D3.1 - Copernicus programme services and datasets

Connecting Europe and Latin America Transforming Today's Data into Tomorrow's Solutions

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PROJECT INFORMATION

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Table of content

1. Definitions, Acronyms and Abbreviations

Acronym	Title
AI	Artificial Intelligence
AMR-C	Advanced Microwave Radiometer – Climate Quality
ARD	Analysis Ready Data
ASI	Italian Space Agency
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
CAMS	Copernicus Atmosphere Monitoring Service
CCM	Copernicus Contributing Missions
CDS	Climate Data Store
CELAC	Community of Latin American and Caribbean States

CEMS	Copernicus Emergency Management Service
CES	cultural ecosystem services
CHIME	Copernicus Hyperspectral Imaging Mission for the Environment
CH4	Methane
CIMR	Copernicus Imaging Microwave Radiometer
CLMS	Copernicus Land Monitoring Services
CMEMS	Copernicus Marine Environment Monitoring Service
CMS	Content Management System
CO	Carbon monoxide
CQC	Coordinated Quality Control
C3S	Climate Change Service
DEM	digital elevation model
DIAS	Data and Information Access Services
DLR	German Aerospace Center
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
ECMWF	European Centre for Medium-Range Weather Forecasts
ECVs	Essential Climate Variables
EEZ	Exclusive Economic Zones
EFAS	European Flood Awareness System
EGMS	European Ground Motion Service
EGNSS	European Global Navigation Satellite System
EMSA	European Maritime Safety Agency
EO	Earth Observation
ESA	European Space Agency
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EuroGOOS	European Global Ocean Observing System
EVI	Enhanced Vegetation Index
EW	Extra Wide Swath
FRP	Fire Radiative Power
GeoJSON	Geographic JavaScript Object Notation
GES DISC	Goddard Earth Sciences Data and Information Services Center
GDU	growing degree units
GHSL	Global Human Settlement Layer
GIS	Geographic Information System

GloFAS	Global Flood Awareness System
GNSS-RO	Global Navigation Satellite System – Radio Occultation
GRD	Ground Range Detected
GWIS	Global Wildfire Information System
HCHO	Formaldehyde
HSU	heat stress units
InSAR	Interferometric Synthetic Aperture Radar
IW	Interferometric Wide Swath
LAC	Latin America and the Caribbean
LRA	Laser Retroreflector Array
LSTM	Land Surface Temperature Monitoring
LTPy	Learning tool for Python on Atmospheric Composition Data
MDA	marine data assimilation
ML	Machine Learning
MODIS	Moderate Resolution Imaging Spectroradiometer
MoU	Memorandum of Understanding
NASA	National Aeronautics and Space Administration
NDVI	Normalised Difference Vegetation Index
NDWI	Normalised Difference Water Index
NESZ	Noise Equivalent Sigma Zero
NIR	near-infrared
NOAA	National Oceanic and Atmospheric Administration
NO2	Nitrogen dioxide
OGC	Open Geospatial Consortium
OLCI	Ocean and Land Colour Instrument
O3	Ozone
QGIS	Quantum Geographic Information System
RMSE	root-mean-square error
ROSE-L	Radar Observing System for Europe in L-band
RSDPS	Remote Sensing Data Processing System
RTK GNSS	Real-time kinematic Global Navigation Satellite System
SAR	Synthetic Aperture Radar
SESA	Security Service Element for Surveillance Applications
SIEM	Security Information and Event Management

SIS	Sectoral Information Systems
SLC	Single Look Complex
SLSTR	Sea and Land Surface Temperature Radiometer
SM	Strip Map Mode
SMOS	Soil Moisture and Ocean Salinity
SO2	Sulfur dioxide
SPOT	Satellite pour l'Observation de la Terre
SRAL	SAR Altimeter
SRTM	Shuttle Radar Topography Mission
SVANTE	Sentinel-5P VAlidatioN and calibraTion Experiment
SWIR	shortwave infrared
TOPS	Terrain Observation with Progressive Scans
TROPOMI	Tropospheric Monitoring Instrument
UNIMINUTO	Corporación Universitaria Minuto de Dios
USGS	U.S. Geological Survey
UV	ultraviolet
VIIRS	Visible Infrared Imaging Radiometer Suite
VOC	volatile organic compound
VRA	Variable Rate Application
WMS	Web Map Service
WV	Wave Mode

2. Project Summary

The COMUNIDAD project, led by Lesprojekt, utilises Copernicus satellite data and the European Global Navigation Satellite System (EGNSS), along with Artificial Intelligence (AI) and Big Data technologies to transfer technologies and know-how to Latin America. The COMUNIDAD project focuses on improving agricultural and forestry management in Chile and Colombia and aims to develop an infrastructure and a platform that serves as the basis for creating applications that enhance precision, efficiency, and sustainability. This initiative contributes to the socio-economic growth of the South American region. Technological advancements are expected to contribute significantly to practical applications.

Lesprojekt, the project coordinator, draws on its expertise in technology applications in agriculture and forestry to guide the consortium. The project provides actionable insights by employing advanced techniques to incorporate Copernicus services, EGNSS and other spatial datasets. These insights help stakeholders, including farmers, advisors, policymakers, and land managers, make informed decisions that support sustainable practices. Essential data on crop health, land use, and forestry conservation are provided, enhancing land management practices and boosting agricultural productivity.

The COMUNIDAD project transfers experiences and know-how through developing technological components and various training activities and creating training materials utilising developed technical components, the infrastructure, and the platform.

The COMUNIDAD project aims to transform agricultural and forestry management in Latin America through technological innovation and international collaboration based on experiences and know-how from European partners and based on international cooperation with partners from Latin America. The integration of cutting-edge technologies with strategic data analysis is set to improve different domains and promote environmental sustainability in the region.

3. Acknowledgement

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5. Executive Summary

The **COMUNIDAD project** is a collaborative effort between Europe and Latin America, aiming to integrate **Copernicus Earth Observation (EO) data** and **EGNSS technologies** to address key environmental and agricultural challenges in Chile and Colombia. Through the use of satellite data, Artificial Intelligence (AI), and advanced analytics, the project seeks to enhance decision-making processes in critical fields such as **agriculture**, **environmental monitoring**, **disaster management**, and **land management**.

This report is structured into several key chapters, outlining the scope and benefits of the **Copernicus Programme** and how its data and services can be applied to support the **CELAC** (Community of Latin American and Caribbean States) region, particularly in **Chile** and **Colombia**. In the first part, the document introduces the Copernicus Programme, providing an overview of its key services and their significance in supporting environmental monitoring and decision-making across diverse sectors. It also outlines the focus of **Work Package 3 (WP3)** in the COMUNIDAD project, which aims to disseminate Copernicus data and services to CELAC countries through training and capacity-building initiatives.

The next chapter delves into the **Copernicus Data and Services**, describing the variety of **Sentinel satellites** and their specific applications, such as **Sentinel-1 for radar imaging**, **Sentinel-2 for land and vegetation monitoring**, and **Sentinel-5P for monitoring atmospheric composition**. It explains how these data streams can be applied across key sectors like agriculture, urban planning, and disaster management, specifically within the contexts of Chile and Colombia.

The report further examines the **Copernicus Land Monitoring Services (CLMS)** in a separate chapter, explaining the structure and application of these services. **CLMS** provides crucial data on land cover and land use, with tools such as the **European Ground Motion Service (EGMS)** for monitoring ground deformation and the **Land Surface Temperature Monitoring (LSTM)** mission for water resource management. These services are vital for sectors such as agriculture, forestry, and urban resilience and are particularly beneficial in addressing the specific challenges faced by the CELAC countries.

The integration of Copernicus data with local infrastructures and tools, such as **Hub4Everybody** will be discussed in a subsequent chapter. This integration enables real-time data visualisation and facilitates decision-making for local stakeholders.

The report also covers existing tools and applications that extend Copernicus services, such as the **RSDPS** (Remote Sensing Data Processing System) and **FieldCalc**, which support satellite data analysis, resource management, and agricultural optimisation. These tools, when integrated with Copernicus data, provide robust solutions for local needs in the CELAC region.

The report also highlights the use of **AI-powered analysis** through the **ALIANCE framework**, which can automate data processing and improve predictive capabilities in areas such as precision agriculture and disaster risk reduction.

In the recommendations section, the report provides guidance on how Copernicus data and additional partner tools can meet the specific needs of **Chile** and **Colombia**. These needs are currently under development, but we communicated this during the preparation of this report. It suggests practical integration pathways for Copernicus data, AI tools, and local infrastructures into the **COMUNIDAD platform**, ensuring that the platform is scalable and accessible for a wide range of users in the region.

Finally, the conclusion summarises the potential impact of the **COMUNIDAD project** on agriculture, environmental monitoring, and disaster management in Latin America. The project has the potential to significantly contribute to sustainable development and environmental resilience in **Chile** and **Colombia**. By emphasising the importance of training, capacity-building, and continued development of digital platforms, the report underscores how Copernicus data and services can help stakeholders in the region make informed decisions, foster innovation, and ensure the socio-economic growth of the region through the adoption of advanced technologies.

6. Introduction

The **Copernicus Programme**[1] is a European Union initiative aimed at developing European information services based on satellite Earth Observation (EO) and in situ (non-space) data. This programme delivers reliable and up-to-date information on various environmental and security issues, supporting decision-making processes in a wide range of domains. It consists of several key services, including land, marine, atmosphere, climate change, emergency management, and security.

Work Package 3 (WP3) of the **COMUNIDAD** project focuses on the development and dissemination of training materials and the organisation of training events to facilitate the use of Copernicus datasets and services. **Task 3.1** aims to provide an overview of the Copernicus programme datasets and services accessible in Europe and identify a subset ready for use in **CELAC** (Community of Latin American and Caribbean States) countries without additional development. This subset will be integrated into the infrastructure developed in **WP2** and utilised in initial workshops.

This deliverable provides a comprehensive description of the available Copernicus data and services, emphasising those particularly relevant to the COMUNIDAD project, with a specific focus on **Colombia** and **Chile**. Additionally, it includes an analysis of the **COPERNICUS LAC (Latin America and the Caribbean) Chile initiative** and the available services tailored for the LAC region.

The report assesses the intended applications of Copernicus data and services and compares them to their actual implementations in Chile and Colombia. This comparison illustrates how these data and services can be effectively presented and utilised in these countries, leveraging the existing solutions provided by European partners. This approach ensures that the selected Copernicus datasets and services are effectively propagated and integrated into local initiatives in the CELAC region.

In the next step, as the **Hub** and educational platform are implemented, the goal is to transfer this content into **online educational lectures**. This will enhance the understanding of the **Copernicus Programme** among CELAC stakeholders, providing a

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[1] https://www.copernicus.eu/en

more accessible and comprehensive view of its advantages. Such an approach will help the **COMUNIDAD** project foster deeper engagement with Copernicus data, enabling CELAC countries to make informed decisions and take full advantage of the programme's offerings.

In summary, this document serves as a foundational reference for understanding the Copernicus programme's offerings, with a targeted analysis of their relevance and application in the context of the COMUNIDAD project, particularly focusing on the needs and conditions of Chile and Colombia.

1   COPERNICUS Data and Services

The Copernicus Programme is a European Earth Observation initiative designed to provide a wide array of services and data products that support environmental monitoring, climate change mitigation, and disaster management. This program delivers reliable and up-to-date information on various environmental and security issues through a combination of satellite Earth Observation (EO) and in situ (non-space) data. Crucial components of Copernicus are the Sentinel satellite missions, which provide high-quality and accessible data for diverse applications.

Copernicus data products are primarily derived from the Sentinel satellites imagery. The Sentinel-1 satellites offer all-weather, day-and-night radar imaging, useful for applications such as monitoring land and marine environments. Sentinel-2 provides high-resolution optical imagery, essential for land cover classification and vegetation monitoring. Sentinel-3 delivers critical data for ocean and land monitoring, including sea surface topography, sea and land surface temperature, and ocean and land colour. Sentinel-4 will monitor key air quality trace gases and aerosols over Europe in support of the Copernicus Atmosphere Monitoring Service (CAMS) at high spatial resolution and with a fast revisit time, but the mission is still under preparation. Sentinel-5P focuses on monitoring atmospheric composition, including pollutants and trace gases, which is vital for air quality assessments. Sentinel-6 contributes to high-precision measurements of sea surface height, supporting climate monitoring and oceanography. In addition to Sentinel data, the ERA5 reanalysis dataset provides detailed information on the atmosphere, land, and ocean state from 1950 to the present, making it a crucial resource

for climate research and historical climate analysis.

The services provided by Copernicus transform the raw data into actionable information, supporting a wide range of environmental and security applications:

- Land Monitoring Service: Offers products and information on land cover and land use, soil moisture, vegetation, and forest monitoring, which are essential for sustainable land management and agricultural practices.
- Marine Environment Monitoring Service: Provides data on the physical state of the oceans and marine ecosystems, supporting maritime safety, coastal and marine environment monitoring, and climate studies.
- Atmosphere Monitoring Service (CAMS): Supplies data on atmospheric composition, including air quality, ozone layer status, and UV radiation levels, which supports policy-making and environmental protection efforts.
- Climate Change Service (C3S): Delivers information on past, present, and future climate conditions, helping societies to mitigate and adapt to climate change. This service includes comprehensive datasets for climate research and policy-making.
- Emergency Management Service (CEMS): Provides information for emergency response and disaster risk reduction, including rapid mapping during emergencies and early warning systems for floods, droughts, and forest fires.
- Security Service: Supports EU policies by providing information on border surveillance and maritime surveillance, as well as support for EU external actions.

Additionally, Copernicus data and services are utilised in educational tools for atmospheric composition studies, enhancing the understanding of environmental monitoring and EO technologies among students and researchers. These diverse services and applications highlight Copernicus' comprehensive approach to Earth observation and environmental monitoring, providing critical information for various sectors and supporting sustainable development goals.

Furthermore, the European Space Agency (ESA) plays a significant role in the Copernicus Data Space Ecosystem[2], which enhances access to Copernicus data and promotes

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[2] https://dataspace.copernicus.eu/

innovation through new data products and services. This ecosystem ensures that the data provided is not only extensive and reliable but also easily accessible and usable for a wide range of applications. The integration of Sentinel data, ERA5 reanalysis data, and the broader ESA Copernicus Data Space Ecosystem underpins the success and utility of the Copernicus Programme, making it a cornerstone of global Earth observation efforts.

1.1 COPERNICUS Data

The Copernicus programme, led by the European Union, is a comprehensive Earth Observation initiative, providing vast amounts of environmental data crucial for monitoring climate change, land use, marine environments, and disaster management. Since 2022, the programme has continued to evolve, focusing on the expansion of its data collection capabilities through the Sentinel satellite fleet and other Contributing Missions. The primary data sources include satellites from the Sentinel family, which capture high-resolution imagery and sensor data across land, atmosphere, and marine domains. This data is made freely available to a wide range of users, including governments, researchers, and businesses, through platforms such as Data and Information Access Services (DIAS) and federated datacube services, ensuring broad access to valuable environmental information.

Recent advancements in the programme have addressed challenges related to the management and processing of "big data" generated by Copernicus. The increased volume, velocity, and variety of data produced by the satellites have necessitated the adoption of advanced technologies. Initiatives like the Copernicus App Lab and ExtremeEarth, which leverage artificial intelligence (AI) and big data technologies, have been critical in improving data accessibility and processing efficiency. These projects aim to streamline user interaction with Copernicus data by developing more scalable platforms and analysis-ready datasets, ensuring faster and more efficient data integration for diverse applications, particularly in domains such as food security and polar monitoring (Koubarakis et al., 2021).

The programme's data reliability has also been a priority in recent years, with the Coordinated Quality Control (CQC) system playing a crucial role. The CQC ensures that the data generated by Sentinel satellites and Contributing Missions meet strict quality standards, providing harmonised and reliable information to users. Furthermore, the

planned expansion of the Sentinel fleet includes new missions, such as ROSE-L, which will enhance the programme's ability to monitor environmental changes with L-band synthetic aperture radar (SAR) technology. These developments will complement existing C-band and X-band capabilities, further strengthening Copernicus' role in global environmental monitoring (Torres et al., 2020).

1.2 Sentinel Data

The Sentinel satellites are a key component of the Copernicus Earth Observation programme, providing a wide range of environmental data used for monitoring and managing land, sea, and atmospheric conditions. The data collected by these satellites is made freely available through the Copernicus Data Space Ecosystem, offering open access to users worldwide.

The Sentinel missions are designed to address various environmental monitoring needs:
- Sentinel-1: This mission consists of two satellites (Sentinel-1A and Sentinel-1B) and provides all-weather, day-and-night radar imagery. It is particularly useful for applications such as land and ocean monitoring, mapping natural disasters like floods, and detecting oil spills.
- Sentinel-2: Sentinel-2 provides high-resolution optical imagery for land monitoring. It captures data on vegetation, soil, water cover, inland waterways, and coastal areas. It is widely used for land cover mapping, agriculture, forestry, and disaster monitoring.
- Sentinel-3: This mission focuses on sea and land monitoring, providing data on sea surface temperature, sea surface topography, and land surface temperature. It supports applications in oceanography, climate monitoring, and environmental management.
- Sentinel-4: This mission will focus on monitoring key air quality trace gases and aerosols over Europe, supporting the Copernicus Atmosphere Monitoring Service (CAMS) at high spatial resolution and with a fast revisit time. The planned launch of the first satellite is during the second half of 2024.
- Sentinel-5P: Sentinel-5 Precursor (Sentinel-5P) provides atmospheric monitoring data, primarily focusing on air quality. It measures trace gases such as ozone, nitrogen dioxide, and carbon monoxide, which are important for monitoring

pollution and greenhouse gas emissions.

- Sentinel-6: The Sentinel-6 mission, also known as Jason Continuity of Service, focuses on precise measurements of global sea-level rise, supporting climate studies, and ocean circulation monitoring.

These datasets are provided in various formats suitable for scientific analysis, supporting a broad range of environmental applications, including agriculture, forestry, water management, urban planning, disaster response, and climate change monitoring. The data is accessible through the Copernicus Data Space Ecosystem, which ensures open and continuous availability for users across sectors.

1.1.1   SENTINEL 1

The **Sentinel-1 mission**[3] consists of two Synthetic Aperture Radar (SAR) satellites, Sentinel-1A and Sentinel-1B. These satellites operate in the C-band frequency and provide continuous, systematic global coverage for a wide range of environmental monitoring applications, including land and marine surveillance, emergency response, and climate change monitoring. Key to Sentinel-1's success is its ability to operate in all weather conditions, day and night, making it particularly valuable for long-term, consistent Earth observation.

1.1.1.1   Orbit Characteristics

Sentinel-1 satellites operate in a near-polar, sun-synchronous orbit at an altitude of approximately 693 km. The satellites complete a full orbit around the Earth in roughly 98.6 minutes. This polar orbit ensures global coverage, with a 12-day repeat cycle per satellite, which is reduced to 6 days when both satellites (1A and 1B) are operational. This short revisit time allows for frequent monitoring of dynamic environmental processes, making it highly useful for different applications such as flood mapping, land deformation studies, and monitoring land use changes.

1.1.1.2   Imaging Modes

The Sentinel-1 mission features four distinct imaging modes, each designed to serve

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[3] https://sentinels.copernicus.eu/web/sentinel/copernicus/sentinel-1

specific operational and scientific purposes:

1. **Interferometric Wide Swath (IW)**: This is the default mode for land applications. It uses Terrain Observation with Progressive Scans in azimuth (TOPS) mode to achieve wide-area coverage, with a swath width of 250 km and a resolution of approximately 5x20 meters. This mode is widely used for interferometric applications such as ground deformation studies, including earthquake and landslide monitoring.

2. **Extra Wide Swath (EW)**: Primarily used for maritime and polar zone observations, this mode offers a larger swath width of 400 km with a coarser resolution (20x40 meters). It is designed to monitor sea ice and provide wide-area ocean surveillance.

3. **Strip Map Mode (SM)**: This mode offers a higher resolution (5x5 meters) but covers a smaller swath of 80 km. It is mainly used in specific areas requiring detailed mapping and analysis.

4. **Wave Mode (WV)**: Used to capture small strips of imagery (20x20 km) over open oceans. This mode provides data primarily for wave height measurements and oceanographic studies.

The IW and EW modes both utilise the innovative TOPS technique, which ensures high-quality data suitable for interferometry by synchronising bursts during repeat-pass acquisitions (Geudtner et al., 2012). This allows for highly accurate interferometric SAR (InSAR) applications, such as subsidence monitoring and the generation of digital elevation models (DEMs).

1.1.1.3 Data Processing and Ground Segment

The Sentinel-1 mission is supported by an extensive ground segment that manages data downlink, processing, quality control, dissemination, and archiving. The ground segment ensures that the large volumes of data generated by the Sentinel-1 satellites are processed into various products with different processing levels:

- **Level-1 (SLC and GRD)**: This level includes Single Look Complex (SLC) products, which retain phase information essential for InSAR applications, and Ground Range Detected (GRD) products, which are radiometrically corrected for wide-

area analysis.

- **Level-2**: This level consists of geophysical products derived from Level-1 data, such as soil moisture, surface deformation, and ocean currents.

1.1.1.4 Performance and Key Parameters

The Sentinel-1 mission is designed to meet stringent performance standards. Key performance parameters include high radiometric accuracy, instrument stability, and a low Noise Equivalent Sigma Zero (NESZ), ensuring data reliability (Torres et al., 2017). These characteristics make Sentinel-1 highly suited for a variety of applications, ranging from environmental monitoring and natural disaster management to scientific research in geodesy and glaciology.

1.1.1.5 Applications and Future Developments

Sentinel-1 data is widely used across several thematic areas, including land surface monitoring, marine and coastal zone monitoring, atmosphere, emergency response, security, and climate change studies. In particular, the mission supports:

- **InSAR applications**: Monitoring land deformation and subsidence, as well as generating precise DEMs.
- **Ocean monitoring**: Tracking sea ice, detecting oil spills, and measuring ocean wave heights.
- **Disaster management**: Providing rapid response data for floods, earthquakes, and other natural disasters.

The Sentinel-1 system's ongoing development includes enhancements to its data processing chain and plans for future mission extensions, including improved orbital baseline management and SAR burst synchronisation, ensuring the continued provision of high-quality Earth observation data for diverse applications (Geudtner et al., 2021).

1.1.1.6 Accessibility of Sentinel-1 Data

Sentinel-1 data is freely and openly available to users worldwide through the Copernicus Data Space Ecosystem. This platform ensures that the large volumes of data generated by Sentinel-1 are accessible to various user groups, including researchers, government

agencies, private companies, and the general public. Users can access Sentinel-1 data products through multiple services, such as:

- **Copernicus Data and Information Access Services (DIAS)**: DIAS platforms offer cloud-based access to Copernicus data, including processing and analysis capabilities, enabling users to work directly with large datasets without the need to download them.
- **Copernicus Data Space Ecosystem**: The newly established Copernicus Data Space Ecosystem superseded the Copernicus Open Access Hub and integrates various data services to facilitate seamless access, processing, and visualisation of Copernicus data, including Sentinel-1. It supports both expert users with specific data needs and non-experts looking for quick insights and solutions.

The data is provided in standard formats, such as GeoTIFF and SAFE, and is accompanied by comprehensive metadata to ensure that it is easily interpretable and usable across a wide range of applications. Sentinel-1 data is also interoperable with other Earth observation datasets, enabling users to integrate it with data from other missions for comprehensive environmental analysis. This open data policy enhances the accessibility of Earth observation data and encourages the development of innovative applications in various fields, from scientific research to commercial services.

In conclusion, Sentinel-1's advanced SAR technology, global coverage, and frequent revisit times make it an indispensable tool in the Copernicus programme, providing critical data for environmental monitoring and disaster management efforts worldwide.

1.1.2   SENTINEL 2

The **Sentinel-2 mission**[4] consists of two optical imaging satellites: **Sentinel-2A** and **Sentinel-2B**. These satellites provide high-resolution multispectral imagery with 13 spectral bands, covering visible, near-infrared, and shortwave infrared wavelengths; however, unlike Landsat satellites, it is missing the thermal band. The mission is specifically designed for land monitoring, delivering valuable data on vegetation, soil, water bodies, and coastal areas, supporting a wide range of applications in agriculture,

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[4] https://sentinels.copernicus.eu/web/sentinel/copernicus/sentinel-2

forestry, urban planning, and disaster management.

1.1.2.1   Orbit and Coverage

Sentinel-2 operates in a near-polar, sun-synchronous orbit at an altitude of approximately 786 km. The orbit configuration enables the satellites to provide global coverage of land surfaces every five days when both satellites are operational. This frequent revisit time is crucial for monitoring dynamic processes such as vegetation growth, crop conditions, and disaster impacts.

1.1.2.2   Spectral Bands and Spatial Resolution

Sentinel-2's 13 spectral bands are designed to capture data across a broad range of the electromagnetic spectrum:

- **Four bands** (Bands 2, 3, 4, and 8) at a high spatial resolution of 10 meters, focusing on visible and near-infrared light, ideal for detailed monitoring of vegetation and land cover.
- **Six bands** (Bands 5, 6, 7, 8A, 11, and 12) at 20-meter resolution, which are optimised for detecting vegetation health, water content, and soil properties.
- **Three bands** (Bands 1, 9, and 10) at 60-meter resolution, primarily for atmospheric correction and cloud screening.

The combination of high spatial, spectral, and temporal resolution makes Sentinel-2 particularly valuable for applications such as precision agriculture, land use mapping, and monitoring natural disasters like floods and forest fires.

1.1.2.3   Data Products and Processing Levels

Sentinel-2 provides three key data product levels:

- **Level-1C**: Top-of-atmosphere reflectance images in UTM/WGS84 projection, with systematic geometric and radiometric corrections applied. This product is widely used for applications where atmospheric effects are not a primary concern.
- **Level-2A**: Surface reflectance images, corrected for atmospheric effects. This product is useful for detailed analysis requiring precise surface measurements,

such as vegetation monitoring and land cover classification.

1.1.2.4   Applications of Sentinel-2 Data

Sentinel-2 data has proven to be versatile across multiple sectors:

1. **Agriculture**: Sentinel-2 is widely used in precision agriculture for monitoring crop health, detecting water stress, and optimising resource use. Its frequent revisits and high-resolution imagery enable the detection of subtle changes in crop conditions, supporting yield prediction and efficient farm management (Lugo-Palacio et al., 2024).
2. **Environmental Monitoring**: Sentinel-2 data is crucial for tracking deforestation, monitoring forest health, and estimating forest stand volume when combined with machine learning techniques. It is also used to monitor water bodies and coastal areas, providing insights into water quality and land use changes.
3. **Disaster Management**: The mission supports disaster response efforts by providing timely data for mapping the extent of floods, fires, and other natural disasters. Sentinel-2's imagery is used to assess damage and aid in recovery planning.
4. **Urban Planning**: Urban growth and land use changes can be effectively monitored with Sentinel-2's multispectral imagery. This data helps city planners track urban sprawl, land conversion, and green space development.

1.1.2.5   Accessibility of Sentinel-2 Data

Sentinel-2 data is freely and openly accessible through the **Copernicus Data Space Ecosystem**, ensuring widespread availability to various users, including researchers, businesses, and governmental agencies. Key access points include:

- **Copernicus Data Space Browser**: This user-friendly interface allows users to explore and download Sentinel-2 data, including real-time imagery and historical datasets. Users can search by date, location, and cloud coverage, making it easy to retrieve data for specific analysis needs.
- **Copernicus DIAS (Data and Information Access Services)**: DIAS platforms provide cloud-based access to Sentinel-2 data, allowing users to process and analyse large datasets without needing to download them locally.

The data is provided in standard formats (such as GeoTIFF and JPEG2000) and is accompanied by metadata, ensuring it is easily usable for a wide range of applications, from scientific research to commercial services. The open access policy ensures that Sentinel-2 data remains a key resource for environmental monitoring and decision-making globally.

1.1.3   SENTINEL 3

The **Sentinel-3 mission**[5] is designed to monitor Earth's oceans, land, atmosphere, and cryosphere with a combination of optical, altimetry, and radiometric instruments. Sentinel-3 consists of two satellites, **Sentinel-3A** and **Sentinel-3B**, providing near real-time data critical for oceanography, land monitoring, and atmospheric studies. The mission delivers key information on sea surface topography, sea and land surface temperature, ocean and land colour, and fire detection.

1.1.3.1   *Orbit and Coverage*

Sentinel-3 operates in a near-polar, sun-synchronous orbit at an altitude of 814 km. This configuration allows for global coverage every 27 days, with a shorter revisit time of under two days at the equator for optical instruments and under one day for altimeter measurements over the oceans. This frequent revisit capability is essential for monitoring dynamic processes, particularly in oceanography and land surface applications.

1.1.3.2   *Instruments and Capabilities*

Sentinel-3's payload includes three main instruments, each designed for specific environmental monitoring tasks:

1. **Ocean and Land Colour Instrument (OLCI)**: OLCI is a multi-spectral optical sensor designed to observe ocean and land colour changes. It operates in 21 spectral bands, providing data for marine ecosystems, vegetation, and water quality monitoring. OLCI's high-resolution imagery is used to assess chlorophyll concentrations, monitor algae blooms, and evaluate land cover changes.

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[5] https://sentinels.copernicus.eu/web/sentinel/copernicus/sentinel-3

2. **Sea and Land Surface Temperature Radiometer (SLSTR)**: SLSTR measures sea and land surface temperatures in both infrared and visible light. The radiometer provides dual-view observations with high accuracy, crucial for climate studies, oceanography, and agricultural monitoring. The SLSTR sensor is also equipped with an **active fire detection** capability, which is useful for identifying and monitoring wildfires globally.

3. **SAR Altimeter (SRAL)**: The SAR altimeter provides precise measurements of sea surface height, wave height, and wind speeds over oceans. It also monitors water bodies such as lakes and rivers and is valuable for tracking ice sheets. SRAL operates in **closed-loop** and **open-loop** modes, depending on terrain type, with newer versions improving detection rates over complex topographies.

1.1.3.3 Data Products and Applications

Sentinel-3 data is processed into multiple levels and products, catering to a wide range of applications:

- **Level-1**: Raw data from the instruments, corrected for radiometric and geometric distortions, available for users needing high-precision datasets.
- **Level-2**: Processed data for specific applications, such as sea surface temperature, land surface reflectance, and fire radiative power (FRP). These products are suitable for direct integration into environmental monitoring models.

The **OLCI** imagery from Sentinel-3 has been used in diverse applications, including the detection of contaminants in marine estuaries (Neckel et al., 2022) and vegetation monitoring, including fuel moisture content estimation. Furthermore, **SLSTR** has been adapted for **daytime fire detection**, showing similar fire patterns to MODIS while expanding the range of detected fires (Xu & Wooster, 2023).

In oceanography, **altimetry products** from Sentinel-3 offer near real-time data for monitoring river water levels and global sea surface height. The **accuracy of Sentinel-3 altimetry** in near real-time products is nearly comparable to the non-time-critical data, with a root-mean-square error (RMSE) of around 21.5 cm, supporting applications such as river monitoring and ocean topography (Jiang et al., 2023).

Sentinel-3 has also shown potential in **methane leak detection**, complementing Sentinel-2 and Sentinel-5p satellites to identify and quantify methane emissions globally (Pandey et al., 2023).

1.1.3.4   Accessibility of Sentinel-3 Data

Sentinel-3 data is freely available through the **Copernicus Data Space Ecosystem**, which provides users with access to various data products. Key platforms include:

- **Copernicus Data Space Browser**: A user-friendly interface allowing real-time exploration and download of Sentinel-3 datasets, including visualisations of ocean colour, land surface temperature, and fire radiative power.
- **Copernicus Open Access Hub**: The primary repository for all Sentinel-3 data, providing free access to archived and real-time data.
- **DIAS (Data and Information Access Services)**: Cloud-based services that offer access to Sentinel-3 data for processing without requiring users to download large datasets locally.

Sentinel-3 data is available in standard formats (e.g., NetCDF, GeoTIFF) and accompanied by comprehensive metadata to support integration into scientific research and operational applications. This open-access policy promotes innovation in environmental monitoring and facilitates collaboration across scientific and commercial sectors.

1.1.3.5   Challenges and Future Developments

While Sentinel-3 offers robust capabilities, challenges remain in **altimetry performance** over complex terrains and reservoirs, particularly in high mountain regions, where water level fluctuations can exceed measurement limits (Yung-Feng Cheng et al., 2023). Future developments aim to address these issues, ensuring more reliable data across diverse environments. Additionally, improvements in **land surface reflectance anisotropy retrieval** and the refinement of vegetation-related products like FAPAR continue to expand Sentinel-3's utility in land surface monitoring (León-Tavares et al., 2024; Gobron et al., 2022).

In summary, Sentinel-3 is a vital component of the Copernicus programme, offering

critical data for oceanography, land surface monitoring, and atmospheric studies. Its open-access data policy and evolving capabilities ensure its ongoing importance in addressing global environmental challenges.

1.1.4   COPERNICUS-5P

The **Sentinel-5 Precursor (Sentinel-5P)**[6], launched in October 2017, is a key part of the Copernicus Earth Observation programme, designed specifically for atmospheric monitoring. It is equipped with the **TROPOMI (Tropospheric Monitoring Instrument)**, which provides high-resolution measurements of trace gases, aerosols, and clouds. Sentinel-5P is the precursor to the full Sentinel-5 mission and plays a critical role in monitoring air quality, climate change, and ozone layer depletion.

1.1.4.1   *Orbit and Coverage*

Sentinel-5P operates in a near-polar, sun-synchronous orbit at an altitude of approximately 824 km. It provides global coverage daily, which is essential for the continuous monitoring of atmospheric composition. The satellite covers the entire globe daily, making it highly effective for tracking short-term atmospheric events like pollution spikes or wildfire smoke plumes.

1.1.4.2   *Instruments and Capabilities*

The primary instrument on board Sentinel-5P is **TROPOMI**, which has several key features designed to measure atmospheric composition with high precision. TROPOMI's capabilities include detecting a wide range of atmospheric trace gases and pollutants, such as:

- **Nitrogen dioxide (NO2)**: A major pollutant related to vehicle emissions and industrial activities.
- **Ozone (O3)**: Both tropospheric ozone, a harmful pollutant, and stratospheric ozone, which protects Earth from UV radiation.
- **Methane (CH4)**: A potent greenhouse gas critical for climate monitoring.
- **Carbon monoxide (CO)**: A harmful gas related to incomplete combustion, which

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[6] https://sentinels.copernicus.eu/web/sentinel/copernicus/sentinel-5p

can indicate pollution from vehicles or wildfires.

- **Sulphur dioxide (SO2)**: Associated with volcanic activity and industrial processes.
- **Formaldehyde (HCHO)**: A marker of volatile organic compound (VOC) emissions relevant to forest fires and urban air pollution.

TROPOMI operates across the ultraviolet (UV), visible, near-infrared (NIR), and shortwave infrared (SWIR) spectral ranges. This wide spectral coverage enables the detection of various gases with high spatial resolution, typically around 7x3.5 km² per pixel, making Sentinel-5P particularly useful for urban air quality monitoring and identifying localised pollution sources.

1.1.4.3   Data Products and Applications

Sentinel-5P data is processed into different levels to meet the needs of various users:

- **Level-1B**: This is the radiometrically and geometrically corrected data, which includes basic atmospheric measurements.
- **Level-2**: This product includes retrieved trace gas concentrations, such as NO2, O3, CH4, CO, SO2, and HCHO. These data products are widely used for atmospheric research, policy-making, and public health applications.

Sentinel-5P data has been instrumental in several research and monitoring applications:

1. **Air Quality Monitoring**: Sentinel-5P's high-resolution NO2 measurements have been used to track air pollution in urban and industrial regions. For example, during the COVID-19 pandemic, Sentinel-5P detected significant reductions in NO2 levels across Europe, attributed to decreased industrial activity and reduced vehicular emissions during lockdowns.
2. **Greenhouse Gas Emissions**: TROPOMI has advanced methane leak detection, which is crucial for mitigating climate change. Sentinel-5P has been used in combination with other satellites to detect methane leaks from oil and gas facilities globally.
3. **Ozone Layer Monitoring**: Sentinel-5P is essential for monitoring the recovery of the stratospheric ozone layer and tracking tropospheric ozone levels, which are

important for both climate regulation and air quality management.

4. **Volcanic Activity Monitoring**: The SO2 detection capabilities of TROPOMI enable real-time monitoring of volcanic emissions, which are critical for aviation safety and public health in regions affected by volcanic activity.

5. **Climate Change Research**: Sentinel-5P contributes to long-term climate change research by providing continuous, global data on greenhouse gases like methane and carbon monoxide, helping scientists track emissions trends and identify mitigation opportunities.

1.1.4.4   Validation and Data Quality

Validation efforts for Sentinel-5P data have been extensive to ensure the accuracy and reliability of its measurements. Ground-based validation campaigns and airborne measurements are routinely conducted to compare satellite data with in-situ measurements. For example, validation studies revealed a 20% bias in total column NO2 measurements compared to ground-based data (Verhoelst et al., 2021). Despite this, the data quality is sufficient for many operational and research applications, and continuous improvements to the processing algorithms are made based on these validation results.

The **Sentinel-5P VAlidatioN and calibraTion Experiment (SVANTE)** is one such initiative aimed at validating TROPOMI's atmospheric products, particularly for trace gases like NO2, HCHO, and SO2, through a combination of airborne and ground-based observations (Van Roozendael et al., 2020).

1.1.4.5   Accessibility of Sentinel-5P Data

Sentinel-5P data is freely accessible to users worldwide through several platforms:

● **Copernicus Data Space Ecosystem**: The primary portal for accessing Sentinel-5P data. Users can search and download data products related to atmospheric trace gases, aerosols, and cloud coverage.

● **NASA's Goddard Earth Sciences Data and Information Services Center (GES DISC)**: This platform provides access to TROPOMI data products, offering tools for data exploration and download.

- **Copernicus Open Access Hub**: Users can access real-time and archived data, allowing researchers, policymakers, and the public to monitor atmospheric conditions and pollution levels.

Sentinel-5P data is available in standard formats (e.g., NetCDF, HDF5), making it easy to integrate into a wide variety of scientific models and applications. Detailed metadata accompanies the data, ensuring users can understand and interpret the measurements accurately.

1.1.4.6 Challenges and Future Developments

While Sentinel-5P has proven to be a highly effective mission for atmospheric monitoring, some challenges remain. For example, there are known biases in NO2 and other trace gas measurements, particularly in regions with complex topography or highly variable weather conditions. Additionally, the spatial resolution, though high, may still be insufficient for detecting very localised sources of pollution in urban areas.

Ongoing improvements to data processing algorithms and continued validation efforts aim to address these challenges. The upcoming full **Sentinel-5 mission**, which is planned to launch in the coming years, will further enhance these capabilities by providing even higher spatial resolution and additional spectral bands for atmospheric composition monitoring.

In conclusion, Sentinel-5P is a critical component of the Copernicus programme, providing vital data for monitoring air quality, greenhouse gases, and climate change. Its open-access policy and high-resolution measurements make it an indispensable tool for researchers, policymakers, and public health officials around the world.

1.1.5 SENTINEL 6

The **Sentinel-6 mission**[7], also known as **Sentinel-6 Michael Freilich**, plays a crucial role in climate monitoring, particularly in measuring sea level rise. Launched in November 2020, Sentinel-6 continues the legacy of previous satellite missions like **TOPEX/Poseidon** and the **Jason series**, ensuring the continuity of the long-term sea level measurement

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[7] https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-6

record. The mission consists of two identical satellites, **Sentinel-6A Michael Freilich** and **Sentinel-6B**, with the second satellite planned for launch in 2025 to ensure continuous data collection through the 2030s.

1.1.5.1   Orbit and Coverage

Sentinel-6 operates in a **non-sun-synchronous orbit** at an altitude of 1,336 km. This orbit ensures global coverage of the Earth's oceans every ten days, providing precise measurements of sea surface height, wave height, and ocean surface winds. The 66° inclination of the orbit allows Sentinel-6 to cover 95% of the Earth's ice-free oceans, a critical area for monitoring sea level changes and ocean dynamics.

1.1.5.2   Instruments and Capabilities

The **Sentinel-6 Michael Freilich** satellite carries state-of-the-art instruments designed to provide high-precision measurements of sea level and atmospheric data:

1. **Poseidon-4 Radar Altimeter**: This is the primary instrument onboard Sentinel-6, responsible for measuring sea surface height with high accuracy. The altimeter operates in **dual-frequency mode (C-band and Ku-band)** and uses **synthetic aperture radar (SAR)** processing to enhance the resolution of the measurements. It continues the legacy of previous altimeter missions (TOPEX/Poseidon, Jason-1, Jason-2, and Jason-3) while introducing advanced technologies to improve data quality.
2. **Advanced Microwave Radiometer – Climate Quality (AMR-C)**: The AMR-C measures atmospheric water vapour, which can affect the accuracy of radar altimetry. This information is critical for correcting the radar signals and improving the precision of sea surface height measurements, particularly in coastal regions and areas with high humidity.
3. **GNSS-RO (Global Navigation Satellite System – Radio Occultation)**: The GNSS-RO instrument provides atmospheric data by tracking signals from navigation satellites as they pass through the atmosphere. This technique is used to derive profiles of atmospheric temperature, pressure, and humidity, contributing to weather forecasting and climate monitoring.
4. **DORIS (Doppler Orbitography and Radiopositioning Integrated by Satellite)**:

DORIS provides precise orbit determination by using ground-based beacons to track the satellite's position, ensuring the accuracy of the altimetry data.

5. **Laser Retroreflector Array (LRA)**: The LRA is used to track the satellite's orbit via ground-based laser systems, further enhancing the precision of sea level measurements.

1.1.5.3   Data Products and Applications

Sentinel-6 provides several levels of data products aimed at different user needs:

- **Level-1**: This includes raw radar altimetry measurements corrected for instrumental effects and atmospheric influences.
- **Level-2**: Processed data providing sea surface height, wave height, and wind speed measurements.
- **Level-3 and Level-4**: These products include gridded data for long-term climate monitoring and modelling.

The data collected by Sentinel-6 serves numerous critical applications:

1. **Sea Level Monitoring**: Sentinel-6 continues the long-term record of sea level measurements, which is essential for tracking global sea level rise—a key indicator of climate change. The mission's high-precision altimeter is designed to measure sea level with an accuracy of a few centimetres, enabling scientists to detect even small changes in global ocean levels over time.
2. **Climate Change Research**: The data provided by Sentinel-6 is essential for climate scientists to monitor the effects of global warming, particularly the thermal expansion of seawater and the melting of ice sheets, both of which contribute to rising sea levels. The continuity of these measurements over decades is crucial for understanding long-term climate trends.
3. **Ocean Dynamics**: In addition to sea level measurements, Sentinel-6 provides data on significant wave height and ocean surface wind speeds, which are vital for understanding ocean circulation patterns, eddies, and ocean currents. These data support oceanographic research and improve our understanding of how the oceans interact with the atmosphere.
4. **Weather Forecasting**: The GNSS-RO instrument aboard Sentinel-6 enhances

weather forecasting by providing high-precision atmospheric profiles. These data are integrated into global numerical weather prediction models to improve forecast accuracy.

1.1.5.4 Position in the Copernicus Programme

Sentinel-6 is fully integrated into the **Copernicus programme**, the European Union's comprehensive Earth observation initiative. Copernicus aims to provide free and open access to vast amounts of environmental data for climate monitoring, disaster management, agriculture, and numerous other applications. Sentinel-6 is a continuation of the **Jason series of satellites**, ensuring the long-term record of sea level measurements, which began with the TOPEX/Poseidon mission in 1992.

The Copernicus programme, led by the European Union in partnership with ESA (European Space Agency), NASA, NOAA, and EUMETSAT, coordinates the **Copernicus Space Component**. This component consists of a series of Sentinel satellites that monitor various aspects of Earth's environment, including land, oceans, atmosphere, and climate. Sentinel-6's integration into Copernicus complements other missions like **Sentinel-1** (radar imaging), **Sentinel-2** (optical imagery), and **Sentinel-3** (ocean and land monitoring), creating a comprehensive global monitoring system that supports scientific research and policy-making.

1.1.5.5 Accessibility of Sentinel-6 Data

Sentinel-6 data is freely and openly accessible through the **Copernicus Data Space Ecosystem** and other platforms such as:

- **EUMETSAT**: As the operational agency for Sentinel-6, EUMETSAT provides near-real-time access to altimetry data through its website, offering a wide range of products suitable for operational and scientific use.
- **Copernicus Open Access Hub**: Users can access archived and real-time data from Sentinel-6, supporting diverse applications in research, policy, and industry.

The open access to this high-quality data ensures that scientists, policymakers, and the public can monitor sea level trends, understand climate change impacts, and improve oceanographic and atmospheric forecasting models.

1.1.5.6 Challenges and Future Developments

While Sentinel-6 provides high-precision measurements, challenges remain in measuring sea level changes in coastal regions and areas with high variability, such as eddies and currents. Future improvements to radar altimetry technologies and data processing algorithms will continue to enhance the accuracy of measurements in these areas.

The **second satellite**, **Sentinel-6B**, will be launched in 2025 to ensure the continuation of this vital data stream into the 2030s. This long-term continuity is essential for understanding the impacts of climate change on the oceans and providing the data necessary for informed environmental policy decisions.

In conclusion, **Sentinel-6 Michael Freilich** is a cornerstone of the Copernicus programme, providing crucial data on sea level rise, ocean dynamics, and atmospheric conditions. Its contributions are vital for climate change research, oceanographic studies, and operational weather forecasting, ensuring that the global community has the tools needed to address the challenges of a changing planet.

1.1.6 Copernicus Contributing Missions

The **Copernicus Contributing Missions (CCM)** are external satellite missions that complement the data provided by the Sentinel satellites. These missions are operated by various agencies and include a wide range of Earth observation satellites from Europe and around the world. The data collected by these missions includes high-resolution imagery, radar data, and other specialised environmental measurements.

The **Contributing Missions** support Copernicus by providing:

- **High-resolution optical imagery**: Data from missions such as SPOT and Pleiades is used to monitor land cover, urban development, and agricultural activity.
- **Radar data**: Satellites such as TerraSAR-X and Cosmo-SkyMed provide radar imagery, which is crucial for applications such as disaster monitoring, land deformation studies, and environmental management.
- **Meteorological data**: Missions like MetOp and Suomi NPP contribute valuable information for weather forecasting and climate monitoring.

1.1.6.1 Availability and Access to Copernicus Contributing Missions Data

Data from the **Copernicus Contributing Missions** is made available through the **Copernicus Data Space Ecosystem** and various access points, depending on the type of mission and data. This ensures that users have a comprehensive view of environmental conditions and can integrate data from multiple sources for detailed analysis and monitoring.

The **Copernicus Contributing Missions data** collections are available in a variety of formats, covering different thematic areas such as land monitoring, ocean observation, and atmospheric data. Access to this data is coordinated through different services, allowing users to select the most relevant datasets for their specific applications.

- **Optical and radar data** is used extensively for land and ocean monitoring, including high-resolution imagery for detailed mapping and radar data for all-weather, day-and-night monitoring.
- **Meteorological and atmospheric data** from Contributing Missions supports climate studies, weather forecasting, and air quality monitoring, enhancing the ability to predict and mitigate environmental impacts.

The availability of these datasets ensures that Copernicus is a truly comprehensive Earth observation programme, integrating data from both dedicated Sentinel satellites and a broad array of external missions.

The **Copernicus programme** is a robust, multi-faceted Earth observation initiative that combines dedicated Sentinel missions with data from **Copernicus Contributing Missions**. This integration ensures that users have access to a wide range of environmental data, supporting applications in climate monitoring, disaster management, and sustainable development. Through its open data policy, Copernicus plays a critical role in global efforts to understand and address environmental and climate challenges.

1.1.7 Federated data sets

Federated Data Sets refer to collections of Earth observation data that are distributed

across multiple data providers and platforms but are integrated and accessible through a unified interface. In the context of the **Copernicus Data Space Ecosystem**, federated data sets are provided by various national, European, and international organisations, complementing the data from the **Sentinel missions** and **Copernicus Contributing Missions**.

The key characteristic of federated data sets is that they are not stored in a single location but remain with their original providers. However, through **federated data access services**, users can search, retrieve, and analyse these data sets from a central platform, making it easier to integrate data from diverse sources.

1.1.7.1 Key Features of Federated Data Sets

1. **Distributed Architecture**: Federated data sets are hosted by multiple organisations or platforms, often using different technical infrastructures. This distributed nature allows data providers to maintain control over their data while making it accessible through a shared system.
2. **Unified Access**: Despite being distributed, these data sets are made accessible through a **centralised portal** like the **Copernicus Data Space Ecosystem**, where users can search, discover, and access data from various providers without needing to interact with each data source separately.
3. **Interoperability**: To ensure that data from different providers can be used together, federated data sets must follow common standards and formats. This enables users to combine data from multiple sources for comprehensive analysis and research.
4. **Enhanced Data Availability**: By federating data from multiple sources, Copernicus expands the range of available Earth observation data, covering various environmental parameters, spatial resolutions, and thematic areas. This supports more in-depth research and application development across multiple domains, such as climate change, agriculture, disaster management, and urban planning.

1.1.7.2 Federated Data Sets:

1. **TerraSAR-X Data**: Provided by the German Aerospace Center (DLR), TerraSAR-X is a radar satellite that offers high-resolution synthetic aperture radar (SAR)

imagery. This data is used for applications such as land cover mapping, disaster monitoring, and infrastructure management.

2. **Pleiades Data**: The Pleiades constellation, operated by Airbus, offers very high-resolution optical imagery. It is used for detailed mapping and monitoring of urban areas, agriculture, and forestry. This data is critical for applications that require high spatial accuracy.

3. **SPOT Data**: SPOT satellites, also operated by Airbus, provide high-resolution optical imagery. SPOT data is widely used for land use, land cover, and agricultural monitoring.

4. **Radarsat-2 Data**: Provided by MDA, Radarsat-2 is a radar satellite offering data for applications such as marine surveillance, ice monitoring, and oil spill detection. This radar data is valuable for monitoring in all weather conditions, day and night.

5. **WorldView Data**: Operated by Maxar Technologies, the WorldView satellite constellation provides ultra-high-resolution optical imagery. WorldView data is essential for precision mapping, urban planning, and environmental monitoring.

6. **COSMO-SkyMed Data**: This radar satellite system, operated by the Italian Space Agency (ASI), provides SAR data for environmental monitoring, disaster management, and security applications. Its all-weather capability makes it ideal for monitoring dynamic environmental processes.

7. **Sentinel-1, Sentinel-2, and Sentinel-3 Data**: While these are Copernicus Sentinel missions, their data is often included in federated data sets alongside data from contributing missions, enhancing the ability to analyse the Earth's surface with both optical and radar datasets.

1.1.7.3   Applications of Federated Data Sets

Federated data sets in the Copernicus Data Space Ecosystem are used in a wide range of applications:

- **Environmental Monitoring**: Federated data sets provide a richer, more comprehensive picture of environmental changes by combining data from multiple providers. This is particularly valuable in monitoring deforestation, urban sprawl, and climate change impacts.
- **Disaster Response**: When responding to natural disasters, federated data sets

allow for rapid access to imagery and data from various sources, enabling timely and coordinated emergency management efforts.

- **Research and Innovation**: Scientists and developers use federated data sets to create new applications and services that require data integration from diverse providers, helping to innovate in areas like precision agriculture, biodiversity conservation, and energy management.

Federated data sets are an essential component of the **Copernicus Data Space Ecosystem**, providing users with a streamlined way to access and integrate data from various Earth observation missions and platforms. By offering a unified interface and ensuring interoperability, federated data sets enhance the usability and scope of Earth observation data, supporting a wide range of environmental, scientific, and operational applications.

1.1.8   Complementary data

Copernicus Complementary Data consists of datasets that enhance and complement the data from the core **Copernicus Sentinel missions**. These datasets are drawn from well-established Earth observation missions and other sources, extending the temporal, spatial, and thematic coverage of the Copernicus programme. They provide additional insight into environmental monitoring, climate change studies, land-use analysis, disaster management, and more.

1.1.8.1   Key Features of Complementary Data

1. **Historical Continuity**: Some of the complementary datasets, such as **Landsat** and **MODIS**, offer decades of historical Earth observation data, enabling long-term trend analysis and retrospective studies.
2. **Broader Thematic and Spectral Coverage**: These datasets provide access to specialised measurements and thematic data that are not available from the Sentinel satellites alone, including thermal data, high-resolution optical imagery, and other unique observations.
3. **Wide Range of Applications**: Complementary data supports a diverse array of applications, including **climate change monitoring**, **agriculture**, **urban planning**, and **natural resource management**.

4. **Interoperability with Sentinel Data**: These datasets are designed to integrate seamlessly with Sentinel data, allowing users to combine them for more comprehensive environmental analyses.

1.1.8.2 List of Copernicus Complementary Data

Here is a list of **Complementary Data** available through the **Copernicus Data Space Ecosystem**:

1. **Landsat** (USGS/NASA)[8]:
   ○ **Landsat** is one of the longest-running Earth observation satellite programs, with over 40 years of data. It provides multispectral imagery at a 30-meter resolution, essential for monitoring land cover changes, deforestation, and agricultural practices. Landsat data is widely used for climate studies, environmental assessments, and urban growth analysis.
2. **MODIS (Moderate Resolution Imaging Spectroradiometer)[9]** (NASA):
   ○ MODIS, aboard NASA's Terra and Aqua satellites, provides daily global coverage across 36 spectral bands, including land, ocean, and atmospheric observations. MODIS is used to monitor large-scale environmental changes, including forest cover, ocean productivity, and atmospheric aerosols.
3. **ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer)[10]**:
   ○ ASTER data provides high-resolution imagery in visible, near-infrared, and thermal infrared wavelengths, which are useful for geological mapping, vegetation analysis, and land surface temperature monitoring. Its thermal data complements Sentinel missions by offering insights into surface heat and energy balances.
4. **Sentinel-1/2/3 L2 Analysis Ready Data (ARD)**:
   ○ These are pre-processed data products derived from the Sentinel missions, designed to be analysis-ready. They include land, ocean, and atmospheric data tailored for quick integration into environmental monitoring models.

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[8] https://www.usgs.gov/landsat-missions

[9] https://modis.gsfc.nasa.gov/

[10] https://asterweb.jpl.nasa.gov/

5. **Landsat ARD (Analysis Ready Data)**:
   - Pre-processed Landsat data optimised for immediate use in time-series analysis, change detection, and environmental assessments. The ARD products provide consistent and standardised measurements for easier integration with other datasets.
6. **SRTM (Shuttle Radar Topography Mission)[11]**:
   - SRTM provides a global digital elevation model (DEM) with a resolution of 30 meters, critical for applications in hydrology, topographic mapping, and disaster risk management. The elevation data from SRTM is widely used in flood modelling, landslide prediction, and infrastructure planning.
7. **CHRIS/Proba[12]** (Compact High-Resolution Imaging Spectrometer aboard Proba):
   - CHRIS provides hyperspectral data for monitoring high-resolution land and vegetation. It is used for precision agriculture, forest health assessments, and monitoring coastal zones.
8. **Sentinel-5P L2 Atmospheric Data**:
   - Provides data on atmospheric trace gases and pollutants such as NO_2, SO_2, O_3, and methane. This dataset is crucial for air quality monitoring, environmental health assessments, and climate change research.
9. **SMOS (Soil Moisture and Ocean Salinity)[13]**:
   - The SMOS mission provides data on soil moisture and ocean salinity. Soil moisture data is important for agricultural planning and drought monitoring, while ocean salinity data contributes to understanding ocean circulation and climate change impacts.
10. **CryoSat[14]**:
    - Provides data on polar ice coverage and thickness. This is essential for monitoring changes in ice sheets and glaciers, helping scientists understand the impacts of climate change on polar regions.

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[11] https://www.earthdata.nasa.gov/sensors/srtm

[12] https://earth.esa.int/eogateway/instruments/chris

[13] https://earth.esa.int/eogateway/missions/smos

[14] https://earth.esa.int/eogateway/missions/cryosat

11. **VIIRS (Visible Infrared Imaging Radiometer Suite)[15]**:
    ○ A key instrument aboard the **Suomi NPP** and **NOAA-20** satellites, VIIRS provides data for monitoring global land, ocean, and atmosphere conditions. It is used extensively for applications such as detecting wildfires, assessing vegetation health, and tracking nighttime lights.

1.1.8.3 Applications of Copernicus Complementary Data

1. **Long-term Environmental Monitoring**: **Landsat** and **MODIS** datasets offer long-term historical data that is invaluable for detecting and analysing changes in land cover, deforestation rates, and urban sprawl over decades.
2. **Disaster Management and Risk Reduction**: **SRTM** provides elevation data critical for flood modelling, while **ASTER** and **VIIRS** support disaster management with thermal and optical imagery that can detect changes in land surface temperature and monitor wildfires in near real-time.
3. **Agriculture and Forestry**: Datasets like **Landsat ARD** and **CHRIS/Proba** offer detailed information on crop health, land use, and forest cover. **SMOS** data is used to assess soil moisture, helping farmers make informed decisions regarding irrigation and drought response.
4. **Climate Change Research**: **CryoSat** provides critical data on ice thickness and extent, which is essential for understanding the effects of climate change on polar ice caps and glaciers. **MODIS** and **VIIRS** also provide global observations of ocean and atmospheric conditions, contributing to climate models.
5. **Urban and Infrastructure Development**: **Landsat** and **Sentinel ARD** products are widely used for urban planning, land use classification, and infrastructure development. They provide the high-resolution imagery needed for mapping cities and understanding how urbanisation impacts natural environments.

1.1.8.4 Access to Complementary Data

Users can access **Complementary Data** through the **Copernicus Data Space Ecosystem**, where they can search, download, and integrate data with Sentinel and other Copernicus datasets. The platform ensures that these datasets are interoperable,

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[15] https://www.earthdata.nasa.gov/learn/find-data/near-real-time/viirs

enabling users to perform complex environmental analyses across multiple data sources.

The **Copernicus Complementary Data** system enriches the overall capabilities of the Copernicus programme by providing additional datasets from well-established Earth observation missions like **Landsat**, **MODIS**, and **ASTER**. These datasets complement Sentinel missions, offering higher resolution, longer historical records, and specialised environmental data. The integration of these complementary datasets into the **Copernicus Data Space Ecosystem** allows for a more comprehensive understanding of the Earth's environment, supporting informed decision-making and advanced research in fields such as climate monitoring, disaster management, and urban planning.

1.1.9   Copernicus Data Space Ecosystem Overview

The **Copernicus Data Space Ecosystem** is a comprehensive and integrated platform that provides access to a wide range of Earth observation data and services, supporting the **Copernicus Programme**. It is designed to offer users easy and open access to various datasets generated by the **Sentinel missions**, **Contributing Missions**, and **Complementary Data** sources, facilitating environmental monitoring, climate change studies, disaster management, and many other applications.

1.1.9.1   *Key Features of the Copernicus Data Space Ecosystem*

1. **Free and Open Access**: The Copernicus Data Space Ecosystem ensures that all users, including scientists, policymakers, businesses, and the general public, have free and open access to Earth observation data. This democratisation of data enables informed decision-making, fosters innovation, and supports research and operational applications across various sectors.
2. **Extensive Data Collections**: The platform hosts data from several key sources, including:
   - **Sentinel Missions**: Data from the Sentinel-1, Sentinel-2, Sentinel-3, Sentinel-5P, and Sentinel-6 missions, each providing specific environmental observations such as radar imagery, optical imagery, and atmospheric data.
   - **Contributing Missions**: Datasets from national and international satellite

missions complement the Sentinel data by offering higher resolution or different thematic coverage.

- ○ **Complementary Data**: Includes long-standing Earth observation missions like **Landsat**, **MODIS**, and other specialised datasets for detailed analysis of land, oceans, and atmosphere.

3. **Data Access and Visualization**: The Copernicus Data Space provides a user-friendly interface that enables users to explore, search, and visualise data before downloading. Users can interact with the data directly through the platform's web-based tools, view time-series data, and analyse trends for specific regions or topics.

4. **Data Processing Tools**: The platform offers integrated data processing services, allowing users to conduct analyses without needing to download large datasets. This feature is particularly useful for handling complex tasks such as image processing, change detection, and environmental monitoring.

5. **Cloud-Based Access**: The Copernicus Data Space is built on a cloud infrastructure, which enhances data accessibility and processing capabilities. This enables users to perform large-scale analyses without requiring extensive local computing resources.

6. **Interoperability and Integration**: The platform ensures that data from various sources, including Sentinel missions and Contributing Missions, are interoperable. This allows users to combine datasets for more comprehensive environmental analysis and supports the creation of new applications and services in fields such as urban planning, climate research, and agricultural monitoring.

1.1.9.2   Data Collections Available in the Copernicus Data Space Ecosystem

1. **Sentinel Data**:
   - ○ **Sentinel-1**: Provides radar imagery for land and ocean monitoring. It is widely used for disaster response, land deformation studies, and monitoring ice coverage.
   - ○ **Sentinel-2**: Offers high-resolution optical imagery in the visible and near-infrared spectrum. It supports land use, agricultural monitoring, and forestry applications.
   - ○ **Sentinel-3**: Delivers data for ocean and land monitoring, including sea

surface height, sea surface temperature, and land surface reflectance. It is vital for climate monitoring and environmental research.

- ○ **Sentinel-5P**: Focuses on atmospheric monitoring, providing data on air quality, including trace gases such as nitrogen dioxide (NO_2), ozone (O_3), and methane (CH_4).
- ○ **Sentinel-6**: Monitors sea level rise with high precision, supporting climate change research and oceanographic studies.

2. **Copernicus Contributing Missions**:
   - ○ Data from external missions operated by various space agencies and organisations complement Sentinel data. These include high-resolution optical imagery, radar data, and thematic datasets that provide additional detail and accuracy for environmental analysis.

3. **Complementary Data**:
   - ○ The **Copernicus Data Space Ecosystem** also integrates data from long-established Earth observation programs such as:
     - ■ **Landsat**: Multispectral optical imagery, useful for long-term land cover and environmental change studies.
     - ■ **MODIS**: Global observations of the Earth's surface, atmosphere, and oceans.
     - ■ **ASTER**: High-resolution thermal infrared data for geological and environmental applications.

4. **Federated Data Sets**:
   - ○ These are data collections hosted by external providers but made accessible through the Copernicus platform, ensuring seamless access to distributed datasets without requiring multiple data portals.

1.1.9.3   Applications of Copernicus Data Space Ecosystem

1. **Environmental Monitoring**: The data available through the Copernicus Data Space supports monitoring of deforestation, urban expansion, and land degradation, helping policymakers and researchers understand and manage environmental change.

2. **Climate Change Research**: The platform provides long-term data sets crucial for tracking sea level rise, global temperature changes, and greenhouse gas

concentrations, supporting climate scientists and environmental agencies.

3. **Disaster Management**: Real-time data from Sentinel-1 and Sentinel-2, combined with other Contributing Mission data, enable rapid assessment of natural disasters such as floods, earthquakes, and wildfires. This supports emergency response and risk mitigation efforts.

4. **Agriculture**: Sentinel-2 and Sentinel-1 imagery are used for precision agriculture, allowing farmers to monitor crop health, optimise irrigation, and improve yield predictions.

5. **Urban Planning**: High-resolution optical and radar data from the Copernicus Data Space Ecosystem support urban planners in monitoring land use changes, infrastructure development, and the expansion of cities.

The **Copernicus Data Space Ecosystem** is a vital resource for accessing and analysing Earth observation data. Its user-friendly interface, free and open access policy, and cloud-based processing capabilities make it an indispensable tool for a wide range of applications, from scientific research to policymaking and commercial ventures. By integrating data from Sentinel missions, contributing missions, and complementary sources, the platform offers a comprehensive and flexible solution for global environmental monitoring.

1.2 COPERNICUS Services

The **Copernicus Services** form a core component of the Copernicus Programme, transforming vast amounts of Earth observation data into actionable information across various sectors. These services provide free and open access to processed data, thematic maps, and analytical tools, supporting environmental monitoring, climate change mitigation, disaster management, and sustainable development. Organised into six key thematic areas, the services offer tailored solutions to address specific environmental and societal challenges.

The **Copernicus Land Monitoring Service (CLMS)**[16] provides geospatial information on land use, cover, and landscape changes essential for agriculture, forestry, urban planning, and biodiversity conservation. A notable feature is the **Global Human**

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[16] https://land.copernicus.eu/

Settlement Layer, which continuously monitors built-up areas to aid in crisis management and urban resilience.

The **Copernicus Marine Environment Monitoring Service (CMEMS)**[17] delivers data on ocean conditions, including temperature, salinity, currents, and sea level, supporting maritime safety, fisheries, and climate research. Recent developments include a roadmap for downstream coastal services aimed at enhancing the usability of marine data for local stakeholders.

The **Copernicus Atmosphere Monitoring Service (CAMS)**[18] focuses on atmospheric composition, offering insights into air quality, greenhouse gases, and ozone levels, which are crucial for environmental health and climate policies.

The **Copernicus Climate Change Service (C3S)**[19] provides comprehensive climate data, aiding climate monitoring, policy development, and adaptation strategies and supporting analyses of historical climate trends and future projections.

The **Copernicus Emergency Management Service (CEMS)**[20] offers rapid mapping and early warning systems for disaster response, aiding authorities in managing natural and man-made crises such as floods, wildfires, and earthquakes. Additionally, the **Copernicus Security Service** enhances EU border surveillance, maritime security, and crisis prevention by leveraging Earth observation data.

Overall, the **Copernicus Services** are central to transforming Earth observation data into practical applications. By providing open access to high-quality information, they support informed decision-making in environmental management, disaster response, climate change mitigation, and security. As new technologies and missions continue to evolve, the services will remain crucial in driving innovation and global sustainability efforts.

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[17] https://marine.copernicus.eu/

[18] https://atmosphere.copernicus.eu/

[19] https://climate.copernicus.eu/

[20] https://emergency.copernicus.eu/

1.2.1 Copernicus Atmosphere Monitoring Service (CAMS)

The **Copernicus Atmosphere Monitoring Service (CAMS)** is one of the core services of the **Copernicus Programme**, designed to provide comprehensive, real-time data on the state of the atmosphere. CAMS delivers information on key atmospheric components such as air quality, greenhouse gases, and ozone layer status, supporting a wide range of environmental and health-related applications. This service integrates satellite observations, ground-based measurements, and advanced modelling to produce high-quality datasets that help address challenges such as climate change, air pollution, and extreme weather events.

1.2.1.1 Key Features of CAMS

7. **Air Quality Monitoring and Forecasting**: CAMS provides real-time air quality forecasts for Europe and other regions, offering detailed information on key pollutants such as nitrogen dioxide (NO_2), particulate matter (PM10, PM2.5), ozone (O_3), and sulphur dioxide (SO_2). Recent advancements include the integration of **machine learning techniques** to improve the accuracy of air quality forecasts, particularly in Europe (Bertrand et al., 2023). These models have enhanced the detection of pollution exceedances and provide timely information on air quality trends.

8. **Greenhouse Gas Monitoring**: CAMS offers continuous monitoring and analysis of greenhouse gases, including carbon dioxide (CO_2) and methane (CH_4). The **CAMS Greenhouse Gas Reanalysis Dataset** (2003–2020) combines satellite and model data to provide a long-term record of these gases (Agustí-Panareda et al., 2023). This dataset supports climate monitoring and research, helping to identify trends and the impact of human activities on the global carbon cycle.

9. **Global Emissions Inventories**: CAMS has developed the **CAMS-GLOB-ANT**, a global anthropogenic emissions inventory providing detailed data on emissions from 36 compounds across 17 sectors from 2000 to 2023 (Soulié et al., 2024). This high-resolution dataset (0.1º x 0.1º) is essential for air quality simulations and reanalyses, allowing researchers to evaluate the sources and contributions of air pollutants over time.

10. **Atmospheric Composition Monitoring**: CAMS delivers information on the

composition of the atmosphere, including data on the ozone layer and aerosol concentrations. The upcoming **Sentinel-4 mission**, currently in the calibration phase, will significantly enhance the ability to monitor air quality from a geostationary orbit, providing hourly observations of pollutants across Europe (Bazalgette Courrèges-Lacoste et al., 2023).

11. **Satellite-Based Analysis of Long-Range Pollution Transport**: CAMS also plays a vital role in tracking the long-range transport of pollutants, including smoke from biomass burning. Satellite observations, combined with atmospheric models, have been used to analyse the transport of smoke across the Atlantic from wildfires in the Western United States, demonstrating the global impact of regional pollution events (Ceamanos et al., 2023).

12. **Data Accessibility and Education Tools**: CAMS ensures that data is openly accessible to users via various platforms, including the Copernicus Data Space Ecosystem. Educational tools such as **LTPy** provide users with hands-on access to atmospheric composition data, enabling researchers, educators, and students to explore environmental data and learn how to analyse it using Python (Wagemann et al., 2023).

1.2.1.2   Recent Advancements in CAMS

Recent research highlights several important advancements in CAMS services:

- **Greenhouse Gas Reanalysis**: The **CAMS Greenhouse Gas Reanalysis Dataset** (2003-2020) is an important tool for studying long-term trends in CO_2 and CH_4 emissions, combining satellite and ground-based data using advanced modelling techniques. This dataset plays a crucial role in understanding the global carbon cycle and assessing climate change impacts.

- **Anthropogenic Emissions Inventory**: The newly developed **CAMS-GLOB-ANT** emissions inventory provides monthly global data on emissions from various human activities. Covering 36 pollutants, this dataset supports both air quality forecasts and climate research, offering a detailed view of emissions at a fine spatial resolution.

- **Machine Learning in Air Quality Forecasting**: Machine learning models have been successfully integrated into European air quality forecasts, improving the

detection of pollution events and the overall accuracy of predictions. These techniques are increasingly being adopted to enhance the precision of environmental forecasting services.

- **Sentinel-4 Mission**: The upcoming **Sentinel-4 mission**, part of the Copernicus programme, is undergoing calibration. This satellite will provide hourly air quality data for Europe, enhancing the capacity for real-time monitoring of key atmospheric pollutants such as NO2, O3, and aerosols.
- **TROPOMI NO2 Data Comparisons**: Comparisons between **Sentinel-5P TROPOMI** NO2 data and CAMS forecasts have led to improvements in the NO2 data products, enhancing their accuracy and providing better insights into atmospheric pollution levels across Europe (Douros et al., 2023).

1.2.1.3   Applications of CAMS

The data and services provided by CAMS have a wide range of applications across different sectors:

- **Climate Change Monitoring**: CAMS supports long-term climate monitoring by providing reliable data on greenhouse gases, aerosols, and other atmospheric components. This information is critical for developing climate policies and assessing the effectiveness of emission reduction strategies.
- **Air Quality Management**: CAMS provides real-time forecasts and historical data on air quality, supporting public health agencies, environmental policymakers, and urban planners in managing air pollution and mitigating its impacts on human health.
- **Emergency Response and Disaster Management**: CAMS plays a crucial role in monitoring the transport of pollutants from natural disasters such as wildfires. By tracking the movement of smoke and other pollutants, CAMS helps inform disaster response strategies and protect public health.
- **Public Awareness and Education**: CAMS data is widely used in educational initiatives and public awareness campaigns to raise understanding of atmospheric science, air quality issues, and climate change. Tools like **LTPy** provide easy access to data and learning resources for students and educators.

The **Copernicus Atmosphere Monitoring Service (CAMS)** is at the forefront of

atmospheric monitoring, providing essential data for understanding and addressing key environmental challenges. Through advancements in greenhouse gas monitoring, air quality forecasting, and emissions inventories, CAMS continues to evolve, supporting a wide range of applications that contribute to climate change mitigation, public health, and environmental protection. By integrating cutting-edge technologies such as machine learning and preparing for new missions like **Sentinel-4**, CAMS ensures that users have access to high-quality, real-time data to make informed decisions about the atmosphere and the environment.

1.2.2   Copernicus Marine Service: Enhancing Ocean and Coastal Monitoring

The **Copernicus Marine Environment Monitoring Service (CMEMS)** plays a critical role within the Copernicus programme by providing essential data and services related to the monitoring and forecasting of the world's oceans and coastal zones. This service supports numerous applications in maritime safety, climate monitoring, marine environment protection, and sustainable resource management. CMEMS delivers high-quality, real-time data on ocean currents, sea surface temperature, sea level, salinity, and biogeochemical properties, contributing to a wide range of environmental and economic activities.

1.2.2.1   Key Capabilities and Applications

1. **Monitoring Polar Regions**: The CMEMS has significantly advanced monitoring and forecasting capabilities in polar regions, particularly in the Arctic and Antarctic. Satellite-based monitoring has identified research gaps in the coverage of sea ice, ocean, and land parameters in these regions, offering recommendations to enhance Copernicus services. Future Copernicus Sentinel Expansion Missions are expected to improve polar data integration and forecasting capabilities (Gabarró et al., 2023). These enhancements will be crucial for maritime safety, resource management, and climate change adaptation in polar areas.

2. **Coastal Flood Awareness**: CMEMS contributes to early warning systems for coastal floods, enhancing Europe's ability to forecast extreme sea-level events. Recent evaluations indicate that CMEMS operational models perform well under average conditions but need improvements in predicting peak water levels during extreme storms. These models can accurately flag 76% of observed extreme

events but also exhibit a false-positive rate of 25%. Continued advancements in model accuracy are essential for improving the effectiveness of pan-European coastal flood awareness systems (Irazoqui Apecechea et al., 2023).

3. **Supporting Sustainable Fisheries**: CMEMS products are increasingly being used by fisheries scientists and policymakers to enhance the sustainable management of marine resources. By linking oceanographic data with fisheries management, Copernicus services are helping to improve the accuracy of fisheries forecasts and support ecosystem-based management strategies. Stronger collaborations between oceanographers and fisheries scientists are recommended to further optimise the use of CMEMS data in fisheries applications (Dunbar, 2023).

4. **Coastal Downstream Services**: EuroGOOS has developed a roadmap that outlines the importance of Copernicus in providing sustainable coastal downstream services, particularly for national and local-scale applications. The roadmap emphasises the integration of coastal observations, modelling, and stakeholder involvement to ensure the successful delivery of coastal services. These downstream services are vital for environmental management, tourism, and coastal protection, supporting multiple sectors dependent on the health of coastal ecosystems (El Serafy et al., 2023).

5. **Cultural Ecosystem Services and Maritime Spatial Planning**: CMEMS data is increasingly being recognised for its value in informing maritime spatial planning, particularly in assessing cultural ecosystem services (CES). These services, which include the recreational and cultural value of marine environments, are critical for the sustainable development of coastal regions. Integrated approaches that combine participatory mapping with Earth observation data are emerging as effective tools for assessing CES, aiding in the balanced use of marine spaces (Banela et al., 2024).

6. **Marine and Coastal Modelling with Machine Learning**: The use of machine learning (ML) in marine and coastal modelling is gaining traction as a means to enhance the sustainable management of marine environments. ML techniques are proving effective in analysing complex datasets, improving predictions of marine phenomena, and supporting decision-making processes. Despite their potential, ML models remain underutilised in marine applications, highlighting the need for further integration of these technologies into CMEMS (Pourzangbar et al.,

2023).

7. **Addressing Anthropogenic Impacts on Marine Ecosystems**: CMEMS data is crucial for studying the impacts of multiple anthropogenic drivers on coastal marine ecosystems. Research has shown that while much of the focus has been on single drivers, there is a need for more comprehensive assessments that consider multiple interacting drivers. Addressing this complexity is essential for better understanding the cumulative impacts of human activities on marine ecosystems and improving policy responses.

8. **Marine Pollution Mitigation**: The role of CMEMS in monitoring and mitigating marine pollution is increasingly important. Emerging technologies, such as cloud-native platforms, artificial intelligence, and decision intelligence, are being employed to enhance the effectiveness of pollution mitigation strategies. CMEMS provides essential data on marine pollution events, including oil spills, heavy metal contamination, and microplastics, supporting global efforts to protect marine ecosystems (Anthony et al., 2023).

The **Copernicus Marine Service (CMEMS)** is at the forefront of ocean and coastal monitoring, providing critical data for a wide range of applications. From supporting polar research and flood awareness systems to advancing fisheries management and pollution mitigation, CMEMS plays a pivotal role in addressing global environmental challenges. The service's continuous improvement in data quality, integration of advanced technologies, and collaboration with stakeholders ensures its relevance in safeguarding marine environments and promoting sustainable development in coastal regions.

1.2.3   Copernicus Land Monitoring Services

The **Copernicus Land Monitoring Service (CLMS)** is an integral part of the European Union's Copernicus Programme, providing crucial data for monitoring the Earth's land surface. With advanced satellite technologies, CLMS supports a variety of applications, from environmental management and urban planning to agriculture and disaster risk reduction. The service offers users free and open access to comprehensive and high-resolution data on land use, land cover, vegetation, water bodies, and built environments. CLMS products are critical for policymakers, scientists, and businesses to

understand and respond to environmental and societal challenges.

1.2.3.1   Key Components and Services

1. **Pan-European and Global Land Monitoring**: CLMS provides two major types of services: **Pan-European** and **Global**. Pan-European land cover and land use products offer harmonised information across Europe with high spatial resolution. Global services deliver data for broader environmental and climate monitoring, supporting international cooperation on issues like deforestation, desertification, and ecosystem degradation.

2. **European Ground Motion Service (EGMS)**: A major innovation within CLMS is the **European Ground Motion Service (EGMS)**, launched to monitor ground deformation across the continent using InSAR (Interferometric Synthetic Aperture Radar) technology from Sentinel-1 satellites. EGMS provides consistent, high-resolution data on land subsidence, landslides, and other ground movement phenomena. The service offers three products: Basic, Calibrated, and Ortho, each providing different levels of data processing for specific applications like infrastructure monitoring and natural hazard prevention (Costantini et al., 2022; Crosetto et al., 2022).

3. **Land Surface Temperature Monitoring (LSTM) Mission**: The **LSTM mission**, part of the CLMS, focuses on providing high-resolution land surface temperature and evapotranspiration data essential for managing water resources and agriculture. This data aids in optimising irrigation, monitoring droughts, and improving agricultural productivity (Bernard et al., 2023).

4. **Global Human Settlement Layer (GHSL)**: The **Global Human Settlement Layer (GHSL)** is another key component of CLMS, offering continuous monitoring of built-up areas and population distributions. GHSL data is critical for urban planning, crisis management, and assessing the impact of human activities on the environment. The service provides up-to-date geospatial data on urbanisation patterns, helping to address challenges related to sustainable development and disaster response (Melchiorri & Kemper, 2023).

5. **ROSE-L and CHIME Missions**: The **ROSE-L SAR mission** and **CHIME hyperspectral imaging mission** are recent additions to CLMS, providing enhanced radar and hyperspectral observations, respectively. ROSE-L focuses on land surface

properties using L-band radar, while CHIME delivers routine hyperspectral observations for applications such as soil composition analysis and vegetation monitoring (Petrolati et al., 2023; Nieke et al., 2023).

6. **Copernicus Data Access and Processing Tools**: CLMS is supported by several **data access hubs** and **processing tools**, making it easier for users to access and manipulate satellite data for a wide range of applications. These tools are crucial for developing satellite-based solutions in fields like agriculture, urban planning, and environmental protection (Apicella et al., 2022).

1.2.3.2   Key Applications

1. **Urban and Spatial Planning**: CLMS data is invaluable for urban planners, helping them to monitor land use changes, urban sprawl, and the expansion of built-up areas. The Global Human Settlement Layer provides detailed insights into population distribution, which is critical for infrastructure development and emergency response planning.

2. **Agriculture and Water Management**: The LSTM mission supports precision agriculture by delivering data on land surface temperature and evapotranspiration, helping farmers optimise irrigation and reduce water usage. This is particularly important in regions prone to droughts and water scarcity.

3. **Environmental Monitoring and Climate Change**: CLMS plays a key role in monitoring environmental changes such as deforestation, land degradation, and desertification. The data provided by CLMS contributes to global efforts to combat climate change and promote sustainable land management practices.

4. **Disaster Risk Reduction**: The European Ground Motion Service provides essential data for identifying areas at risk of ground subsidence, landslides, and other geological hazards. This information is critical for disaster preparedness and mitigation efforts, especially in regions prone to natural disasters.

The **Copernicus Land Monitoring Service (CLMS)** is a powerful tool for monitoring and managing the Earth's land resources. Its wide range of data products and services supports critical applications across various sectors, including urban planning, agriculture, environmental monitoring, and disaster risk management. With innovations such as the EGMS, LSTM and missions like ROSE-L and CHIME, CLMS continues to enhance

its capabilities, providing decision-makers with the data they need to address pressing environmental and societal challenges.

1.2.4 Copernicus Climate Change Services (C3S)

The **Copernicus Climate Change Service (C3S)**, a cornerstone of the Copernicus Programme, is managed by the European Centre for Medium-Range Weather Forecasts (ECMWF). C3S provides comprehensive climate data and services to help stakeholders across various sectors better understand and address the challenges posed by climate change. These services are designed to support decision-making in areas such as policymaking, environmental protection, disaster risk reduction, and resource management.

1.2.4.1 Objectives and Scope

C3S aims to provide reliable, open, and free access to **essential climate data** and tools, supporting climate monitoring and adaptation strategies. The service integrates satellite observations, climate models, and in-situ measurements to generate datasets covering key **climate indicators** such as temperature, precipitation, greenhouse gases, and sea-level rise. It also supports the **Destination Earth** initiative, which aims to create a high-precision digital model of Earth to enhance environmental monitoring and decision-making.

1.2.4.2 Key Components of C3S

1. **Climate Data Store (CDS)**: The **Climate Data Store** is the primary access point for C3S users. It offers a wealth of information, including historical climate data, real-time monitoring, and future climate projections. The CDS contains datasets related to temperature, precipitation, soil moisture, and more. It serves a broad range of users, including scientists, policymakers, businesses, and the public, enabling them to analyse past trends and model future scenarios.
2. **Essential Climate Variables (ECVs)**: C3S produces **Essential Climate Variables (ECVs)** that are critical for understanding the Earth's climate system. For instance, **global surface albedo** estimates from Sentinel-3 data have been validated against other datasets, showing significant improvements in spatial resolution

and accuracy (Sánchez-Zapero et al., 2023). ECVs include land, atmospheric, and oceanic parameters, contributing to long-term climate monitoring and analysis.

3. **Climate Indicators and Sectoral Information Systems (SIS)**: C3S offers **climate indicators** such as global temperature trends, sea ice coverage, and sea level rise. These indicators are crucial for tracking climate change impacts and informing adaptation strategies. Additionally, **Sectoral Information Systems (SIS)** provide tailored climate information to sectors like energy, water management, agriculture, and health, enabling users to assess the specific impacts of climate variability on their operations.

4. **Greenhouse Gas Monitoring**: The C3S plays a significant role in monitoring **greenhouse gases** such as CO2 and methane. For example, the **CAMS greenhouse gas reanalysis** provides a comprehensive dataset of CO2 and methane concentrations, covering the period from 2003 to 2020. This data supports both scientific research and policy decisions related to emissions reduction and climate mitigation.

1.2.4.3 Recent Advancements

1. **ROSE-L, CIMR, and CHIME Missions**: The **ROSE-L** (Radar Observing System for Europe at L-band), **CIMR** (Copernicus Imaging Microwave Radiometer), and **CHIME** (Copernicus Hyperspectral Imaging Mission for the Environment) are recent Earth observation missions that enhance the Copernicus Programme's capacity for climate monitoring (Petrolati et al., 2023; Galeazzi et al., 2023; Nieke et al., 2023). These missions provide advanced radar, microwave, and hyperspectral data for land, ocean, and atmospheric monitoring, contributing to a better understanding of climate dynamics and natural resource management.

2. **Surface Albedo and Land Surface Temperature Monitoring**: Recent research has shown that global surface albedo estimates from Sentinel-3 data align well with existing products, offering improved spatial resolution and spectral information. Furthermore, the **Land Surface Temperature Monitoring (LSTM)** mission is set to provide high-resolution data for land surface temperature and evapotranspiration, essential for water management and agricultural applications (Bernard et al., 2023).

3. **AI4Copernicus Initiative**: The **AI4Copernicus** framework integrates artificial

intelligence (AI) with Earth observation data to foster innovation and address climate challenges. By linking AI communities with Copernicus data, this initiative enhances data-driven decision-making across various sectors (Troumpoukis et al., 2023).

1.2.4.4 Destination Earth

A key initiative within the broader Copernicus programme is **Destination Earth**, which is designed to create a digital twin of the Earth. Managed by ECMWF, this project aims to enhance climate monitoring and environmental management by simulating Earth's systems with unprecedented precision. By incorporating vast amounts of climate, environmental, and socio-economic data, Destination Earth will allow users to explore different climate scenarios and test potential policy responses, making it a powerful tool for climate resilience planning.

The **Copernicus Climate Change Service (C3S)** represents a vital component of Europe's efforts to monitor and adapt to the changing climate. Through its comprehensive datasets, innovative tools like the Climate Data Store, and tailored sectoral information systems, C3S supports a wide range of applications in climate monitoring, policymaking, and environmental management. With ongoing advancements in satellite technology and data integration, including initiatives like AI4Copernicus and Destination Earth, C3S continues to push the boundaries of climate science, providing critical insights into the Earth's changing climate and supporting sustainable solutions for the future.

1.2.5 Copernicus Security Services

The **Copernicus Security Services**, part of the broader Copernicus Programme, provide crucial Earth Observation (EO) data and services designed to enhance the safety and security of the European Union and its member states. These services support various security applications, including **border surveillance**, **maritime security**, and **crisis management** in natural disasters and humanitarian emergencies. Leveraging the power of satellite data and integrating advanced technologies like Artificial Intelligence (AI) and data processing, Copernicus Security Services improves decision-making capabilities for national and international security actors.

1.2.5.1   Key Security Services

1. **Maritime Security** – The **Copernicus Maritime Security Service** addresses safety and security at sea by providing EO data that aids in monitoring illegal activities such as smuggling, piracy, illegal fishing, and oil spills. **The European Maritime Safety Agency (EMSA)** plays a pivotal role in coordinating these services, ensuring the secure and sustainable use of marine resources. The maritime services use **Synthetic Aperture Radar (SAR)** data from satellites such as **Sentinel-1** to detect suspicious vessels and illegal activities, offering real-time insights to improve maritime domain awareness. EMSA's integration with **Copernicus Maritime Surveillance** focuses on ensuring efficient monitoring of the EU's coastline and Exclusive Economic Zones (EEZ), especially in addressing **irregular migration** and **pollution events**. The **SESA (Security Service Element for Surveillance Applications)** portal enhances access to these security-relevant datasets, offering tailored information to support law enforcement agencies in surveillance operations.

2. **Border and Migration Monitoring** – Copernicus Security Services supports **border surveillance** by providing real-time, high-resolution satellite imagery for monitoring land borders and migration flows. These services are used by agencies like **Frontex** (European Border and Coast Guard Agency) to detect and manage irregular migration and to combat cross-border crimes. The integration of **SAR** data allows for the detection of infrastructure changes, identification of irregular movements, and surveillance in remote or inaccessible areas. Border monitoring services are particularly vital for detecting **cross-border smuggling** and illegal infrastructure developments. The use of **artificial intelligence (AI)**, as highlighted by the **AI4Copernicus framework**, enhances the processing of Earth observation data, improving the detection and prediction of irregular activities.

3. **Crisis and Disaster Management** – The **Copernicus Emergency Management Service (EMS)** is crucial in responding to natural and man-made disasters, such as floods, earthquakes, and industrial accidents. EMS provides **rapid mapping** capabilities, offering satellite-based maps for emergency responders during and after disasters. These maps help authorities understand the extent of damage, plan rescue operations, and allocate resources effectively.

4. **Conflict Prevention and Crisis Monitoring Copernicus Security Services** – plays a key role in conflict prevention by providing **situational awareness** in regions experiencing instability. The integration of **AI and EO data** enhances data-driven decision-making capabilities, allowing for better prediction of emerging threats. Research indicates that the convergence of **Earth Observation (EO) and Artificial Intelligence (AI)** technologies enables real-time monitoring and forecasting of security-related events. These advancements are particularly relevant in areas where traditional monitoring methods are insufficient due to lack of access or the scale of the crisis.

5. Additionally, **Security Information and Event Management (SIEM) systems** have been emphasised as critical tools for handling security data, particularly in cybersecurity contexts, where large volumes of logs must be analysed to detect and respond to threats (Macaneata, 2024). The use of Copernicus data in cybersecurity applications, such as the protection of **critical infrastructure** and **healthcare systems**, is becoming increasingly significant in light of evolving cyber threats (Gupta, 2023).

1.2.5.2   Integration of AI and EO in Security Services

One of the key advancements in Copernicus Security Services is the integration of **Artificial Intelligence (AI)** to enhance **data processing** and **analysis capabilities**. The **AI4Copernicus framework** bridges the gap between EO and AI, creating a platform for data-driven innovations in security applications. This integration improves the efficiency of **surveillance systems**, **threat detection**, and **crisis management** by allowing for faster data interpretation and more accurate predictions.

For instance, in **urban resilience planning**, AI-enhanced Earth observation data from Copernicus services can assess risks such as **flooding**, **landslides**, and **infrastructure vulnerability** (Chrysoulakis et al., 2023). The role of AI in analysing large datasets, detecting anomalies, and forecasting potential threats is becoming more prominent in enhancing Europe's security posture.

1.2.5.3 Future Developments

Ongoing advancements in the **Copernicus Programme**, such as the development of the **ROSE-L** (L-band SAR mission) and **CHIME** (hyperspectral imaging mission), will further bolster the capabilities of Copernicus Security Services. These missions will provide enhanced imaging technologies that can monitor land, sea, and urban areas with greater precision and reliability, supporting both **environmental security** and **disaster management**.

Additionally, new missions and technological developments will improve the **cybersecurity** capabilities of Copernicus, as demonstrated by research that highlights the growing importance of coordinated responses to increasingly complex cyber threats. The integration of **SIEM systems** and enhanced **cyber defence strategies** within the Copernicus ecosystem is expected to address challenges posed by evolving cyber threats and infrastructure vulnerabilities.

The **Copernicus Security Services** are essential for ensuring the safety and security of Europe and its partners, addressing a broad spectrum of challenges from maritime and border security to crisis management and cybersecurity. By combining **Earth observation data**, **Artificial Intelligence**, and advanced security tools, Copernicus enhances Europe's ability to respond to threats, mitigate risks, and safeguard critical infrastructure and populations. As technological advancements continue, particularly in AI and satellite capabilities, Copernicus Security Services will remain at the forefront of global security and crisis management efforts.

1.2.6 Copernicus Emergency Management Services (CEMS)

The **Copernicus Emergency Management Service (CEMS)** is a core component of the Copernicus Programme, designed to support disaster response, risk management, and environmental monitoring through real-time Earth observation data and geospatial analysis. CEMS plays a crucial role in providing rapid and accurate information to decision-makers, emergency responders, and civil protection authorities during and after emergency situations, such as natural disasters, humanitarian crises, and environmental hazards.

1.2.6.1 Key Services and Features of CEMS

1. **Rapid Mapping** – The **Rapid Mapping service** delivers geospatial information to support emergency response within hours to days after a disaster occurs. This service uses satellite imagery to create maps that show the extent of damage, affected areas, and impacted infrastructure. It covers natural and man-made disasters such as floods, earthquakes, wildfires, and industrial accidents, providing essential data for timely response.

2. **Risk and Recovery** – The **Mapping Risk and Recovery Mapping** offers geospatial information for risk reduction, prevention, and disaster recovery. This service supports long-term planning by providing detailed maps of vulnerable areas and assessing post-disaster recovery efforts. It is particularly useful for building resilience and planning reconstruction activities, enabling authorities to better prepare for future events.

3. **Early Warning Systems** – CEMS includes several **Early Warning and Monitoring Systems** for flood and wildfire events:
   - **European Flood Awareness System (EFAS):** Provides flood forecasts and alerts for riverine floods in Europe up to 10 days in advance, helping authorities to take pre-emptive action.
   - **Global Flood Awareness System (GloFAS):** Extends flood forecasting globally, offering flood risk information across countries and regions.
   - **European Forest Fire Information System (EFFIS):** Monitors forest fire danger, providing real-time data on fire weather indices and fire activity across Europe.
   - **Global Wildfire Information System (GWIS):** A global extension of EFFIS, offering global wildfire monitoring and early warning.

4. **Global Human Settlement Layer (GHSL)** – The **Global Human Settlement Layer (GHSL)** is a critical component that provides global built-up surface and population data. It supports crisis management by offering insights into the spatial distribution of human settlements, enabling a better understanding of population exposure to hazards.

1.2.6.2 Recent Developments in CEMS

Recent research highlights advancements in CEMS capabilities, driven by the integration of Earth observation technologies and innovations like AI and machine learning. Notable developments include:

- The **Global Human Settlement Layer** has improved built-up surface mapping with high-resolution data, essential for crisis management and urban resilience planning.
- New missions like **ROSE-L** (L-band SAR imaging) and **CHIME** (hyperspectral imaging) enhance CEMS by providing more detailed observations, especially for monitoring land surface changes and environmental conditions.
- The **AI4Copernicus** framework is bridging the gap between Earth observation and artificial intelligence, enabling better data integration and innovation in emergency services.

1.2.6.3 Applications and Impact

The CEMS plays a vital role in supporting European and global policies aimed at reducing disaster risks and managing crises. By providing timely and accurate geospatial data, CEMS enhances decision-making capabilities in sectors such as civil protection, environmental monitoring, humanitarian aid, and urban planning. The service has been instrumental in recent disaster events, offering critical insights for emergency response and post-crisis recovery.

In summary, CEMS is an indispensable tool for managing and mitigating the impacts of disasters, using cutting-edge Earth observation technology to provide real-time, actionable data that supports resilience-building and effective disaster response strategies.

1.2.7 Copernicus Services in CELAC: Focus on Chile and Colombia

The Copernicus Programme has made significant inroads in Latin America, particularly within Chile and Colombia, where it supports key areas such as environmental monitoring, disaster management, and scientific research. These countries already utilize a range of Copernicus services, from land and ocean monitoring to emergency

response. However, current services primarily support small to medium-scale applications, offering general environmental data that does not always meet specific decision-making needs at a larger, localized scale.

1.2.7.1   Copernicus in Chile

Chile is a leader in the Latin American region for the application of Earth observation technologies, largely due to its active involvement in Antarctic research and environmental sustainability initiatives. The country benefits from various **Copernicus services**, including land monitoring, ocean monitoring, and emergency management.

1. **Land Use and Land Cover Monitoring** – Chile uses **Copernicus Land Monitoring Services** to track changes in land use and land cover. This data is essential for managing natural resources, agriculture, and urban expansion. The **Urban Atlas** provided by Copernicus offers detailed information on land use in urban areas, aiding in urban planning and resilience to natural disasters like earthquakes, which are frequent in Chile.
2. **Ocean Monitoring** – The **Copernicus Marine Environment Monitoring Service (CMEMS)** plays a crucial role in monitoring Chile's vast coastline, which stretches over 4,000 kilometres. This service provides data on sea surface temperature, sea level rise, and ocean currents, which are critical for managing fisheries, maritime activities, and environmental protection. The integration of the **CIMR** mission for high-resolution microwave radiometry enhances Chile's ability to monitor sea ice concentration and surface temperatures, contributing to climate change research and marine resource management.
3. **Emergency Services** – Chile faces various natural hazards, including earthquakes, wildfires, and volcanic eruptions. **Copernicus Emergency Management Services (CEMS)** offers rapid mapping and risk assessment tools that are essential for disaster preparedness and response. These tools provide near-real-time satellite data to assess damage and coordinate recovery efforts. Recent advancements, such as the **ROSE-L SAR mission**, enable more precise monitoring of land deformation and environmental changes caused by such disasters.
4. **Antarctic Research** – Chile's involvement in Antarctic research has been significantly enhanced through access to **Copernicus data**, particularly in

studying ecosystems, geosciences, and biotechnology (González-Aravena et al., 2023). The country's increasing scientific output aligns with global climate change studies, utilising satellite data for tracking environmental changes in the Antarctic region.

1.2.7.2   Copernicus in Colombia

Colombia has actively integrated **Copernicus services** into its national policies for environmental monitoring, disaster management, and scientific education. With its diverse geography, including rainforests, mountains, and coastlines, Colombia benefits from a variety of Copernicus services to support sustainable development and risk management.

1. **Satellite Image Processing and Education** Colombia has made significant strides in training professionals in the field of satellite image processing. **UNIMINUTO**, a leading academic institution, is utilising **Copernicus satellite data** to develop satellite image processing algorithms (Dávila Sguerra, 2023). These educational initiatives are aimed at building the nation's capacity to monitor Earth phenomena, such as deforestation, urbanisation, and climate change, using satellite technology.
2. **Land Monitoring and Urban Planning** Colombia leverages **Copernicus Land Monitoring Services** to address land use challenges, especially in the Amazon rainforest and Andean regions. The **Global Human Settlement Layer (GHSL)** provides critical data for mapping urban expansion, land degradation, and population distribution, supporting sustainable urban planning and environmental conservation efforts.
3. **Ocean Monitoring** Like Chile, Colombia is also enhancing its capacity for **ocean monitoring** through Copernicus services. The **CMEMS** provides crucial data for managing Colombia's Caribbean and Pacific coasts, supporting maritime activities, fisheries, and environmental conservation.
4. **Disaster Management** Colombia faces frequent natural disasters such as floods, landslides, and hurricanes. The **CEMS** plays a vital role in disaster risk reduction and emergency response by providing real-time data for risk mapping and crisis management. Access to satellite data enhances Colombia's ability to monitor

vulnerable areas and plan effective disaster responses.

1.2.7.3 Collaborative Projects and Objectives

The **Copernicus LAC project** is a key initiative aimed at enhancing the use of Copernicus data in Latin America. The project focuses on capacity building, providing access to in-situ data, and supporting the development of national and regional policies that incorporate Earth observation data. Key objectives include:

- **Building local capacity** in Earth observation data analysis and usage, particularly in sectors such as land use, ocean monitoring, and disaster management.
- **Promoting the use of Copernicus data** for decision-making in environmental monitoring, urban resilience, and disaster preparedness.
- **Enhancing collaboration** between Latin American countries and European institutions to share knowledge and best practices in using satellite data for sustainable development and risk management.

The **Copernicus Programme** is making a significant impact in **Chile** and **Colombia**, providing critical data and services for environmental monitoring, urban planning, and disaster management. Both countries are taking advantage of satellite technology to advance their scientific research, particularly in fields like land use, ocean monitoring, and disaster resilience. The collaboration between Copernicus and CELAC nations highlights the importance of Earth observation technologies in supporting sustainable development, environmental protection, and emergency response across Latin America.

1.2.7.4 Added Value of the COMUNIDAD Project

COMUNIDAD will build upon this existing framework by introducing additional services and training programs that specifically address identified knowledge gaps. By leveraging Copernicus' foundational infrastructure, COMUNIDAD will provide large-scale, high-resolution mapping and monitoring capabilities tailored to meet the nuanced requirements of local stakeholders. These new services will enable detailed decision-making for sectors such as agriculture, forestry, and urban planning, directly responding to user-defined needs. Training initiatives will further equip local professionals with

advanced skills in utilizing Earth Observation (EO) data, fostering local capacity in satellite data processing, and enhancing response strategies for both environmental management and disaster resilience.

The enhanced functionality COMUNIDAD introduces will allow Chile and Colombia to achieve new levels of operational effectiveness in EO-based initiatives, creating a framework that ensures long-term adaptability and growth in these applications across the Latin American region.

2 Existing Partners extensions of COPERNICUS Data and Services

Section 2 details the tools and platforms forming COMUNIDAD's technical foundation for integrating Copernicus data within Chile and Colombia, structured into **Infrastructure and Platform Tools** and **Application Services**:

1. **Infrastructure and Platform Tools**: This section introduces the **Remote Sensing Data Processing System (RSDPS)**, **Hub4Everybody and FIE20** — existing tools developed in other scientific projects, now adapted and dedicated to COMUNIDAD. Selected components or modules of these tools collectively form the core infrastructure, providing robust support for data integration, management, and accessibility. Through their integration in conjunction with integration with other tools, COMUNIDAD will establish a unified, scalable platform that enhances the usability of Copernicus data for local stakeholders.

2. **Application Services**: The application services section highlights tools that demonstrate practical uses of Copernicus data and services. These applications aim to engage users by showcasing potential use cases, fostering demand, and enabling tailored implementations that address specific local requirements. By possible adaptation of these tools for COMUNIDAD, stakeholders in Chile and Colombia or in other countries in South America in the expansion of COMUNIDAD activities gain access to relevant, customized Copernicus-based solutions that support effective decision-making.

This structured approach combines reliable infrastructure with adaptable application

tools, maximizing COMUNIDAD's capacity to deliver Copernicus data and services that meet the unique demands of regional stakeholders.

2.1 Infrastructure and Platform Tools

The Infrastructure Tools section addresses the core technical systems essential for COMUNIDAD. The integration of RSDPS and Hub4Everybody is critical for establishing a comprehensive and flexible data infrastructure. Currently used individually, these systems will be unified within COMUNIDAD to provide an efficient and user-oriented platform that supports data management, public awareness, and training programs. By consolidating these tools, COMUNIDAD will offer stakeholders a robust and accessible platform, setting a foundation for future use and integration with various Copernicus data streams.

2.1.1   Remote Sensing Data Processing System (RSDPS)

The Remote Sensing Data Processing System (RSDPS) developed by Lesprojekt is designed to streamline the process of extracting meaningful information from satellite imagery. By automating tasks such as data acquisition, processing, and publication, the system enables efficient and effective remote sensing analysis.

2.1.1.1   System Architecture

The RSDPS consists of the following key components (Figure 1):

- **Data Acquisition:** Downloads raw Sentinel 1 and 2 scenes from the Copernicus Data Space Ecosystem portal
- **Metadata Extraction:** Extracts relevant metadata, including date, scene nomenclature, and cloud coverage, and stores it in a metadata catalogue.
- **Pre-processing:** Applies appropriate pre-processing techniques to optical and radar images, correcting for sensor bias and atmospheric effects.
- **Product Generation:** Creates various products, such as vegetation indices, supervised classifications, and machine learning-based analyses.
- **Data Storage and Publication:** Stores processed data and original imagery and provides a web interface for searching, downloading, and publishing data.
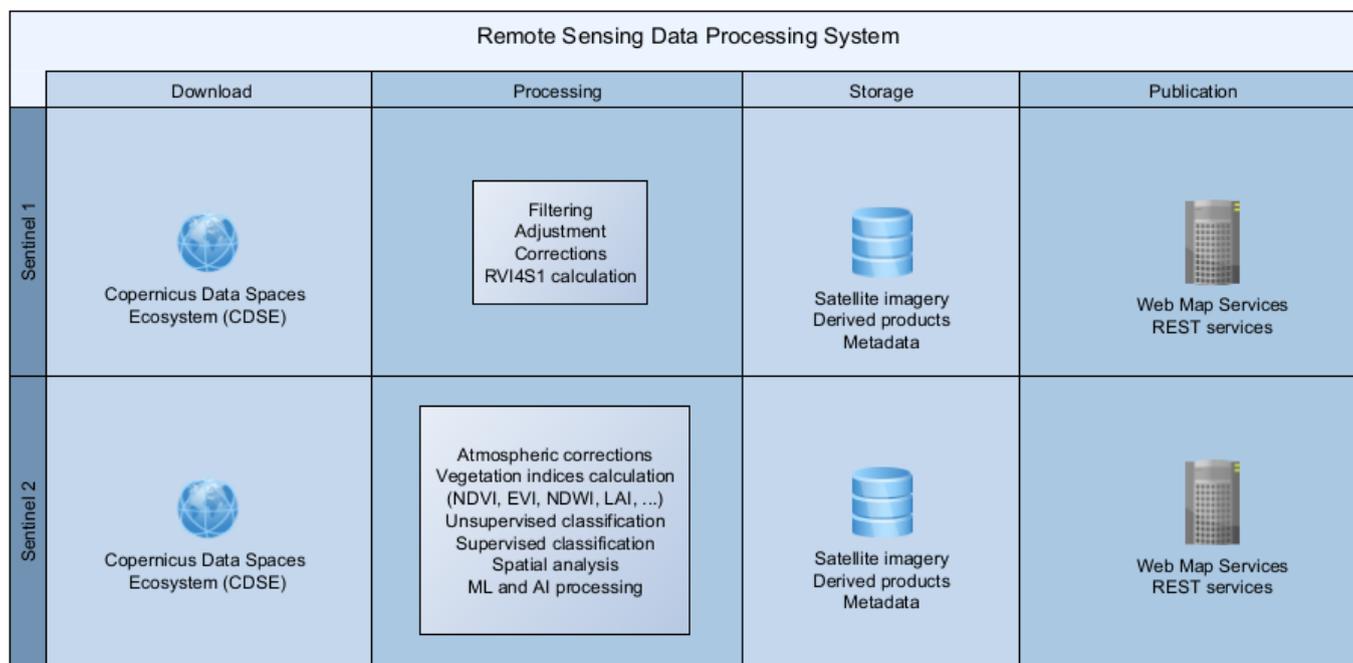
Remote Sensing Data Processing System			
Download	Processing	Storage	Publication
Sentinel 1 Copernicus Data Spaces Ecosystem (CDSE)	Filtering Adjustment Corrections RVI4S1 calculation	Satellite imagery Derived products Metadata	Web Map Services REST services
Sentinel 2 Copernicus Data Spaces Ecosystem (CDSE)	Atmospheric corrections Vegetation indices calculation (NDVI, EVI, NDWI, LAI, ...) Unsupervised classification Supervised classification Spatial analysis ML and AI processing	Satellite imagery Derived products Metadata	Web Map Services REST services

Figure 1 - RSDPS scheme

2.1.1.2   Data Processing Pipeline

The RSDPS follows a sequential data processing pipeline:

1. **Data Acquisition:** Downloads raw satellite scenes.
2. **Metadata Extraction:** Extracts and stores metadata.
3. **Pre-processing:** Applies appropriate pre-processing techniques.
4. **Product Generation:** Creates products based on user-defined requirements.
5. **Data Storage and Publication:** Stores and publishes data.

2.1.1.3   Products and Applications

The RSDPS offers a wide range of products, including:

- **Vegetation Indices:** Calculate indices such as NDVI, NDWI, and EVI to assess vegetation health and water content.
- **Supervised Classifications:** Use machine learning algorithms to classify land cover types, such as forests, agriculture, and urban areas.

- **Machine Learning-Based Analyses:** Apply advanced techniques to extract information on deforestation, soil moisture, and other environmental parameters.

The RSDPS can be used for various applications, such as:

- **Forest Management:** Monitor forest health, detect deforestation, and assess carbon sequestration.
- **Agriculture:** Monitor crop growth, assess soil moisture, and detect pests and diseases.
- **Urban Planning:** Analyse land use patterns, monitor urban sprawl, and assess infrastructure development.
- **Environmental Monitoring:** Track changes in water bodies, detect pollution, and assess climate change impacts.

The RSDPS is a powerful tool for remote sensing data analysis, providing a comprehensive solution for processing satellite imagery and extracting valuable information. Its REST interface and flexible product options make it suitable for a wide range of applications.

2.1.2   Hub4Everybody

Hub4Everybody is an advanced web-based platform designed for the publication, sharing, and collaborative management of spatial data. It provides a versatile, open-source solution for creating knowledge hubs tailored to a wide range of users, including professionals, researchers, educators, and other stakeholders. The platform is designed to manage geographical datasets, professional data, research results, and educational content, offering an integrated environment for data visualisation, collaboration, and learning.

Key features of **Hub4Everybody** include:

- **Map Interaction and Data Linking**: Users can interact with maps and link external data sources, allowing for comprehensive geographic data analysis and visualisation.
- **Data Upload and Sharing**: The platform allows easy uploading, updating, and sharing of spatial data, with customisable access settings for different user

groups.

- **Integration with Desktop and Mobile GIS**: The platform supports integration with desktop GIS applications like **QGIS** and mobile applications derived from **QField**, enabling users to work seamlessly across multiple devices.
- **E-Learning Module**: Hub4Everybody features an e-learning module that allows editors to create courses with quizzes and certificates, making it a powerful tool for education and training.
- **Cloud and Local Storage Options**: The platform can store data either in its own cloud or within the user's infrastructure, providing flexibility for different use cases.

The technical architecture of **Hub4Everybody** includes several key components (Figure 2):

- **Wagtail CMS**: A flexible content management system that allows editors to manage web content easily, with support for rich text editing, image management, and multilingual content.
- **LayMan Server**: Manages the publication of spatial data in OGC-compliant formats, ensuring compatibility with various geospatial tools.
- **Metadata Catalogue**: A comprehensive catalogue system that stores metadata for all published datasets, enabling extensive search and data retrieval capabilities.
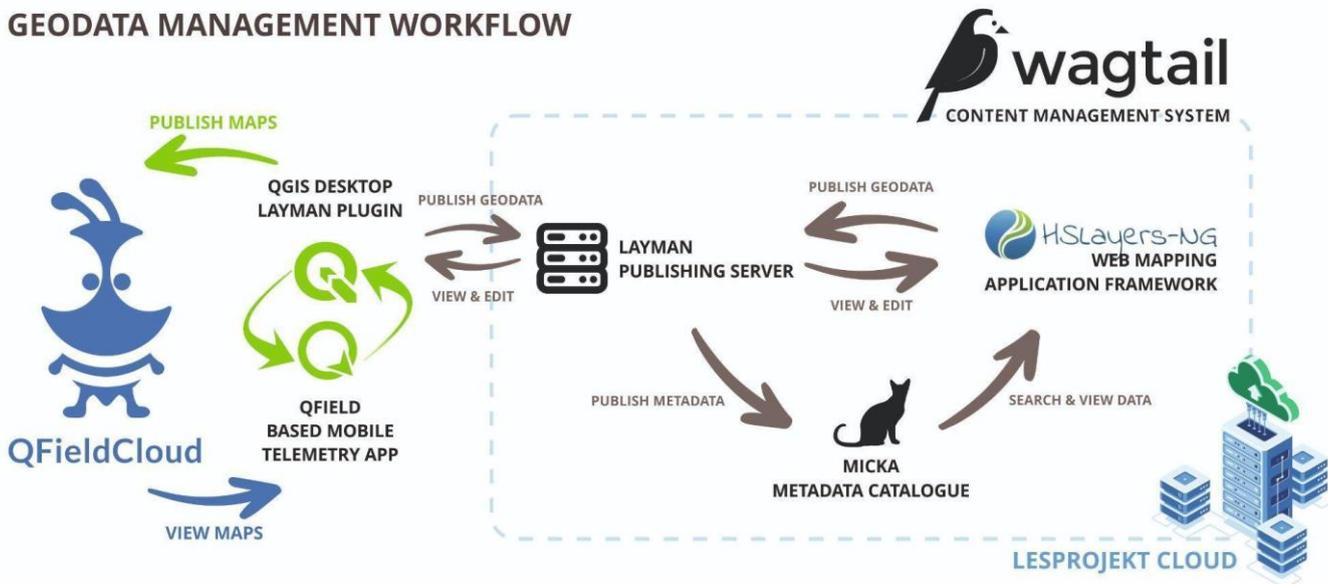
Figure 2 Hub4Everybody scheme

The platform is designed to be scalable and adaptable to the needs of different users. Its integration with **3D visualisation tools**, **AI-powered data analysis**, and **Jupyter Notebook** further enhances its capabilities, allowing users to perform advanced data manipulation, visualisation, and analysis in real time. Additionally, the platform supports interaction with various external data sources and APIs, enabling a broader integration of data for more comprehensive analysis.

2.1.2.1   Training platform

The **Hub eLearning module** is a powerful and customisable solution designed for **Wagtail CMS**, which can be integrated as part of the **Hub4Everybody platform**. This module offers a comprehensive set of features to support online learning and training, making it ideal for educational institutions, training organisations, and professional development programs.

Key features of the eLearning module include:

- **Course Management**: Users can create, organise, and manage courses with multiple lessons and chapters. Each course can include various content types,

such as text, images, videos, maps, and quizzes, providing a rich, interactive learning experience.

- **User Enrolment**: The platform allows administrators to manage student registration and course enrolments and track their progress through each course.
- **Interactive Quizzes**: The module supports different types of quizzes, including multiple-choice and short-answer questions. This helps evaluate students and assess their understanding of the course material.
- **Certificates and Badges**: Upon course completion, the system can automatically generate certificates and badges, recognising students' achievements.
- **Discussion Forums**: Each course can include discussion forums to facilitate interaction between students and instructors, fostering an engaging learning environment.

In addition to the core functionalities, **Artificial Intelligence (AI)** can be integrated into the eLearning module to automate the creation of lectures directly from text. This advanced capability allows for the efficient generation of learning content from provided material, streamlining the course creation process. With the help of AI, lectures can be quickly transformed into interactive lessons with embedded multimedia, quizzes, and other educational elements. This significantly reduces the time and effort required to develop new learning materials.

For demonstration purposes, **Annex 1** includes two examples of AI-generated lectures, showcasing how text can be transformed into complete eLearning content. These examples illustrate the potential of integrating AI within the Hub eLearning module, further enhancing its usability and making it a cutting-edge solution for modern online education.

2.1.3 FIE20

FIE20[21] is a standalone application developed under the FIE20 experiment within the SmartAgriHubs project. As an advanced concept platform, FIE20 demonstrates the effective integration of sensor data, Earth Observation (EO) data, and weather models to provide a comprehensive decision-support system for precision agriculture. Currently

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[21] https://pites37.lesprojekt.cz/

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independent, FIE20 could be integrated with COMUNIDAD's Platform as a powerful tool to assist farmers in Chile and Colombia with precise, data-driven field management practices.

The **FIE20 experiment** (Charvát et al., 2022), conducted under the **SmartAgriHubs project**, focuses on integrating various data sources — such as local sensors, weather models, and Earth observation (EO) data — into a unified system designed to assist farmers in precision agriculture. This experiment leverages advanced technologies to create an expert decision-support system that helps farmers optimise field interventions, manage water resources, and monitor crop health through a user-friendly web-based platform.

The primary objective of the FIE20 experiment is to provide farmers with comprehensive, real-time information by integrating diverse data types, including groundwater and meteorological sensors, Earth observation data, and weather models. Groundwater and soil moisture sensors capture localised data on key environmental variables, while **Copernicus Sentinel-2 satellite data** offers insights into vegetation indices like the **Normalized Difference Vegetation Index (NDVI)**, which is essential for monitoring crop health. The solution also integrates **weather forecasts** to predict short-term conditions, enabling more effective planning for irrigation, fertilisation, and other field activities.

All this information is visualised through a web map interface, allowing users to access real-time sensor data, long-term EO data, and weather forecasts. This combination provides farmers with a holistic view of their agricultural environment, helping them make more informed decisions to improve yields and resource efficiency.

The system offers a suite of analytical functions that can extend the set of basic functionalities and provide essential decision-support tools. For instance, sowing **soil trafficability analysis** helps determine whether the ground is suitable for machinery operations based on soil moisture and weather conditions. While **sowing and spraying windows,** identify the optimal times for planting and applying pesticides based on short-term weather forecasts. Additionally, the **frost risk prediction** tool uses historical weather data and current forecasts to help farmers mitigate frost damage during sensitive crop growth phases (Figure 3).

The FIE20 system is built on a scalable, cloud-based platform utilizing open-source

components such as SensLog for sensor data management and Jupyter Notebooks for executing analytical models. SensLog is a versatile tool that supports the management of both static and dynamic data, making it highly adaptable to various agricultural applications. In addition to managing static climatic data, SensLog can process dynamic data streams from diverse sources, including GNSS receivers, which capture spatial and temporal data critical for monitoring other environmental and operational parameters. This capability enables FIE20 to incorporate real-time measurements, enhancing the accuracy and responsiveness of the platform.

The flexibility of SensLog and the cloud-based infrastructure ensure that FIE20 can be tailored to meet the specific needs of different regions and farming operations, providing localized insights that support precision agriculture. The platform also allows for the integration of a wide range of additional data sources, such as commercial satellite data, drone imagery, and weather forecast-based analysis. These integrations expand FIE20's functionality, enabling comprehensive environmental monitoring and decision support that considers multiple data dimensions. This versatility positions FIE20 as a powerful tool for sustainable and data-driven agriculture, adaptable to both current and emerging data sources in diverse geographic contexts.

One of the key strengths of the FIE20 solution is its ability to combine both long-term and short-term data analysis. Long-term satellite data, such as those from the **Copernicus Sentinel-2**, are used to define **yield productivity zones (Figure 4)**, enabling farmers to understand field variability and apply fertilisers more efficiently. Meanwhile, short-term NDVI trends offer real-time insights into crop development, allowing farmers to take immediate action when necessary.

The FIE20 application provides several key benefits to farmers, agronomists, and agricultural advisors. By delivering accurate data on soil conditions, crop health, and weather forecasts, the system helps optimise the use of resources like water, fertilisers, and pesticides, reducing both costs and environmental impacts. With long-term data and real-time monitoring, farmers can better manage yields, monitor plant health, and react quickly to potential issues such as drought or disease. Moreover, integrating weather forecasts, sensor data, and satellite imagery gives farmers a comprehensive understanding of field conditions, empowering them to make more informed decisions

about when to sow, irrigate, or harvest.

FIE20 leverages long-term satellite data, including Sentinel-2 and future integrations with Sentinel-1, to provide valuable insights into both yield productivity zones and broader vegetation patterns. By analyzing historical data on vegetation indices such as NDVI and EVI, FIE20 helps farmers and agronomists understand how vegetation responds to various climatic factors over time. This analysis supports assessments of field variability not only in terms of crop productivity but also in the context of climate resilience, water availability, and soil health.

With these capabilities, FIE20 can identify trends in vegetation growth and health that are influenced by local climate conditions, enabling users to make informed decisions regarding crop selection, irrigation planning, and sustainable land management. This comprehensive approach supports long-term agricultural strategies that account for both productivity goals and environmental resilience, making it an adaptable tool for regions facing varying climate challenges.

By integrating advanced data sources, FIE20 provides even deeper insights into the interplay between vegetation and climatic factors, enabling users to predict and mitigate the impacts of climate variability on agricultural productivity. This functionality positions FIE20 as a versatile resource that could be effectively incorporated into COMUNIDAD to support climate-adaptive agricultural practices in Chile and Colombia.
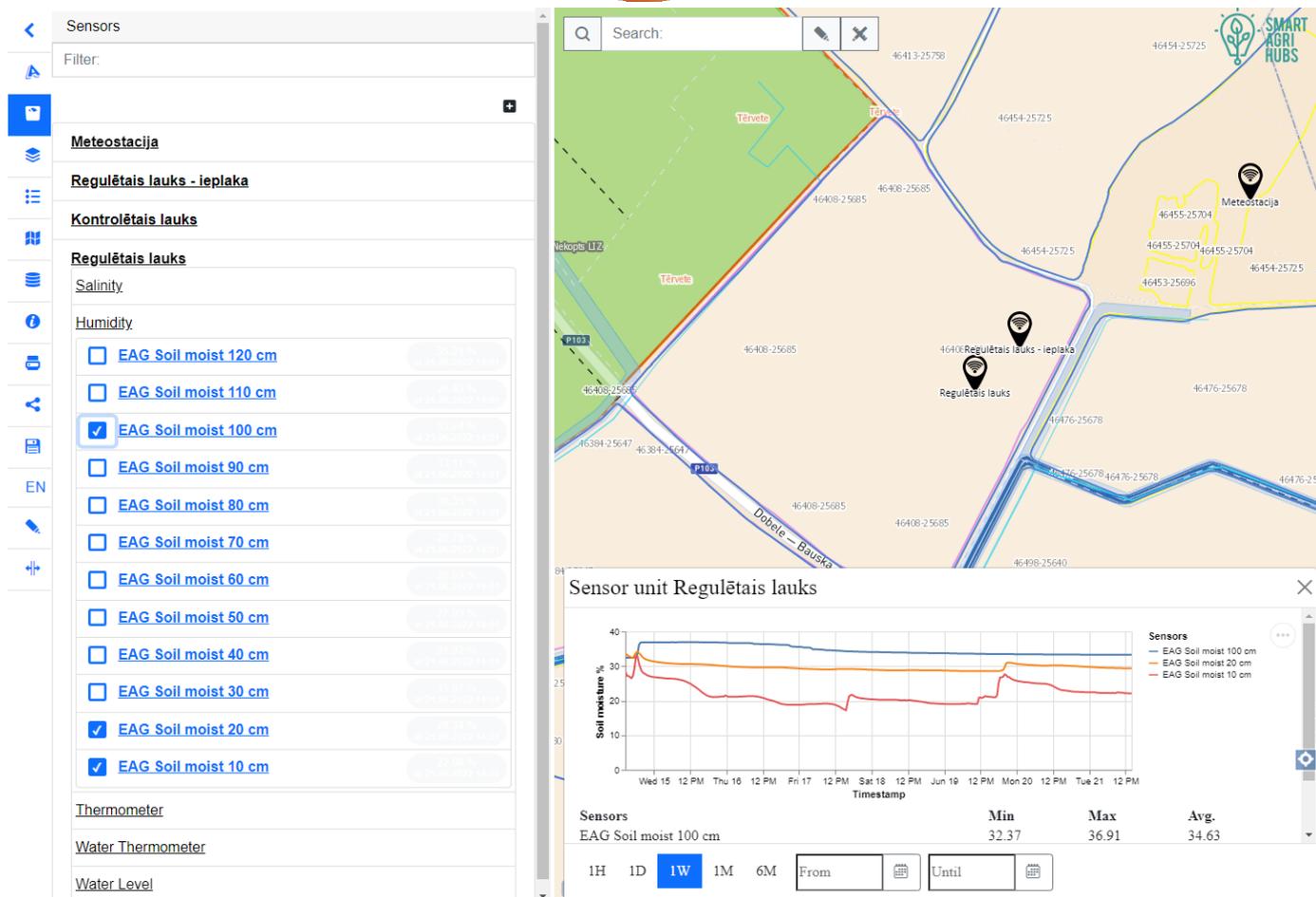
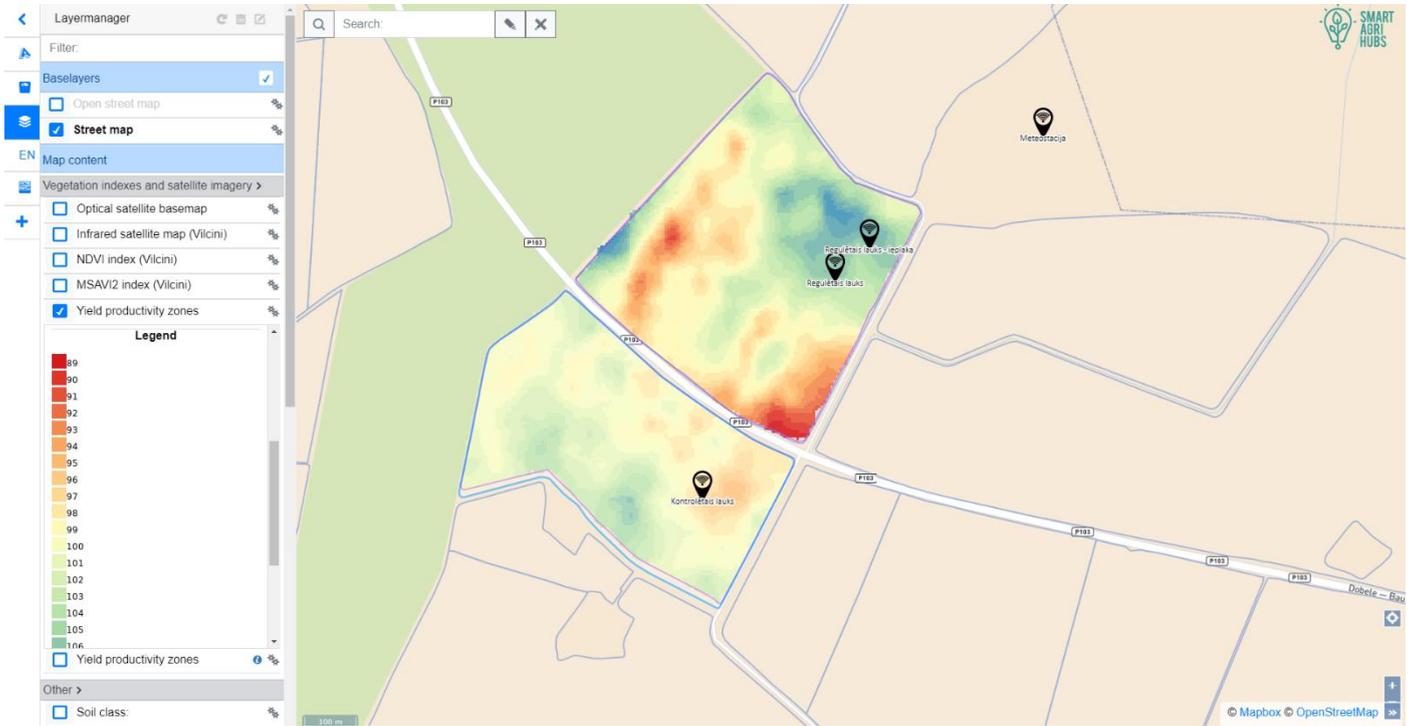*Figure 3 FIE20 Sensor Measurement panel and chart visualisation*

Figure 4 FIE20 Combination of Sensors with the layer Yield Potential Zones

2.2 Application services

The Application Services section outlines various Copernicus-based tools and services that demonstrate the scope of EO applications. This section is intended to assist users in understanding potential use cases for COMUNIDAD both in the context of the pilots in Chile and Colombia, both in the context of the pilots in Chile and Colombia, or further use of the COMUNIDAD platform beyond the scope of these pilots. These services provide examples of the capabilities available and can be customized to align with COMUNIDAD-specific requirements, facilitating user engagement and ensuring that the platform delivers targeted and valuable insights across agricultural, urban, and environmental sectors.

2.2.1   FieldCalc

FieldCalc[22] is currently a standalone satellite-based analytical tool and is not integrated with Hub4Everybody. As a demonstration tool, it illustrates the potential of zoning images

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[22] https://fieldcalc.lesprojekt.cz

to enhance precision agriculture, showcasing how Copernicus data can be applied in agricultural contexts. If COMUNIDAD requires such functionality, FieldCalc's zoning capabilities could be integrated into the project's infrastructure, supporting local applications of precision farming techniques. The report presents FieldCalc, among other application,s to help users understand the diverse possibilities of Copernicus data processing.

FieldCalc is an advanced satellite-based analytical tool designed to enhance precision agriculture by generating **Variable Rate Application (VRA)** maps that help optimise the use of fertilisers, water, and other agricultural inputs. FieldCalc empowers farmers and agricultural service providers with a robust system for **data-driven field management**. By integrating various data sources, including satellite imagery from **Sentinel-1** and **Sentinel-2**, soil moisture data, and weather forecasts, FieldCalc creates precise application maps, enabling more efficient farming practices, reducing costs, and minimising environmental impacts.

One of the core features of FieldCalc is its ability to support **Variable Rate Application (VRA)** by dividing fields into **management zones**, which represent different areas of a field where crop health and soil conditions vary. These zones receive tailored recommendations for inputs such as fertilisers, ensuring that resources are applied where they are most needed, optimising both cost and yield. Using **satellite data**, FieldCalc processes key vegetation indices like the **NDVI** and **EVI**, which provide insights into crop health and growth patterns. Additionally, FieldCalc overcomes the limitations posed by cloud cover through the integration of **radar data from Sentinel-1**, ensuring that crop monitoring continues uninterrupted in all weather conditions.

In practical terms, FieldCalc produces **management zone maps** and **fertiliser application maps**, which can be exported to agricultural machinery for automated input application. These maps allow precision farming equipment to adjust the rate of inputs based on the specific needs of each zone, further enhancing efficiency. As a result, farmers can reduce their use of fertilisers and other inputs, leading to significant **cost savings** while promoting more sustainable farming practices.

FieldCalc is also designed to operate on **cloud-based platforms**, providing scalability and easy access to data for a wide range of users, including farmers, developers, and

agricultural service providers. By leveraging this cloud-based approach, the tool can be deployed across different regions and adapted to various crops, making it a versatile solution for modern agriculture.

FieldCalc (Figure 5) demonstrates advanced zoning capabilities by utilizing satellite data to create management zones within the area. These zones represent distinct areas with varying crop health and soil conditions, allowing for targeted management practices based on the specific needs of each region. While initially developed for precision agriculture, this zoning functionality can be adapted for other applications where spatial differentiation is valuable.

By analyzing vegetation indices such as NDVI and EVI, FieldCalc provides insights into spatial variability, enabling tailored recommendations for resource application. The tool integrates radar data from Sentinel-1 to ensure continuous monitoring, even under cloudy conditions and offers a long-term analysis feature that assesses historical productivity, enhancing resilience to yearly anomalies.

FieldCalc's zoning capabilities can thus support diverse applications beyond agriculture, including forestry, land-use planning, and environmental monitoring. This flexibility makes it a valuable asset for COMUNIDAD, where zoning technology may be integrated into broader Earth observation efforts to address varied sectoral needs in Chile and Colombia.
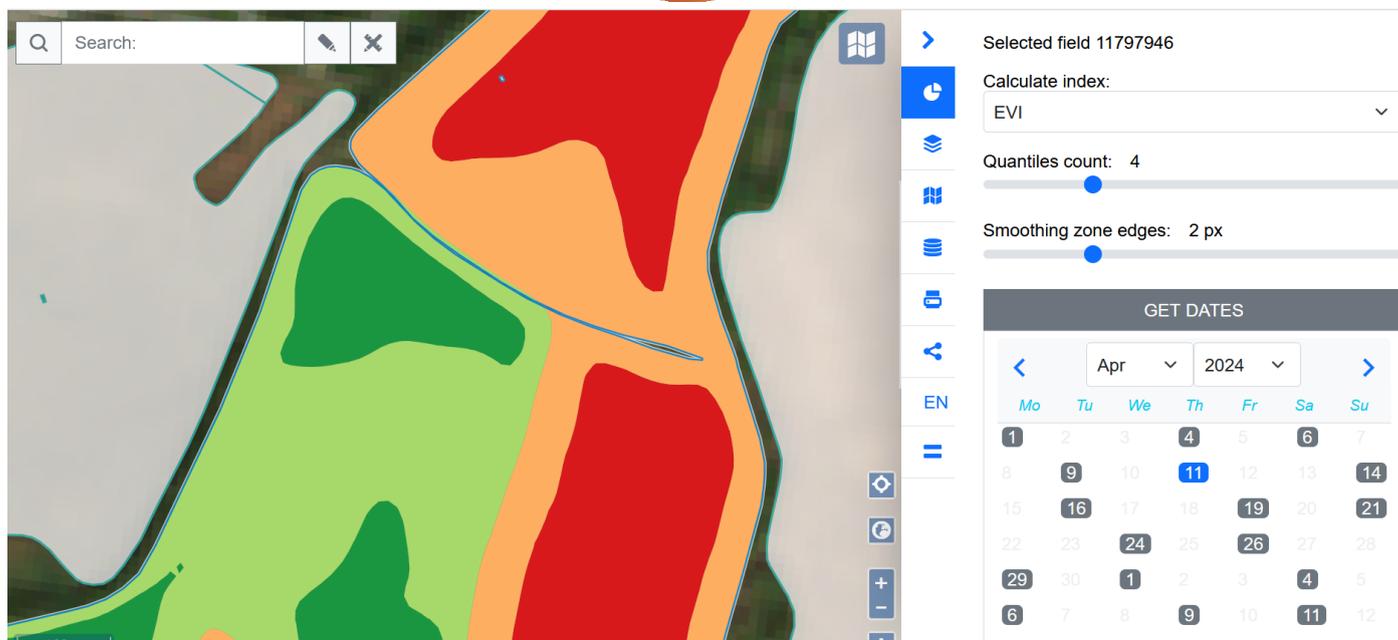
Figure 5 FieldCalc visualisation of zones of EVI index

2.2.2 Agricultural Climatic Atlas

The **Agricultural Climatic Atlas[23]** is currently a standalone application that provides climate data relevant to agricultural planning. For COMUNIDAD, this tool will be adapted to address the specific vegetation types found in the pilot regions, including crops such as coffee and forest ecosystems. The Atlas offers detailed, region-specific climatic data that, when integrated with other platform components, can support localized decision-making processes.

The Agricultural Climatic Atlas (Jedlička et al., 2021) is a comprehensive tool designed to calculate and analyse agro-climatic factors, which are crucial for understanding and optimising crop growth and field management. By using global climatic data from sources such as the ERA5-Land dataset, a product of the Copernicus Climate Change Service, the atlas offers valuable insights into temperature patterns, soil conditions, precipitation, and other environmental factors that influence agricultural productivity.

One of the key features of the Agricultural Climatic Atlas is its ability to calculate a wide

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[23] https://www.agrihub.cz/maps/AgroClima

range of agro-climatic factors, including frost-free periods, growing degree units (GDU), heat stress units (HSU), water balance, and solar radiation. These metrics help farmers assess the optimal times for planting, irrigation, and harvesting, as well as identify potential risks like frost or heat stress. For instance, frost-free periods indicate the last spring frost and first fall frost dates, guiding planting and harvesting schedules. Similarly, growing degree units provide a measure of the accumulated heat necessary for crops to grow, helping farmers gauge the length and productivity of the growing season. The water balance, which combines precipitation, evapotranspiration, and runoff data, assists in managing irrigation more effectively, while solar radiation data helps optimise crop placement for maximum energy use.

The atlas leverages the ERA5-Land dataset, a high-resolution global climatic data source that covers an extended time period from 1981 onward. This dataset ensures that the atlas can be used across various regions, offering accurate calculations for different agro-climatic factors. Additionally, the long-term data allows for the analysis of climate trends, which is essential for understanding how changing weather patterns impact agriculture over time.

A significant aspect of the atlas is its focus on temperature-related calculations, such as frost dates, growing degree units, and heat stress. These calculations provide crucial insights into the optimal growing conditions for different crops and allow farmers to anticipate and mitigate risks from extreme weather events, such as frost or excessive heat. The atlas is adaptable, enabling users to adjust temperature thresholds to match the specific needs of various crops, ensuring its relevance to diverse farming practices.

The atlas also includes powerful visualisation tools, such as detailed maps and graphs, which depict the spatial and temporal distribution of agro-climatic factors. These visualisations are essential for understanding how climatic conditions evolve over time and across different geographical areas, helping farmers make informed, data-driven decisions about crop management and field interventions.

Accessible as a cloud-based service, the Agricultural Climatic Atlas allows users to calculate agro-climatic factors on demand. This makes the tool highly flexible and

suitable for a wide range of users, from individual farmers to large agricultural enterprises. It also enables easy integration with other digital farming tools, enhancing its utility in modern precision agriculture.

The Agricultural Climatic Atlas has numerous applications in farming. It helps in field management and crop planning by providing accurate information on frost dates, growing degree days, and water availability, allowing farmers to optimise their activities and improve crop yields. Additionally, by offering data on water balance and solar radiation, the atlas promotes sustainable resource use, particularly in regions facing water scarcity or excessive heat. This helps farmers manage irrigation and crop placement more efficiently.

Moreover, the atlas supports risk assessment and climate change adaptation by highlighting trends in frost-free periods, temperature variability, and heat stress. These insights enable farmers and agricultural planners to assess the risks posed by climate change and develop strategies to adapt to shifting weather patterns, ensuring the long-term sustainability of their farming practices.

The Agricultural Climatic Atlas (Figure 6) is a vital tool for modern agriculture, providing a detailed analysis of the climatic factors that influence crop growth and field management. By integrating global climatic data with advanced algorithms, the atlas offers farmers the insights they need to optimise agricultural practices, manage risks, and ensure sustainable resource use. Its adaptability, visualisation capabilities, and cloud-based accessibility make it a key resource for precision agriculture and long-term climate planning.

The integration with **ALIANCE AI tools** will enhance the functionality of the Climatic Atlas, allowing for advanced analysis and predictive modelling based on climate and vegetation interactions. As part of COMUNIDAD's infrastructure, the Atlas will provide stakeholders with vital information on climate trends, drought risk, temperature fluctuations, and rainfall patterns, helping to mitigate climate-related risks in agricultural operations. This approach offers COMUNIDAD the opportunity to provide relevant and actionable climate insights tailored to local agricultural practices in Chile and Colombia.
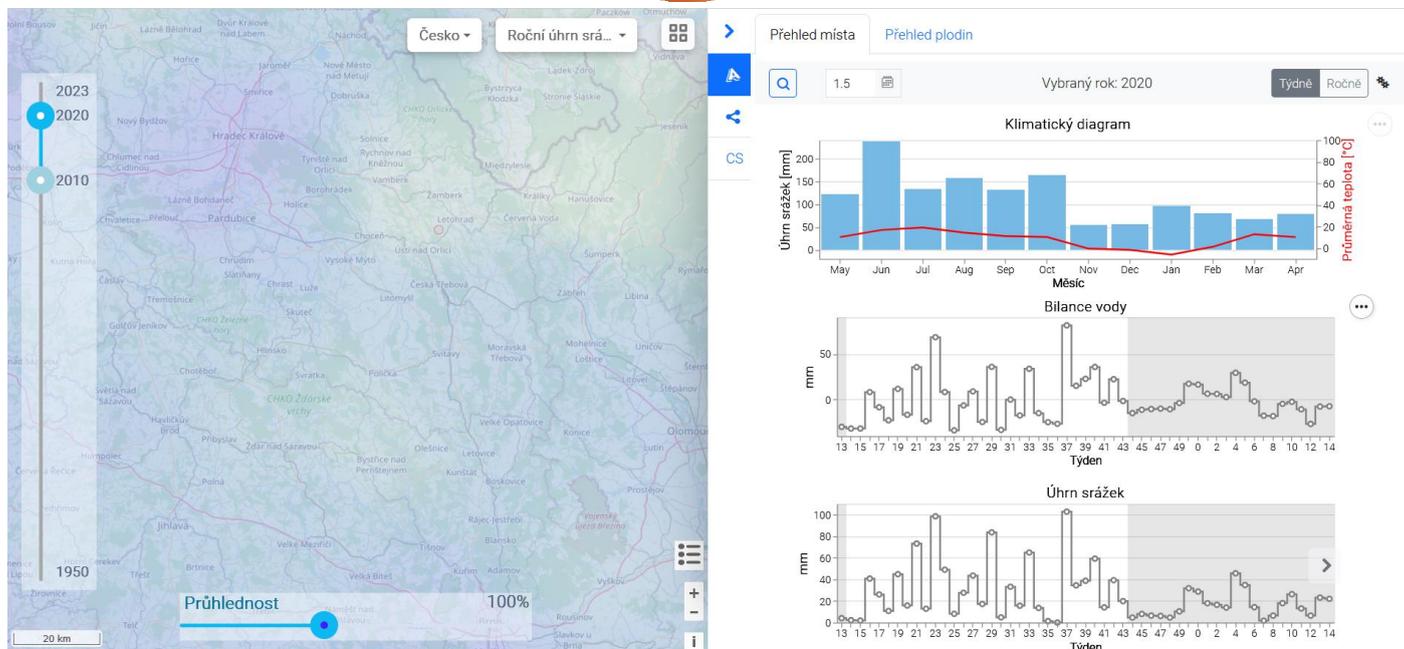
Figure 6 Climatic Atlas outputs

2.2.3 ALIANCE

The **ALIANCE project** focuses on integrating advanced technologies such as satellite data, machine learning, and precision agriculture tools to enhance agricultural monitoring and forecasting. The project aims to improve the efficiency of resource use in farming by providing real-time data on crop health, soil conditions, and weather forecasts, helping farmers optimise interventions and increase productivity. Recently, **ALIANCE** signed a **Memorandum of Understanding (MoU)** with **COMUNIDAD**, enabling both projects to collaborate and share research achievements. This cooperation allows COMUNIDAD to leverage ALIANCE's innovations and research outcomes, enhancing its own capabilities in Earth observation and precision agriculture. This partnership fosters knowledge exchange and strengthens the impact of both initiatives.

The **ALIANCE project** brings advanced technologies, including machine learning algorithms and precision agriculture tools that enhance monitoring and forecasting capabilities. While ALIANCE is currently a backend solution without an end-user interface, there is a relatively easy possibility of integration with tools that are part of the COMUNIDAD infrastructure and platform.

2.2.3.1 ALIANCE Service for Cloud Removal in Satellite Images for Crop Monitoring

The **ALIANCE service** for cloud removal is designed to address one of the biggest challenges in satellite-based crop monitoring: **cloud cover**. Clouds can obscure optical satellite imagery, making it difficult for farmers to continuously monitor crop health and growth. This is particularly problematic in regions with frequent cloud cover, where relying solely on optical data can leave significant gaps in monitoring.

The ALIANCE cloud removal service addresses the challenges posed by cloud cover in satellite-based monitoring by leveraging data from both **Sentinel-1 and Sentinel-2** satellites. Sentinel-1 provides radar imagery, which can penetrate through clouds and maintain consistent data collection regardless of weather conditions. This radar data is combined with optical imagery from Sentinel-2, which includes detailed spectral information that is valuable for monitoring vegetation health and other environmental variables.

To reconstruct cloud-free images, the cloud removal service employs advanced machine learning techniques, including the **UnCRtainTS neural network model**. This model processes both the radar and optical data, learning patterns of correlation between clouded and non-clouded data to accurately fill in obscured areas. The UnCRtainTS model is particularly effective due to its capacity to handle the inherent uncertainty in cloud-prediction scenarios, resulting in reliable data outputs that are well-suited for precision agriculture applications.

During the **training process,** a **subset of cloud-free Sentinel-2 images is reserved as testing data to assess the model's accuracy objectively**. These testing images are not used for model training, allowing for a clear comparison between the model-generated images and the actual, cloud-free reference images. This approach enables an objective evaluation of the model's ability to reproduce accurate, cloud-free data across different vegetation indices.

Figure 7 illustrates the comparison of model-generated and real data in true colour, while **Figure 8** shows this comparison for NDVI values. Although NDVI is highlighted in this example, the same methodology can be applied to other vegetation indices, validating the robustness of the cloud removal process across multiple metrics. **Figure 9** then

presents a clouded image in its original state, highlighting the limitations of optical satellite data in cloudy conditions and the necessity of cloud removal.

This integration of Sentinel-1 and Sentinel-2 data, together with machine learning methods like UnCRtainTS, can offer the COMUNIDAD project the possibility to provide high-quality, cloud-free imagery that supports continuous crop monitoring, even in challenging weather conditions. This capability ensures that stakeholders in Chile and Colombia have reliable access to actionable data throughout the agricultural season.

By providing clear, uninterrupted satellite images, the ALIANCE cloud removal service helps farmers maintain a consistent overview of their fields, enhancing their ability to make informed decisions throughout the growing season. This service is particularly valuable for **precision agriculture**, where accurate, real-time information is crucial for optimising resource use and maximising yields.

The **cloud removal service** can be integrated as part of the **Remote Sensing Data Processing System (RSDPS)** in COMUNIDAD. This service uses radar data from Sentinel-1 combined with optical data from Sentinel-2 and machine learning algorithms to reconstruct cloud-free images, overcoming the limitations posed by frequent cloud cover in satellite-based monitoring. This integration will allow COMUNIDAD users to obtain uninterrupted, high-quality satellite imagery, enabling continuous monitoring of crop health and timely interventions.
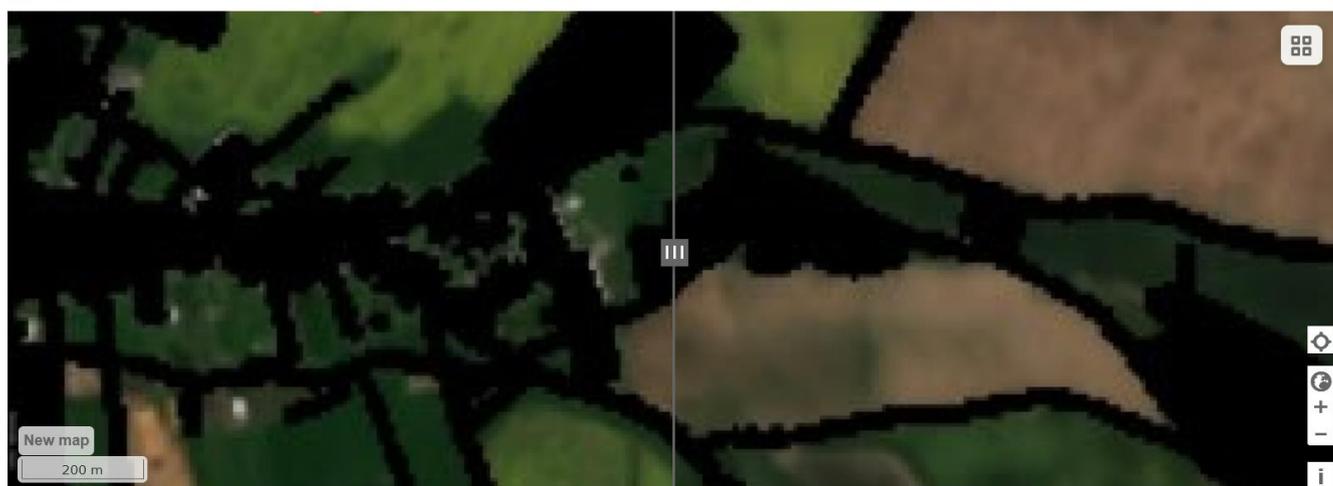

Real S-2 | Predicted S-2

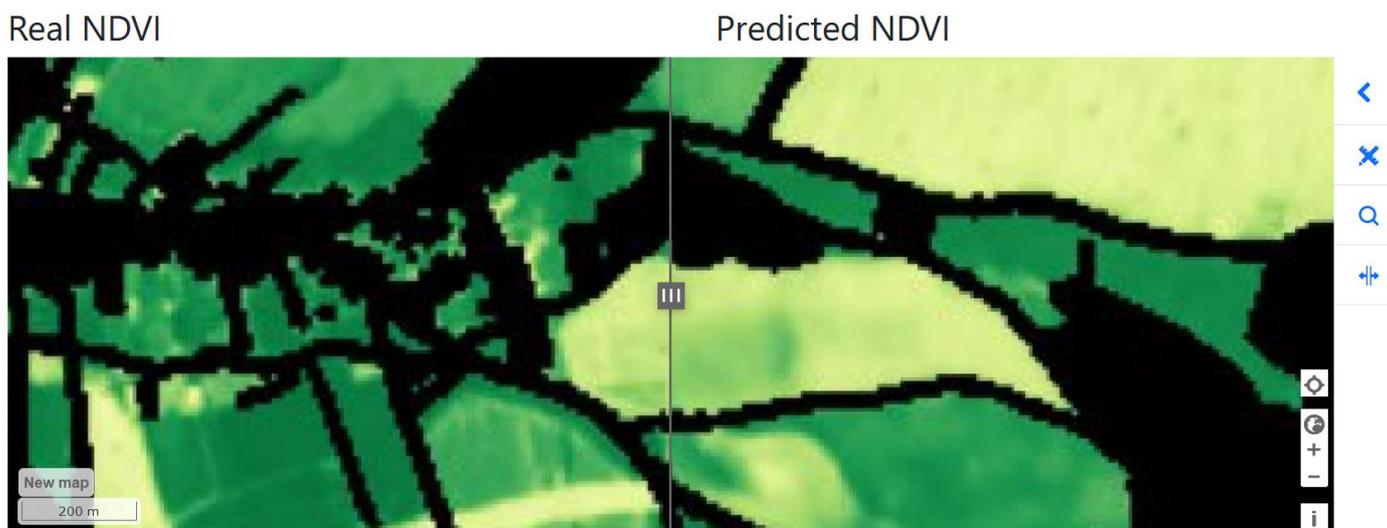*Figure 7 Comparision of real and model data in real colour*

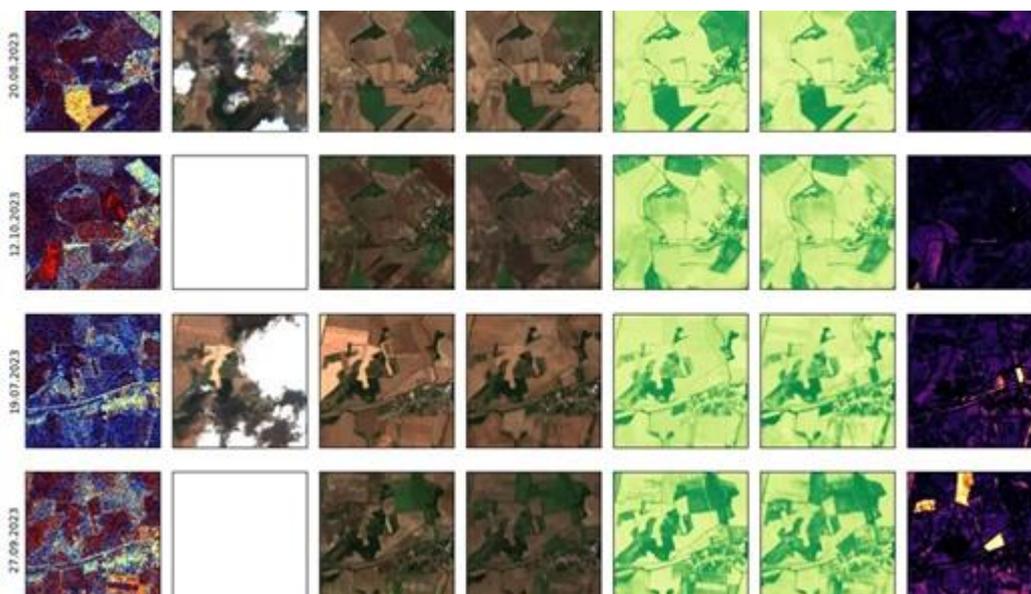Figure 8 Comparision of real and model data in real colour

Figure 9 Cloud removing algorithms

2.2.3.2 ALIANCE Service for Improving Weather Forecast Accuracy in Agriculture

The **ALIANCE service** for improving weather forecasts provides a much-needed solution

for farmers who depend on highly accurate local weather predictions to make decisions about their crops. In many cases, global weather forecasts lack the precision needed for specific local conditions, and this can lead to inefficient farming practices, wasted resources, or even crop losses.

To enhance the accuracy of local weather predictions, ALIANCE combines **local weather station data** with global weather models, such as the **Global Forecast System (GFS)** and **ERA5-Land reanalysis** data. By merging these datasets, the service creates more precise, localised forecasts that are better suited for agricultural planning. Advanced **machine learning techniques**, including **CatBoost** and **LSTM neural networks**, are employed to process the data and make predictions more accurate.

This improved forecasting enables farmers to better plan for weather events, such as rainfall, frost, or heatwaves. For example, accurate predictions of rain can help farmers avoid over-irrigation and save water, while early frost warnings can prevent crop damage by allowing farmers to take protective measures.

The integration of **global and local data** makes this service a powerful tool for **precision agriculture**, helping farmers optimise their operations, reduce waste, and increase productivity by aligning farming activities with accurate weather forecasts. Additionally, by improving the accuracy of short-term weather predictions, the ALIANCE service helps farmers mitigate weather-related risks, contributing to more sustainable and resilient farming practices. (Figure 10).
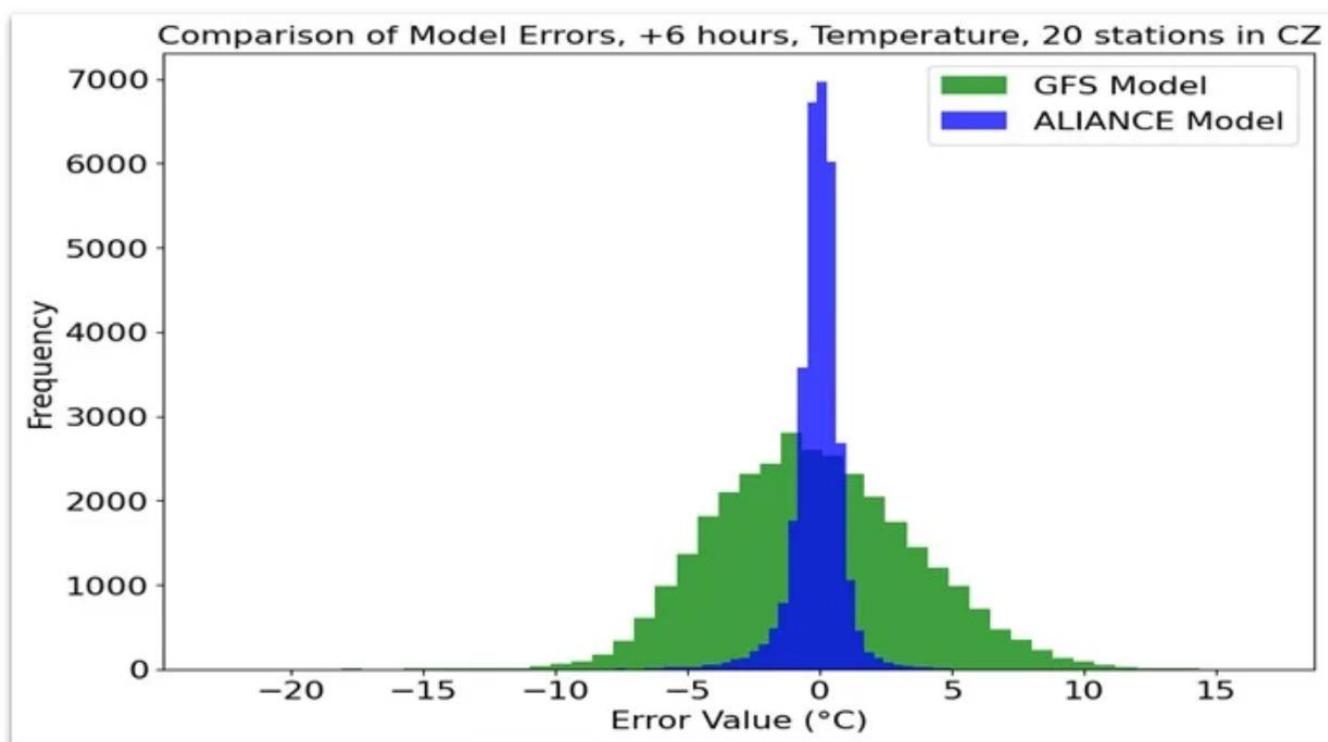
Figure 10 Comparison of local and global forecast

2.2.4 MapWhiteboard

MapWhiteboard is an innovative tool that facilitates real-time, collaborative map editing and browsing. It allows multiple users to work together on a shared map, viewing and editing data simultaneously. Like popular online collaboration tools, MapWhiteboard makes it easy for users to interact with spatial data, add or edit layers, and work collaboratively on geographic projects.

Key features of **MapWhiteboard** include:

- **Real-Time Collaboration**: Users can see each other's actions, including cursor locations, in real time. This makes it ideal for collaborative projects where multiple users need to contribute to the same map.
- **Layer Management**: Supports the addition and editing of **GeoJSON** and **WMS layers**, enabling users to manage and visualise different types of spatial data.
- **Shared Editing**: Users can collaboratively edit features in predefined layers, creating new layers or modifying existing ones as needed.

- **Data Publishing**: Geometries and features can be published into layers from third-party applications through web services.

The technical structure of MapWhiteboard consists of the following:

- A **JavaScript extension** for **OpenLayers**, which captures and propagates map events between users.
- A **WebSocket server** that facilitates communication between users by handling map and layer events.
- A REST API for managing maps and data, ensuring that the system can be integrated with other GIS tools and services.

MapWhiteboard is designed to support real-time collaboration in a wide range of applications, from urban planning to environmental management. It provides a flexible, interactive platform for sharing and editing spatial data, allowing users to work together seamlessly on complex geographic projects. The tool is built for integration with existing web GIS systems and can be extended to include AI tools and additional geoportal functionalities. In particular, the possibility to discuss different issues with users and stakeholders and to use an interactive map that can be simultaneously viewed and edited by all participants can be useful to the COMUNIDAD project in finding the right approaches to address user needs.

3 Recommendation

The **Copernicus Programme** offers a wide range of Earth Observation (EO) data and services that can significantly benefit the **CELAC pilot projects** in Chile and Colombia. These pilots focus on improving agricultural, environmental, and disaster risk management practices, requiring targeted solutions tailored to the unique challenges in these regions. The following recommendations outline how Copernicus data and additional partner tools can address these needs effectively.

3.1 Leveraging Copernicus Data for CELAC Pilots

3.1.1 Agricultural and Forestry Monitoring:

In both Chile and Colombia, **Sentinel-1** and **Sentinel-2** data provide high-resolution optical and radar imagery, enabling real-time monitoring of crop health, soil conditions, and vegetation indices such as NDVI and EVI. In Colombia, this data integration is especially valuable for coffee plantation management, where precise mapping and monitoring are critical for optimizing land use and improving crop yield.

In the Colombia pilot, RTK GNSS systems will be integrated through SensLog, which is part of the FIE20 infrastructure. SensLog is capable of handling real-time GNSS data, allowing for highly accurate geolocation that complements the satellite imagery from Sentinel-1 and Sentinel-2. By synchronizing GNSS positioning data with Sentinel-derived insights, SensLog facilitates precise spatial analysis of coffee plantations. This integration enables more accurate mapping, efficient resource allocation, and targeted interventions based on real-time conditions and crop requirements, supporting sustainable and data-driven plantation management.

For **Chile's Patagonia**, particularly the **Aysén region**, Copernicus data is essential for managing both **agriculture** and **forestry**. Forestry is critical in this region, where **sustainable forestry management** and the preservation of **native forests** are priorities. **Sentinel-2** data supports monitoring of forest health, deforestation rates, and regeneration efforts, while **Sentinel-1** assists in tracking forest degradation and land-use changes in all weather conditions.

The **Land Surface Temperature Monitoring (LSTM) Mission** provides high-resolution temperature data essential for **water resource management**, which is key for both **agricultural activities** and **forest management** in Patagonia. The LSTM data helps optimise irrigation, monitor droughts, and manage water resources in regions like the **Aysén region**, where forestry and agriculture face significant environmental challenges.

3.1.2 Disaster Risk Reduction:

The **European Ground Motion Service (EGMS)**, based on **Sentinel-1** data, offers high-

resolution information on ground deformation, which is crucial for monitoring risks such as **landslides** and **ground movement** in the **Andean regions** of both Chile and Colombia. This service helps track land subsidence and other geological hazards that threaten both agriculture and forestry activities, ensuring early warning and prevention strategies can be implemented.

The **Copernicus Emergency Management Service (CEMS)** provides vital tools for early warning and rapid mapping of disasters such as **floods**, **forest fires**, and **landslides**. This service is particularly important for **Chile's Patagonia**, where forest fires and environmental degradation due to changing climate conditions are significant risks. For Colombia's **coffee-growing regions**, CEMS provides tools for managing disasters like landslides, ensuring better preparedness and response in vulnerable areas.

3.1.3   Environmental and Climate Monitoring:

The **Copernicus Climate Change Service (C3S)** delivers comprehensive climate datasets that are crucial for assessing the impact of **climate variability** on agriculture and forestry in both Chile and Colombia. For **Chile's forestry sector**, C3S data can be used to understand how climate change affects **forest health**, water resources, and forest regeneration efforts. In Colombia, C3S supports efforts to mitigate climate risks that impact **coffee cultivation**.

Additionally, the **Marine Environment Monitoring Service (CMEMS)** provides data on ocean conditions, vital for managing Chile's coastal ecosystems and supporting the **Patagonia** region's environmental monitoring. This helps ensure the sustainable use of marine resources and monitors the impact of climate change on **coastal forestry ecosystems**.

By integrating Copernicus data with local insights and leveraging advanced tools such as **RTK GNSS**, **geospatial analysis**, and real-time monitoring, the CELAC pilots in Chile and Colombia can significantly enhance their capacity for **agricultural optimisation**, **sustainable forestry management**, **disaster preparedness**, and **environmental monitoring**. For **Chile's Patagonia**, in particular, these tools will be critical in promoting sustainable forestry practices and protecting the region's valuable natural resources.

3.2 Recommendations for Infrastructure Data and Tools for the COMUNIDAD Platform

These recommendations aim to guide the development of the COMUNIDAD platform's infrastructure and tools, contributing to the objectives set out in WP5, Deliverable 5.1. By focusing on effective integration and optimization of existing resources, these recommendations support the establishment of a robust and scalable infrastructure that leverages existing tools like the ALIANCE framework, Hub4Everybody, RSDPS, and FIE20

1. **Integration of Data Sources**:
    -   Establish a connection between the **Remote Sensing Data Processing System (RSDPS)** and the **Hub4Everybody platform**. This will enable seamless data acquisition, processing, and publication of satellite imagery, improving the platform's ability to handle large amounts of Copernicus EO data.
    -   Integrate data from **FIE20**, which combines local sensor data and weather models, into the Hub. This integration will allow for better analysis and visualisation of crop conditions and meteorological factors, providing more accurate insights into agricultural practices.
    -   The combined data from RSDPS, FIE20, and Copernicus will enhance the ability to monitor environmental factors such as soil moisture, crop health, and weather conditions in real time, supporting the pilot regions' agricultural and environmental goals.

2. **AI-Powered Data Processing with ALIANCE Framework**:
    -   Use the **ALIANCE framework** to integrate **Artificial Intelligence (AI)** tools that automate data analysis and provide predictive models for crop health, weather forecasts, and disaster risk. The ALIANCE framework, combined with Copernicus data, will enable advanced data processing, offering key insights for decision-makers in agriculture, urban planning, and disaster management.
    -   Leverage **machine learning** and **AI-driven predictive analytics** within the platform to enhance the processing of satellite data and deliver actionable insights in areas such as precision agriculture and disaster preparedness.

3. **Data Accessibility and User Interaction**:
   - Integrate **Hub4Everybody** with the **MapWhiteboard** tool to enable real-time collaboration and data sharing among different stakeholders, including farmers, researchers, and policymakers. The integration of these platforms will allow users to collaboratively interact with spatial data, adding and editing layers as needed.
   - This collaborative functionality will be crucial for enabling decision-makers to work together on shared datasets, ensuring effective management of resources and timely responses to environmental or agricultural challenges.

4. **Educational Tools and Knowledge Sharing**:
   - Utilise **Hub4Everybody**'s e-learning module to provide comprehensive training materials and organise workshops for end-users in Chile and Colombia. The platform's e-learning capabilities will help stakeholders learn how to use Copernicus data effectively in their specific contexts.
   - AI-driven tools from the **ALIANCE framework** can assist in the automated generation of educational content, such as online lectures and interactive courses, ensuring scalable knowledge transfer and capacity building for local stakeholders.

5. **Platform Scalability and Future Developments**:
   - Ensure the platform's **cloud-based infrastructure** is scalable, allowing it to accommodate expanding datasets and additional tools. The integration of cloud services will support the platform's long-term use across various sectors and regions.
   - Continue to develop the platform to include **new Copernicus missions** and future innovations from the ALIANCE framework, ensuring the platform remains at the forefront of environmental and agricultural monitoring in Chile and Colombia.

By following these recommendations, the **COMUNIDAD platform** will effectively utilise existing infrastructures and tools, enabling Chile and Colombia to leverage the full potential of Copernicus data, the **ALIANCE framework**, and other technologies to support sustainable agriculture, environmental management, and disaster resilience.

To ensure effective integration and optimization of existing tools and infrastructures for

COMUNIDAD, a structured approach will be followed. Tools and platforms will first undergo validation based on user requirements, ensuring alignment with practical, local needs. This process will involve comprehensive user training, and tool functionalities will be tested in hackathons, allowing stakeholders to assess and adapt applications in real-world scenarios. Core tools—Hub4Everybody, FIE20 and RSDPS—will form the foundational layer of the COMUNIDAD technical solutions, responsible for managing data and services. Basic applications will be integrated with this infrastructure to provide essential functionalities. Additional tools should then be incorporated according to user demand, with ALIANCE suitable for operating as a backend service supporting advanced data processing, while other tools should be introduced as user-facing applications tailored to specific requirements. This approach provides COMUNIDAD with a flexible, user-centered platform that can evolve based on stakeholder feedback and emerging needs.

13. Conclusion

The **COMUNIDAD project** represents a significant initiative aimed at leveraging European **Copernicus data** and **EGNSS technologies** to enhance agricultural and environmental management practices in Latin America, particularly in Chile and Colombia. Through a collaborative effort between European and CELAC partners, this project integrates advanced technologies like **satellite Earth Observation (EO)**, **Artificial Intelligence (AI)**, and **Big Data** into a unified platform that provides actionable insights for various sectors. The detailed analysis of Copernicus services, as highlighted in this report, shows their potential for supporting sustainable development, disaster management, and climate change mitigation in the CELAC region.

By integrating **Copernicus data and services** with existing local infrastructures and platforms, such as the **Hub4Everybody** and **FIE20** COMUNIDAD ensures that local stakeholders can access and effectively utilise real-time data for decision-making. These tools are essential for modernising agricultural practices, improving land management, and enhancing disaster resilience in the region. In addition, the possibilities to extend platform's AI capabilities, facilitated by the **ALIANCE framework**,

will help automate data analysis, enabling more efficient and predictive insights that support both long-term planning and real-time interventions.

As the project progresses, continued efforts to implement **online educational modules** will strengthen capacity-building efforts in Chile and Colombia, ensuring that local professionals, farmers, and decision-makers have the knowledge and tools necessary to maximise the use of Copernicus services. By making the content accessible through educational lectures and AI-powered training programs, the project will help local stakeholders better understand and benefit from the full potential of Copernicus data.

Overall, COMUNIDAD is well-positioned to contribute to the socio-economic growth of the South American region by promoting sustainable agricultural practices, improving environmental monitoring, and supporting disaster management strategies. Through the continued development of the platform and training initiatives, the project will help ensure that the benefits of Copernicus services are fully realised in the CELAC region, fostering a more sustainable and resilient future.

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15.   Annex 1 - Examples of lectures from this document

a. Lecture: Introduction to the Copernicus Programme

Introduction The **Copernicus Programme** is a European Earth Observation initiative that plays a crucial role in monitoring environmental changes, supporting climate change mitigation, and aiding in disaster management. By integrating data from spaceborne and in situ (ground-based) sources, Copernicus delivers reliable, up-to-date information across various sectors. Its primary data sources are the **Sentinel satellites**, which provide high-quality data to support numerous applications, from land and marine monitoring to atmospheric studies.

Sentinel Satellite Missions At the heart of the Copernicus Programme are the **Sentinel satellites**, each designed with specific capabilities:

- **Sentinel-1**: Offers all-weather, day-and-night radar imaging. It is particularly useful for monitoring land and marine environments, providing data regardless of weather conditions.
- **Sentinel-2**: Provides high-resolution optical imagery crucial for land cover classification, vegetation monitoring, and agricultural practices.
- **Sentinel-3**: Focuses on ocean and land monitoring, delivering key data on sea surface topography, land and sea surface temperature, and ocean and land colour.
- **Sentinel-5P**: Specializes in monitoring atmospheric composition, including pollutants and trace gases, vital for air quality assessments.
- **Sentinel-6**: Contributes to high-precision measurements of sea surface height, playing a significant role in climate monitoring and oceanography.

In addition to these satellite missions, the **ERA5 reanalysis dataset** provides comprehensive information on the state of the atmosphere, land, and oceans dating from 1950 to the present. This dataset is invaluable for climate research and historical climate analysis.

Copernicus Services Beyond data collection, Copernicus transforms this information into actionable insights through a series of services tailored to different environmental

and security applications:

1. **Land Monitoring Service**: Provides detailed information on land cover, soil moisture, and forest health, supporting sustainable land management and agricultural practices.
2. **Marine Environment Monitoring Service**: Supplies data on the physical state of oceans and marine ecosystems, aiding maritime safety, coastal monitoring, and climate studies.
3. **Atmosphere Monitoring Service (CAMS)**: Focuses on atmospheric composition, providing data on air quality, ozone levels, and UV radiation, which supports policy-making and environmental protection.
4. **Climate Change Service (C3S)**: Delivers comprehensive information on climate conditions—past, present, and future—helping societies adapt to and mitigate the impacts of climate change.
5. **Emergency Management Service (CEMS)**: Offers real-time mapping and early warning systems for natural disasters like floods, droughts, and forest fires, helping in emergency response and disaster risk reduction.
6. **Security Service**: Supports EU policies on border surveillance, maritime security, and external actions by providing timely and accurate information.

Educational Applications Copernicus data is also integrated into educational tools, particularly for atmospheric composition studies. These tools enhance the understanding of environmental monitoring and Earth Observation (EO) technologies among students, researchers, and professionals.

The Role of ESA and the Copernicus Data Space Ecosystem The **European Space Agency (ESA)** is instrumental in supporting the **Copernicus Data Space Ecosystem**, which ensures that Copernicus data is accessible, reliable, and easy to use. This ecosystem promotes innovation by providing new data products and services, further enhancing the utility of the Copernicus Programme.

Conclusion The Copernicus Programme is an essential component of global Earth observation efforts, providing data and services that support sustainable development, climate change mitigation, and emergency response. Its comprehensive approach—integrating data from Sentinel satellites, ERA5 reanalysis datasets, and a robust data

space ecosystem—ensures that a wide range of sectors benefit from its capabilities.

b. Quiz Questions

1. **Which Sentinel satellite provides all-weather, day-and-night radar imaging?**
   - Sentinel-2
   - **Sentinel-1**
   - Sentinel-3
   - Sentinel-5P
   - Sentinel-6

2. **What is the main focus of the Sentinel-5P mission?**
   - Sea surface temperature
   - **Monitoring atmospheric composition, including pollutants and trace gases**
   - Land cover classification
   - Vegetation monitoring
   - Monitoring soil moisture

3. **Which Copernicus service focuses on providing data for climate change adaptation and mitigation?**
   - **Climate Change Service (C3S)**
   - Land Monitoring Service
   - Marine Environment Monitoring Service
   - Emergency Management Service (CEMS)
   - Atmosphere Monitoring Service (CAMS)

4. **What kind of data does the ERA5 reanalysis dataset provide?**
   - High-resolution optical imagery
   - **Comprehensive information on the atmosphere, land, and oceans from 1950 to the present**
   - Real-time flood monitoring
   - Vegetation health indices
   - Satellite-based radar data

5. **Which Copernicus service supports emergency response and disaster risk**

reduction?
   - ○ Marine Environment Monitoring Service
   - ○ **Emergency Management Service (CEMS)**
   - ○ Security Service
   - ○ Atmosphere Monitoring Service (CAMS)
   - ○ Land Monitoring Service

c. Lecture: Introduction to Copernicus Land Monitoring Services (CLMS)

Introduction The **Copernicus Land Monitoring Service (CLMS)** is a vital part of the European Union's Copernicus Programme, offering high-resolution data on land use, land cover, vegetation, water bodies, and built environments. CLMS supports a wide range of applications in environmental management, agriculture, urban planning, and disaster risk reduction. It provides open access to data that is crucial for decision-makers, scientists, and businesses to address environmental and societal challenges.

Key Components of CLMS

1. **Pan-European and Global Land Monitoring**: CLMS offers two major types of services:
   - ○ **Pan-European**: Provides harmonised information across Europe with high spatial resolution.
   - ○ **Global**: Delivers data for broader environmental and climate monitoring, supporting international efforts to address deforestation, desertification, and ecosystem degradation.
2. **European Ground Motion Service (EGMS)**: The **EGMS** uses **Interferometric Synthetic Aperture Radar (InSAR)** technology from **Sentinel-1** satellites to monitor ground deformation. This service offers three products—Basic, Calibrated, and Ortho—providing data on land subsidence, landslides, and other geological hazards.
3. **Land Surface Temperature Monitoring (LSTM) Mission**: The **LSTM mission** provides high-resolution land surface temperature and evapotranspiration data, crucial for managing water resources, monitoring droughts, and optimising agricultural productivity.

4. **Global Human Settlement Layer (GHSL)**: The **GHSL** continuously monitors built-up areas and population distribution. It provides critical data for urban planning, crisis management, and assessing human impact on the environment, aiding in sustainable development and disaster response efforts.

5. **ROSE-L and CHIME Missions**: Recent additions to CLMS include the **ROSE-L SAR mission** and the **CHIME hyperspectral imaging mission**. ROSE-L focuses on land surface properties using L-band radar, while CHIME provides hyperspectral observations for applications like soil analysis and vegetation monitoring.

Copernicus Data Access and Processing Tools CLMS is supported by several **data access hubs and processing tools**, making it easy for users to access and manipulate satellite data for a wide range of applications. These tools are essential for developing satellite-based solutions in fields such as agriculture, urban planning, and environmental protection.

Key Applications of CLMS

1. **Urban and Spatial Planning**: CLMS data helps urban planners monitor land use changes, track urban sprawl, and plan infrastructure development. The **Global Human Settlement Layer** provides detailed insights into population distribution, which is crucial for emergency response and sustainable urban development.

2. **Agriculture and Water Management**: The **LSTM mission** supports precision agriculture by delivering data on land surface temperature and evapotranspiration, allowing farmers to optimise irrigation and reduce water usage, especially in drought-prone areas.

3. **Environmental Monitoring and Climate Change**: CLMS plays a crucial role in monitoring environmental changes, such as deforestation and desertification, contributing to global climate change mitigation efforts and sustainable land management.

4. **Disaster Risk Reduction**: The **European Ground Motion Service** provides essential data for identifying regions at risk of geological hazards like landslides and subsidence. This information is critical for disaster preparedness and risk mitigation.

Conclusion The **Copernicus Land Monitoring Service (CLMS)** is a powerful tool for

monitoring and managing the Earth's land resources. With its innovative services like the **European Ground Motion Service (EGMS)** and the **Land Surface Temperature Monitoring (LSTM) Mission**, CLMS provides decision-makers with the data they need to tackle pressing environmental and societal challenges. Its extensive data products play a key role in urban planning, agriculture, disaster risk management, and environmental monitoring, supporting sustainable development across various sectors.

d. Quiz Questions

1. **What is the main focus of the European Ground Motion Service (EGMS)?**
   - Monitoring air quality
   - **Monitoring ground deformation using InSAR technology**
   - Tracking ocean temperatures
   - Monitoring atmospheric gases
   - Measuring land surface temperature

2. **Which Sentinel satellite is used in the European Ground Motion Service to detect land subsidence?**
   - Sentinel-2
   - **Sentinel-1**
   - Sentinel-3
   - Sentinel-5P
   - Sentinel-6

3. **What does the Land Surface Temperature Monitoring (LSTM) mission primarily monitor?**
   - Vegetation health
   - **Land surface temperature and evapotranspiration**
   - Population distribution
   - Air quality
   - Soil moisture content

4. **Which CLMS service provides data on built-up areas and population distribution?**
   - EGMS

- **Global Human Settlement Layer (GHSL)**
- LSTM
- Marine Environment Monitoring Service
- Atmosphere Monitoring Service (CAMS)

5. **Which of the following missions focuses on providing hyperspectral observations for applications like soil analysis?**
   - Sentinel-2
   - **CHIME**
   - ROSE-L
   - Sentinel-3
   - Sentinel-5P

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