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European Commission

CORDIS Results Pack on

the evolution of Copernicus services

A thematic collection of innovative EU-funded research results

December 2024

Advancing Earth observation research to meet global environmental, emergency and security challenges

Research and Innovation

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Editorial

Advancing Earth observation research to meet global environmental, emergency and security challenges

Copernicus, the Earth observation (EO) component of the EU Space Programme, is dedicated to monitoring our planet using satellites in conjunction with ground-based, airborne and seaborne sensors. Its six core services provide researchers, policymakers, industry and the general public with continuous, detailed environmental data covering everything from sea levels to land use. EU-funded research & innovation projects are enabling the Copernicus services to evolve in line with emerging user needs, evolving technologies and expanding policy requirements.

Copernicus, the EO component of the EU Space programme, is one of the most ambitious and successful initiatives of its kind worldwide, and a true European success story in space. It offers continuous, accurate and accessible information on various aspects of the planet, including land, oceans and the atmosphere.

The backbone of Copernicus relies on a set of dedicated satellites (the current Sentinel family, and the upcoming Sentinel Expansion and Sentinel Next Generation missions), as well as valuable data from the Copernicus Contributing Missions (other public and commercial satellites) and Earth-based (*in situ*) sensors. The Copernicus services process, analyse and transform this wealth of data through its six thematic core services: Copernicus Atmosphere Monitoring Service (CAMS), Copernicus Climate Change Service (C3S), Copernicus Marine Environment Monitoring Service (CMEMS), Copernicus Land Monitoring Service (CLMS), Copernicus Security Service (CSS) and Copernicus Emergency Management Service (CEMS).

These value-adding information services, as well as the data from which they are derived, are made accessible on a full, free and open basis, and are used by its rapidly growing user community for a diverse range of applications. Examples include greenhouse gas monitoring, climate change mitigation and adaptation efforts, the protection of natural resources, reinforcing food security, crisis management and border management.

As a world-class and user-driven EO Programme, the continuous evolution of Copernicus is essential to addressing constantly evolving environmental, emergency and security challenges. Therefore, European Health and Digital Executive Agency (HaDEA) funded an important portfolio of Horizon 2020 R&I projects that effectively accelerated future evolutions of the respective Copernicus services. Addressing so-called Tier-3 research activities, the projects targeted medium- to long-term R&D over several years focusing on key upgrades of the services in line with EU and global policy priorities.

This CORDIS Results Pack presents the work of 10 EU-funded projects that aimed at enabling each of the six services to better respond to emerging user requirements and policy needs, while leveraging the latest scientific and technological advances.

These efforts build on the extensive portfolio of EU-funded research projects that have supported Copernicus services since the 7th Framework Programme (FP7) and continue under Horizon Europe. Key short- and long-term R&D priorities for future evolution of the Copernicus services under Horizon Europe and beyond are outlined in the Earth Observation Strategic Research and Innovation Agenda (SRIA).

By highlighting these project successes, this Results Pack facilitates future exploitation and uptake of project results by the Copernicus community – and beyond.

Data-driven monitoring and alerts to protect the Arctic

Accurate monitoring of the Arctic region is critical to protecting the area from environmental degradation. Software developed by the EU-funded ARCOS project uses satellite data to detect industrial development, clandestine fishing vessels and more.

Arctic sea ice is shrinking by 74 000 square kilometres per year, averaging a loss of 13 % per decade. As the region becomes more accessible, there has been an increase in maritime activities such as shipping and fishing.

While this economic activity can benefit local inhabitants, it brings with it risks. Uncontrolled fishing can lead to the decimation of stocks, while the extraction of natural resources such as fossil fuels can have significant environmental impacts.

It is critical that such activities are carefully monitored, to ensure the protection of this fragile ecosystem, but this is challenging.

"Extreme weather and rapidly changing land and sea conditions have often made it difficult to detect changes in the Arctic," explains ARCOS project coordinator, Massimo Sernicola from e-GEOS, a joint venture between the Italian Space Agency and spaceflight services company Telespazio. He adds: "The opening up of shipping routes and access to natural resources has also raised new security concerns."

Detecting suspicious behaviour

The ARCOS project sought to strengthen EU situational awareness of the Arctic region by making better use of satellite data. The project created a comprehensive monitoring system that combines EO data from Copernicus satellites with non-EO data, AI and human expertise. This system offers a global picture of Arctic trends, as well as early warnings.

"The multi-component platform processes EO data, and then combines it with other sources such as sensory data and human intelligence," explains Sernicola. Users can activate specific services based on their knowledge and needs, and can design reports and dashboards based on their analyses. The platform can be used to detect suspicious behaviour, such as unusual vessel movements, and alert users immediately when such anomalies are detected.

Extreme weather and rapidly changing land and sea conditions have often made it difficult to detect changes in the Arctic.

Surveillance in the Arctic

Several pilots were implemented to test and validate the system, including maritime surveillance and land activity monitoring. "We used the system to identify 'dark vessels' that don't broadcast their position," notes Sernicola. "We were also able to detect changes in specific sites of interest on land, such as the size of industrial plants."

These pilots demonstrated how the ARCOS system can provide analysts and regulatory bodies with new insights into unusual vessel behaviour and other activities. The detection of icebergs, for example, can help to minimise the risk to ship traffic. Such insights are critical for maintaining security and environmental protection in the Arctic.

"We were able to show how EO data, non-EO data and AI can be successfully integrated, to produce useful spatial information," says Sernicola. "The platform we developed can be customised to meet various user needs, be it for research or operational purposes. This adaptability makes ARCOS a valuable tool for continuous monitoring in the Arctic."

Improved AI models

The ARCOS system is an important development in enriching the Copernicus Service on Support to EU External and Security Actions (SESA). This European geospatial information service aims to assist the EU and its Member States by enhancing situational awareness in security-related domains.

Moving forward, Sernicola identifies the development of advanced AI models that can handle the complex environmental conditions of the Arctic as a key challenge. The lack of training data that specifically targets the Arctic is an important topic that still needs to be addressed.

"Looking ahead, we need to further refine our AI models and include more data sources," he says. "We need this to improve our capabilities in vessel detection, to discriminate vessel from rocks or icebergs, for example. This will provide for even greater accuracy and predictive capabilities."

PROJECT
ARCOS – Arctic Observatory for Copernicus SEA Service

COORDINATED BY
e-GEOS in Italy

FUNDED UNDER
Horizon 2020-LEIT-SPACE

CORDIS FACTSHEET
cordis.europa.eu/project/id/101004372

PROJECT WEBSITE
arcos-project.eu

Effective monitoring of coastal and inland waters

By improving access to satellite data on water quality in coastal areas, estuaries and inland waters – together with new tools to make sense of this information – the EU-funded CERTO project is helping protect these valuable ecosystems.

Monitoring water quality for substances such as plankton and sediment is essential to ensuring consumer safety and protecting against environmental degradation. To this end, the EU's Copernicus services use satellites to cover large bodies of water at frequent intervals, supplementing water samples tested in labs.

"Fertilisers washed into rivers, lakes and coastal areas can lead to large plant-plankton blooms, which can smell very nasty and take oxygen out of the water when they breakdown," explains CERTO project coordinator Steve Groom from Plymouth Marine Laboratory in the United Kingdom. "Similarly, sediment brought

down by rivers can block up harbours and marinas. Satellites can be useful to monitor if this is happening."

Easy access to water-quality data

A persistent challenge for scientists and monitoring agencies looking to access water-quality data for coastal and inland waters has been identifying which Copernicus service to use. This is because water-quality data for these regions has historically been split across three services: Marine, Climate Change and Land.

"We recognised the need to harmonise these data, and to fill the data gap for transitional water bodies such as estuaries, lagoons and lakes," says Groom. "We also wanted to harmonise the methods and approaches used across the services."

To do this, the project developed data-processing techniques to produce usable water-quality data. One issue tackled was atmospheric correction, to remove haze and mask cloud cover. Another complex processing technique involved using colour differentiations from satellite images to classify the type of water.

"The next thing we did was consider what end users are looking for," adds Groom. "For example, 'are plankton blooms happening earlier, and lasting longer?'." For this, key indicators were established, and the processed water-quality data for transitional areas was made easily accessible on a dedicated experimental data visualisation platform.

We recognised the need to fill the data gap for transitional water bodies such as estuaries, lagoons and lakes.

A range of transitional water environments

These new techniques were trialled across six regions, which provided a range of transitional water environments. The Danube Delta, for example, located in the south-eastern part of Romania and the south of Ukraine, is a natural heritage site with the status of a UNESCO biosphere reserve.

In situ sampling, satellite data and historical records were used to characterise these optically complex waters and provide a more comprehensive understanding of spatial and seasonal variations in water quality. In the Elbe estuary in Germany, meanwhile, the project's monitoring tools were used to characterise these highly dynamic and changing waters.

Plug into existing Copernicus services

The prototype data portal, which includes all the analytical tools developed through the project, is downloadable and can be used by anyone. Among its current users is the United Kingdom's Earth Observation Climate Information Service (EOCIS).

"The portal can be used by PhD students, or someone in a country without expertise or resources," says Groom. "They don't need to be satellite experts. They just need to talk to us, and we can show them how the data can be accessed."

The project's results are also being used in the EU-funded DANUBIUS project, which aims to bring together research on rivers and seas. A more long-term aim is to 'plug' the portal into the three Copernicus services, providing water-quality data in a harmonised and applicable way.

PROJECT
CERTO – Copernicus Evolution – Research for Transitional-water Observation

COORDINATED BY
Plymouth Marine Laboratory in the United Kingdom

FUNDED UNDER
Horizon 2020-LEIT-SPACE

CORDIS FACTSHEET
cordis.europa.eu/project/id/870349

PROJECT WEBSITE
certo-project.org/

A prototype service to detect CO_2 and CH_4 emissions from human activities

The EU-funded Copernicus Atmosphere Monitoring Service will launch a European operational service for monitoring human-caused greenhouse gas emissions such as carbon dioxide and methane. This cutting-edge service should help countries measure their progress in meeting their climate targets set by the Paris Agreement.

The EU has set ambitious targets to cut emissions as part of its broader strategy to transition towards a low-carbon economy. Critical to this effort is a reliable and objective system to monitor human-caused CO_2 and CH_4 emissions across countries and track their changes over time. This system should provide consistent, reliable information to support informed policy decisions at national and European levels. To maintain independence in this domain, the EC has initiated setting up a Monitoring and Verification Support (MVS) capacity as part of Copernicus – the EO component of the European Union's Space programme.

The MVS capacity is a technical system aiding policymakers and the scientific community by providing additional evidence on emission levels and trends. It links human activities with atmospheric greenhouse gas concentrations, helping to improve national greenhouse gas inventories and supporting the reporting efforts of the United Nations Framework Convention on Climate Change. The MVS uses top-down verification from independent atmospheric observations, including high-resolution data from spaceborne sensors.

Pioneering advanced systems for CO_2 monitoring

The EU-funded CoCO2 project was established to create the prototype systems for this MVS, which will integrate all available information streams in a globally consistent way. To this end, the initiative brought together expertise, existing resources and innovative ideas from various European and international players.

"We made significant progress in developing prototype systems for the MVS. Key components included assessing the current state of *in situ* observation sites needed to monitor human-caused greenhouse gas emissions and using prior knowledge of emissions and natural fluxes as inputs to the MVS," notes project coordinator Richard Engelen. "We also worked on integrating observations into models to estimate emissions as accurately as possible. The prototype systems considered CO_2 emissions at global, regional and local scales." Furthermore, specific emission sources such as power plants and urban emissions were examined. Ultimately, new methods were devised to evaluate and control data quality for emissions that cannot be directly observed.

A major challenge involved dealing with uncertainties in various parts of the MVS. These uncertainties typically exist in parts such as observations, prior information, modelling and data assimilation. Researchers also developed a user interface to ensure that the MVS would be highly beneficial and easy to use.

Blueprint for Europe's planned Copernicus CO_2 service

"CO2MVS is pushing the scientific boundaries needed for accurate and timely monitoring of greenhouse gas emissions. All project results are supporting the design and development of the new service element within the Copernicus Atmosphere Monitoring Service (CAMS)," highlights Engelen.

By combining satellite observations with the Earth system modelling and data assimilation capabilities of CAMS, the new MVS capacity will provide consistent and reliable information that can be used to support policy- and decision-making with respect to human-caused CO_2 and CH_4 emissions at local, national and European levels. The main elements of the MVS prototype were delivered in 2023, and the system should be fully operational by 2026.

CO2MVS is pushing the scientific boundaries needed for accurate and timely monitoring of greenhouse gas emissions.

Further progress towards building the MVS is expected from two other EU-funded research projects. CORSO is looking at how information on CO_2 emissions can be obtained by observing other emitted species, while CATRINE will improve the numerical aspects of the transport of atmospheric tracers, with an emphasis on long-lived greenhouse gases.

PROJECT
CoCO2 – Prototype system for a Copernicus CO_2 service

COORDINATED BY
European Centre for Medium-Range Weather Forecasts in the United Kingdom

FUNDED UNDER
Horizon 2020-LEIT-SPACE

CORDIS FACTSHEET
cordis.europa.eu/project/id/958927

PROJECT WEBSITE
coco2-project.eu/

Better air and ground data can help predict deadly heatwaves

Aerosols and land properties can both influence the likelihood of extreme weather events. The EU-funded project CONFESS takes a fresh approach to analysing this data, driving improvements to forecasting services.

The rise in frequency and severity of extreme weather events worldwide is the most apparent consequence of global warming. Today, ensuring accurate and reliable climate monitoring and forecasting has become paramount.

Contributing to the advance of climate modelling, the CONFESS project has made groundbreaking strides, supporting the Copernicus Climate Change Service (C3S) in providing authoritative information about the past, present and future climate in Europe and the world. Specifically, the project has

enhanced the representation of tropospheric aerosols in climate models and has identified and harmonised different data sets of land use, land cover and vegetation.

"The CONFESS developments and exploration of their impacts on seasonal and decadal predictions have contributed to advancing the state-of-the-art capabilities for weather and climate predictions and the next generation of reanalysis, in areas urgently needed for adaptation to climate change," says Magdalena Alonso Balmaseda, CONFESS project coordinator.

Vegetation appears to mitigate or enhance long-term warming trends in some regions of the globe – a critical aspect for climate change adaptation and mitigation.

Tracking aerosol impacts

A major step of the project relates to the treatment of tropospheric aerosols – tiny particles suspended in the Earth's lower atmosphere – in reanalysis and seasonal forecasts. CONFESS produced a multi-decadal record of time-varying tropospheric aerosols and thoroughly evaluated it in long-term climate simulations, seasonal reforecasts and medium-range forecasts. The work offers synergies with the Copernicus Atmosphere Monitoring Service (CAMS).

Due to its high quality, this record will be incorporated into the next generation of seasonal forecasts from the European Centre for Medium-Range Weather Forecasts (ECMWF) and into the upcoming C3S atmospheric reanalyses.

For instance, by analysing the record, scientists can observe the reduction in sulphates from industrial emissions in Europe, contrasted with an increase in these emissions in China, India and the Middle East. "The temporal changes in aerosols impact not only the local radiation balance, directly influencing surface temperature, but also large-scale atmospheric circulation patterns. The analysis of the results highlights the need to include the indirect effects of aerosols in the models used for reanalysis and seasonal forecasts," explains Balmaseda.

Harmonising land data

Additionally, CONFESS has successfully identified and harmonised different data sets related to land use, land cover and vegetation. By implementing them in different climate models, researchers were able to obtain, for the first time, a quantitative assessment of the impact of time-varying land properties in multi-year land simulations and seasonal forecasts.

The assessment revealed that these properties, particularly vegetation, significantly influence trends and extremes in surface temperature. An example is the intense and long-lasting heatwave experienced by Europe in the summer of 2003. The hot, dry conditions decreased the vegetation fraction, which in turn contributed to the intensity of the heat. "Including time-varying vegetation in the models used for seasonal forecasts should result in improved predictions of temperature extremes. Results also indicate that vegetation appears to mitigate or enhance long-term warming trends in some regions of the globe – a critical aspect for climate change adaptation and mitigation," notes Balmaseda.

Further research is still needed before incorporating land properties into the C3S system, but the most recent period of the new data sets will be used in the ECMWF operational prediction systems.

The developments accomplished by CONFESS also form the foundation for the CERISE project, which aims to improve the quality of the C3S reanalysis and seasonal forecast systems in terms of land-atmosphere assimilation and coupling.

PROJECT
CONFESS – Consistent representation of temporal variations of boundary forcings in reanalyses and seasonal forecasts

COORDINATED BY
European Centre for Medium-Range Weather Forecasts in the United Kingdom

FUNDED UNDER
Horizon 2020-LEIT-SPACE

CORDIS FACTSHEET
cordis.europa.eu/project/id/101004156

PROJECT WEBSITE
confess-h2020.eu/

Turning Copernicus data into meaningful urban climate action

Targeted Earth observation data tools developed by the EU-funded CURE project can help urban planners address climate resilience, in a way that takes account of local needs.

© European Union, Copernicus Sentinel-2 imagery

Identifying risks associated with climate change is critical to ensuring that our cities are made safe and liveable for future generations. Anticipating the challenges ahead means we can adapt our urban environments to mitigate climate change, and better cope with climate change impacts such as heatwaves and flooding.

Copernicus, the EO component of the EU Space programme, provides urban planners with a huge amount of high-quality data, but they often face difficulties processing and analysing all this information and turning it into actionable information.

"Urban communities face significant obstacles in effectively using EO intelligence," says CURE project coordinator Nektarios Chrysoulakis from the Foundation for Research and Technology – Hellas (FORTH) in Greece. "We recognised a need to better integrate EO programmes' outputs into urban resilience strategies, in the face of these climate change challenges."

To achieve this, the project gathered targeted environmental information from four core Copernicus services: the Copernicus Land Monitoring Service (CLMS), the Copernicus Atmosphere Monitoring Service (CAMS), the Copernicus Climate Change Service (C3S) and the Copernicus Emergency Management Service (CEMS). This was then combined with third-party data and processed using state-of-the-art methods to produce disaggregated environmental information.

Tapping Copernicus potential

Using this material, the project developed 11 cross-cutting applications, designed to provide urban planners with the granular detail they need to support decision-making. These applications cover topics related to climate change adaptation and mitigation, urban health, as well as economic development. All are publicly accessible from the CURE portal.

"We wanted our system to deliver reliable, usable and relevant intelligence that could enhance resilience planning in cities throughout Europe," adds Chrysoulakis. These applications were developed and applied across four 'front-runner' cities (Berlin, Copenhagen, Sofia and Heraklion), as well as in one or more of the six 'follower cities' (Bristol, Ostrava, Basel, Munich, San Sebastian and Vitoria-Gasteiz).

"Through workshops and collaborations with these 10 pilot cities, we were able to take on board specific needs and requirements in terms of urban resilience and spatial planning," explains Chrysoulakis.

The application which reports local surface temperature dynamics, for example, was used by all cities involved in the project to identify hotspots and plan heat mitigation measures for sustainable urban development.

Another application monitoring CO_2 emissions in time and space was implemented in Heraklion and Basel. The information helped these cities identify anthropogenic and natural sources and sinks of greenhouse gases, and develop strategies to reduce emissions.

More resilient cities

Chrysoulakis says that the project demonstrates how EO data can support cities in climate mitigation and adaptation efforts. "The value of the CURE platform is that it combines data from different sources to support urban resilience planning," he notes. "We were able to exploit the potential of Copernicus by offering these cross-cutting applications."

The project has made a range of resources available to support policymakers in utilising Copernicus data, and help them in their efforts to implement the New Urban Agenda, the EU Adaptation Strategy as well as the EU Missions on Climate-neutral and Smart Cities and Adaptation to Climate Change.

"Our hope is that we can promote more efficient urban planning that delivers on climate change mitigation and adaptation objectives," adds Chrysoulakis. "This will also result in benefits including improved thermal comfort, better air quality and enhanced energy efficiency."

Our hope is that we can promote more efficient urban planning that delivers on climate change mitigation.

PROJECT
CURE – Copernicus for Urban Resilience in Europe

COORDINATED BY
Foundation for Research and Technology – Hellas (FORTH) in Greece

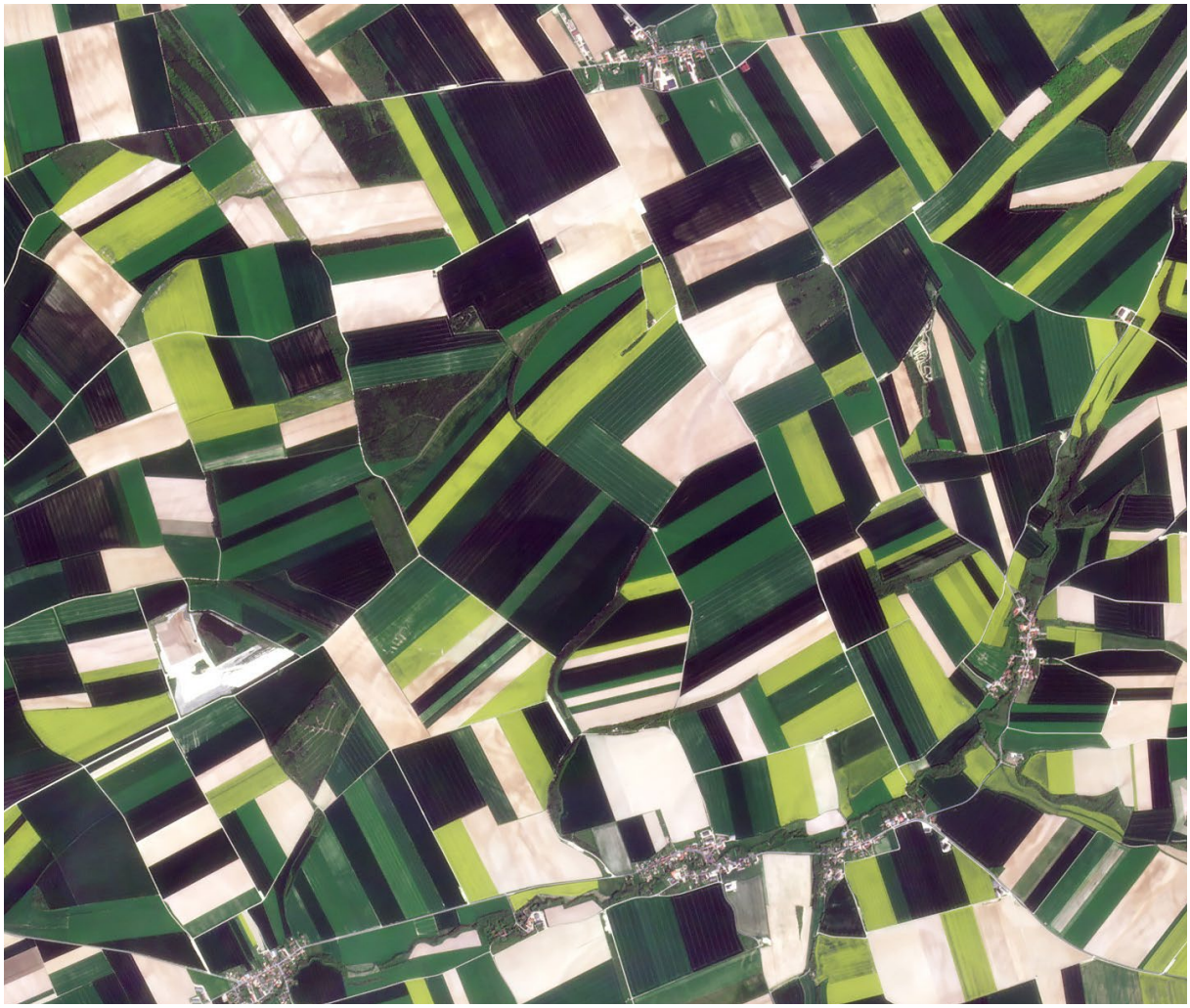
FUNDED UNDER
Horizon 2020-LEIT-SPACE

CORDIS FACTSHEET
https://cordis.europa.eu/project/id/870337

PROJECT WEBSITE
cure-copernicus.eu/

AI traces the human footprint on our planet

By combining cutting-edge AI and remote sensing technologies, RapidAI4EO has created solutions for improved land monitoring systems, paving the way for a more sustainable future.



EO data provides information about the Earth's surface, atmosphere, and oceans. It is typically collected from various sources and platforms using remote sensing technologies, such as satellites, aircraft, drones, and ground-based sensors. EO data plays a crucial role in understanding and monitoring the Earth's environment, weather, climate change, and land use.

To meet the United Nations Sustainable Development Goals (SDGs) and achieve a better and sustainable future for all, there is a need for more accurate measurements of environmental indicators including land use and land cover. The spatial resolution and temporal frequency of these measurements are central to detecting changes which give a comprehensive picture of activities which are changing the land surface such as urban expansion and deforestation.

Using AI for mapping land cover and use

To improve monitoring processes and understand the impact of humans on our planet, the EU-funded RapidAI4EO project combined remote sensing with advances in AI. The aim was to automate the mapping process of land cover updates to obtain information in a timely manner and through this assist in the effective environmental management and sustainability.

"Our goal was to deliver solutions for continuous observation and mapping to better prepare for and address the potential consequences of human activities on the planet and its climate," states technical coordinator Annett Wania from Planet Labs.

For AI models to rapidly detect changes, they must be trained using sequences of images taken at frequent times and from different sensors. As there are no data sets that satisfy all these requirements, the RapidAI4EO consortium developed the RapidAI4EO corpus – a training data set containing satellite imagery for some half a million locations distributed across Europe.

A new detailed source of land imagery

The images used to create the RapidAI4EO corpus were drawn from the public Copernicus constellation Sentinel-2 and from the commercial imaging product Planet Fusion. The RapidAI4EO corpus of dense time series satellite imagery is the key project outcome and is accessible to the entire remote sensing community on Source Cooperative, Radiant Earth's new cloud-based data publishing utility.

This detailed imagery data set provides unprecedented insights into the spatial and temporal characteristics of land use and land cover on the continent. At the same time, it is an invaluable resource for training machine learning and deep learning algorithms, realising the full potential of combined data sources.

The RapidAI4EO corpus, given its multimodal and multi-resolution imagery, geographically diverse sampling and dense time series offers an improved choice for EO tasks. It has enabled scientists to develop solutions for land cover mapping and change detection which exceed the spatial resolution of the CORINE land cover inventory by 10 to 20 times and allow to provide quarterly updates.

Towards more integrated land mapping solutions

Overall, the RapidAI4EO project has made notable progress in advancing methods and prototypes for land monitoring, leveraging the latest trends in machine learning and data streams from multiple satellite constellations. The methods and prototypes developed within the RapidAI4EO project serve as fundamental building blocks that can be combined and integrated to create more efficient, improved, and evolving mapping solutions that address diverse user needs and requirements.

"By harnessing the strengths of each method and capitalising on their complementary capabilities, it is possible to develop a comprehensive and robust land monitoring system that offers enhanced accuracy, timeliness, and scalability," emphasises Wania.

Delivering continuous observation and mapping capabilities has an enormous potential to help understand and address the potential consequences of human activities on Earth and its climate.

Our goal was to deliver solutions for continuous observation and mapping to better prepare for and address the potential consequences of human activities on the planet and its climate.

PROJECT
RapidAI4EO – Advancing the State-of-the-Art for Rapid and Continuous Land Monitoring

COORDINATED BY
VITO in Belgium

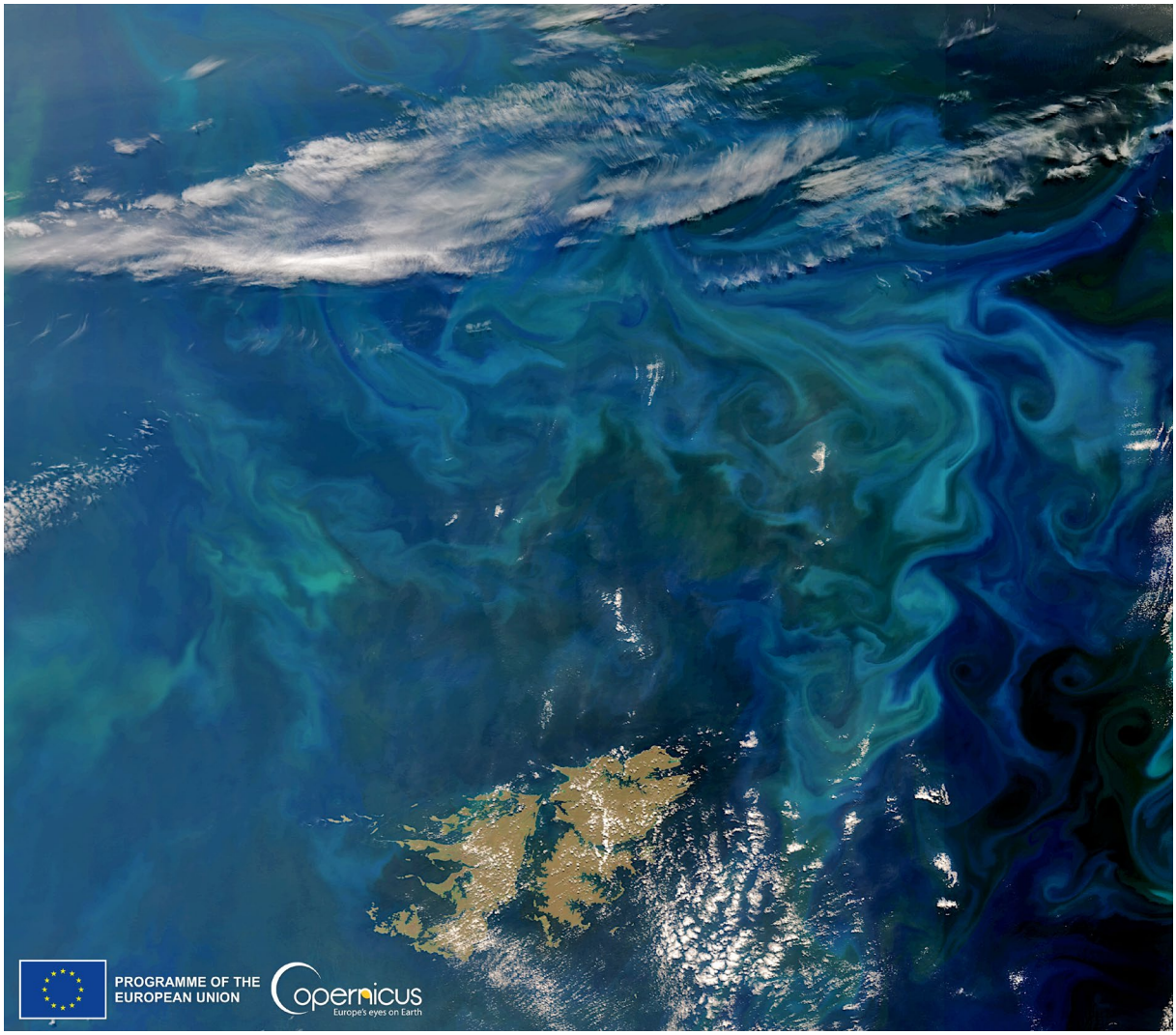
FUNDED UNDER
Horizon 2020-LEIT-SPACE

CORDIS FACTSHEET
cordis.europa.eu/project/id/101004356

PROJECT WEBSITE
rapidai4eo.eu/

Advancing Copernicus for improved ocean monitoring

Oceans play a critical role in climate change and food security. However, these ecosystems are increasingly vulnerable. The EU-funded SEAMLESS project aimed to transform how we monitor and forecast ocean changes.



Our oceans are essential, absorbing 30 % of human-generated carbon emissions and 90 % of excess heat, as well as providing 17 % of the world's animal protein. Understanding its processes is vital to our own climate and food security.

The Copernicus Marine Environment Monitoring Service (CMEMS) provides systematic reference data on the physical and biogeochemical state of the marine environment (including sea ice), as well as data on dynamics across the global ocean. This is the foundation on which many marine models are built.

However, marine ecosystem models have offered limited predictive ability, forecasting harmful events such as oxygen depletion and nutrient pollution only five to six days ahead. These forecasts often lacked precision due to insufficient integration with real-world data. The SEAMLESS project set out to advance CMEMS' capability to more accurately evaluate climate change impacts on ocean ecosystems and food security.

New knowledge will inform policies to promote sustainable management of Europe's oceans.

"CMEMS often lacks reliable information about model uncertainty and the relationships between observed and unobserved parts of the marine system," explains project coordinator Jozef Skakala, from Plymouth Marine Laboratory in the United Kingdom. "This limits the quality of forecasts and ecosystem simulations."

SEAMLESS set out to deliver a more complete understanding of how human activity and climate change affect marine ecosystems. By improving the accuracy of models, the project has provided critical insights into ocean health, and this new knowledge will inform policies and practices to promote sustainable management of Europe's marine resources.

New methods were developed to integrate data from physics and biogeochemistry, using observations from both satellites and *in situ* sources. By using new data assimilation methods that can account for model uncertainty, this prototype system better connects different simulated processes and variables that affect ecosystem indicators, linking plankton dynamics, carbon cycling and other critical processes.

Bridging gaps

The enhanced ocean model data provided by SEAMLESS improves our ability to monitor and assess marine ecosystem health in policy frameworks, implement marine spatial planning, operate aquaculture and fisheries, and investigate the impact of climate change and human activities on ocean ecosystems.

Additionally, new observation platforms such as sea gliders and biogeochemical Argo floats were integrated into Copernicus, enhancing data accuracy and depth.

SEAMLESS also equipped five European forecasting centres within the Copernicus Marine Service with tools to better predict oceanic changes in the North Sea, North Atlantic, Mediterranean Sea, Baltic Sea and Arctic Sea. These advancements helped forecast harmful events such as nutrient pollution and algal blooms, while deepening understanding of how ecosystems respond to human activity and climate change. "New knowledge will inform policies to promote sustainable management of Europe's oceans," says Skakala.

Significant outcomes

By the end of the project, SEAMLESS had significantly advanced CMEMS' ability to provide improved simulations of the past and future predictions regarding ocean conditions. These reanalyses and forecasts will be valuable to various stakeholders, including policymakers, coastal planners, monitoring institutions, aquaculture farmers and climate change scientists.

Additionally, the project has created an open-source, user-friendly assimilative modelling prototype that is already training stakeholders on how to run marine forecasts – helping to build the next generation of experts who will protect our oceans.

PROJECT
SEAMLESS – Services based on Ecosystem data AssiMiLation: Essential Science and Solutions

COORDINATED BY
Plymouth Marine Laboratory in the United Kingdom

FUNDED UNDER
Horizon 2020-LEIT-SPACE

CORDIS FACTSHEET
cordis.europa.eu/project/id/101004032

PROJECT WEBSITE
seamlessproject.org/

Harnessing Copernicus to tackle air quality emission evaluation

Advanced tools for tracking pollutant emissions, developed by the EU-funded SEEDS project, are enhancing the Copernicus Atmosphere Monitoring Service. Satellite data, inverse modelling and machine learning deliver precise insights that support a new way to monitor and evaluate air quality emissions.

Traditionally, air pollution sources have been estimated using statistical data and ground-based measurements and models, but this data has been difficult to evaluate and validate independently. SEEDS aimed to change that, using the advanced capabilities of the TROPOMI instrument on board the Sentinel-5P satellite, to introduce new satellite-based emission data sets, refine air quality forecasts and provide a proof of concept.

Leonor Tarrason, SEEDS project coordinator and research director for environmental solutions at the independent Norwegian Institute for Air Research (NILU), explains: "With accurate data, policies designed to protect public health and ecosystems – whether from smog-causing nitrogen oxides or other harmful pollutants – can be better targeted and enforced.

Pioneering satellite solutions

The project's goals were ambitious, ranging from improving emissions data to linking air pollution with ecological impacts. Through advanced modelling and machine learning, SEEDS set out to use Copernicus Sentinel satellites to deliver new cutting-edge estimates of pollutants such as nitrogen oxides, ammonia and ozone, and compare these with the current Copernicus Atmosphere Monitoring Service (CAMS) emissions data.

The team also focused on identifying key areas where satellite technology could improve existing methods or introduce new ones to address both scientific challenges and policy needs, including measuring the temporal evolution of human-caused emissions, estimating natural emissions and coupling air quality and land surface modelling to understand how droughts, heatwaves and vegetation affect pollutant deposition and agricultural yield production.

SEEDS laid the groundwork for future developments in Copernicus, establishing how hourly data from upcoming Copernicus satellites such as Sentinel-4 will be used to refine air pollution monitoring.

Innovative approaches to emissions data

SEEDS developed a variety of new data sets, including satellite-based estimates of nitrogen dioxide and ammonia, as well as biogenic volatile organic compounds (BVOCs) emitted by natural sources such as forests. By blending land surface models with atmospheric data, the project provided a more nuanced understanding of how pollution interacts with ecosystems.

Another of their core objectives was to support stakeholders across sectors, from agricultural leaders to urban planners. SEEDS worked closely with key players in the economic, industrial and agricultural sectors to ensure that its innovations could be practically applied and widely adopted.

Not all sectors were equally enthusiastic. Engaging large polluters proved challenging, as they were reluctant to participate in independent assessments of their emissions. "We found that simply presenting the project as a tool for better policymaking wasn't enough – we had to demonstrate how it could add value for industries themselves," says Tarrason.

Despite these challenges, SEEDS achieved its goals of improving emissions data and creating new tools for monitoring deposition. In total, the project generated 18 distinctive data sets, now available to researchers and policymakers through an interactive data portal. The project's data is currently being used by emission experts across Europe, both within CAMS and in the Task Force for Emission Inventories and Projections.

Sowing SEEDS for the future

One of the project's key findings was the importance of real-time emission data, and how satellite-based data can provide good independent information on how air pollution sources change over time. Although the project initially focused on analysing past insights, the team realised that real-time emissions data could have a more immediate impact on improving air quality forecasts. As future satellites like Sentinel-4 come online, this capability will only improve.

SEEDS also highlighted the need for better cooperation between researchers and industries such as agriculture. While emission experts and environmental authorities were quick to see the benefits of satellite data for improving emission estimates, large industrial and agricultural players were harder to engage. Moving forward, projects like SEEDS will need to focus on making satellite data more accessible and demonstrating its value to broader stakeholder groups.

With accurate data, policies designed to protect public health can be better targeted and enforced.

PROJECT
SEEDS – Sentinel EO-Based Emission and Deposition Service

COORDINATED BY
Norwegian Institute for Air Research in Norway

FUNDED UNDER
Horizon 2020-LEIT-SPACE

CORDIS FACTSHEET
cordis.europa.eu/project/id/101004318

PROJECT WEBSITE
seedsproject.eu

A roadmap for improved water services in the Copernicus programme

As climate change intensifies, floods and droughts are becoming more severe, and water quality is deteriorating at a global scale. The EU-funded Water-ForCE project was launched to address the critical need for more accurate information to help mitigate these pressures.

© Tiit Kutser

Copernicus is the world's largest provider of free-to-access EO data, and delivers invaluable services in various domains. However, as water-related tools are fragmented across six Copernicus services, they have not always been given the focus they deserve.

"There is no life on Earth without water, and we are increasingly feeling the effects of climate change through water extremes," explains project coordinator Tiit Kutser from the University of Tartu in Estonia. "We need high-quality data to make informed decisions for public health, climate adaptation and environmental management."

The Water-ForCE project was launched to address this. The project assessed services across Copernicus, and developed proposals for how these could be improved, in order to provide better information for policy development, managing water resources and responding to the impacts of climate change. Together, these offer a roadmap for the evolution of water-related Copernicus services.

Identifying bottlenecks

The water domain of the Copernicus services was comprehensively analysed with input from 20 project partners and engagement with over 800 water experts, including policymakers, researchers and industry leaders. From their extensive research, Water-ForCE identified eight key bottlenecks that limit the effective use of Copernicus services by stakeholders.

Some of these, such as suboptimal performance of current satellites for inland waters, have been resolved by Water-ForCE. Using technical specifications provided by the project, the Sentinel-2 Next Generation satellites will have the spectral bands necessary for inland and coastal water remote sensing.

According to Kutser, it is essential to improve the water part of the Copernicus services in order to keep it relevant for users. "The private sector and other countries are making rapid progress both in building and launching satellites, as well as in developing ground segments (data storage, processing, product development). The Copernicus services have to make fast progress if they want to stay relevant for water domain users."

Water quality vs quantity

One of the biggest barriers to Copernicus' progress is the lack of *in situ* data, and lack of control over the data collection.

The Copernicus water quantity portfolio consists of more than 800 products developed and validated by data from global weather stations and hydrological networks. Yet only two water quality products are currently available for a limited number of lakes worldwide.

The validation of other products, which may already be delivered at a local scale, requires data across the full range of lake types worldwide before they can be integrated into the Copernicus portfolio.

Such data is typically gathered through infrequent research projects that cover only a small number of waterbodies. Water-ForCE identified this gap, and initiated discussions with the European Commission and the European Environment Agency (EEA) to address the issue.

Roadmap for the future

Based on their key findings, the project developed a comprehensive roadmap for the future of Copernicus water-related services. Their guidelines provide analysis of the water component, propose scenarios on how to improve the situation and offer recommendations in order to better serve policymakers, researchers, international organisations, local authorities, industry and the general public.

While the project itself has been a success, its true impact will be felt in the years to come. If the water domain is adequately recognised within Copernicus, and the steps outlined in the roadmap are implemented, we can expect a broader portfolio of water-related services. This will lead to accurate and reliable water products and information being delivered to users globally, in a user-friendly manner, helping us navigate our future in a changing climate.

We need high-quality data to make informed decisions for public health, climate adaptation and environmental management.

PROJECT
Water-ForCE – Water scenarios For Copernicus Exploitation

COORDINATED BY
University of Tartu in Estonia

FUNDED UNDER
Horizon 2020-LEIT-SPACE

CORDIS FACTSHEET
cordis.europa.eu/project/id/101004186

PROJECT WEBSITE
waterforce.eu/

Monitoring European water quality from space

A new system draws on Europe's satellite programme to monitor drinking water quality from above.

Europe is rich in lakes and open surface water reservoirs giving us fresh drinking water. Monitoring water quality can be arduous and time-consuming, but advanced technology offers water utility companies a way to check open surface water reservoirs from a distance.

In the EU-funded WQeMS project, researchers took advantage of the EU's Copernicus satellite programme to deliver a new modular and adaptable operational water quality emergency monitoring service.

WQeMS can be used to monitor flood events, provide alerts about quickly developing phenomena such as harmful algal blooms, mud inflows, oil spills or other pollution, and support sustainable water management towards reaching the EU's set objectives.

"During the project a continuous and iterative co-design and co-creation approach took place with water utilities and relevant governmental agencies," explains Ioannis Manakos, principal researcher in remote sensing at the Centre for Research and Technology – Hellas (CERTH).

Drawing on Europe's satellite network

The WQeMS service elements rely on frequently acquired space-borne Copernicus data from the Sentinel-1 and -2 satellites.

The team initially consulted end users to conceptualise the project. Estimation of water quality features began using existing algorithms and software employed by the private sector and research facilities.

These were then further improved through numerous experimentations and iterations in the project benefiting from the latest developments in data retrieval from space, airborne and *in situ* sensors and analysis, while adjusting the knowledge generation system to specific user needs.

Field experimentation and a new platform

New software emerged. This was then tested in five areas across Europe in real-field conditions to prove the system's concept and efficiency.

During the project a continuous and iterative co-design and co-creation approach took place with water utilities and relevant governmental agencies.

"Another three areas were introduced during the last year of the project to showcase and verify capacity, credibility and transferability of the service elements," adds Manakos.

The latest semantic standards and informatics tools were applied, exploiting European infrastructures, such as DIAS, to generate this new modular, adaptable and easy-to-use operational platform.

The WQeMS platform can deliver multiple services and products to a range of existing decision support systems, to either a machine or a human, according to market standards and within a competitive time frame and cost. It is fully adaptable, and service elements can be tuned upon request by users.

Water companies can easily follow self-explaining pathways across the WQeMS online platform to make their requests, including specific data, alert systems, visualisations and customised reports. They can provide and access information through a dedicated app.

"Users can also enjoy domain-oriented user-specific free online capacity building, service guidelines and support," notes Manakos.

A system already in operation

The project delivered a range of important results, including several new technological improvements in full compliance and interoperability with international requirements and EU policies, and increased efficiency for monitoring and capacity building for its users. This includes the ability to work across borders and monitor difficult-to-access or unevenly shaped open surface water resources.

The service is fully operational across Europe now and its commercialisation is in deployment towards sustainability. Research-wise, there are already ongoing activities to advance the underlying workflows, while the latest developments have been published in peer-reviewed journals.

"We are thankful to the Horizon Results Booster for its support," says Manakos.

PROJECT
WQeMS – Copernicus Assisted Lake Water Quality Emergency Monitoring Service

COORDINATED BY
Centre for Research and Technology – Hellas (CERTH) in Greece

FUNDED UNDER
Horizon 2020-LEIT-SPACE

CORDIS FACTSHEET
cordis.europa.eu/project/id/101004157

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