies. For instance, although GNSS has demonstrated effectiveness under vegetation cover, signal loss can be significant depending on the type and moisture content of the vegetation.

Furthermore, concerning RTK solutions, the accuracy of positioning diminishes based on the distance between the rover receiver and the base station. The requirement is that a base station is located within 10km at all times for a single station, limiting the effectiveness in large farms. While the upper limit of base station distance can be 50km if a network of RTK stations is available (NRTK), users indicate a preference of lower ranges to ensure accuracy.

While network RTK solutions typically overcome this challenge, they are costly to implement, and **remote geographical areas** tend to lack access to such solutions. Uptake of these solutions is particularly challenging in developing countries, which face obstacles in implementing high-precision applications like automatic steering due to lack of necessary infrastructure. Additionally, inadequate GSM coverage (which may be the only available connecting technology in remote areas due to old infrastructure) especially prevalent in developing markets with expansive farms (e.g., Chile, Kazakhstan, and Iran), may hinder the transmission of RTK corrections. PPP-RTK methods, either PPP standalone or the combination of the two methods can help to overcome challenges related to the distance from base stations.

Another important limitation, related however to **cost-benefit considerations** rather than technical constraints, is that of applying PA solutions in **small-to-medium sized farms**. As rule of thumb, the experts indicate that technologies with an average cost to the farmer higher than 10 euros per hectare are considered too expensive. Therefore, affordability is an important aspect for a precision farming solution to be actually adopted, especially in Europe where the average size of farms is quite small, limiting economies of scale.

EO Limitations

Cloud cover for soil monitoring is an identified limitation, as well as incompatibility with different data sets and a lack of standardization of data.

More specifically for crop yield forecasting, which is an important application due to its relationship with the insurance sector, as well as for global food prices, several limitations were identified. Temporal resolution of EO data provides a limitation when considering the application of crop yield forecasting as harvest times approach data must be collected on a daily basis. Another obstacle concerning yield forecasting is when using satellite and weather data as proxies for yield estimation on the regional level is delineating crop boundaries. This is an issue in countries where the crop field boundary and crop-specific layers are not available. Cloud cover was as well among the listed challenges when estimating crop yield according to some stakeholders.

The average farmer relies on enterprises providing solutions via EO data rather than performing processes themselves. Acquiring high-resolution satellite imagery may involve costs, limiting access for smaller-scale farmers or organizations with budget constraints.

2.4.3 Prospective use of GNSS and EO in Agriculture

The dominant technological trends driving the use of **GNSS** in agriculture include:

- Affordable and dependable Satellite-Based Augmentation System (SBAS) solutions, which are expanding markets for entry-level users and facilitating the adoption of advanced solutions.
- The increased availability of GNSS signals in the multi-constellation era, enhancing performance and reliability in challenging environments.
- The proliferation of dual-frequency receivers and authentication/high-accuracy options provided by Galileo HAS, supporting various existing and potential applications.
- Reduced prices for Real-Time Kinematic (RTK) and Differential GNSS (DGNSS) solutions, coupled with the emergence of Precise Point Positioning (PPP) solutions, are driving broader adoption among farmers.
- Fusion and integration with other technologies within Whole-Farm Management Solutions (Integrated Farm Management or Farm Management Information Systems).

Considering these overarching trends, the following section provides a concise overview of the expected evolution of GNSS utilization in agriculture.

- **Innovations in Galileo High Accuracy Service**: Several analyses indicate that the Galileo High Accuracy Service (HAS) E6-B signal is well-suited for transmitting Precise Point Positioning (PPP) information. It ensures a sufficient update rate to achieve decimetre-level accuracy when combined with a user PPP processing algorithm and under nominal conditions. HAS permits the transmission of different data from various satellites, significantly increasing the total bandwidth. While HAS is not currently at the same level as commercial PPP solutions, it can be used for Low Variable Rate technology applications in the agriculture sector. Lastly, the authentication feature of Galileo HAS holds particular relevance in sectors governed by regulatory considerations and for validating documentation processes, as noted in [RD41].

Integrated Farm Management Solutions. A prominent trend in technology-driven agriculture is the integration of data and technologies into 'one-stop-shop' solutions. This includes satellite remote sensing, RPAS (Remotely Piloted Aircraft Systems), Big Data analytics, Internet-of-Things, and Future ICT solutions within a highly digitized and interconnected framework. These technologies capture spatial and temporal variability data of crops across farms, facilitating informed decision-making and strategy development for farmers. The information-driven approach extends beyond individual farms, offering valuable insights applicable to diverse regions and farm types. Integrated farm management solutions combine real-time modelling, data collection, legal guidance, and expert systems, tailoring practices for individual farms or groups. GNSS plays a crucial role in these systems by enabling the "site-specific" dimension of collected data. Challenges in implementing integrated farm management solutions include extracting useful information from diverse data sources, interoperability issues, and connectivity challenges. Despite these challenges, the future of integrated farm management appears promising, with a projected increase from 10% to 40%, especially in high-end markets like Germany.

Robotics. The use of automation and robots is expected to grow in the future for various tasks in the farm. Apart from the previously mentioned RPAS, fully autonomous or robotic machines are now being used more in small-scale, high-profit-margin agriculture, like growing wine grapes, nursery plants, and certain fruits and vegetables.

In Europe, research projects such as GALIRUMI, Robofarm, Clever Robots for Crops, and Sweeper are exploring different ways robots can be used in farming. The idea behind using robots in precision farming is to increase crop yields by optimizing growth and harvesting processes. This approach also aims to reduce the need for fertilizers and pesticides while enhancing soil quality through more precise interventions.

The robots operate autonomously in the field, thanks to automatic steering technologies and high-precision positioning provided by GNSS solutions. Japan is at the forefront of introducing robotic solutions due to its strong global position in robotics overall. In the United States, particularly in California where high-value crops are cultivated, there is also an increasing use of autonomous machines.

Satellite-based Remote sensing. Remote sensing techniques play a vital role in providing timely and accurate data for various aspects of agricultural production. Technologies such as yield mapping, forecasting, weather monitoring, soil mapping, and land cover changes. This involves utilizing a combination of satellite imagery, meteorological data, agrometeorological and biophysical modelling, and statistical analyses. High to low-resolution, multispectral optical sensors are employed to monitor critical parameters related to crop and vegetation health, including crop type, area, Leaf Area Index, and Normalized Difference Vegetation Index (NDVI). Assimilation models, coupled with multi-temporal Synthetic Aperture Radar (SAR) data, contribute to optimizing irrigation practices and fertilizer utilization, as well as monitoring soil moisture and composition.

Initiatives like Copernicus, with Sentinel missions, offer free and open data, significantly advancing remote sensing in precision agriculture. Sentinel-2 provides a 10-meter resolution with a 5-day revisit time, suitable for individual land parcels and crop dynamics monitoring. The Sentinel-1 SAR mission enables remote sensing in all weather conditions. Copernicus enhances the delivery of weather and climate-related information crucial for farmers.

Besides Copernicus, global initiatives like the US FAS Global Agricultural Monitoring Project, FAO's Global Information and Early Warning System (GIEWS), JRC's MARS, and the Crop Watch Program in China provide crop monitoring, alerts, and forecasts. In conjunction with GNSS, remote sensing is pivotal in Biomass Monitoring and Soil Sampling for creating prescription maps and crop management zones in precision agriculture. The emerging use of GNSS reflectometry in satellite-based remote sensing applications is also highlighted.

2.4.4 Summary of drivers for user requirements

As discussed in previous chapters, there is a wide range of applications in agriculture where GNSS serves as either the primary facilitator or a crucial component. These applications can be broadly classified into four categories: Guidance systems, Variable Rate Applications, Site-Specific Data Analysis applications, and tracking/delineation. Each category has distinct GNSS performance requirements, and meeting these requirements is crucial from the user's perspective for accepting the proposed technology.

Most in-field cultivation operations necessitate accuracy levels ranging from centimetres to sub-meters (pass-to-pass). This is achieved through RTK, DGNSS, or SBAS-based solutions. Operations requiring a return to precise locations at different times demand high repeatability or minimal GNSS drifts. In addition to accuracy-related requirements, users are interested in increased signal availability, reliability, and, in the future, the authenticity of GNSS signals. Beyond the "quantitative" requirements, several "qualitative" factors, primarily linked to social or economic aspects, significantly impact the adoption of various solutions. Factors such as farmer education, age, income, and geographic location play a pivotal role in the acceptance of technological solutions.

The greatest factor influencing the acceptance of GNSS-based precision agriculture solutions is the potential for increased profitability. In addition to this, several other key parameters play a pivotal role in driving the adoption and formulation of user requirements for GNSS-based precision agriculture solutions. These factors encompass optimizing machine utilization (through automatic machine setting and steering), acquiring larger volumes of reliable site-specific information (such as yield mapping and soil sampling), minimizing overlapping and skipping costs, reducing labour and stress (via guidance systems), optimizing input utilization (utilizing nitrogen sensors, geo-referenced soil sampling, and Variable Rate (VR) maps), and facilitating integrated farm management solutions (including machine monitoring).

Policies and regulatory frameworks are also among the top drivers for the adoption of space-based solutions in agriculture. PA solutions contribute not only to enhanced competitiveness of the agricultural sector (increased crop yield and profitability) but also to sustainable utilisation of resources and minimisation of environmental impact. In that context, the specific policy measures and regulation put forward to ensure the fulfilment of long-term objectives, not only benefit from the uptake of innovative technologies such as GNSS but also act as a key driver for innovation.

2.4.5 Additional User Requirement considerations

2.4.5.1 Guidance systems

GNSS receiver performance: farm machinery guidance solutions should offer a pass-to-pass accuracy of 10-30 cm ensured through SBAS or DGNSS. Automatic steering solutions, as well as advanced machinery guidance (i.e., planters, weeders), require cm-level (2.5 - 10 cm) accuracy ensured via RTK solutions. For activities where the farmer returns to an exact location at a different time (e.g., strip tillage, Control Traffic Farming) high repeatability is also necessary, translating into smaller effects from GNSS drift. RTK has essentially no impact from GNSS drift, whereas DGNSS and SBAS can have drifted 4m or less [RD14].

The current agriculture segment applications that fall under these requirements are **Automatic Steering**, and **Farm Machinery Guidance**. Apart from accuracy requirements, availability, and continuity in the reception of GNSS signals, specially to mitigate operating environment and multi-path impacts are critical. In view of the automation/robotisation trends requirements on high-accuracy, availability and continuity will become increasingly stringent.

2.4.5.2 Variable Rate Applications

The widespread adoption of variable rate applications depends primarily on the development of business strategies that can justify the costs associated with investing in these expensive and complex technologies. This justification for farmers and other stakeholders in the agriculture sector rests on the potential benefits derived from reduced input costs and enhanced yield production. For instance, there is currently a lack of a standardized business approach to evaluating the profitability of variable rate applications compared to the uniform application of N-fertilizers.

Additionally, decision support tools must be capable of implementing site-specific solutions based on prescription maps for variable inputs. GNSS accuracy requirements vary depending on the specific farming processes involved. Activities like spreading, spraying, and harvesting bulk crops necessitate sub-meter to decimetre accuracy, which can be provided by SBAS/DGNSS. Conversely, precision-demanding tasks such as seeding, planting, and weeding require centimetre-level accuracy, achievable through RTK.

Finally, seamless activation and deactivation of spreaders based on the precise location of operation. Essential considerations also include ISOBUS compliance and the visualization of variable rate application prescription maps.

The applications previously described that fall within these requirements are **Precision Irrigation**, **Variable Rate Application**.

2.4.5.3 Site Specific Data Analysis Applications

Site specific Data analysis applications that rely on different, site-specific, geo-referenced data, through (mainly) optical ground-based sensors, remote sensors, or physical sample sensors. This group of applications includes the previously described **Biomass monitoring**, **Crop Yield Forecasting**, **Soil Conditions Monitoring**, and **Vegetation Monitoring**.

In all three cases, the positioning accuracy required falls in the sub-metre regime met by SBAS-based solutions. Of equal importance to positioning accuracy is the quality of the data collected either by optical (e.g., nitrogen and crop health sensors) and precision (mass flow, soil moisture, depth, magnetic, etc.) sensors on the ground, or of those onboard satellites or RPAS. Process automation (e.g., in the case of soil sampling), data compatibility and handling, ease of documentation and integration within whole-farm management (e.g., yield maps or crop management zones are relevant for VRA) are also important to farmers.

2.4.5.4 Tracking and Delineation

This grouping contains monitoring and tracking applications **Farm Management Systems** and **Livestock Wearables** and **Field Definition**. GNSS accuracy requirements vary depending on the application from sub-metre to metre level; they can be typically satisfied by SBAS-enabled or DGNSS solutions.

Farm Management Systems requires the determination of the position of several farm assets with sub-metre to metre accuracy. A key aspect is a compatibility with existing devices mounted on the machines, thus avoiding the need for additional investment.

In the case of **Livestock Wearables**, GNSS accuracy requirements are less demanding (metre level) and can be satisfied by SBAS or even GNSS solutions. The functions of the collar within which the tracker is also embedded are of key importance. They should enable determination of the position using alternative tools in case of GNSS un-availability (e.g., GPRS, VHF), permit geo-referencing of data collected by other sensors (thermometer, mortality sensor, etc.) and deliver stimuli to constrain animals within specific boundaries (virtual fencing). Regarding adoption requirements, pricing remains a key issue.

Concerning the **Field Definition**, the specifications are predominantly influenced by policy measures and regulations, both at the EU level (CAP) and on a national scale. Consequently, the distinct accuracy criteria mandated by various Member States necessitate the adoption of diverse correction services to meet these requirements. Farmers are actively seeking GNSS receivers that align with these specifications for multifaceted applications. The same nexus of policy and regulation extends to GNSS accuracy prerequisites for geo-traceability, where achieving meter-level accuracy is deemed sufficient.

2.4.5.5 CAP Monitoring

CAP Monitoring is a special case among applications as it blends multiple technologies relying on more than GNSS and EO based solutions, but also financial schemes provided for by the specified authorities. As previously described in Section 2.3.1, CAP mandates the use of Area Monitoring Systems (AMS) across all Member States in order to promote sustainability and food security. In the Context of Space-based solutions applications such as the maintenance of permanent grassland or the diversification of crop species, can all be monitored and enforced using EO data or geotagged photos using GNSS.

Several objectives pertinent to precision agriculture have been introduced, encompassing goals such as enhancing agricultural competitiveness, promoting innovation, increasing farm income, delivering environmental public goods, and addressing climate change mitigation and adaptation. Additionally, several articles within the CAP outline measures that either currently benefit or have the potential to benefit from applications enabled or supported by GNSS.

2.5 User Requirements Specification

The chapter provides a synthesis of the EO user requirements described in section 2.4.1. The content of this section will be updated, completed and expanded by EUSPA in the next releases of the RUR based on the results of further investigations discussed and validated in the frame of the UCP.

2.5.1 Synthesis of Requirements Relevant to EO

This section will only address the applications of Type A (identified in Chapter 2). The applications of Type B and C will not be covered in the current version of the RUR.

ID	Application	Users	User needs					Service provider offer		Service provider satellite EO requirements				Service inputs	
			Operational scenario	Size of area of interest	Scale	Frequency of information	Other (if applicable)	What the service does	How does the service work	Spatial resolution	Temporal resolution	Data type/ spectral range	Other (if applicable)	Satellite data sources	Other data sources, *not satellite-based*
EUSPA-EO-UR-AGR-0001	*Crop yield forecasting*	Farmers, agricultural policy makers, insurance companies, commodity traders	Crop yield forecasting: **rice**	Area of rice fields (typically 150-300 ha)	30m	Bi-weekly	Data on precipitation, mean temperature	Remote sensed estimation of rice yield throughout the 120-day growth period of the rice	Chlorophyll plays a crucial role in the photosynthetic activity of the rice plant, contributing to the production of carbohydrates for the formation of rice plant tissue and grains. It has a notable impact on the rice yield during harvesting. Consequently, there is a close association between the chlorophyll content of the biomass and rice yield. Digital image processing: NDVI and therefore crop yield forecasting is assessed via measurements of plant height and leaf greenness throughout the growth period of the rice.	10-30m	Weekly	Multispectral, Enhanced thematic mapper plus (EMT+)	n.a.	Sentinel-1 and 2, Scanning radiometer, AVHRR, multispectral bands, NDVI, RGB	Not satellite-based: field sensors, drones, airborne LiDAR and RADAR sensors
EUSPA-EO-UR-AGR-0002	*Crop yield forecasting*	Farmers, agricultural policy makers, insurance companies, commodity traders	Crop yield forecasting: **soybeans**	Area of soybeans fields (typically 150-300 ha)	10-30m	Weekly	Day-time land surface temperature and average precipitation	To predict soybean yield utilizing vegetation indices like NDVI and EVI, along with independent variables such as land surface temperature and precipitation.	Crop yield is forecasted from data collected about the vegetation indexes, average land surface temperature and precipitation using machine learning algorithms.	10m	Weekly	Multispectral	n.a.	Sentinel-1 and -2, MODIS	Not satellite-based: field sensors, drones, airborne LiDAR and RADAR sensors, MODIS surface Reflectance products
EUSPA-EO-UR-AGR-0003	*Crop yield forecasting*	Farmers, field suppliers insurance companies, commodity traders	Crop yield forecasting scenario: **cereal grains**	Area of cereal grains fields (typically big farms, 100 ha and bigger)	10m for centre of field and 5m for field boundaries	Weekly, Daily during harvesting periods	n.a.	Crop monitoring software, builds field boundaries and estimates crop yields starting 2-3 months before harvest time	The service uses EO data to define fields and estimate crop yield of cereal grains.	5-10m	Weekly/daily	Multispectral	n.a.	Sentinel-1 &-2, Eumetsat, Planet	n.a.

ID	Application	Users	User needs					Service provider offer		Service provider satellite EO requirements				Service inputs	
			Operational scenario	Size of area of interest	Scale	Frequency of information	Other (if applicable)	What the service does	How does the service work	Spatial resolution	Temporal resolution	Data type/ spectral range	Other (if applicable)	Satellite data sources	Other data sources, *not satellite-based*
EUSPA-EO-UR-AGR-0004	*Crop yield forecasting*	Farmers, agricultural policy makers, insurance companies, commodity traders	Monitoring of soil health parameters for crop yield forecasting	Sub-square-km level	10m	Weekly/monthly	n.a.	Keeping track of soil health due to its impact on overall crop yield	Three soil health parameters, soil moisture, soil salinity and soil organic carbon, are utilized to estimate yield forecast in wheat crops. Soil moisture is estimated from optical, thermal, and microwave remote sensors, soil salinity is deduced from band rationing multispectral bands from multispectral measurements, high moisture content in soil is also related to higher organic matter.	10m	Weekly/monthly	Multispectral, SAR backscatter, thermal, microwave	n.a.	Sentinel-1 and -2	Not satellite-based: field sensors, drones, airborne LiDAR and RADAR sensors
EUSPA-EO-UR-AGR-0005	*Precision irrigation*	Farmers	Crop health assessment from water stress detection	30-50m^2	10m	Daily-weekly	n.a.	Help water management in agriculture based on plant water stress	Water stress in crops diminishes both photosynthesis and transpiration in plants, which can be measured via earth observation. EO is used to collect water stress detection data, satellite imagery and vegetation indices, of crops focusing on geographical areas where water stress detection is most likely to occur. This is done by 'sampling'30-50m^2 grids (depending on plant species) of crops within larger (10s of ha) agricultural areas.	10m	Daily-weekly	Microwave/ synthetic aperture RADAR (SAR) and optical multispectral	n.a.	Sentinel-1 and -2	Field sensors, drones

ID	Application	Users	User needs					Service provider offer		Service provider satellite EO requirements				Service inputs	
			Operational scenario	Size of area of interest	Scale	Frequency of information	Other (if applicable)	What the service does	How does the service work	Spatial resolution	Temporal resolution	Data type/ spectral range	Other (if applicable)	Satellite data sources	Other data sources, *not satellite-based*
EUSPA-EO-UR-AGR-0006	*Variable rate application*	Farmers and other stakeholders in the agricultural industry	Fertilization timing	Sub-square-km level	10m	Monthly	n.a.	Assess when fertilization of a crop is needed based on chlorophyll content and other vegetation indexes such as nitrogen status	Data regarding nitrogen absorption by crops and the nitrogen nutrition index is available, enabling farmers to make informed decisions about precise nitrogen applications, geolocalised fertilizer spreaders can utilize Sentinel-2 sensed data to apply fertilizer in fields, ensuring a balanced application based on the specific needs of crops in each zone.	10m	Weekly-monthly	Multispectral, NIR	n.a.	Sentinel-2	Not satellite-based: Field work and drones

2.5.2 Sources for the requirements

As this document is mostly based on interviews, the requirements come from the feedback from experts and various UCP participants. The sources vary with the specific application. The majority of input came from the people interviewed. The community participated as well via the UCP.

User requirements were also collected via secondary sources outside of interviews and these are listed as follows:

- Ali, A. M., Abouelghar, M., Belal, A. A., Saleh, N., Yones, M., Selim, A. I., Amin, M. E. S., Elwesemy, A., Kucher, D. E., Maginan, S., & Savin, I. (2022). Crop Yield Prediction Using Multi Sensors Remote Sensing (Review Article). In *Egyptian Journal of Remote Sensing and Space Science* (Vol. 25, Issue 3, pp. 711–716). Elsevier B.V. https://doi.org/10.1016/j.ejrs.2022.04.006
- Khaki, S., Pham, H., & Wang, L. (2021). Simultaneous corn and soybean yield prediction from remote sensing data using deep transfer learning. *Scientific Reports*, *11*(1). https://doi.org/10.1038/s41598-021-89779-z
- Lowenberg-Deboer, J., & Erickson, B. (2019). Setting the record straight on precision agriculture adoption. In Agronomy Journal (Vol. 111, Issue 4, pp. 1552–1569). American Society of Agronomy. https://doi.org/10.2134/agronj2018.12.0779
- Muruganantham, P., Wibowo, S., Grandhi, S., Samrat, N. H., & Islam, N. (2022). A Systematic Literature Review on Crop Yield Prediction with Deep Learning and Remote Sensing. In <i>Remote Sensing</i> (Vol. 14, Issue 9). MDPI. https://doi.org/10.3390/rs14091990</div>
- Nazir A, Ullah S, Saqib ZA, Abbas A, Ali A, Iqbal MS, Hussain K, Shakir M, Shah M, Butt MU. Estimation and Forecasting of Rice Yield Using Phenology-Based Algorithm and Linear Regression Model on Sentinel-II Satellite Data. Agriculture. 2021; 11(10):1026. https://doi.org/10.3390/agriculture11101026
- Nuarsa, I. W., Nishio, F., & Hongo, C. (2011). Rice Yield Estimation Using Landsat ETM+ Data and Field Observation. *Journal of Agricultural Science*, *4*(3). https://doi.org/10.5539/jas.v4n3p45
- Perez-Ruiz, M., & K., S. (2012). GNSS in Precision Agricultural Operations. In *New Approach of Indoor and Outdoor Localization Systems*. InTech. https://doi.org/10.5772/50448
- Radočaj, D., Plaščak, I., & Jurišić, M. (2023). Global Navigation Satellite Systems as State-of-the-Art Solutions in Precision Agriculture: A Review of Studies Indexed in the Web of Science. *Agriculture*, *13*(7), 1417. https://doi.org/10.3390/agriculture13071417
- Radočaj, D., Jurišić, M., & Gašparović, M. (2022). The Role of Remote Sensing Data and Methods in a Modern Approach to Fertilization in Precision Agriculture. In Remote Sensing (Vol. 14, Issue 3). MDPI. https://doi.org/10.3390/rs14030778
- Schwalbert, R. A., Amado, T., Corassa, G., Pott, L. P., Prasad, P. V. V., & Ciampitti, I. A. (2020). Satellite-based soybean yield forecast: Integrating machine learning and weather data for improving crop yield prediction in southern Brazil. Agricultural and Forest Meteorology, 284. https://doi.org/10.1016/j.agrformet.2019.107886
- Segarra, J.; Buchaillot, M.L.; Araus, J.L.; Kefauver, S.C. Remote Sensing for Precision Agriculture: Sentinel-2 Improved Features and Applications. Agronomy 2020, 10, 641. https://doi.org/10.3390/agronomy10050641
- Tripathi, A., Tiwari, R. K., & Tiwari, S. P. (2022). A deep learning multi-layer perceptron and remote sensing approach for soil health-based crop yield estimation. *International Journal of Applied Earth Observation and Geoinformation*, *113*. https://doi.org/10.1016/j.jag.2022.102959
- Virnodkar, S. S., Pachghare, V. K., Patil, V. C., & Jha, S. K. (2020). Remote sensing and machine learning for crop water stress determination in various crops: a critical review. In *Precision Agriculture* (Vol. 21, Issue 5, pp. 1121–1155). Springer. https://doi.org/10.1007/s11119-020-09711-9

- Wang, X., Huang, J., Feng, Q., & Yin, D. (2020). Winter wheat yield prediction at county level and uncertainty analysis in main wheat-producing regions of China with deep learning approaches. *Remote Sensing*, *12*(11). https://doi.org/10.3390/rs12111744

3 FORESTRY

3.1 Executive Summary

This report aims to enhance the understanding of market evolution, strengths, limitations, key technological trends and main drivers related to the uptake of GNSS and EO data and services across the forestry domain. These elements are essential to frame the appropriate technology and service offering development against the requirements of the respective users.

Key trends and market evolution

The forestry market is undergoing significant evolution driven by the following key trends:

- Protection and conservation of the forestry ecosystem
- Big data
- Application of smart technologies to forestry

Forestry protection and conservation efforts have risen to the forefront of legislative efforts as more information about the negative impacts of deforestation on the local, and global, climate and ecosystems. There is a push by governmental and environmental organizations to implement regulations to preserve biodiversity and ecosystems while ensuring the long-term viability of timber resources. These measures are reshaping the forestry market by influencing logging practices, timber sourcing strategies and consumer preferences for sustainably sourced wood products.

The adoption of smart technologies and the advent of bit data is transforming how forestry management is operated. Large amounts of data made available from EO and remote sensing technologies and the ability to manipulate this data into useful information about different aspects of their forestry resources, enables stakeholders in the forestry industry to make more accurate and informed decisions about the practices that will increase productivity, reduce costs, and improve the sustainability of forestry practices. A full overview of the forestry market evolution is presented in section 3.2.1.

Current and prospective use of GNSS and EO in the forestry segment

The recent trends indicate that the market will focus on the deepening of technological integration to enhance the traceability of wood and other forest products, the monitoring of forests' health, trafficability prediction, and forest regeneration.

Drivers for users' requirements

In addition to the key market trends mentioned above, user requirements are driven by policy, regulation and standards covered in section 2.3, mainly the Regulation on deforestation-free products and the initiatives under the EU Green Deal.

3.2 Market Overview & Trends

3.2.1 Market Evolution and Key Trends

Introduction to the Forestry Segment

Forests are an incredibly valuable global resource, with forested land accounting for nearly one-third of Earth's land cover. Forests purify the air we breathe, promote rainfall, provide essential resources for products that we use daily (wood, paper, food, medicines), and absorb and store large amounts of carbon dioxide from the atmosphere. Deforestation, defined as the conversion of forests to other land uses, negatively impacts all of the prelisted benefits of healthy forests as well as adversely affecting biodiversity, local and global temperature regulation and destroying a fossil fuel emission sink at a global level. Historically, forestry operations focused on timber extraction, often at the expense of environmental conservation and sustainability. Viewing forests as a source of important raw materials has led to the adoption of short-sighted incautious practices of deforestation and degradation in the past decades. Un-regulated and hasty deforestation practices continue, but forest loss is slowing down and protecting the health and resilience of forests is a priority for the EU[7]. EO and GNSS enable innovative, responsible, and sustainable practices for monitoring and protecting forestry and its biodiversity, as well as playing a role in enforcing forestry protection regulations. EO technologies, such as satellite imagery and aerial surveillance, provide detailed and up-to-date information on forest cover, land use changes, and illegal logging activities. By leveraging EO data, regulatory authorities can monitor vast forested areas more effectively, identify instances of non-compliance with forestry protection regulations, and take enforcement actions accordingly. GNSS technology complements EO by enabling precise geolocation and tracking of forestry activities, facilitating the enforcement of spatial regulations and monitoring of logging operations in remote or inaccessible areas. Overall, the combination of EO and GNSS technologies empowers regulatory agencies to ensure compliance with forestry protection measures, safeguarding forest ecosystems and promoting sustainable forest management practices.

The integration of these technologies in the forestry sector is rapidly emerging as a pivotal tool for enhancing the efficiency of forestry monitoring and management operations for governments, international organisations and businesses. The integration of space-based data and technologies into forestry operations facilitates more precise and proactive management strategies in the forestry sector. Data driven insights from data collected via EO and GNSS allow forestry stakeholders to optimise resource allocation enhancing productivity and minimizing environmental impact, identify potential risks such as pests or wildfires, and comply with regulatory standards.

For instance, EO and GNSS can be used to:

- Conduct inventories of timber.
- Track carbon stocks in forests to support climate change mitigation efforts.
- Assess forest health, including detecting diseases, pests, and stress factors.
- Monitor biodiversity by mapping habitats and protected areas.
- Combat illegal logging.
- Improve the operations and logistics of the actors of the forestry value chain.

7 https://www.fao.org/forest-resources-assessment/2020/en/

Moreover, EO and GNSS technologies will be critical for the implementation of the recently adopted Regulation (EU) 2023/1115[8] on the making available on the Union market and the export from the Union of certain commodities and products associated with deforestation and forest degradation.

Key Market Trends

The following trends drive the user needs and requirements in the forestry sector:

The new EU forest strategy for 2030. This strategy aims at enhancing the quantity and quality of EU forests while simultaneously strengthening their protection, restoration and resilience to the effects of climate change. The strategy's objective is to adapt European forests to the new weather patterns observed such as temperature and weather extremes as well as a high level of uncertainty about the future of the climate. EO data is crucial for this desired increased resilience in forests by providing almost near real time analysis of the state of forests in different conditions. The health of forests and the factors affecting their health (droughts, forest fires, storms, etc.) are directly monitored by EO technologies.

The new EU forest strategy for 2030 also stresses promoting sustainable forest management. EO technology, when combined with GNSS, enables multiple precision forestry operations which decreases the impacts of forestry. These include the precise guidance of machinery, drones equipped with hyperspectral and LIDAR imaging capabilities, and the accurate positioning of "on-tree" health sensors. Forestry companies and research institutions have successfully integrated GNSS and EO data for precision forestry.

These technologies are enabling an unprecedented connectivity and collaboration across various players, allowing to optimise the operations of the forestry supply chain. For instance, companies are now able to better match timber sellers and buyers than in the past, thanks to collected data on forests' property size and timber volume, but also tree species, height, diameter, age, and tree count. Forestry data is also being used by businesses to give customised recommendations for forest management and loggings and to provide suggested proposals for conservation purposes.

Forest information Services. The EU is also active in the monitoring of forest degradation. The Forest Information System for Europe (FISE) has been launched to gather EU-wide information on forests. This information system allows researchers and regulators to design evidence-based policies for ensuring the wellbeing, diversity, and resilience of Europe's forests. FISE encourages the involvement of communities at various levels to join the efforts of forest conservation by leveraging digital technologies and satellite information. Individual citizens and organisations can freely explore forest-related data and contribute to its wealth by reporting planted trees using the dedicated app[9]. Recently the European Commission proposed the **Forest Monitoring Law** aimed at creating a comprehensive knowledge base to address information gaps and enable better responses to the growing stress on forests. This new monitoring system would enable the collection and sharing of comparable forest data obtained through EO technology and ground measurements[10].

The most pressing issue confronting forests is not deforestation, but forest degradation. Forest degradation is when forest ecosystems lose the ability to provide important goods to and services to people and nature. This has been recognised as a major concern and has recently been addressed with data collection and analysis[11]. For example, the World Wide Fund for Nature (WWF) is utilising publicly

[8] https://eur-lex.europa.eu/eli/reg/2023/1115

[9] https://mapmytree.eea.europa.eu/

[10] https://commission.europa.eu/news/new-law-proposed-improve-resilience-european-forests-2023-11-22_en#:~:text=The%20Commission%20has%20proposed%20a,to%20growing%20pressures%20on%20forests.

[11] https://www.worldwildlife.org/projects/saving-forests-with-big-data-and-forensics

available big data analytics to quickly and accurately flag suspicious timber imports. This organisation is also contributing to the development of tools and algorithms that could support governmental organisations and other law enforcement agencies in their activities.

Forestry e-commerce. Specialised IT platforms facilitate e-commerce within the forestry industry, representing a growing niche in digital business solutions. These platforms foster smooth collaboration among various stakeholders in the forestry supply chain, such as forest managers, harvest contractors, transportation firms, timber traders and forest-based industries. They make use of technologies like Global Navigation Satellite System (GNSS) data to pinpoint wood pile locations and track their movement for logistics. Earth Observation (EO) data is used to monitor and optimise forestry operations. These innovative methods allow various participants to improve planning and coordinate supply chain operations across different companies.

These platforms provide all-encompassing solutions that cover a broad range of forestry-related activities and can smoothly integrate with frequently used IT systems. Recently, these e-business platforms have seen an increased uptake in the forestry sector. Numerous online marketplaces for timber and forestry services have been established, encouraging business alliances and streamlining transactions, especially in rural areas.

Protection and conservation of the forestry ecosystem. EO and GNSS technologies provide the capability to remotely monitor and assess the health of forest inventories. Through satellite imagery and remote sensing, it becomes possible to gain real-time insights into the condition of forests, including factors like tree health, density, and growth rates. In recent years, the EU's Copernicus Programme have been instrumental in continuously monitoring forested areas, allowing for the assessment of forest health and changes in vegetation cover. EO technologies also play a role in identifying and addressing challenges like illegal logging, which has garnered considerable global concern due to the escalating vulnerability of forest resources. Organizations can leverage EO data to monitor real-time forest cover changes and identify areas facing a high risk of deforestation. These data-driven initiatives significantly contribute to conservation efforts worldwide.

Technology trends

While a description of the specific technology solutions that will be uptaken in the forestry sector can be conjectural, there is every reason to believe that an increased attention to reduce site impacts is a top priority considering the growing popularity of sustainable forestry practices. Proper planning and forestry management is the most effective way of decreasing site impact, more than new machinery, and one may expect a rapid success of **low-cost intelligent solutions**, supported by remote sensing, UAV surveys and accurate site mapping.

Arguably, the most significant progress in the integration of emerging technology and data with the commercial forest sector lies in forest inventory and monitoring, areas that attract substantial investment. Considering the extensive spatial and temporal scales involved in forest resource planning, compared to other sectors, and the associated cost and time constraints, the demand for reliable, cost-effective, and manageable technology and data for forest inventories and monitoring is crucial.

Data-driven forest management is an incredibly effective way to reduce environmental impact while increasing productivity in forestry activities. **Machine learning applications** applied to: harvest optimisation, modelling environmental impact of deforestation, modelling of carbon sequestration in forests, and predictive growth of trees in forests is expected.

Data fusion approaches, which involve combining multiple technologies and data inputs to generate more accurate and precise information, offer new opportunities for both research and practical applications. For instance, forestry research stands to benefit significantly from crowdsourced and open-source data sharing and management systems, including smartphone applications and web-based platforms, facilitating data collection using various methods across different contexts. Cooperative surveillance, such as using multiple UAVs simultaneously, has been proposed as a method to leverage diverse sources of information and data inputs for monitoring complex forest environments. Additionally, future research could explore combining LiDAR-equipped UAVs with self-driving cars for fully autonomous forest inventories. Another avenue is the utilization of multi-sensor tool, which integrates LiDAR, hyperspectral, and thermal sensors on a UAV, offering more cost-effective, agile, and autonomous approaches to forest inventorying and monitoring.

Research gaps

The use of modelling techniques for forest growth and dynamics. Methods centred on forest modelling operate on the assumption that management recommendations, like thinning intensity and interval, remain consistent throughout the analysed timeframe. However, this assumption is unlikely, particularly in long-term analyses. Consequently, modelling intricate forest dynamics, such as forest growth, shifts in species composition, and competition among trees, shrubs, and grasses, remains a significant challenge for future research efforts.

Improved advanced data processing techniques. The main applications for machine and deep learning where forestry is concerned are forestry resource surveys, tree species identification, wood moisture content prediction, and others. Developing an effective remote sensing image recognition method for forest resources using deep learning holds significant practical value in future endeavours related to forest resource assessment, forest vegetation coverage analysis, and monitoring and evaluation of plant growth status.

Currently this type of machine learning and algorithmic based analysis cannot replace all traditional methods in forestry. First and foremost, these theoretical models are difficult for those responsible for forestry management to apply. Researchers in forestry face significant time and energy investments to grasp and effectively apply machine learning knowledge for specific engineering tasks. These types of models also require vast amounts of data (typically several thousands of samples), the size of the dataset directly influences the performance of the model. When insufficient training data is provided, models applied to small datasets often encounter overfitting issues. Gathering an adequate number of data samples in forestry is typically challenging, as it necessitates professional image acquisition equipment for tasks like forest remote sensing imagery.

GNSS Market Evolution

Accurate spatial information about forests is crucial for various purposes such as environmental monitoring, research, nature conservation, and forest management, with a particular focus on "precision forestry." Therefore, acquiring extensive spatial data about forests using remote sensing techniques is essential. This trend is primarily motivated by the effectiveness of remote sensing methods when combined with sufficient accuracy, as demonstrated by various studies. Overall, the GNSS market in forestry applications has evolved from basic mapping and navigation tools to sophisticated systems that support a wide range of forestry tasks, offering improved accuracy, efficiency, and functionality for forestry professionals.

As illustrated by Figure 5, forest asset management is the largest market share of the revenues from GNSS device sales and services by application and is expected to have steady growth over the decade. Revenues from Forest inventory monitoring are expected to decrease, likely owing to the fact that **forest asset management**, which is already the dominant technology, provides telematics data from forestry assets and will replace forest inventory monitoring. Over the decade there is a slight increase in the revenues from forest machinery guidance, a technology that will continue to be uptaken by stakeholders in the forestry industry.

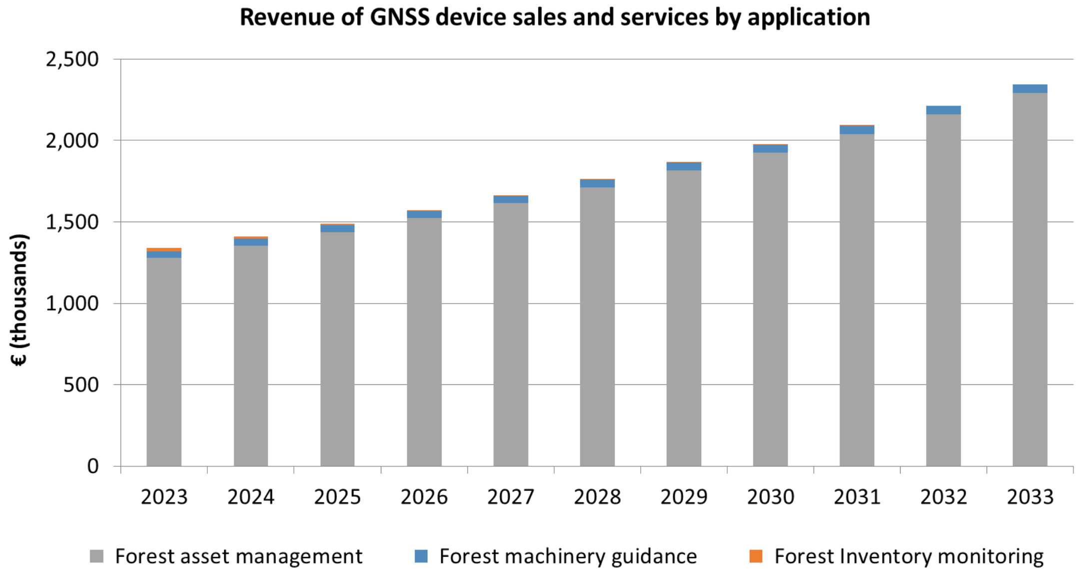

Figure 5: Expected evolution of revenues for GNSS device sales and services by forestry applications.

Source: EUSPA EO and GNSS Market Report – Issue 2 2024

EO Market Evolution

Over the past 35 years, EO technology has witnessed widespread adoption in forestry applications. Various global forest cover and change products, as well as forest disturbance products covering extensive areas and long time periods, are now readily available. Additionally, maps and data products detailing forest types or tree species information, derived from time series of passive optical satellite data, are being generated for regions of diverse scales. These products play a crucial role in enhancing estimates of official national sampling programs, such as national forest inventories, and provide spatially explicit assessments of forest attributes in many jurisdictions.

Future trends for the forestry sector include deepening the combination of GNSS and EO data with other technologies, like AI and blockchain. This will allow for increased traceability in the industry, ensuring accurate and transparent tracking of timber from its source to market, and strengthening sustainability efforts.

The EO market in forestry is evolving to enhance traceability, forest health monitoring, trafficability prediction, and forest regeneration. EO data has become instrumental in minimizing ecological and economic impacts. Moreover, EO, when integrated with blockchain technology, is expected to play a central role in ensuring the traceability and conservation of forests. With the provision of accurate, real-time data, EO enables early detection of disease outbreaks and environmental stressors, safeguarding forest ecosystems and optimizing timber yields. Figure 7 below shows the evolution of the revenues from EO data and service sales by application in the forestry sector: the revenues are forecasted to steadily growth with forest inventory monitoring and illegal logging monitoring having nearly the same share of the market and same level of growth. Percentagewise, the revenues generated from the application **forest vegetation health monitoring** is expected to experience the largest growth, unsurprising due to the expected impacts of climate change on forest ecosystems and stakeholders in the sector investment in minimising the effects of climate change on their forestry assets.

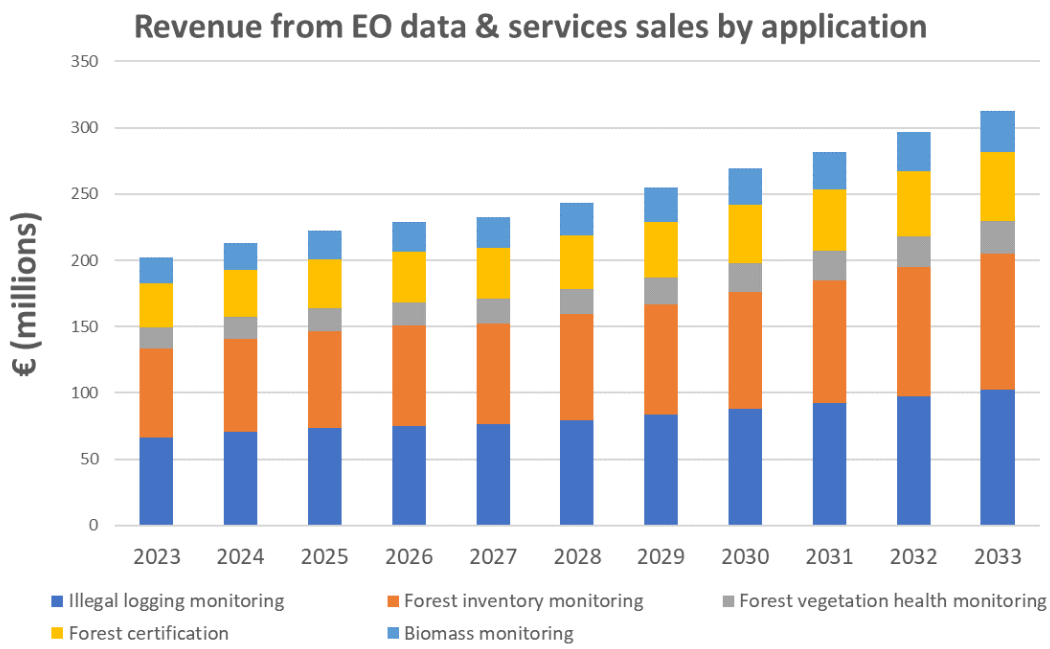

Figure 6: Predicted market evolution of EO data and service sales revenues in Forestry 2023-2033

Source: EUSPA EO and GNSS Market Report – Issue 2 2024

3.2.2 Main User Communities

The main user communities are listed below, which partly shape the forestry users' needs and requirements.

- **Governments.** National and regional forest agencies employ satellite data to monitor and manage forest resources, enforce regulations, and support sustainable forestry practices. They also integrate satellite data to make informed decisions about balancing forestry with urban development and conservation for planning the use of urban and rural land.
- **Environmental and Conservation Organizations.** These groups use satellite technology to monitor deforestation, protect critical habitats, and advocate for sustainable forestry and conservation efforts. Additionally, NGOs often collaborate with governmental agencies and forestry companies to promote sustainable forestry practices using satellite information.
- **Key associations.** Associations such as The European State Forest Association, Confederation of European Forest Owners, and others whose goals are to achieve sustainable forestry management to grow the bioeconomy.
- **Research Institutions.** Academic and research institutions leverage satellite data for studies on forest ecology, biodiversity, climate change impacts, and sustainable forestry practices.
- **Forestry companies and the timber industry.** Commercial and state-owned forestry operations utilize satellite technology for various purposes, including forest inventory management, monitoring logging activities, and optimizing resource allocation. Companies involved in timber processing and wood product manufacturing utilize satellite data for timber inventory, quality control, and supply chain management.
- **Insurance companies.** Insurance providers may utilize satellite data to assess risks related to forestry operations and offer forest-specific insurance products.
- **Forestry managers.** Forestry managers use EO and GNSS technologies for the applications: forest inventory management, monitoring logging activities, and optimizing resource allocation.

- **Forest owners.** Due to the increased availability of space for data for forestry applications, forest owners can be active users of this data in their daily activities. The increase of regulations on sourced timber and the location of products has also increased the burden of surveillance for forest owner. A requirement highlighted repeatedly at the UCP was that forest owners need time and resources to adapt to regulations.

3.2.3 Main Market Players

Some of the main players involved in EO and GNSS are depicted the value chains below.

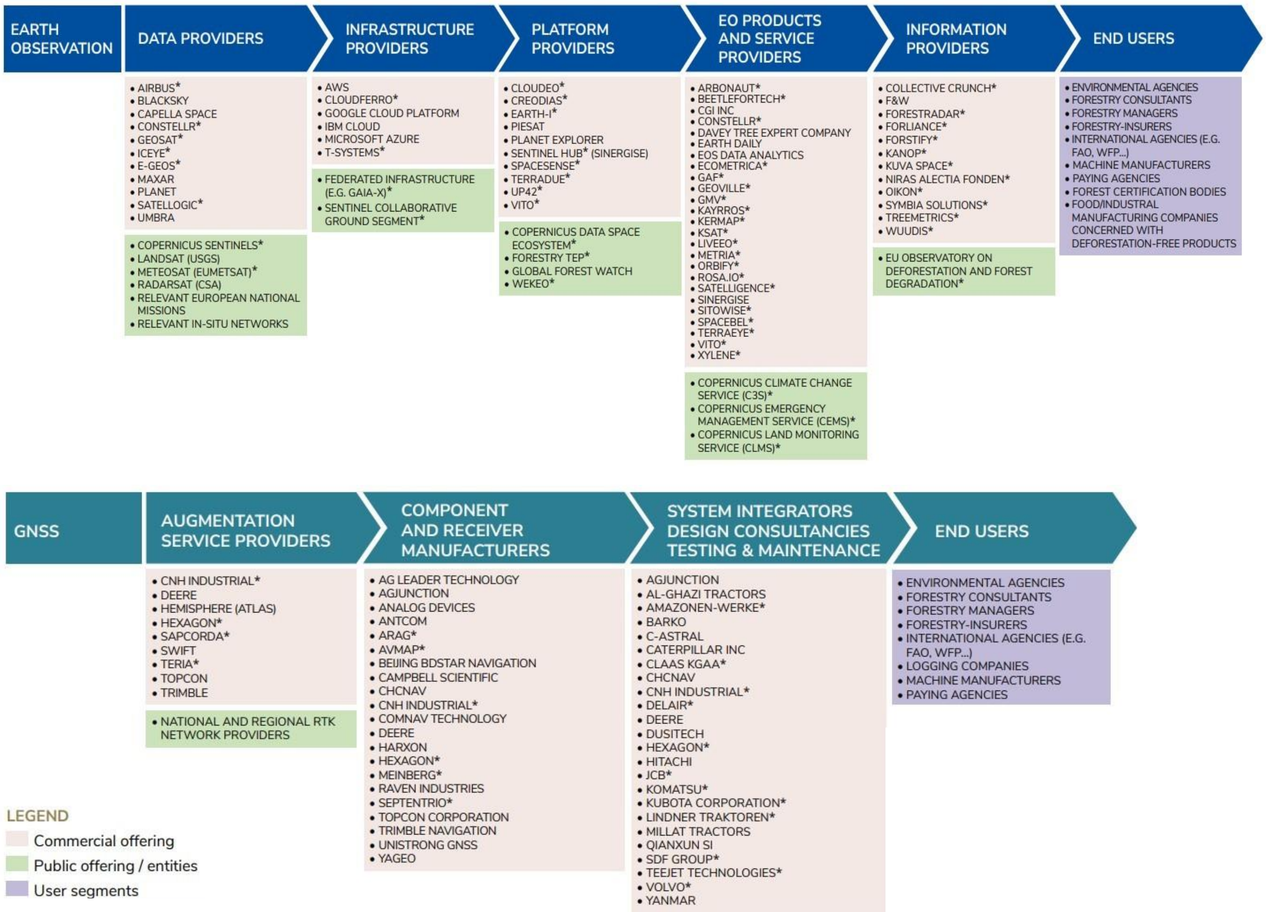

Figure 7 - Earth Observation and GNSS Forestry value chains.

* European-based companies. The region is defined with respect to the headquarters of the company, though the actual area of activity might be wider.
Source: EUSPA EO and GNSS Market Report – Issue 2 2024

3.3 Policy, Regulations and Standards

Different forestry policy is subject to national member state competence. The current CAP covers not only agriculture but also forestry, in order to address comprehensively the same environmental and climate objectives. For instance, payments allocated with eco-schemes will also support practices for improving the environment, climate and animal welfare conditions applied to the agri-forestry field.

3.3.1 Policies

- **The Green Deal**, adopted in 2019, is a comprehensive policy framework setting out the course for the EU's transition to a sustainable, low-carbon, and circular economy. It is implemented through legislative measures, funding programs, research and innovation, and partnerships with stakeholders. The Commission monitors the progress and adapts the policies as needed to achieve the set objectives. At the heart of the Green Deal is the ambition to achieve climate neutrality by 2050 and economic growth decoupled from resource use.

Other relevant initiatives for forests include:

- The **EU forestry strategy for 2030**[12], published in July 2021, represented a pivotal step forward in the EU's commitment to sustainable forest management and environmental protection. This strategy underlines the key role that forests play in mitigating climate change, conserving biodiversity, and fostering rural development. This strategy is aligned with the objectives of the European Green Deal and the Biodiversity strategy for 2030. It emphasises how forests are to be managed in line with the European Green Deal and contributes to the EU's climate objectives, establishing a clear path toward carbon neutrality by 2050. By promoting sustainable forest practices, enhancing the resilience of forest ecosystems, and addressing emerging challenges such as climate change impacts and the protection of primary and old-growth forests, the EU's new forestry strategy seeks to strike a balance between ecological, economic, and social considerations. Through close collaboration with member states, stakeholders, and international partners, this strategy aims to secure the long-term health and vitality of European forests. Key elements of the strategy are:
    - Enhancing forest monitoring, reporting, and data collection through a strategic approach such as applying Copernicus' Land Monitoring Service (CLMS). CLMS contains products, at no cost to users, that has historical data about forestry and small woody, making the monitoring of deforestation accessible to users.
    - Strengthening research and innovation efforts to advance our understanding of forests.
    - Establishing an inclusive and unified EU forest governance framework.
    - Intensifying the execution and oversight of existing EU acquis.
- The **EU Biodiversity Strategy for 2030** outlines a roadmap for preserving and revitalizing biodiversity within the EU. This strategy seeks to stop the decline in biodiversity across the EU by 2030 and establish protected areas covering 30% of EU land and seas by 2030. By doing so, several benefits are expected, such as enhanced biodiversity and strengthened ecological resilience.
- The **EU Soil Strategy for 2030** is an initiative designed to address the challenges associated with soil management and conservation within the EU. Its primary objectives are to halt soil degradation, protect and enhance soil biodiversity, and harness soil's potential in climate

[12] https://environment.ec.europa.eu/strategy/forest-strategy_en / Forest strategy (europa.eu)

mitigation. By promoting sustainable land use and agriculture, reducing soil sealing, restoring ecosystems, and enhancing carbon sequestration, the strategy strives to ensure soil health, resilience, and long-term productivity. Furthermore, it emphasizes the importance of public awareness and education to foster responsible soil stewardship.

- **COP15** (global biodiversity conference) and the Kunming-Montreal Global Biodiversity Framework. The EU participated in the COP15, adopted the Global Biodiversity Framework and signed additional agreements with countries committed to the protection of nature. For instance, the EU signed an agreement with Guyana13 on the sustainable trade of legal timber.
- The EU also cooperates with other countries to address deforestation and illegal logging via partnership agreements, forest agreements and multilateral environmental agreements. Examples include the EU-China bilateral coordination mechanism on timber legality and other partnerships and multilateral agreements. More details can be found at this link.

3.3.2 Applicable regulations

Regulation on deforestation-free products. The EU is committed to tackling deforestation and forest degradation and has a broad plan of action to protect and restore forests[14]. The Regulation (EU) 2023/1115[15] on deforestation-free products entered into force on 23 June 2023 and repealed the EU Timber Regulation[16] (Regulation (EU) No 995/2010). It obliges operators or traders who place commodities (soy, beef, palm oil, wood, cocoa, coffee, rubber, and cattle) and their derivatives on the EU market to prove that the products do not originate from recently deforested land or have contributed to forest degradation.

- Authorities within each Member State will enforce the Regulation through inspections and sanctions as needed. To assist Member States, an online system will facilitate information exchange on products in the EU market. Companies engaged in importing or exporting these products, whether directly or through third parties, must conduct thorough due diligence as per the EU deforestation-free regulation, involving three key steps:
- It requires those commercialising commodities or deriving products to acquire the geolocation data of all plots of land where the relevant commodities were sourced or produced, providing at least one latitude and longitude point, using at least six decimal points, for plots of land greater than four hectares. This information should be provided with polygons, such as those sourced via satellite imagery, to prove the land of origin of those commodities was not covered by forests, and therefore deforested for commercial exploitation.
- Evaluating compliance risks related to the EU deforestation-free regulation.
- Implementing risk mitigation measures to minimize non-compliance.

---

13 https://international-partnerships.ec.europa.eu/news-and-events/news/cop-15-eu-and-guyana-sign-agreement-sustainable-trade-legal-timber-2022-12-15_en

14 https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1565272554103&uri=CELEX:52019DC0352 / EUR-Lex - 52019DC0352 - EN - EUR-Lex (europa.eu)

15 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023R1115&qid=1687867231461 / EUR-Lex - 32023R1115 - EN - EUR-Lex (europa.eu)

16 https://environment.ec.europa.eu/topics/forests/deforestation/illegal-logging/timber-regulation_en

3.3.3 Other relevant standards and practices

The Forest Information System for Europe (FISE)[17] has been established to collect comparable and consistent information on the status of forests in the EU. The main aim to provide policymakers, foresters and land managers with data to design policies meeting the EU objectives on sustainability, biodiversity, rural development, and climate change.

European harmonised standards on forestry exist only in relation to safety aspects of the tractors and machinery used for agriculture and forestry (EN 16590, EN 609, EN 709, etc[18].). However, sustainable forest management has emerged as a pressing global concern, driven by rising consumer expectations for responsibly sourced wood products. The International Organization for Standardization (ISO) is developing standards on wood products and sustainable forest management:

- *ISO 38200:2018 - Chain of custody of wood and wood-based products*. Promotes sustainable forestry by enabling the tracking of wood products, offering customers of wood suppliers the assurance that their products originate from legally harvested sources throughout the entire supply chain. This, in turn, encourages the utilization of sustainable wood resources while discouraging the use of illicit practices.
- ISO 14055-1:2017 - Environmental management — Guidelines for establishing good practices for combatting land degradation and desertification. Offers recommendations for implementing effective land management practices to prevent or mitigate land degradation and desertification.
- ISO 8347 - Measurement procedures associated with the chain of custody in native tropical forest management areas (under development by ISO/PC 287). Sets forth a procedure for assessing the extraction of native vegetation in tropical regions under forest management plans. This process encompasses the measurement and surveillance of the harvested area, aiding to verify the wood's legal origin through the analysis of the chain of custody. The International Standard introduces indicators to serve as potential flags for detecting discrepancies between documented wood volumes during transport and commercialization and the actual volumes sourced from the indicated tropical forest origin.
- *ISO 13391* (under development by ISO/PC 287). Will specify how calculations of different parts can be combined into a carbon balance calculation for the entire value chain related to wood and wood-based products.
- *ISO* TR 4083 - Wood and wood-based products - Overview related to the concepts of renewability, reusability, recoverability, recyclability, compostability, biodegradability and circularity (under development by ISO/PC 287). Will specify the terminology and existing methodologies on these topics.

[17] https://forest.eea.europa.eu/

[18] The full list can be found at: https://ec.europa.eu/docsroom/documents/55577

3.4 User Requirements Analysis

This chapter provides a detailed analysis of user needs and requirements pertaining to the forestry segment's applications introduced before, describing the different roles and needs covered by GNSS and EO and, ultimately, identifying the corresponding requirements from a user perspective.

Table 22 below depicts the main applications making use of GNSS and/or EO technologies in the forestry segment. The list of applications is non-exhaustive and is expected to potentially grow and adapt according to the expected adoption of space technologies in the coming years and the innovations that should come with it. The current report focuses on User Needs and Requirements relevant to EO, applications using GNSS technology will not be covered in this iteration of the report. This report is a living and evolving document that will periodically be updated and expanded by EUSPA in its next releases.

While each one of the applications addressed in this document can benefit from GNSS and/or EO, the current issue the RUR does not cover in detail the needs and requirements of all applications. A categorisation was performed prioritising some applications based on their maturity level and relevance to the market trends and drivers. Other applications are foreseen to be covered in more detail in future versions of this RUR.

The following applications categorisation reflects the depth of information available in section 5:

Application Type A: these applications correspond to those for which an in-depth investigation is presented, and for which needs and requirements relevant to GNSS and/or EO have been identified and validated with the forestry user community at the UCP.

Application Type B: these applications correspond to those not selected for in-depth investigation in the current version of the RUR, for which a partial specification of needs and requirements is provided, limited at this stage to the ones relevant to GNSS.

Application Type C: these applications correspond to GNSS or EO-based applications, not selected for in-depth investigation in the current version of the document. A high-level description of the application is included considering that they will be further analysed and developed in next versions of the RURs.

The following list of applications and their categorisation are expected to evolve in the next versions of the document.

Legend

EO only application

GNSS only application

Hybrid/synergetic application (combined use of EO and GNSS)

Table 22: list of sub-segments and applications for forestry

Sub-segments	Applications	Types of Application/ Level of Investigation	
Environmental monitoring	Biomass monitoring	A	
	Deforestation/degradation monitoring	A	
Natural resources monitoring	Forest inventory monitoring	C	

	Forest vegetation health monitoring	C	
	Illegal logging monitoring	C	
Operations management	Automatic steering	B	
	Forest asset management	B	
	Forest certification	A	
	Forest machinery guidance	B	

The next section 3.4.1 addresses first "type A" applications, then "type B" applications and finally "type C" applications, for which the level of provided information is currently the less developed.

Each EO-based "Type A" application will cover the needs and requirements for potentially several operational scenarios. For each scenario, a table summarises the EO related needs and requirements.

3.5 Current GNSS and EO use and requirements per application

3.5.1.1 Biomass monitoring – Type A application

Monitoring forest biomass is essential for assessing forest health and carbon sequestration, both critical components of sustainable forest management and climate change mitigation. To achieve this, EO technologies provide valuable tools for collecting accurate and timely data. EO is used in the application of biomass monitoring by: SAR being used to estimate forest biomass through changes of radar signal characteristics, measuring the density and moisture content of trees. Multispectral or hyperspectral imaging of forested areas and forest canopies can be used to assess forest health and used indirectly to calculate biomass. Biomass estimations can be used to estimate the carbon content of trees. Biomass estimations of forests combined with carbon density conversion factors can be used to estimate the total carbon content stored in a specific forested area.

This section explores the user requirements for biomass monitoring in the context of forest health and carbon sequestration using remote sensing, highlighting the need for precise measurements, spatial coverage, and temporal monitoring to inform informed decision-making and environmental conservation efforts. Three operational scenarios for the application biomass monitoring were chosen for further development. These operational scenarios were chosen based on expert feedback in terms of which of their services related to biomass monitoring use the most EO data. Please note that most if not all EO forestry applications are usually supplemented with other data sources mainly supplied through field work in certain areas of forestry zones.

Operational scenario 1: monitoring of forest health is performed on two scales, fine and gross, as presented in **Table 23**. This operational scenario monitors trees' health for the purpose of carbon sequestration. The health and species of a tree play crucial roles in determining its capacity to absorb and sequester carbon dioxide, a vital process in mitigating climate change. Healthy trees exhibit specific spectral signatures, and any deviations from these signatures may indicate stress, disease, or other issues. Through various EO-derived indicators and data layers, it is possible to measure a tree's health as well as biomass of a forest can be assessed. From this, the biomass and carbon uptake capabilities of a tree can be used for carbon stock estimation that can be applied in multiple areas of forestry.

Operational scenario 2: it leverages EO technologies to determine the baseline of carbon storage in a forest ecosystem, focusing on biomass monitoring as a means of establishing national baselines for potential carbon sequestration capability. Biomass is estimated from data such as height and basal and mid height area, and uptake can be estimated from biomass and variable parameters such as soil nutrient and moisture content. These baselines are applicable in the field of carbon trading and assessing the pre-existing carbon storage in forests nationally.

Operational scenario 3: One of the early environmental concerns raised regarding acidic deposition was the possible long-term accumulation of pollutants in the soil, leading to increased acidity and altered nutrient levels. These changes in soil composition were thought to have implications for the health and productivity of forests. EO enables the observation of soil acidity which directly affects the available biomass of a forest to uptake carbon.

Table 23: Biomass monitoring operational scenario 1: Monitoring of forest health (in terms of carbon sequestration)

ID	EUSPA-EO-UR-FOR- 0001
Application	Biomass monitoring
Users	Foresters, timber companies, research institutions, governmental organizations
User Needs	
Operational scenario	**Monitoring of forest health (in terms of carbon sequestration capability)**
Size of area of interest	Regional to country size (1000s of ha)
Scale	n.a.
Frequency of information	For pest management: weekly For other aspects: seasonally
Other (if applicable)	n.a.
Service Provider Offer	
What the service does	Monitor environmental elements that affect forest health and its ability to absorb carbon
How does the service work	Monitoring of pests based on high resolution data of trees combined with field work. Soil moisture monitoring is performed to calculate water stress in trees, which reduces their ability to protect themselves against pests and disease.
Service Provider Satellite EO Requirements	
Spatial resolution	For pest management: - 5-10m, supplemented with drone footage and field work. Other aspects of forest health: 10m resolution or coarser (up to 250m)
Temporal resolution	Weekly or seasonally
Data type / Spectral range	Multispectral, SAR
Other (if applicable)	n.a.
Service Inputs	
Satellite data sources	Sentinel-1 and -2, Landsat, Planet
Other data sources	Drone footage, plane LiDAR, and data collected during field work (manual measurements for a sample of trees, used to complement and validate satellite data)

Table 24: Biomass monitoring operational scenario 2: Forest carbon sequestration capability baseline monitoring

ID	EUSPA-EO-UR-FOR- 0002
Application	Biomass monitoring
Users	Foresters, timber companies, research institutions, governmental organizations, carbon trade enterprises
User Needs	
Operational scenario	**Forest carbon sequestration capability baseline monitoring**
Size of area of interest	Country scale (1000s of ha)
Scale	10m
Frequency of information	Seasonally
Other (if applicable)	n.a.
Service Provider Offer	
What the service does	In essence, biomass monitoring, provides national baselines of possible carbon uptake.
How does the service work	The number of trees, their species, their species, size and the density of the forest is gleaned from EO data. This data is processed via algorithmic models that calculate carbon uptake depending on the above-mentioned parameters and the constants of carbon uptake per species.
Service Provider Satellite EO Requirements	
Spatial resolution	10m
Temporal resolution	Quarterly/seasonally
Data type / Spectral range	Multispectral, optical
Other (if applicable)	n.a.
Service Inputs	
Satellite data sources	Sentinel-1 and 2, Landsat
Other data sources	Drone footage, LiDAR, field work (manual measurements for a sample of trees, used to complement and validate satellite data)

Table 25: Biomass monitoring operational scenario 3: Soil acidity monitoring

ID	EUSPA-EO-UR-FOR- 0003
Application	Biomass monitoring
Users	Foresters, timber companies, research institutions, governmental organizations, carbon trade enterprises
User Needs	
Operational scenario	**Soil acidity monitoring**
Size of area of interest	From local to regional scale
Scale	50m

Frequency of information	Seasonally
Other (if applicable)	n.a.
Service Provider Offer	
What the service does	Monitors forest soil acidity via leaves/canopies spectral signature
How does the service work	The pH of the soil is gathered via observations of EO data of leaf health/profile. Soils which are too acidic effect a trees ability to uptake carbon (and other nutrients) and accumulate biomass. The data needed is Multispectral as Hyperspectral imagery is prone to saturation in dense forests.
Service Provider Satellite EO Requirements	
Spatial resolution	50m
Temporal resolution	Quarterly/seasonally
Data type / Spectral range	Multispectral, Hyperspectral (in sparse forest cover)
Other (if applicable)	n.a.
Service Inputs	
Satellite data sources	Sentienl-1 and -2, Landsat
Other data sources	Drone footage, field work (manual measurements for a sample of trees, used to complement and validate satellite data)

Table 26: Forestry GNSS User requirements for biomass monitoring

GNSS user requirements for biomass monitoring		
Accuracy	Horizontal (cm-level/sub-metre level/m-level)	Sub-metre-level
	Vertical	Sub-metre-level
Availability	Canopy	Yes
	High/medium/low	High (95% or greater)
Robustness	High/medium/low	Low
Authentication	High/medium/low	Low
Integrity and reliability	High/medium/low	Medium
Size, weight, autonomy	Relevance (Yes/No)	n.a.
	Autonomy (>hour)	n.a.
TTFaF	Seconds/minutes/>20min	A few seconds

3.5.1.2 Deforestation/degradation monitoring – Type A application

Effective monitoring of deforestation, forest degradation, reforestation, and the preservation of protected areas is paramount for ensuring sustainable land management and biodiversity conservation. Optical and radar data can be used to measure forest vegetation intensity (through the generation of various indices such as NDVI), forest canopy cover and land use changes associated with deforestation/degradation.

The following table illustrates the user requirements for tracking land changes, safeguarding protected areas, and fostering reforestation efforts through remote sensing, emphasizing the necessity for accurate, real-time information, and global coverage to support informed environmental policies and land-use planning.

Table 27: Deforestation/degradation monitoring operational scenario 1

ID	EUSPA-EO-UR-FOR- 0004
Application	Deforestation/degradation monitoring
Users	Foresters, timber companies, governmental organizations, environmental monitoring agencies
User Needs	
Operational scenario	**Land use change tracking**
Size of area of interest	Local scale (100s of ha)
Scale	250m
Frequency of information	Seasonally/yearly
Other (if applicable)	n.a.
Service Provider Offer	
What the service does	Classification of the different land uses, and the change between the last classification, used machine learning with EO data
How does the service work	This service tracks land use changes over a seasonally and/or yearly basis and reports to the clients with the same time frames. The service provider however requires a monthly temporal resolution. This monthly supplied data is used to train an algorithm for identification of land use changes with 250m resolution. If needed finer resolution is used.
Service Provider Satellite EO Requirements	
Spatial resolution	1-10m
Temporal resolution	Monthly
Data type / Spectral range	SAR, Multitemporal, near-infrared
Other (if applicable)	n.a.
Service Inputs	
Satellite data sources	Sentinel-1, and -2, LandSat for historical data, PLANET and other commercial satellite data providers.
Other data sources	Drone footage, field work (manual measurements for a sample of trees, used to validate satellite data),

Table 28: Deforestation/degradation monitoring operational scenario 2

ID	EUSPA-EO-UR-FOR- 0005
Application	Deforestation/degradation monitoring
Users	Foresters, timber companies, research institutions, governmental organizations
User Needs	
Operational scenario	**Monitoring of forest health**
Size of area of interest	10s of ha
Scale	250m
Frequency of information	Seasonally
Other (if applicable)	n.a.
Service Provider Offer	
What the service does	Monitor environmental elements that affect forest health such as soil moisture, and life cycle of trees
How does the service work	Earth observation data is used to monitor the state of trees' health throughout the year and is combined with data collected from field work. Depending on the size and maturity of the tress and their canopies aspects of soil composition cannot always be measured. 10s of ha is appropriate for these measurements.
Service Provider Satellite EO Requirements	
Spatial resolution	10m
Temporal resolution	Seasonally
Data type / Spectral range	Multispectral, hyperspectral
Other (if applicable)	n.a.
Service Inputs	
Satellite data sources	MODIS, Sentinel-1 and -2, Landsat
Other data sources	Drone footage, plane LiDAR, and data collected during field work (manual measurements for a sample of trees, used to validate satellite data)

Table 29: Deforestation/degradation monitoring operational scenario 3

ID	EUSPA-EO-UR-FOR- 0006
Application	Deforestation/degradation monitoring
Users	Timber companies, governmental organizations, research institutions
User Needs	
Operational scenario	**Fire risk assessment/post-fire forest health monitoring**
Size of area of interest	10s of ha
Scale	10-250m
Frequency of information	Weekly-monthly
Other (if applicable)	n.a.
Service Provider Offer	

What the service does	Monitors the health of the forest after a degradation event, such as a forest fire
How does the service work	Collects data on tree health and soil characteristics via EO and monitors them after a forest fire.
Service Provider Satellite EO Requirements	
Spatial resolution	10m
Temporal resolution	Weekly-quarterly
Data type / Spectral range	Multispectral
Other (if applicable)	n.a.
Service Inputs	
Satellite data sources	Sentinel-1 and -2 , Landsat
Other data sources	Field work (manual measurements for a sample of trees, used to complement and validate satellite data)

3.5.1.3 Forest certification – Type A application

Forest certification is integral to responsible forest management, emphasizing sustainable practices, and the prevention of illegal logging. To meet these requirements, remote sensing offers valuable tools for tracking land changes and detecting illicit activities. This introduction delves into the essential user requirements for forest certification, highlighting the need for accurate, high-resolution remote sensing data, real-time monitoring capabilities, and the capacity to identify unauthorized logging activities, all of which contribute to ensuring the integrity of certified forests and promoting environmental conservation.

Two operational scenarios were identified for this application, **monitoring land use changes and illegal logging detection of species-specific tree**. Illegal logging detection of specific timber species was chosen as the second operational scenario as it is a more fined tuned operational scenario when compared to illegal logging detection of general areas, which has the same user requirements of monitoring land use changes.

Table 30: Forest certification operational scenario 1

ID	EUSPA-EO-UR-FOR- 0007
Application	Forest certification
Users	Timber lumber suppliers, governmental organizations, environmental agencies
User Needs	
Operational scenario	**Monitoring land use changes**
Size of area of interest	100s of ha to regional scale
Scale	250m
Frequency of information	Weekly
Other (if applicable)	n.a.
Service Provider Offer	
What the service does	If there is information about illegal activities then changes are searched for via pre-existing satellite data and monitored there after
How does the service work	Monitoring of subtle or dramatic land use changes via satellite imagery and determining the land changing agent.
Service Provider Satellite EO Requirements	
Spatial resolution	250m
Temporal resolution	Weekly
Data type / Spectral range	Multispectral
Other (if applicable)	n.a.
Service Inputs	
Satellite data sources	MultisSentinel-1 and -2 and Landsat
Other data sources	Drone imagery, field work (manual measurements for a sample of trees, used to validate satellite data)

Table 31: Forest certification operational scenario 2

ID	EUSPA-EO-UR-FOR- 0008
Application	Forest certification
Users	Timber suppliers, plantation owners, foresters, governmental organizations
User needs	
Operational scenario	**Illegal logging detection of specific timber species**
Size of area of interest	10s of ha
Scale	10m
Frequency of information	Seasonally, weekly through the months of Sept-Oct
Other (if applicable)	n.a.
Service Provider Offer	
What the service does	This service provides identification of illegal logging for specific tree species in heavily forested areas
How does the service work	To identify individual trees, with a combination of LiDAR and microwave.
Service Provider Satellite EO Requirements	
Spatial resolution	10m (taking into account the need for continuous information: the provided LiDAR and Sentinel is ok)
Temporal resolution	Seasonally/weekly
Data type / Spectral range	Multispectral, hyperspectral, SAR
Other (if applicable)	n.a.
Service Inputs	
Satellite data sources	Sentinel-1 and -2, Landsat, commercial multispectral satellite data
Other data sources	Drone photography, field work (manual measurements for a sample of trees, used to complement and validate satellite data), LiDAR

Table 32: Forest certification operational scenario 3: Remote auditing inspections

ID	EUSPA-EO-UR-FOR- 0009
Application	Forest certification
Users	Timber suppliers, plantation owners, foresters, governmental organizations
User Needs	
Operational scenario	**Remote auditing inspections**
Size of area of interest	1/10 hectare
Scale	5-10m
Frequency of information	Seasonally
Other (if applicable)	n.a.
Service Provider Offer	
What the service does	Identify different tree species for certification
How does the service work	Individual canopies are identified through fine hyperspectral resolution imaging, to create an index for biodiversity status project, can identify individual trees, with a combination of LiDAR and microwave, similar to forestry certificates
Service Provider Satellite EO Requirements	
Spatial resolution	5-10m
Temporal resolution	Seasonally/weekly

Data type / Spectral range	Multispectral, hyperspectral, SAR
Other (if applicable)	e.g. non-functional, latency, availability of historical data, reanalysis, pre-processing...
Service Inputs	
Satellite data sources	Sentinel-1 and -2, Landsat, other commercial EO providers
Other data sources	Aerial LiDAR

3.5.1.4 Automatic steering – Type B application

Automatic steering completely takes over steering of the forestry machinery from the driver allowing the operator to engage in core forestry tasks.

Table 33: GNSS user requirements for automatic steering

GNSS user requirements for [Application]		
Accuracy	Horizontal (cm-level/sub-metre level/m-level)	10-30cm
	Vertical	Sub-metre-level
Availability	Canopy	Yes
	High/medium/low	High
Robustness	High/medium/low	Low
Authentication	High/medium/low	High
Integrity and reliability	High/medium/low	High
Size, weight, autonomy	Relevance (Yes/No)	n.a.
	Autonomy (>hour)	n.a.
TTFaF	Seconds/minutes/>20min	A few minutes

3.5.1.5 Forest asset management – Type B application

GNSS provides insightful telematics data from forestry assets to help increase traceability/efficiency, monitor workforces and reduce costs.

Table 34: GNSS user requirements for forest asset management

GNSS user requirements for forest asset management		
Accuracy	Horizontal (cm-level/sub-metre level/m-level)	Sub-metre to metre-level
	Vertical	Metre-level
Availability	Canopy	Yes
	High/medium/low	High
Robustness	High/medium/low	Medium
Authentication	High/medium/low	Medium
Integrity and reliability	High/medium/low	High
Size, weight, autonomy	Relevance (Yes/No)	n.a.
	Autonomy (>hour)	n.a.
TTFaF	Seconds/minutes/>20min	A few seconds

3.5.1.6 Forest machinery guidance – Type B application

GNSS positioning can assist drivers of forest machinery in following the optimal path when conducting activities, thus minimising risks of overlaps.

Table 35: GNSS user requirements for forestry machinery guidance

GNSS user requirements for forestry machine guidance		
Accuracy	Horizontal (cm-level/sub-metre level/m-level)	10-30cm
	Vertical	Sub-metre-level
Availability	Canopy	Yes
	High/medium/low	High
Robustness	High/medium/low	Low
Authentication	High/medium/low	Low
Integrity and reliability	High/medium/low	High
Size, weight, autonomy	Relevance (Yes/No)	n.a.
	Autonomy (>hour)	n.a.
TTFaF	Seconds/minutes/>20min	A few minutes

3.5.1.7 Type C applications:

These applications correspond to those not selected for further investigations under SC1 and which were not addressed in the previous RURs. The content of the preceding section will be limited to a description of the application(s). These applications might be analysed, and corresponding sections developed in the next editions of the RURs. Please note that the following applications have overlapping use cases with the applications chosen for further investigation in this report and are covered in some aspect.

- Forest inventory monitoring: EO and GNSS enable the monitoring of the timber inventories using various optical measurements, radar measurements and in-situ sensors.
- Forest vegetation health monitoring: The health of forest vegetation can be monitored and managed using EO. Optical and radar data can be used to measure forest vegetation intensity (through the generation of various indices such as NDVI) to infer the health of trees and forest vegetation.
- Illegal logging monitoring: EO can help in the identification of illegal logging. By using optical and radar data to monitor land use changes and measure forest vegetation cover, illegal destruction of forests can be detected and monitored.

3.6 Limitations of GNSS and EO

GNSS Limitations

One notable limitation is the impact of forest canopy cover on signal reception. In dense forests, the **canopy** can obstruct satellite signals, leading to signal attenuation. This interference can result in reduced positioning accuracy and reliability. Additionally, the presence of **steep terrain** and deep valleys may further exacerbate **signal obstructions**, affecting the ability of GNSS receivers to maintain continuous and accurate positioning.

Furthermore, GNSS signals are susceptible to reflection and scattering within the forested environment. This phenomenon, known as **multipath** error, introduces inaccuracies in position calculations as the signals reflected off surrounding surfaces reach the receiver with a delay. As a consequence, GNSS receivers in forestry applications may encounter challenges in distinguishing between direct and reflected signals, impacting the precision of location-based data.

These limitations are particularly relevant for automatic steering. Trees and foliage obstruct the line of sight to satellites, leading to signal attenuation and multipath errors. As a result, automatic steering systems relying solely on GNSS may experience interruptions and reduced accuracy in navigation. In densely wooded areas, limited satellite visibility can compromise the number of satellites in view. Insufficient satellite coverage affects the reliability of GNSS positioning, especially in situations where real-time, high-precision navigation is crucial.

EO Limitations

Due to the nature of the slow growth of forests, and the frequent revisit time of most sensors, there are little to no significant limitation when concerning temporal resolution for the identified applications and operational scenarios outlined in this report.

While newer satellites like SENTINEL offer enhanced spatial capabilities, cloud masking remains an issue. The challenge is to **harmonize data from different satellite constellations**, such as LANDSAT and SENTINEL, considering their differences in resolution, spectral and frequency characteristics. The available tools, like ESA's cloud clearing tool, aim to address this, yet achieving a seamless integration of data from diverse sources remains a complex task. Metadata availability is generally robust, facilitating data understanding and utilization. However, a significant issue is the lack of a centralized database that encourages sharing, quality control, and adherence to standards.

Uptake of imagery other than visible spectrum

Hyperspectral data provides detailed information, but the redundancy of bands and strong correlations between neighbouring bands can complicate analysis. This can affect the accuracy of applications such as above-ground biomass estimation.

3.7 Prospective use of GNSS and EO in Forestry

As the forestry industry evolves, so does the role of GNSS and EO technologies. Ongoing innovation and research in GNSS and EO applications offer significant potential for addressing emerging challenges within the sector. From enhancing resource allocation and optimizing transportation networks to monitoring biodiversity and gauging the impact of climate change on forests, these technologies stand as a crucial tool in shaping the future of sustainable forest management. .

To maximise the potential uses of GNSS and EO in the forestry sector, there must be a fostering awareness and providing training on GNSS and EO technologies to forestry professionals. Supplying them with the knowledge and skills to leverage GNSS and EO capabilities enables informed decision-making, encourages responsible forest practices, and contributes to the conservation of our planet's invaluable forest resources.

Multi-frequency and multi-constellation GNSS solutions. The onset of the multi-constellation era has delivered numerous advantages to forestry stakeholders engaged in various applications. Notably, this includes heightened availability, particularly in challenging environments, accelerated ambiguity resolution, and improved coverage, particularly beneficial for regions at higher latitudes. Considering that precision forestry tasks, such as automatic steering, demand double-frequency receivers, the introduction of Galileo High Accuracy Service opens the door for end-users to leverage triple-frequency solutions.

Carbon sequestration and the Carbon market. GNSS and EO technologies provide the data needed for forestry carbon sequestration modelling. By leveraging GNSS for precise location data and remote sensing for comprehensive remote analysis, forestry professionals can assess and map the carbon content within forests. This information is invaluable for understanding the effectiveness of various forest management practices aimed at enhancing carbon sequestration. Furthermore, in the context of the carbon market, GNSS and remote sensing technologies can contribute by providing reliable data to quantify and verify carbon credits. This verification process is essential for stakeholders participating in carbon offset projects, ensuring transparency and credibility in the carbon market. Overall, the integration of GNSS and remote sensing in forestry for carbon sequestration purposes holds great potential for fostering sustainable forest management practices and facilitating participation in carbon markets to mitigate climate change.

Biodiversity Monitoring. GNSS and EO technologies are powerful tools for biodiversity monitoring, Currently the technologies, while valuable for monitoring broader ecosystem characteristics, often lack the precision to identify individual tree species for example. This application would be incredibly useful in monitoring targeted deforestation of specific species and a more detailed and accurate understanding of forests biodiversity, currently these applications must be modelled and supplemented with field work. Recognizing the limitations of current technology, it becomes evident that future advancements in Earth observation, featuring improved resolution, should be a focal point. Such advancements hold the potential to revolutionize biodiversity monitoring by allowing for the identification and tracking of individual tree species, thereby providing invaluable insights into the intricacies of forest ecosystems.

Forest Planning and Management. The integration of GNSS and remote sensing technologies in forestry emerges as a game-changer for forest planning and management, with the potential to significantly enhance profitability. GNSS technology provides precise geospatial data, enabling accurate mapping of forested areas and facilitating efficient resource allocation. Combined with remote sensing, which offers detailed information on forest structure and health, these technologies empower forestry professionals to develop comprehensive management plans. By leveraging GNSS and remote sensing, stakeholders can optimize logging routes, monitor timber health, and assess the overall forest ecosystem. This data-driven approach not only streamlines operations but also contributes to increased profitability through improved decision-making, reduced resource wastage, and enhanced conservation practices.

3.7.1 Summary of drivers for user requirements

The main trends driving greater adoption of the integration and adoption of GNSS and EO technologies include increased productivity for plantation and forest owners, complying with regulations, tracking and monitoring of timber and other products and sustainability and biodiversity.

EUDR. With a focus on soy, beef, palm oil, wood, cocoa, coffee, rubber, and cattle products, the regulation mandates operators and traders to demonstrate that these commodities and their derivatives, when placed on the EU market, are not linked to recent deforestation or forest degradation. Stakeholders in the forestry sector are increasingly driven to adopt space-based technologies to comply with the stringent requirements of the regulation. Remote sensing, particularly through satellite imagery, becomes a crucial tool for acquiring geographic data and assessing the origin of commodities, ensuring transparency and accountability in the supply chain. Companies involved in importing or exporting these products are compelled to undergo thorough due diligence, involving compliance risk assessments and the implementation of risk mitigation measures.

Sustainability and Biodiversity. The growing emphasis on sustainability and biodiversity in the forestry sector is a compelling motivator for stakeholders to embrace remote sensing technologies. These advanced tools offer a comprehensive and nuanced perspective on forest ecosystems, enabling stakeholders to assess and monitor biodiversity levels, habitat health, and overall ecosystem dynamics. Remote sensing facilitates the identification of critical biodiversity indicators, allowing for precise interventions to protect endangered species and preserve ecological balance. Additionally, the technology aids in evaluating the impact of forestry practices on biodiversity, ensuring that conservation goals are met. Remote sensing can provide essential data on forest structure, composition, and dynamics, helping stakeholders make informed decisions aligned with sustainability objectives.

Forest planning and management. Improved forest planning and management can be a significant driver for stakeholders in the forestry sector to adopt remote sensing technologies. Precise and up-to-date information about forested areas, such as tree species distribution, density, and health, is crucial for developing effective management plans. Additionally, remote sensing aids in monitoring forest health, detecting early signs of diseases or infestations, and assessing the impact of climate change. Remote sensing technologies, including satellite and aerial imagery, LiDAR, and drones, offer the capability to collect comprehensive and real-time data over large forested landscapes. This wealth of information allows stakeholders to make informed decisions regarding timber harvesting, conservation strategies, and ecological restoration efforts. The integration of such technologies provides a holistic understanding of the forest environment, facilitating sustainable practices, minimizing environmental impact, and ensuring compliance with forestry regulations. As a result, stakeholders are incentivized to embrace remote sensing technologies as indispensable tools in fostering efficient, informed, and environmentally responsible forest planning and management practices.

3.8 User Requirements Specification

The chapter provides a synthesis of the EO user requirements described in section 3.4.1. The content of this section will be updated, completed, and expanded by EUSPA in the next releases of the RUR based on the results of further investigations discussed and validated in the frame of the UCP.

3.9 Synthesis of Requirements Relevant to EO

This section will only address the applications of Type A (identified in Chapter 3). The applications of Type B and C will not be covered in the current version of the RUR.

ID	Application	Users	User needs					Service provider offer		Service provider satellite EO requirements				Service inputs	
			Operational scenario	Size of area of interest	Scale	Frequency of information	Other (if applicable)	What the service does	How does the service work	Spatial resolution	Temporal resolution	Data type/spectral range	Other (if applicable)	Satellite data sources	Other data sources, *not satellite-based*
EUSPA-EO-UR-FOR- 0001	*Biomass monitoring*	Foresters, timber companies, research institutions, governmental organizations	Monitoring of forest health (in terms of carbon sequestration capability)	Regional to country size (1000s of ha)	n.a	For pest management: weekly For other aspects: seasonally	n.a.	Monitor environmental elements that affect forest health and its ability to absorb carbon	Monitoring of pests based on high resolution data of trees combined with field work. Soil moisture monitoring is performed to calculate water stress in trees, which reduces their ability to protect themselves against pests and disease.	For pest management: - 5-10m Other aspects: 10-250m	Weekly or seasonally	Multispectral, SAR	n.a.	Sentinel-1 and -2, Landsat, Planet	Drone footage, plane LiDAR, and data collected during field work (manual measurements for a sample of trees, used to complement and validate satellite data)
EUSPA-EO-UR-FOR- 0002	*Biomass monitoring*	Foresters, timber companies, research institutions, governmental organizations, carbon trade enterprises	Forest carbon sequestration capability baseline monitoring	Country scale to large scale (1000s of ha)	10m	Seasonally	n.a.	In essence, biomass monitoring, provides national baselines of possible carbon uptake.	The number of trees, their species, size and the density of the forest is gleaned from EO data. This data is processed via algorithmic models that calculate carbon uptake depending on the above-mentioned parameters and the constants of carbon uptake per species.	10m	Quarterly-seasonally	Multispectral	n.a.	Sentinel-1 and 2, Landsat	Drone footage, LiDAR, field work (manual measurements for a sample of trees, used to complement and validate satellite data)
EUSPA-EO-UR-FOR- 0003	*Biomass monitoring*	Foresters, timber companies, research institutions, governmental organizations, carbon trade enterprises	Soil acidity monitoring	From local to regional	50m	Seasonally	n.a.	Monitors forest soil acidity via leaves/canopies spectral signature	The pH of the soil is gathered via observations of EO data of leaf health/profile. Soils which are too acidic effect a trees ability to uptake carbon (and other nutrients) and accumulate biomass. The data needed is Multispectral as Hyperspectral imagery is prone to saturation in dense forests.	50m	Quarterly/seasonally	Multispectral, Hyperspectral (in sparse forest cover)	n.a.	Sentienl-1 and -2, Landsat	Drone footage, field work (manual measurements for a sample of trees, used to complement and validate satellite data)

ID	Application	Users	User needs					Service provider offer		Service provider satellite EO requirements				Service inputs	
			Operational scenario	Size of area of interest	Scale	Frequency of information	Other (if applicable)	What the service does	How does the service work	Spatial resolution	Temporal resolution	Data type/spectral range	Other (if applicable)	Satellite data sources	Other data sources, *not satellite-based*
EUSPA-EO-UR-FOR- 0004	*Deforestation/ degradation monitoring*	Foresters, timber companies, governmental organizations, environmental monitoring agencies	Land use track changing	Local (100s of ha)	250m	Seasonally-yearly	n.a.	Classification of the different land uses, and the change between the last classification, used machine learning with EO data	This service tracks land use changes over a seasonally and/or yearly basis and reports to the clients with the same time frames. The service provider however requires a monthly temporal resolution. This monthly supplied data is used to train an algorithm for identification of land use changes with 250m resolution. If needed finer resolution is used	1-10m	Monthly	Multitemporal, NIR	n.a.	Sentinel-1, and -2, LandSat for historical data, PLANET and other commercial satellite data providers.	Drone footage, field work (manual measurements for a sample of trees, used to validate satellite data),
EUSPA-EO-UR-FOR- 0005	*Deforestation/ degradation monitoring*	Foresters, timber companies, research institutions, governmental organizations	Monitoring of forest health	10s of ha	250m	Seasonally	n.a.	Monitor environmental elements that affect forest health such as soil moisture, and life cycle of trees	Earth observation data is used to monitor the state of trees' health throughout the year and is combined with data collected from field work. Depending on the size and maturity of the tress and their canopies aspects of soil composition cannot always be measured. 10s of ha is appropriate for these measurements.	10m	Seasonally	Multispectral, hyper spectral	n.a.	MODIS, Sentinel-1 and -2, Landsat	Drone footage, plane LiDAR, and data collected during field work (manual measurements for a sample of trees, used to validate satellite data)
EUSPA-EO-UR-FOR- 0006	*Deforestation/ degradation monitoring*	Timber companies, governmental organizations, research institutions	Fire detection and management/post-fire forest health monitoring	10s of ha	10-250m	Weekly-monthly	n.a.	Monitors the health of the forest after a degradation event, such as a forest fire	Collects data on tree health and soil characteristics via EO and monitors them after a forest fire	10m	Weekly-quarterly	Multispectral	n..	Sentinel-1 and -2, Landsat	Field work (manual measurements for a sample of trees, used to complement and validate satellite data)
EUSPA-EO-UR-FOR- 0007	*Forest certification*	Timber lumber suppliers, governmental organizations, environmental agencies	Monitoring land use changes	100s of ha to regional scale	250m	Weekly	n.a.	If there is information about illegal activities, then changes are searched for vis pre-existing satellite data and monitors there after	Monitoring of subtle or dramatic land use changes via satellite imagery and determining the land changing agent.	250m	Weekly	Multispectral	n.a.	Sentinel-1 and -2, Landsat	Drone imagery, field work (manual measurements for a sample of trees, used to validate satellite data)

ID	Application	Users	User needs					Service provider offer		Service provider satellite EO requirements				Service inputs	
			Operational scenario	Size of area of interest	Scale	Frequency of information	Other (if applicable)	What the service does	How does the service work	Spatial resolution	Temporal resolution	Data type/spectral range	Other (if applicable)	Satellite data sources	Other data sources, *not satellite-based*
EUSPA-EO-UR-FOR- 0008	*Forest certification*	Timber suppliers, plantation owners, foresters, governmental organizations	Illegal logging detection of specific lumber species	10s of ha	10m	Seasonally, weekly through the months of Sept-Oct	n.a.	This service provides identification of illegal logging for specific tree species in heavily forested areas	To identify individual trees, with a combination of LiDAR and microwave data	10m (taking into account the need for continuous information: the provided LiDAR and Sentinel is ok)	Seasonally, weekly through the months of Sept-Oct	Multispectral, hyperspectral, SAR	n.a.	Sentinel-1 and -2, Landsat, commercial multispectral satellite data	Drone photography, field work (manual measurements for a sample of trees, used to complement and validate satellite data), LiDAR
EUSPA-EO-UR-FOR- 0009	*Forest certification*	Timber suppliers, plantation owners, foresters, governmental organisations	Remote auditing inspection	1/10 hectare	5-10m	Seasonally	n.a.	Identify different trees for certification	Individual canopies are identified through fine hyperspectral resolution imaging, to create an index for biodiversity status project, can identify individual trees, with a combination of LiDAR and microwave, similar to forestry certificates	5-10m	Seasonally/ weekly	Multispectral, hyperspectral, SAR	n.a.	Multispectral satellite data, Sentinel-1 and -2, Landsat, TANDEMX hyperspectral	e.g., non-functional, latency, availability of historical data, reanalysis, pre-processing...

3.10 Sources for the requirements

As this document is mostly based on interviews, the requirements come from the feedback from experts and various UCP participants. The sources vary with the specific application. The majority of input came from the people interviewed while the community participated as well via the UCP.

User requirements were also collected via secondary sources outside of interviews and these are listed as follows:

- Bravo, F. (2019). ETH Library Modelling approaches for mixed forests dynamics prognosis. Research gaps and opportunities. https://doi.org/10.3929/ethz-b-000349182
- Hazlett, P., Emilson, C., Lawrence, G., Fernandez, I., Ouimet, R., & Bailey, S. (2020). Reversal of forest soil acidification in the Northeastern United States and Eastern Canada: Site and soil factors contributing to recovery. Soil Systems, 4(3), 1–22. https://doi.org/10.3390/soilsystems4030054
- Mutanga, O., & Adelabu, S. A. (2016). Remote sensing of aboveground forest biomass: A review. www.tropecol.com
- Nitoslawski, S. A., Wong-Stevens, K., Steenberg, J. W. N., Witherspoon, K., Nesbitt, L., & Konijnendijk van den Bosch, C. C. (2021). The Digital Forest: Mapping a Decade of Knowledge on Technological Applications for Forest Ecosystems. In Earth's Future (Vol. 9, Issue 8). John Wiley and Sons Inc. https://doi.org/10.1029/2021EF002123
- Verma*, H. C., Ahmed, T., & Rajan, S. (2020). Mapping and Area Estimation of Mango Orchards of Lucknow Region by Applying Knowledge Based Decision Tree to Landsat 8 OLI Satellite Images. International Journal of Innovative Technology and Exploring Engineering, 9(3), 3627–3645. https://doi.org/10.35940/ijitee.B8109.019320
- Wang, Y., Zhang, W., Gao, R., Jin, Z., & Wang, X. (2021). Recent advances in the application of deep learning methods to forestry. In Wood Science and Technology (Vol. 55, Issue 5, pp. 1171–1202). Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1007/s00226-021-01309-2
- Zhu, Z., Qiu, S., & Ye, S. (2022). Remote sensing of land change: A multifaceted perspective. In Remote Sensing of Environment (Vol. 282). Elsevier Inc. https://doi.org/10.1016/j.rse.2022.113266

4 ANNEXES

A.1 Definition of key GNSS performance parameters

This annex provides a definition of the most commonly used GNSS performance parameters, taken from [RD2] GNSS Technology Report and includes additional details which are relevant for *Agriculture and Forestry* community.

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: takes into account 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 WiFi base stations for WiFi-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).

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.2 Definition of key EO performance parameters

This annex provides a definition of the most commonly used EO performance parameters and includes additional details which are relevant for *Agriculture and Forestry* community.

Spatial resolution relates to the level of detail that can be retrieved from a scene. In the case of a satellite image, which consists of an array of pixels, it corresponds to the smallest feature that can be detected on the image. A common way of characterising the spatial resolution is to use the Ground Sample Distance (GSD) which corresponds to the distance measured on the ground between the centres of two adjacent pixels. 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 is the number and width of spectral bands of the sensor. The higher the spectral resolution, the narrower the wavelength range for a given channel or band. 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.3 Other performance parameters

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.

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).

A.4 List of Acronyms

Acronym	Definition
EC	European Commission
EGNOS	European Geostationary Navigation Overlay Service
EGNSS	European Global Navigation Satellite System
EO	Earth Observation
ESA	European Space Agency
EU	European Union
EUSPA	European Agency for the Space Programme
GNSS	Global Navigation Satellite System
HAS	High Accuracy Service
MR	Market Report
EUSPA	European Union Agency for the Space Programme
OSNMA	Open Service Navigation Message Authentication
PNT	Positioning, Navigation and Timing
R&D	Research and development
RUR	Report on User needs and Requirements
R&I	Research and Innovation
SATCOM	Satellite communications
SME	Small and Medium-sized Enterprise
SoL	Safety of Life Service
SST	Space Surveillance and Tracking
UCP	User Consultation Platform

A.5 Reference Documents

Id.	Reference	Title	Date
[RD1]	EUSPA Market Report	EUSPA EO and GNSS Market Report (*Issue 1*)	Jan. 2022
[RD2]	GNSS Technology Report	GSA GNSS Technology Report (*Issue 3*)	Sept. 2020
[RD3]	11th International Symposium on Digital Earth (ISDE 11)	Developing Standards for Earth Observation Data Products	2020
[RD4]	EUSPA-MKD-UM-MOM-v_1.0_UCP2023_AGRICULTURE_session MOM - FINAL - 14122023 - EY	UCP 2023 MINUTES OF MEETING OF THE AGRICULTURE MARKET SEGMENT PANEL	2023
[RD5]	EUSPA-MKD-UM-MOM-v_1.0_UCP2023_FORESTRY_session MOM - FINAL - 14122023 - EY	UCP 2023 MINUTES OF MEETING OF THE FORESTRY MARKET SEGMENT PANEL	2023
[RD6]	GSA-MKD-AG-UREQ-250286	Report on User Needs and Requirements, Outcome of the EUSPA User Consultation Platform	2021
[RD7]		Interview with Norbert Huebner	Oct. 2023
[RD8]	Egyptian Journal of Remote Sensing and Space Science, Ali, A. M. et al.	Crop Yield Prediction Using Multi Sensors Remote Sensing (Review Article).	2022
[RD9]	*Scientific Reports*, Khaki, S. et. al.	Simultaneous corn and soybean yield prediction from remote sensing data using deep transfer learning	2021
[RD10]	American Society of Agronomy, Lowenberg-Deboer, J., & Erickson, B.	Setting the record straight on precision agriculture adoption	2019
[RD11]	Remote Sensing, Muruganantham, P. et al.	A Systematic Literature Review on Crop Yield Prediction with Deep Learning and Remote Sensing	2022
[RD12]	*Journal of Agricultural Science*, Nuarsa, I. W., et. al.	Rice Yield Estimation Using Landsat ETM+ Data and Field Observation	2011
[RD13]	*New Approach of Indoor and Outdoor Localization Systems*, Perez-Ruiz, M. et al.	GNSS in Precision Agricultural Operations	2012
[RD14]	S. Marila, et al. *Navigation Conference* (ENC), Helsinki, Finland.	Performance comparison of differential GNSS, EGNOS and SDCM in different user scenarios in Finland	2016
[RD15]	*Web of Science Agriculture*, Radočaj, D., et. al.	Global Navigation Satellite Systems as State-of-the-Art Solutions in Precision Agriculture: A Review of Studies	2023
[RD16]	Remote Sensing, Radočaj, D., et al.	The Role of Remote Sensing Data and Methods in a Modern Approach to Fertilization in Precision Agriculture	2022
[RD17]	*Agricultural and Forest Meteorology*, Schwalbert, R. A. et al.	Satellite-based soybean yield forecast: Integrating machine learning and weather data for improving crop yield prediction in southern Brazil	2020
[RD18]	*Agronomy*, Segarra, J. et al.	Remote Sensing for Precision Agriculture: Sentinel-2 Improved Features and Applications	2020
[RD19]	*International Journal of Applied Earth Observation and Geoinformation*, Tripathi, A. et al.	A deep learning multi-layer perceptron and remote sensing approach for soil health-based crop yield estimation	2022
[RD20]	*Precision Agriculture*, Virnodkar, S. et. al.	Remote sensing and machine learning for crop water stress determination in various crops: a critical review	2020

Id.	Reference	Title	Date
[RD21]	*Remote Sensing*, Wang, X. et al.	Winter wheat yield prediction at county level and uncertainty analysis in main wheat-producing regions of China with deep learning approaches	2020
[RD22]		Interview with Tuomo Kauranne, ARBONAUT	Oct. 2023
[RD23]		Interview with Jose Luis (Agresta S. Coop.)	Oct. 2023
[RD24]		Interview with Ana Sebastian Lopes (GMV)	Oct. 2023
[RD25]		Interview with Ruben Sahba (HYPERPLAN)	Oct. 2023
[RD26]	Press release	Commission proposes comprehensive monitoring to improve resilience of European forests	Nov. 2023
[RD27]	*Journal of Forestry Research*, McEwan, A. et al.	Past, present and future of industrial plantation forestry and implication on future timber harvesting technology	Aug. 2019
[RD28]	*Current Forestry Reports*, J. Stoddart, et al.	Continuous Cover Forestry and Remote Sensing: A Review of Knowledge Gaps, Challenges, and Potential Directions	Nov 2023
[RD29]	Forestry Systems, F. Bravo	Modelling approaches for mixed forests dynamics prognosis. Research gaps and opportunities	Apr. 2019
[RD30]	*Nature Communications*. M.R. Felipe-Lucia et al.	Multiple forest attributes underpin the supply of multiple ecosystem services	Nov. 2018
[RD31]	*Forest Policy and Economics*, G. Winkel et al.	Governing Europe's forests for multiple ecosystem services: Opportunities, challenges, and policy options	Dec. 2022
[RD32]	*Current Forestry Reports*, S. Nocentini et al.	Managing Mediterranean Forests for Multiple Ecosystem Services: Research Progress and Knowledge Gaps	April 2022
[RD33]	*Wood Science and Technology*, Y. Wang et al.	Recent advances in the application of deep learning methods to forestry	Sep. 2020
[RD34]	*Environmental Management*, J. Scholz	Digital Technologies for Forest Supply Chain Optimization: Existing Solutions and Future Trends	Aug. 2018
[RD35]	*Earth's Future, American Geophysical Union*, S.A. Nitoslawski	The Digital Forest: Mapping a Decade of Knowledge on Technological Applications for Forest Ecosystems	
[RD36]	*Soil Systems*, P. Hazlett et al.	Reversal of Forest Soil Acidification in the Northeastern United States and Eastern Canada: Site and Soil Factors Contributing to Recovery	Aug. 2020
[RD37]	*Remote Sensing of Environment*, Z. Zhu et al.	Remote sensing of land change: A multifaceted perspective	Aug. 2022

EUSPA Mission Statement

The mission of the European Union Agency for the Space Programme (EUSPA) 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 European Union.

The EU Agency for the Space Programme:

- Provides state-of-the-art, safe and secure positioning, navigation and timing services based on Galileo and EGNOS, cost-effective satellite communications services for 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, 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; EUSPA operates the Galileo Service Monitoring Centre.

The Security Accreditation Board established within the Agency is the security accreditation authority for all of the Programme's components, where Member States take accreditation decisions in a strictly independent manner from the Programme.

EUSPA: linking space to user needs.

www.euspa.europa.eu

@EU4Space
@space4eu
EU4Space
EUSPA
EUSPA
@EUSPA@social.network.europa.eu

#EUSpace

EUSPA European Union Agency for the Space Programme