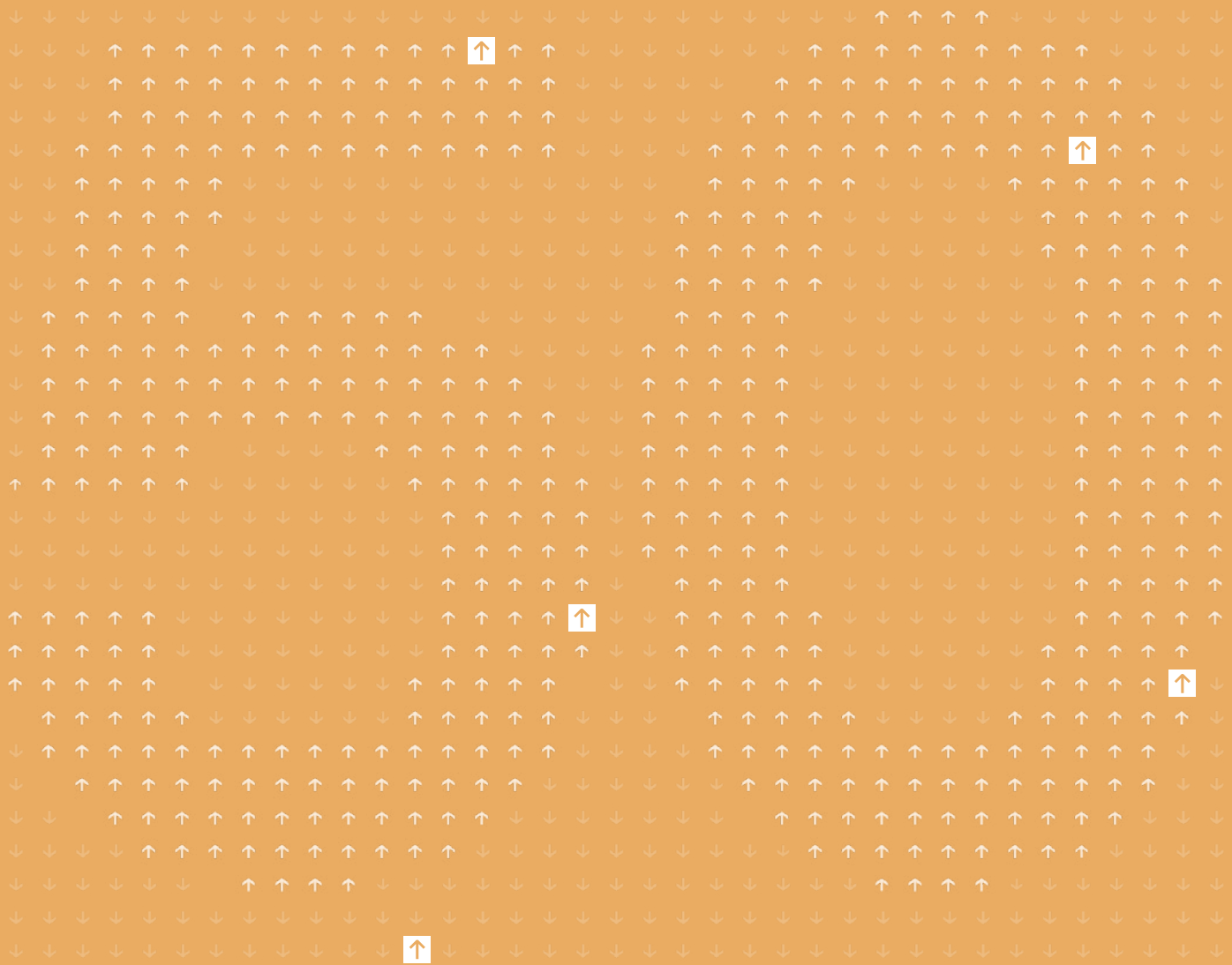
Ten years of Copernicus at ECMWF



ADVANCING WEATHER SCIENCE
THROUGH COLLABORATION

ECMWF | 50

PUBLICATION 03

Ten years of Copernicus at ECMWF

ABSTRACT

The Copernicus Programme, the European Union's flagship Earth observation initiative, provides free and open access to high-quality environmental data, supporting decision-making in climate monitoring, air quality, ocean and land monitoring as well as emergency management, for the benefit of public and private economic sectors.

Since its establishment in 2014, part of the Copernicus Programme has been implemented by the European Centre for Medium-Range Weather Forecasts (ECMWF) in partnership with European and international institutions, with ECMWF playing a leading role in the Copernicus Atmosphere Monitoring Service (CAMS) and the Copernicus Climate Change Service (C3S). These services deliver essential operational products covering air quality, climate reanalysis, seasonal forecasts, greenhouse gas monitoring, and solar radiation. CAMS and C3S serve thousands to tens of thousands of direct users worldwide (respectively) and reach millions of indirect users. The services support policymakers, businesses, and researchers with authoritative climate and environmental information, including the widely used ERA5[1], ECA4[2] and EGG4[3] reanalyses.

ECMWF is also a key contributor to the Copernicus Emergency Management Service (CEMS), under the leadership of the Joint Research Centre (JRC), supporting global flood and fire forecasting. ECMWF is the Computational Centre of the European Flood Awareness System (EFAS) and Global Flood Awareness System (GloFAS), delivering flood forecasts up to 30 days in advance and a hydrological outlook several months ahead, helping national and international agencies anticipate and mitigate flood risks. In parallel, ECMWF is also responsible for producing daily fire danger assessments. These assessments, which include high-resolution and ensemble forecasts extending up to 15 days, are integrated into the European Forest Fire Information System (EFFIS) and the Global Wildfire Information System (GWIS) to support national authorities in managing forest fires across Europe and neighbouring regions as well as worldwide. This complements nicely the Global Fire Assimilation System (GFAS) of CAMS, which integrates satellite-based fire radiative power observations to estimate global biomass burning emissions, feeding into atmospheric composition models to assess the impact of wildfires on air quality and climate.

With Copernicus Phase 2 (2021–2028), ECMWF is expanding its contributions, including the Copernicus Anthropogenic CO_2 Emissions Monitoring and Verification Support Capacity (CO2MVS), which will provide independent observation-based assessments of global greenhouse gas emissions. These innovative services will build upon the space component of the Copernicus Programme including the launch of a new generation of satellites between 2025 and 2028 (in particular geostationary Sentinel 4, Sentinel 5, the constellation CO_2M and the Copernicus Contributing missions). New initiatives also include the first global coupled Earth system reanalysis and National Collaboration Programmes tailored to EU Member States' needs to expand and support Copernicus services and data uptake.

Through its expertise in numerical modelling, data assimilation, and Earth system science, ECMWF continues to ensure that Copernicus services deliver world-class, actionable environmental intelligence for Europe and beyond.

1 Fifth generation ECMWF atmospheric reanalysis

2 Fourth generation ECMWF global reanalysis of atmospheric composition

3 Fourth generation ECMWF global reanalysis of greenhouse gases

INTRODUCTION →

The EU's Copernicus Programme is a comprehensive Earth observation initiative designed to provide valuable data for monitoring the Earth's environment using space and in-situ observations. In particular, the Copernicus Sentinel missions are a fleet of Earth observation satellites developed by the European Space Agency (ESA) to support the Copernicus Programme, providing high-resolution, continuous, and freely available environmental data. Each Sentinel satellite series is designed for specific monitoring purposes: Sentinel-1 provides all-weather radar imaging for land and ocean surveillance, Sentinel-2 captures high-resolution optical imagery for land monitoring, Sentinel-3 measures sea and land surface temperatures, ocean colour, and altimetry, Sentinel-4 and Sentinel-5 focus on atmospheric composition monitoring, while Sentinel-6 ensures precise sea level measurements. These satellites, complemented by a wide variety of in-situ observations, work in synergy to provide critical data for climate change monitoring, disaster response, land and ocean management, and air quality assessments, forming the backbone of Europe's environmental and security services. Harnessed to these observations, Copernicus delivers operational datasets and information services in a range of topical areas (see Figure 1). From these baseline services many other value-added products can be tailored to more specific public, policy and commercial needs.

Figure 1: Conceptual description of the Copernicus Programme. Reproduced from https://climate.copernicus.eu/about-us.

The Programme includes six thematic core services: atmosphere monitoring, marine environment monitoring, land monitoring, climate change, emergency management, security. The Copernicus Atmosphere Monitoring Service (CAMS) (Peuch et al., 2022) and Copernicus Climate Change Service (C3S) (Thépaut et al., 2018 and Buontempo et al., 2022) serve as central pillars for monitoring atmospheric composition and climate change, and have been managed by ECMWF since 2014. These services enable governments, industries, researchers, and the public to access critical information for research, decision-making, and policy development. Indeed, CAMS and C3S contribute significantly to global efforts in understanding environmental and climate issues. Their data and forecasting capabilities support a broad range of applications, from air quality monitoring to long-term climate projections, enabling informed decisions across sectors. CAMS provides real-time atmospheric composition analyses and forecasts as well as reanalyses, while C3S delivers authoritative climate data to assess past, present, and future climate

conditions. Both services have been instrumental in shaping European and international policies on air quality, climate mitigation, and adaptation strategies.

As part of ECMWF's broader mission, Copernicus services leverage cutting-edge numerical modelling and data assimilation techniques to provide high-quality and accurate environmental information. ECMWF's expertise in weather forecasting, combined with collaborations across institutions in Europe, ensures that CAMS and C3S products remain at the forefront of Earth system monitoring. This collaboration not only strengthens scientific research and innovation but also enhances operational efficiency, making environmental data more accessible and useful for policymakers and businesses.

CAMS and C3S are deeply embedded in Europe's scientific and operational infrastructure, drawing on expertise from ECMWF and its Member and Co-operating States, which contribute to roughly 70% of the activities. This synergy fosters a collaborative approach, ensuring that data quality, accessibility, and usability continue to evolve in response to emerging challenges.

Through continuous advancements in data assimilation, model improvements, and user engagement, Copernicus services at ECMWF are well positioned to remain a key driver of environmental monitoring and climate resilience in Europe and beyond.

BACKGROUND AND CONTEXT →

As part of the Copernicus Programme, CAMS and C3S were designed to build upon ECMWF's operational infrastructure and numerical modelling expertise, providing decision-makers, researchers, and businesses with essential environmental intelligence. CAMS focuses on forecasting and monitoring air pollutants, greenhouse gases, and their emissions, while also delivering air quality assessments with products tailored to policy users' needs and solar radiation products. C3S offers authoritative data about past, present and future climate through observations, reanalyses, seasonal forecasts, climate predictions and projections, contributing to both scientific research and evidence-based policymaking across Europe and globally.

CAMS and C3S stand on the shoulders of a series of pioneering research and development projects, such as Global Earth-system Monitoring (GEMS), Monitoring Atmospheric Composition and Climate (MACC) and MACC-II (Hollingsworth et al., 2008; Flemming et al., 2015), and the ERA reanalysis projects such as ERA-20C (Poli et al., 2016). These precursor projects laid much of the foundation for the operational implementation of CAMS and C3S, transforming state-of-the-art research in numerical weather prediction, data assimilation, and Earth system modelling into fully operational and globally recognised services. The investment in these services has been sustained, deliberate, and consistent, ensuring that scientific breakthroughs are not confined to academic circles but are swiftly integrated into operational frameworks that benefit public authorities, industry, and citizens alike. From the outset, Copernicus was conceived with a user-driven approach, engaging stakeholders at every stage to ensure its products and services address real-world needs. This commitment to co-development with meteorological services, space and environmental agencies, research institutions, and private-sector actors has resulted in a dynamic ecosystem where feedback loops continuously refine and enhance service offerings. The participatory nature of Copernicus ensures that its data and tools remain relevant, actionable, and aligned with evolving policy and economic demands.

A defining characteristic of Copernicus is its full, free, and open data policy, which has been instrumental in driving innovation and fostering a new wave of public and private sector applications. By lowering barriers to data access, Copernicus empowers businesses, researchers, and policymakers to develop cutting-edge solutions in areas such as urban planning, agriculture, disaster response, energy management, and climate risk assessment. This democratisation of data amplifies the impact of Copernicus, ensuring that its scientific and technological advancements translate into tangible economic and societal benefits.

Beyond its direct operational value, Copernicus plays a strategic role in positioning the EU as a global soft power in environmental monitoring and climate action. As a provider of authoritative and independent Earth observation data, Copernicus enhances Europe's leadership in global climate governance, supporting international frameworks such as the United Nations Framework Convention on Climate Change (UNFCCC), the Paris Agreement[4] and its Global Stocktake, and the Global Methane Pledge (GMP)[5]. It also supports the implementation of EU regulations in the air quality, climate and energy fields. Its data and services are used worldwide, reinforcing the EU's ability to shape international environmental policy, support humanitarian efforts, and foster global scientific collaboration.

Through continuous investment, strong research foundations, and an unwavering commitment to operational excellence, Copernicus has evolved from an ambitious vision into a cornerstone of global environmental intelligence. As it progresses into its second phase, it continues to set the benchmark for integrated, policy-relevant, and user-driven Earth observation services, ensuring that Europe remains at the forefront of tackling climate and environmental challenges on a global scale.

METHODOLOGY →

The methodologies employed in CAMS and C3S are built on advanced data collection, assimilation, and modelling techniques. These methodologies ensure that datasets are accurate, comprehensive, and accessible to a broad range of users. CAMS and C3S integrate vast amounts of observational data from satellites, ground-based instruments, and reanalysis products to generate state-of-the-art climate and atmospheric monitoring systems. ECMWF, as the implementing body for both services, plays a critical role in advancing these methodologies, leveraging decades of expertise in numerical weather prediction (NWP) and operational forecasting.

> "ECMWF'S EXPERTISE IN NUMERICAL WEATHER PREDICTION AND OPERATIONAL FORECASTING PROVIDES AN ESSENTIAL FOUNDATION FOR THE COPERNICUS SERVICES THAT IT IMPLEMENTS."

A cornerstone of both services is data assimilation (see ECMWF 50th anniversary paper on data assimilation), which combines observational data with numerical models to generate reliable and consistent datasets. ECMWF's Integrated Forecasting System (IFS) (see ECMWF 50th anniversary paper on Earth system modelling) is central to this approach, assimilating over 100 satellite data streams for both services and a wide range of climate observations for C3S. The assimilation process, particularly through four-dimensional variational data assimilation (4D-Var), ensures that data used in atmospheric and climate models align with the principles of atmospheric physics and past observations. This system, initially developed for NWP, has seen major advancements since the late 1990s, leading to a step change in the accuracy of atmospheric and climate monitoring.

4 https://unfccc.int/process-and-meetings/the-paris-agreement

5 https://www.globalmethanepledge.org/

CAMS builds on this capability to generate real-time and reanalysis products for global atmospheric composition. The system produces global analyses and five-day forecasts twice a day, covering greenhouse gases (GHG), reactive gases, and aerosols.

CAMS also incorporates a sophisticated fire emissions monitoring system, the Global Fire Assimilation System (GFAS), which processes satellite data on active fires to estimate emissions from wildfires and biomass burning (in particular carbon and particulate matter emissions). GFAS emission datasets are a key component of the input datasets (emissions inventories, meteorological fields, in-situ measurements and remote sensing observations) that feed the global and regional modelling systems to create high-resolution air quality and atmospheric composition forecasts and analyses. The combination of these datasets allows CAMS to deliver comprehensive and reliable information about atmospheric composition patterns, which are used by policymakers, researchers, and businesses for air quality management, climate impact assessments, and design of emissions mitigation strategies.

C3S focuses on providing reliable, long-term climate data through observational climate records, reanalyses, seasonal forecasts, and climate projections, with its Climate Data Store (CDS) serving as a cloud-based platform that provides seamless access to the vast range of these climate datasets. Designed to be highly accessible, the CDS offers a programming interface (e.g. application programming interfaces (APIs) and Jupyter notebooks) that enables users to analyse data online without requiring extensive computational resources, facilitating data processing, visualisation, and analysis for various sectors such as agriculture, energy, insurance, and water resource management. Over time, the CDS has evolved significantly, enhancing user capabilities to develop custom applications, filter data by region and date, and present information in various formats.

Building on this success, CAMS launched the Atmosphere Data Store (ADS) in June 2020, extending the concept to atmospheric composition data and providing a unified platform for accessing the various global and regional datasets. This evolution reflects a concerted and synergetic effort to streamline data accessibility and usability across Copernicus services, ensuring that scientists, businesses, and policymakers can efficiently leverage climate and atmospheric data for research, decision-making, and environmental policy development (see section on synergies between the two services).

Both CAMS and C3S employ rigorous quality control and evaluation measures to ensure the reliability and scientific integrity of their data products. These quality assurance processes have been at the heart of both services and have progressively been developed in synergy (see section on synergies between CAMS and C3S).

A significant feature of both services is their emphasis on user engagement and application development. CAMS and C3S have actively collaborated with stakeholders, including national meteorological agencies, environmental organisations, and industry partners, to ensure that their data products meet real-world needs. The services offer tailored applications and sector-specific indicators that support decision-making in climate adaptation, risk assessment, and environmental monitoring. For example, C3S produces the European State of the Climate report annually (jointly with WMO since 2023), providing a comprehensive overview of climate trends and anomalies across Europe. Similarly, CAMS delivers policy-relevant assessments, such as the annual European air quality reports that describe air quality status in Europe (since 2013) and its evolution with respect to the implementation of EU regulations, considering health and environmental impact indicators.

MAIN ACHIEVEMENTS →

CAMS and C3S have made significant advancements in delivering high-quality atmospheric and climate information, addressing a wide range of user needs. Their services provide open and free access to data, supporting scientific research, policy development, and operational decision-making across multiple sectors. CAMS has about 40,000 registered users, while C3S has 390,000.

CAMS MAIN ACHIEVEMENTS

CAMS has established itself as a global leader in air quality and atmospheric composition monitoring. Its data products cover global and European air quality forecasts, analyses and reanalyses, greenhouse gas (GHG) and air pollutant emission inventories, solar irradiance assessments, and climate forcings. These products support a broad range of applications, from real-time monitoring to information for the general public and policy-driven needs.

CAMS integrated global and regional modelling systems offer a unique consistent framework that takes stock of numerous in-situ and satellite observations to provide best estimates of air pollutants and greenhouse gas concentrations in Europe and worldwide.

For example, CAMS provides global aerosol information by assimilating satellite observations into the ECMWF IFS-COMPO[6] model to deliver twice daily forecasts of the distribution of various aerosol types, including desert dust, sea salt, organic matter, black carbon, sulphate, and nitrate, offering insights into phenomena like dust storms, biomass burning, and pollution events. The service's real-time fire emissions monitoring system, GFAS, based on assimilation of satellite-based fire radiative power data, brings additional key information. Therefore, the CAMS global forecasting system can track long-range air pollution events triggered by natural (wildfires, dust storms, volcanoes) and anthropogenic sources anywhere in the world. This information can be used by national authorities to understand transboundary patterns and to run national systems (as boundary conditions or input data for machine learning downscaling algorithms).

CAMS global analyses and forecasts also provide boundary conditions for implementing the CAMS air quality services over Europe. Managed by Météo-France, these services are built upon 11 European air quality models run in 10 countries with a 10 km resolution, that are combined to derive products that are more robust and are of overall better quality than the individual systems.

Policy tools are also available that aim to quantify the relative contribution of various sources to air pollution episodes, in forecast mode, to help policymakers assess the efficacy of short-term mitigation measures. This panel of tools is deemed sufficiently relevant and consistent with policy needs to be quoted as a valuable source of information in the revised ambient Air Quality Directive adopted by the European Council in 2024[7]. Predictions of when the weight of natural dust in particulate matter exceeds regulatory limits is one of the most popular applications.

Regarding CAMS' role in raising public awareness of air pollution, a good example of CAMS data uptake is its integration into the Windy.com platform, a popular weather application. Users can access CAMS forecasts at global and European scales of surface concentrations of nitrogen dioxide, fine particulate matter, and aerosol optical depth (AOD). This integration enables users to track the movement of aerosol plumes from various sources, including dust, biomass burning, air pollutants, sea sprays, and volcanic eruptions. Figure 2 shows an example of a CAMS European forecast of surface nitrogen dioxide (NO_2) visualised on the Windy.com web-based application.

6 A configurable extension of the IFS used for modelling atmospheric composition.

7 https://eur-lex.europa.eu/eli/dir/2024/2881/oj/eng.

Figure 2: Sample CAMS European forecast of surface nitrogen dioxide (NO_2) visualised on Windy.com. Four-day forecasts of 8 different CAMS variables (from the global system and, when zooming in over Europe, from the regional ensemble system) can be explored: NO_2, ozone (O_3) and carbon monoxide (CO) surface concentrations; PM2.5 (fine particles with a diameter smaller than 2.5 micrometres) and desert dust particles surface mass concentrations; and vertically-integrated column of aerosol (aerosol optical depth), sulphur dioxide (SO_2) and ozone. Source: Windy.com.

To conclude on the regional near-real-time CAMS services, it should be noted that CAMS also deals with pollen. Six pollen species (alder, birch, grass, mugwort, olive, and ragweed) are monitored and forecasts of their airborne concentrations are produced to help users anticipate exposure issues (see Figure 3).

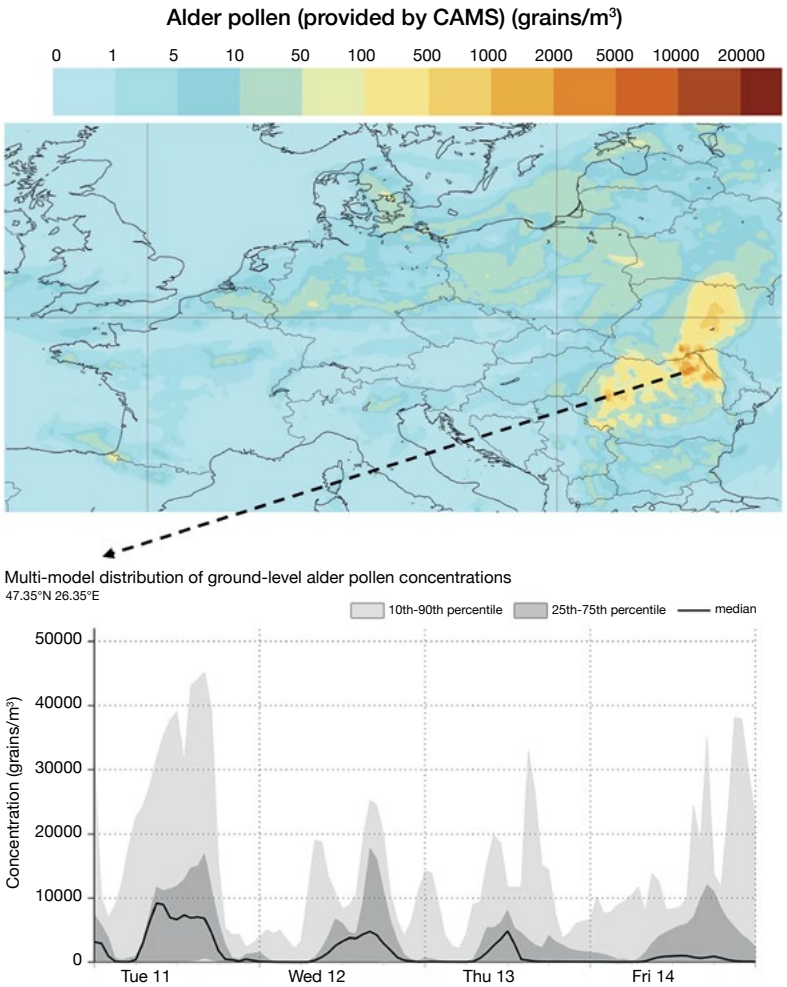


Figure 3: European-scale alder tree pollen forecast (from 11 March 2025). Alder pollen peaks in the first months of the year, affecting tens of millions in the European population. With appropriate medical support and advice, this information can help allergy sufferers manage their symptoms. This forecast is provided by a large consortium led by Météo-France and Ineris, with specific scientific support from the Finnish Meteorological Institute. Eleven individual regional models are used to consolidate the forecasts and assess uncertainty. See CAMS daily pollen forecasts at: https://atmosphere.copernicus.eu/charts/packages/cams_air_quality/products/europe-air-quality-forecast-pollens

Another notable achievement of CAMS is the routine provision of relevant information about the evolution of stratospheric ozone concentrations and the ozone hole. Every year on 16 September, International Day for the preservation of the ozone layer, we launch the Antarctic ozone hole monitoring season and publish regular information about its evolution compared to the previous years (see Figure 4). With these kinds of products, CAMS contributes to major international assessments, such as the Montreal Protocol for the ozone layer, the Intergovernmental Panel on Climate Change (IPCC), the United Nations Framework on Climate Change, and the Global Methane Pledge. One of the most recent achievements to support climate and methane regulation is the new methane hotspot explorer service, developed in collaboration with the Netherlands Institute for Space Research (SRON), to monitor and characterise methane plumes detected by the TROPOMI instrument embedded on the Sentinel-5P satellite.

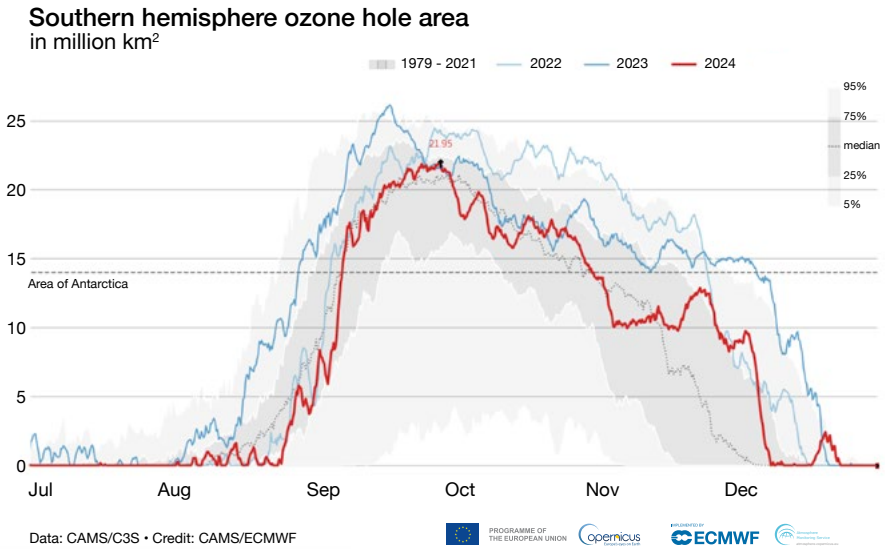


Figure 4: Evolution of the southern hemisphere ozone hole area in 2024 compared to 2022 and 2023. The shaded areas show the 1979 to 2021 envelope.

Beyond real-time applications, CAMS is delivering two global reanalyses: one for aerosols and reactive gases (EAC4) (Inness et al., 2019) and another for greenhouse gases (EGG4) (Agustí-Panareda et al., 2023). These datasets provide long-term atmospheric composition records that are widely used in atmospheric sciences, aiding both researchers and policymakers in assessing air pollution trends and climate impacts. By integrating data from over 100 satellite sensors and combining them with numerical models, these reanalyses ensure consistency in historical datasets, supporting research on air quality, emissions regulation, and climate change mitigation. Regional air quality reanalyses over Europe are also available since 2013.

CAMS also provides information on ultraviolet radiation, supporting health-related applications, and offers detailed assessments of climate radiative forcing, quantifying the impact of different atmospheric components on global warming.

A key area where CAMS has gained official recognition is in European policies. It is explicitly mentioned in the EU's Methane Strategy and the Air Quality Directive as a tool that supports Member States in their monitoring and reporting duties. This reflects the service's increasing role in regulatory compliance and environmental governance. The service's ability to provide tailored data for policymakers has led to the development of dedicated policy-support tools, including assessments of emission mitigation strategies and air pollution attribution reports.

Similarly, C3S has achieved significant milestones in climate data provision and analysis. Its ERA5 reanalysis dataset (Hersbach et al., 2020) has become one of the most widely used climate data products globally, providing detailed information on atmospheric conditions from 1940 to the present. ERA5 supports a wide range of applications, including climate risk assessments, infrastructure planning, and environmental research. The dataset has been cited extensively in scientific literature, including hundreds of references in the latest IPCC reports. ERA5-land (a rerun of the land component of the ERA5 climate reanalysis with a finer spatial resolution of 9 km (Muñoz-Sabater, 2021)) complements the reanalysis offer, providing hourly high-resolution information of surface variables.

In addition to historical climate analyses, C3S has also implemented a multi-system seasonal forecasting service that combines products from WMO Global Producing Centres in Europe (currently ECMWF, Météo-France, Deutscher Wetterdienst (DWD) in Germany, the UK Met Office and the Euro-Mediterranean Center on Climate Change (CMCC) in Italy) and elsewhere (USA, Japan, Canada) according to common requirements, in terms of variables provided, length of forecast, ensemble size and various technical aspects such as timeliness, data formats, etc. Data products based on both individual contributions and the combined C3S multi-system forecast are published monthly and are available on regular 1^0x1^0 latitude-longitude grid at 12-hourly intervals. These seasonal forecasts assist in adaptation planning across various sectors, including water management, agriculture, and energy, to name a few. See one example in Figure 5, which shows a C3S multi-system sea-surface temperature anomaly forecast in the tropical eastern Pacific, for the recent 2023 El Niño event.

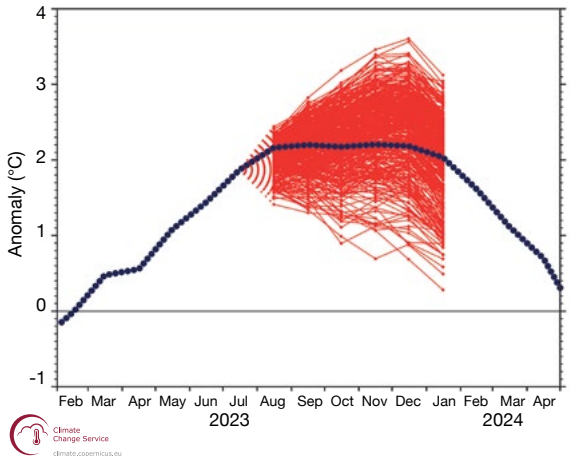
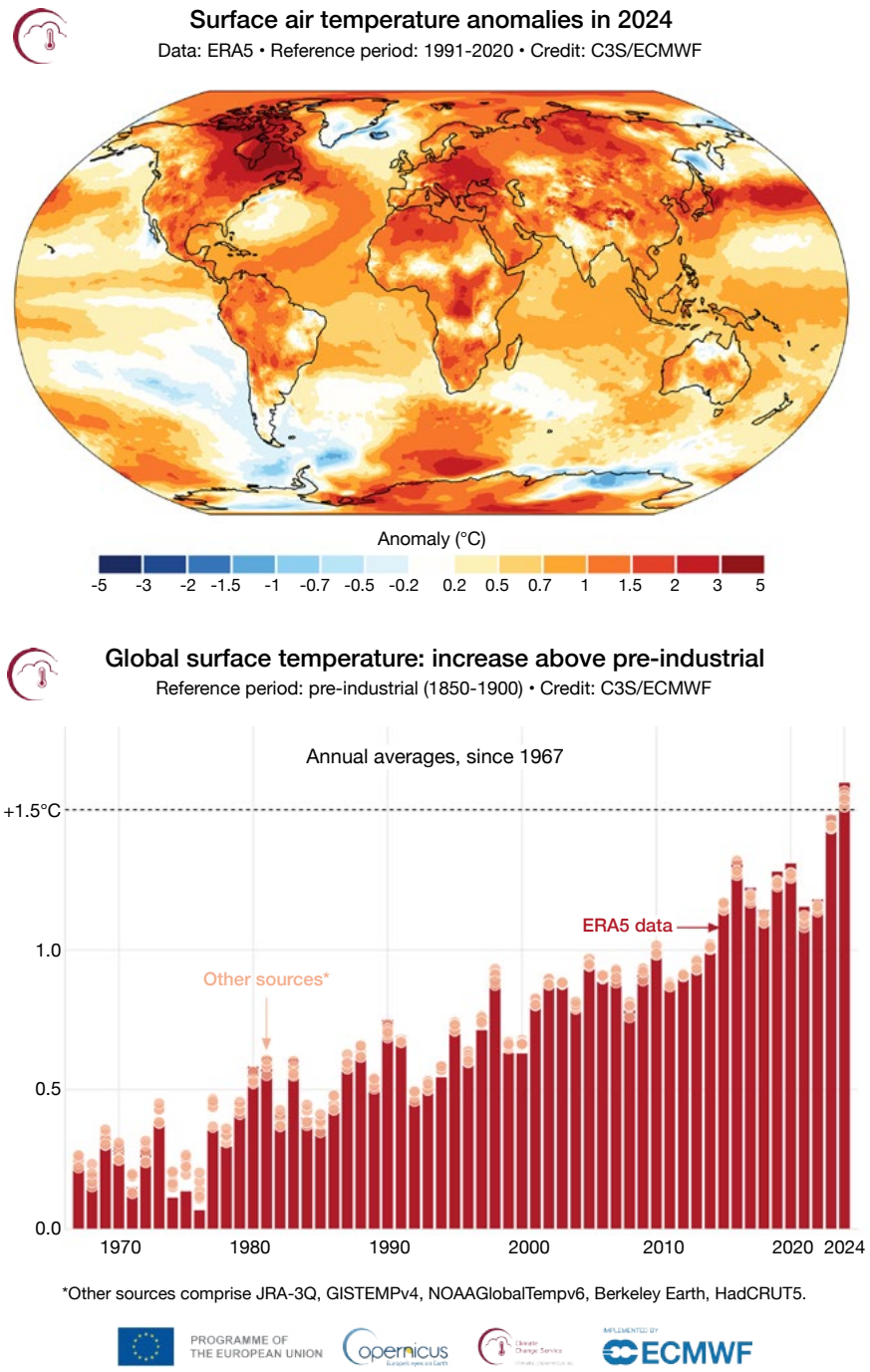


Figure 5: Niño-3 sea-surface temperature (SST) anomaly forecast from 1 August 2023 based on the C3S multi-system seasonal forecast (from ECMWF, UK Met Office, Météo-France, Euro-Mediterranean Center on Climate Change (CMCC), Deutscher Wetterdienst (DWD), US National Centers for Environmental Protection (NCEP), Japan Meteorological Agency (JMA), Environment and Climate Change Canada (ECCC)). The forecast captures well the peak of El Niño towards the end of 2023. The Niño-3 SST anomaly index is an indicator of eastern tropical Pacific El Niño conditions. It is calculated with SSTs in the box 150°W - 90°W, 5°S - 5°N.

One of C3S's flagship initiatives is the European State of the Climate report, which provides an annual overview of climate trends and extreme weather events across Europe. Figure 6 shows two example illustrations of the wealth of information about the global and European climate available in these reports.

These reports, along with monthly C3S Climate Bulletins (see Figure 7), have become key references for policymakers and climate scientists. The European State of the Climate reports (jointly published with WMO since 2023) offer detailed analyses of temperature anomalies, precipitation patterns, and other climate indicators, supporting adaptation strategies and informing the public about climate variability and change. In addition, many data from C3S are routinely used in WMO climate assessments and contribute to international climate monitoring efforts.

Figure 6: Surface air temperature anomaly (°C) for 2024 relative to the average for the 1991–2020 reference period. Data: ERA5 (above). Global surface air temperature (°C) increase above the average for 1850–1900, the designated pre-industrial reference period, based on several global temperature datasets shown as annual averages since 1967 (below).



More broadly, C3S has operationalised the production of Essential Climate Variables (ECVs) by integrating satellite and in situ observations, reanalyses (as mentioned above), and climate models into a single, quality-controlled framework. Through the CDS, C3S provides access to more than 20 ECVs, covering the atmosphere, ocean, cryosphere, and land biosphere, ensuring consistency with Global Climate Observing System (GCOS) standards. The service collaborates with over a hundred entities, including EUMETSAT and its Satellite Application Facilities (SAFs), ESA (and its Climate Change Initiative (CCI)), NASA and NOAA, to secure reliable long-term

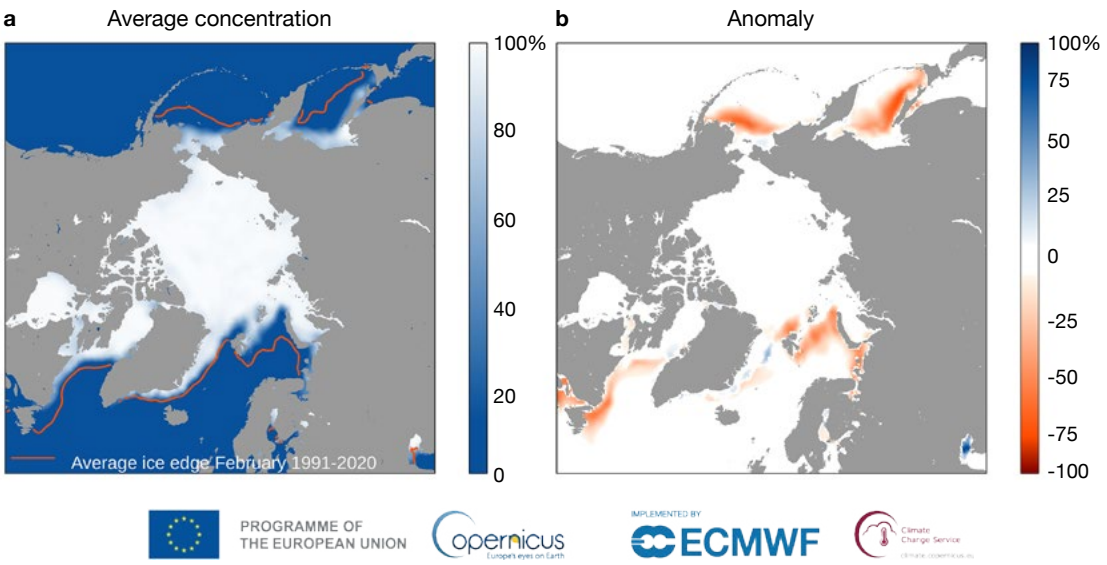


Figure 7: (a) Average Arctic sea ice concentration for February 2025. The thick orange line denotes the climatological sea ice edge for February for the period 1991–2020. (b) Arctic sea ice concentration anomaly for February 2025 relative to the February average for the period 1991–2020. This information is provided as part of the C3S Climate Bulletins published during the first week of each month[8].

Climate Data Records (CDRs), which are regularly updated. Historical datasets, some extending back to 1755 over land and 1851 over the ocean, are complemented by atmospheric data from different networks. To address data gaps, C3S operates a Data Rescue Service in partnership with the initiative of the WMO (International Data Rescue Initiative (I-DARE)), digitising historical meteorological and early satellite observations to improve reanalyses, particularly for the 1960s and 1970s. High-resolution datasets, such as E-OBS (see e.g. Cornes et al., 2018), enhance European climate records. These efforts support global climate policies, including the Paris Agreement, by ensuring consistent, authoritative climate monitoring, allowing policymakers and scientists to track long-term trends and assess climate risks.

Another major achievement of C3S is its role in supporting the European Union's climate policies. The service provides essential data for climate adaptation and mitigation strategies, including indicators relevant to the Paris Agreement and the Sustainable Development Goals (SDGs). Through partnerships with various EU institutions and international organisations, C3S ensures that its data products align with global climate governance needs.

C3S has also actively engaged in developing capabilities for attributing extreme weather events to climate change. Between November 2019 and June 2021, C3S implemented a prototype service that established protocols for rapid attribution studies, enabling swift assessments of how human-induced climate change influences specific extreme events. The operationalisation of this capability is now under way.

Both CAMS and C3S have seen growing user engagement, with their data being used by businesses, governments, and media outlets worldwide. C3S has been instrumental in supporting climate services across Europe, while CAMS has become a reference for air quality forecasting and emissions monitoring. Their outputs are frequently cited in global media, reinforcing their role as authoritative sources for environmental and climate information.

8 https://climate.copernicus.eu/climate-bulletins

SYNERGIES BETWEEN CAMS AND C3S →

The synergy between the Copernicus Atmosphere Monitoring Service (CAMS) and the Copernicus Climate Change Service (C3S) is built upon shared infrastructure, scientific methodologies, and complementary objectives, creating an efficient and integrated framework for environmental monitoring. Both services are implemented by ECMWF and leverage its operational capabilities to provide high-quality data for users across various sectors.

> THE COPERNICUS ATMOSPHERE MONITORING AND CLIMATE CHANGE SERVICES ARE BUILT ON SHARED INFRASTRUCTURE, METHODOLOGIES AND OBJECTIVES."

Starting with the Data Stores and as already mentioned above, the Climate Data Store (CDS), which underpins C3S, has transformed access to climate data by providing a cloud-based platform where users can retrieve, process, and visualise datasets. With hundreds of thousands of registered users, the CDS has enabled researchers, businesses, and decision-makers to leverage climate information in an efficient and scalable manner. CAMS launched its own data store following the same principles as the CDS but focusing on atmospheric composition data (the Atmosphere Data Store (ADS)). This joint evolution ensures that both climate and air quality information remain easily accessible, fostering wider adoption of Copernicus products. A graphic of the Data Stores' architecture is provided in Figure 8.

As a result, the CDS and ADS **both** serve as cloud-based portals. An important point is that these user-friendly platforms share a common architecture, ensuring interoperability and allowing users to seamlessly extract, process, and analyse both climate and atmospheric composition data within the ECMWF-managed Common Cloud Infrastructure (CCI), which hosts not only the CDS and ADS but also the European Weather Cloud. This integration enables efficient data retrieval and processing, reducing barriers for users who need to combine datasets from both services for applications such as climate risk assessments and air quality studies, with the option to combine these with core weather products from ECMWF.

Effective decision-making using environmental and climate information requires high-quality data, rigorous evaluation, and strong user support. Evaluation and quality control is paramount to maintain trust and authority. CAMS and C3S have therefore developed comprehensive quality assurance frameworks tailored to their specific objectives. ECMWF ensures strict quality control across all CAMS production systems, providing independent assessments and automated

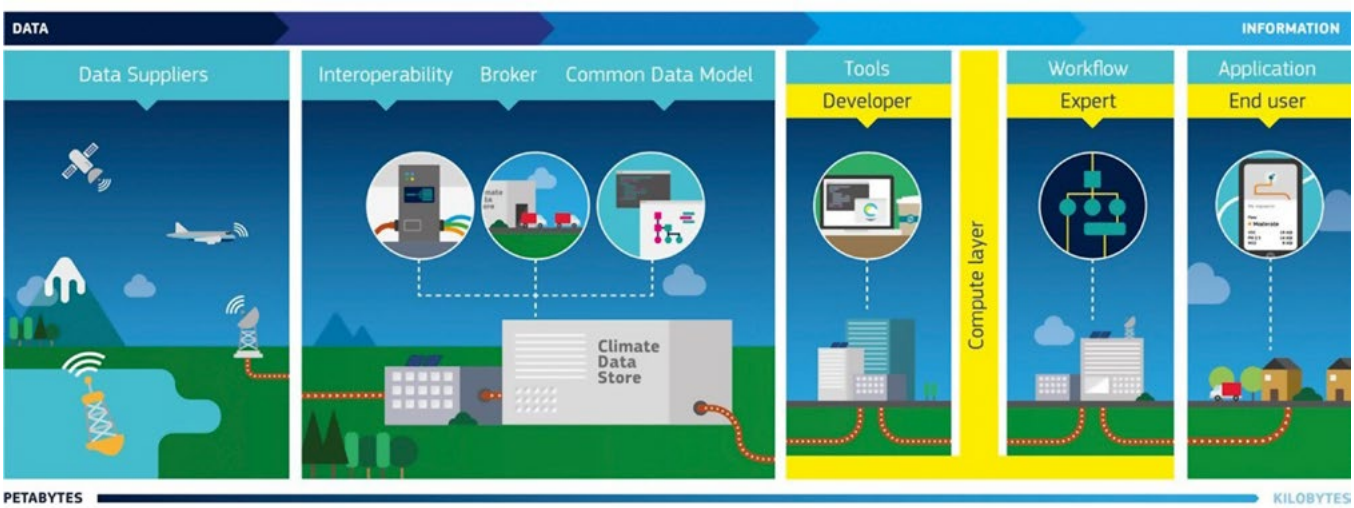


Figure 8: Visual representation of the information flow through the Climate Data Store.

monitoring of forecast skill scores, statistical performance metrics, and user uptake. CAMS also produces detailed Evaluation and Quality Assurance (EQA) reports quarterly, incorporating expert reviews and long-term observational comparisons. C3S has developed similar quality assurance protocols for climate data, tools, and applications, which are published in the Climate Data Store (CDS). Quality Assurance Reports (QARs) provide detailed insights into data integrity, completeness, uncertainty, and usability, following standardised templates for observational, predictive, and projected datasets. CDS applications undergo rigorous evaluations based on relevance, accessibility, clarity, completeness, and reliability, ensuring compliance with international standards and best practices. Additionally, real-time quality monitoring of the CDS infrastructure is available through interactive dashboards, providing transparency on service performance and data usage. Through these efforts, CAMS and C3S ensure that their data products remain robust, reliable, and fit for policy and research applications.

User engagement and communication are also areas where CAMS and C3S align closely. The services collaborate on training, outreach, and policy support, ensuring that stakeholders, from policymakers to businesses and researchers, can effectively utilise their products. Joint initiatives include co-organised workshops, media collaborations, and tailored user-driven applications that highlight the intersection between atmospheric monitoring and climate change adaptation.

CAMS and C3S prioritise user engagement to ensure their data and services meet evolving user needs. This approach involves collaboration with international organisations (e.g. EUMETSAT, WMO, ESA, UNFCCC), EU institutions, national authorities, industry, and the public to enhance visibility and uptake of their offerings. A User Requirements Database (URDB) systematically collects and analyses user feedback, guiding the services' evolution. A dedicated user support team maintains resources such as FAQs, knowledge bases, documentation, tutorials, and user forums, complemented by a help desk operating during European business hours. To broaden service adoption, CAMS and C3S support the development of use cases and demonstrators across various sectors, including air quality, health impacts, tourism, agriculture, and insurance.

Communication and outreach efforts target diverse audiences through press activities, content creation, media collaborations, and participation in major scientific conferences like the UNFCCC Conference of the Parties (COP). Their websites receive millions of page views annually, featuring climate monitoring products such as the C3S Climate Bulletins and the European State of the Climate report, which gain extensive media coverage. Additionally, CAMS and C3S sponsor environmental programmes on networks like Euronews and CNN, reaching millions globally. Training initiatives include workshops and online materials. Massive Open Online Courses (MOOCs), sometimes attended by more than 5,000 people, have been organised on topics such as monitoring atmospheric composition, using Jupyter Notebooks to exploit CAMS datasets, renewable energy, and applications of artificial intelligence and machine learning. These events are often organised jointly with partners such as EUMETSAT, ESA, Mercator Ocean International, or the European Environment Agency (EEA).

This strong synergy between the services ultimately enhances the operational efficiency and impact of both services. By aligning their methodologies and infrastructure, CAMS and C3S provide users with a coherent suite of tools and datasets that support informed decision-making in domains ranging from air pollution management to long-term climate adaptation and mitigation strategies.

EXAMPLES OF APPLICATIONS AND DOWNSTREAM SERVICES →

CAMS and C3S have facilitated a vast ecosystem of applications and downstream services that support decision-making across multiple sectors. From regulatory compliance to public health protection and economic risk assessment, these services provide actionable intelligence based on state-of-the-art atmospheric and climate data. CAMS products play an integral role in European Union environmental policies, particularly in air quality management and greenhouse gas (GHG) mitigation, while C3S data serve as a foundation for climate adaptation planning, influencing energy production, agriculture, and disaster resilience strategies.

One of the most impactful applications of CAMS is in public health, where air quality forecasts inform the public and authorities about pollution levels. These forecasts assist national and local air quality monitoring systems, enabling timely interventions to mitigate health risks. Urban planners use CAMS data to develop pollution-reduction strategies, while health agencies rely on its ultraviolet (UV) radiation monitoring capabilities to provide sun safety advisories. Additionally, the service supports smartphone applications and wearable technologies that alert users to high pollution levels, thus empowering individuals to make informed choices about outdoor activities.

As mentioned above, the inclusion of CAMS data in Windy.com enhances public access to real-time air quality information, empowering individuals and organisations to make informed decisions related to health, environmental management, and planning. This collaboration exemplifies how CAMS' advanced atmospheric composition forecasting capabilities are effectively used in widely accessible platforms, thereby extending their reach and impact.

CAMS also provides critical support for policy-driven air quality management. By delivering detailed pollutant emission datasets, the service enables policymakers to assess the effectiveness of emission control measures and track compliance with international agreements such as the EU Air Quality Directive. Regulatory agencies use CAMS data to pinpoint pollution sources, evaluate long-term air quality trends, and design targeted mitigation policies. The service's reanalysis products, such as EAC4 for aerosols and reactive gases and EGG4 for greenhouse gases, serve as vital tools for tracking atmospheric changes over time, helping governments and international bodies to fine-tune their environmental policies.

One of the emerging applications of CAMS is in emission monitoring and verification support, particularly for methane emissions. CAMS provides real-time and retrospective data on methane levels, which are essential for tracking emissions from agriculture, fossil fuel extraction, and landfills. These data are crucial in the context of the European Union's Methane Strategy, which emphasises reducing emissions from key sectors. By integrating satellite-based methane observations with atmospheric modelling, CAMS enables regulators and industries to implement more effective mitigation measures.

On the economic front, C3S provides indispensable climate intelligence for businesses. Energy companies leverage seasonal forecasts to optimise energy production and distribution, ensuring a stable and cost-effective supply of electricity. For instance, hydropower operators use C3S data to anticipate changes in water availability, while wind and solar energy producers utilise its datasets to forecast resource variability. Insurers, on the other hand, rely on C3S climate projections to assess weather-related risks, set premium rates, and design long-term risk mitigation strategies. The latest report[9] on the economic value of ERA5 underscores its growing importance as a reference dataset for financial risk modelling.

9 https://climate.copernicus.eu/new-study-era5s-socio-economic-benefits

Another notable example is the European Energy and Climate Data Explorer, which integrates ERA5 reanalysis and regional climate projection data to provide insights into the impact of climate variability on energy demand and supply. This tool supports policymakers, energy companies, and grid operators in designing resilient energy systems that can withstand changing climate conditions. Also, and by leveraging C3S data, companies such as Vortex enhance the precision of their wind energy assessments, contributing to more reliable and efficient renewable energy solutions. Moreover, C3S and the European Network of Transmission System Operators for Electricity (ENTSO-E) have established a collaborative partnership to enhance the integration of climate data into energy sector planning and strategic decision-making for a climate-resilient European electricity grid. These applications demonstrate how C3S's extensive climate datasets empower the energy sector to make data-driven decisions, ultimately promoting the adoption of sustainable energy practices.

A compelling example of C3S's contribution to the climate services landscape is its role in machine-learning driven weather prediction. The ERA5 reanalysis dataset serves as the natural foundation for numerous machine-learning models developed by research institutions and private companies worldwide (see ECMWF 50th anniversary papers on Earth system modelling, data assimilation and machine learning (in preparation)). By training artificial intelligence systems on high-resolution historical climate data, these models can generate more accurate weather forecasts, ultimately benefiting industries ranging from aviation to agriculture.

C3S has also fostered the development of innovative climate monitoring tools. The ERA5 Explorer application, for instance, provides a user-friendly interface for generating local statistics on climate variables based on reanalysis data. Meanwhile, the Global Temperature Trend Monitor helps researchers and policymakers assess long-term warming trends and estimate when the planet might reach the warming threshold of 1.5°C proposed in the Paris Agreement. Such applications exemplify how C3S bridges the gap between raw climate data and real-world decision-making.

The health sector has also benefited from C3S applications. The Monthly Climate Explorer application for COVID-19, for instance, examines possible links between weather patterns, air pollution, and COVID-19 mortality rates, offering valuable insights into the interplay between climate and public health. Such applications highlight the expanding role of climate services in addressing cross-sectoral challenges.

A recurring theme in these applications is the integration of data across multiple domains. The European Climate Data Explorer, hosted on the Climate-ADAPT platform and managed by the European Environment Agency, provides interactive access to numerous climate indices, supporting national and local adaptation strategies across Europe. The CDS and ADS infrastructures, along with application programming interfaces (APIs) and web-based analysis tools, ensure that users from diverse backgrounds can harness the full potential of Copernicus data.

These examples illustrate the transformative impact of CAMS and C3S in fostering a data-driven approach to environmental management, economic planning, and policy development. By enabling a wide range of downstream services, these Copernicus services are not only advancing scientific research but also driving real-world action to address climate change and atmospheric pollution.

ECMWF CONTRIBUTION TO THE COPERNICUS EMERGENCY MANAGEMENT SERVICE →

Beyond the two major services, CAMS and C3S, which ECMWF operates on behalf of the European Union, ECMWF contributes to the Copernicus Emergency Management Service (CEMS), under the leadership of the JRC, in particular the early warning systems for flood and wildfire.

FLOOD AWARENESS SYSTEMS

ECMWF has an inspiring and fruitful long-standing collaboration with the JRC, especially to support the development, implementation and operational delivery of CEMS-Flood, the Early Warning for floods component of the Copernicus Emergency Management Service (see Figure 9). CEMS-Flood, managed by the JRC and delivered by a network of centres, currently covers two domains to deliver kilometre-scale hydrological forecasts from short-range (Europe only) to seasonal forecast horizons (global).

In 2004 ECMWF signed a collaboration agreement to provide ensemble forecasts as input to the newly developed experimental 'European Flood Alert System', the precursor of the European Flood Awareness System (EFAS), run as a prototype by the JRC. In 2011, EFAS became an operational service as one of the CEMS Early Warning Systems, and ECMWF was designated as the computational centre for CEMS-Flood. At the same time, ECMWF and the JRC pioneered the set-up of a global flood forecasting system by coupling ECMWF's Integrated Forecasting System with the JRC's hydrological routing component of its distributed hydrological model, OS-LISFLOOD. ECMWF ran the system experimentally until 2017, when it became an official CEMS-Flood service (the Global Flood Awareness System (GloFAS)). The collaboration continued with ECMWF remaining the CEMS hydrological forecast computational centre for the 2nd and 3rd framework contracts (ending in 2027).

Figure 9: Schematic of ECMWF's role in CEMS-Flood.

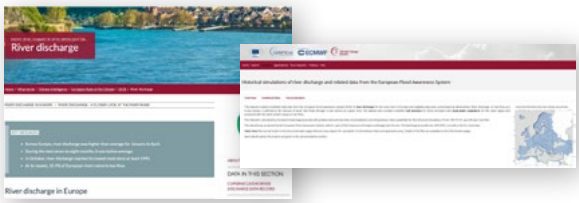
2002 devastating floods Europe

ECMWF

European Commission

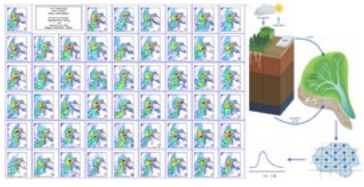
Collaboration agreement between JRC and ECMWF IFS-ENS input to EFAS

ECMWF awarded 2nd CEMS-Hydro computational centre framework contract (2017–2021)
GloFAS becomes operational
EFAS River discharge included in 2nd C3S ESoTC
CEMS-Hydro simulations in MARS and then CDS



2002 2003 2004–5 2011–12 2017–18 2021

JRC and expert MS develop the 'European Flood Alert System' funded by EC forced by DWD deterministic forecasts



ECMWF and JRC develop a prototype Global Flood Awareness System based on IFS/HTESSEL + LISFLOOD routing
EFAS becomes operational with ECMWF the computational centre

ECMWF awarded 3rd CEMS-Hydro computational centre framework contract (2021–2027)
LISFLOOD replaces HTESSEL in GloFAS
CEMS-Hydro seasonal forecasts part of C3S Hydro multi-model ensemble

As the CEMS hydrological forecast computational centre, ECMWF is responsible for the data acquisition from the CEMS-Flood Meteo and Hydrological Data Collection Centres and numerical weather prediction centres such as DWD and the COSMO consortium, for the operational running and maintenance of hydrological forecast chains, and for the delivery of data and associated products to authorised users. It also develops and maintains tools to support the role of the Hydrological Analytics and Dissemination Centre and provides technical and product user support and guidance. In collaboration with the JRC, ECMWF is at the core of technical service development, including building new modelling modules, conducting hydrological model calibration, designing forecast products, optimising modelling chains and product software, and improving all data services. By March 2025, more than 15 separate modelling chains served CEMS-Flood hydrological forecasting operations, with nearly 80 products updated and pushed daily on the EFAS and GloFAS web interface.

Through its role as the computational centre for CEMS hydrological forecasts and entrusted entity of C3S and CAMS, ECMWF has been instrumental in exploiting synergies across the different services. Since 2017, the daily hydrological simulations of EFAS initial conditions have served as reference data for the C3S Climate Intelligence activities, including the European State of the Climate report and the Climate Bulletins, with CEMS-Flood simulated river discharge first appearing in 2018 as a spotlight variable before becoming a core variable from the 2020 edition onward. ECMWF has also leveraged its in-house expertise in data archiving and discovery, offering to run the CEMS Early Warning Data Store, a tool for data cataloguing and data access built on the same infrastructure as the C3S and CAMS data stores. Between August 2023 and February 2025, over 170 terabytes of CEMS-Flood data have been downloaded through the Data Store to serve more than 620,000 requests from 110 countries.

Until the end of the framework contract as the computational centre for CEMS hydrological forecasting, ECMWF will implement a new web infrastructure to better serve EFAS and GloFAS products, deliver at least one major and several minor service releases for each European and global domain component, and work on new products, continuing the long-standing collaboration with the JRC to advance the service.

Through partnerships and collaborations with the JRC and all CEMS-Flood centres, including DWD, Kister, Ghenova Digital, SMHI, SHMU and Dutch Rijkswaterstaat, ECMWF has taken pride in delivering part of the CEMS-Flood service.

CEMS FOREST FIRE AND WILDFIRE INFORMATION SYSTEMS

Under CEMS, ECMWF also has the responsibility for producing fire danger forecasts. This complements ECMWF's role under CAMS on various aspects of fires, partly in the context of the Global Fire Assimilation System (GFAS), focusing on detection of active burning fires, their emissions and their impact on atmospheric composition and air quality (see earlier sections). This section covers the CEMS aspects.

ECMWF has been producing fire danger forecasts operationally since 2018 as part of CEMS. A pre-exploitation phase started in 2015, conducted with the support of a grant issued by the JRC, which aimed to explore the use of weather forecasts for the delivery of global fire danger information (Di Giuseppe et al., 2016). Until then, most available systems relied on environmental monitoring through surface weather stations. See Figure 10 for the timeline of ECMWF involvement in support of the fire component of CEMS Early Warning.

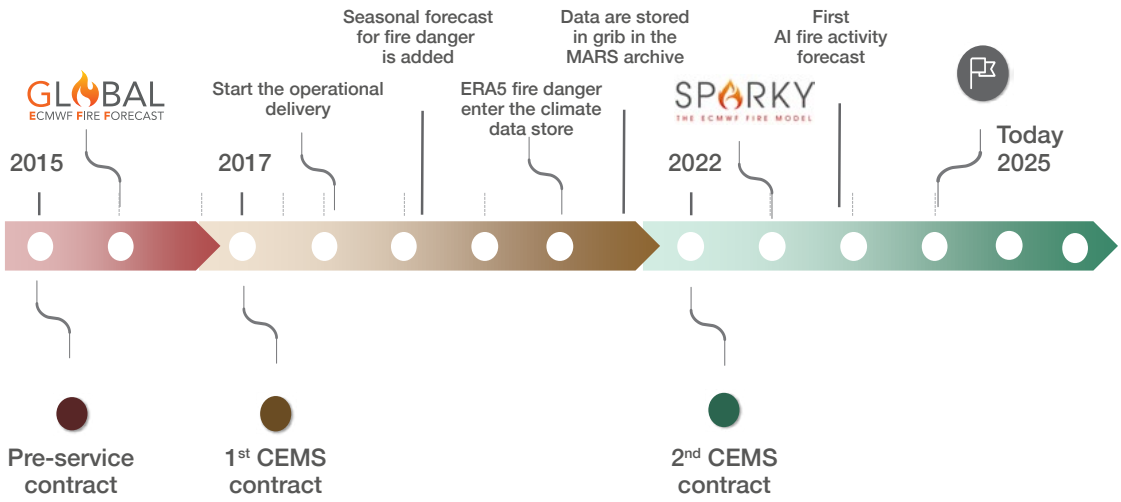


Figure 10: Timeline of fire activities and key milestones for ECMWF fire-related work under the Copernicus Emergency Management Service. During the pre-exploitation phase ECMWF built the Global ECMWF Fire Forecasting (GEFF) model, a model able to calculate fire danger indices from several models developed in the US, Canada and Australia. During the two service contracts ECMWF expanded the availability of data including seasonal prediction and real-time monitoring of fire danger from ECMWF reanalyses. In recent years ECMWF has been exploring the possibility of forecasting fire activity by directly leveraging ML methods and physically-based models of fuel status.

During the pre-exploitation phase, ECMWF developed a global fire danger model, the Global ECMWF Fire Forecasting (GEFF) model, which allows the simultaneous calculation of several fire danger metrics developed in Canada, the US, and Australia. Using GEFF, ECMWF has been delivering forecast products to both the European Forest Fire Information System (EFFIS)[10] and the Global Wildfire Information System (GWIS) platforms. Today, GEFF remains one of the open-source resources widely used by both operational services (e.g. NOAA) and technology companies (e.g. IBM).

After an initial research phase, ECMWF was awarded two consecutive Copernicus service contracts in 2017 and 2022. Thanks to the two service contracts, the range of available products has expanded to include seasonal predictions, and a real-time monitoring dataset based on ERA5, which can be accessed directly through the CDS. ERA5-Fire ranks among the most downloaded datasets in the CDS and is widely used in the fire community for studying changing patterns of landscape flammability worldwide. Through the Copernicus Programme, ECMWF has also introduced a new discipline and data template in the governance of meteorological data managed by the WMO. As a result, fire forecast variables can now be codified similarly to traditional weather variables.

While the first phase focused on adopting existing methods, in recent years, ECMWF has been exploring novel approaches to fire forecasting. By leveraging advances in machine learning and its own weather prediction model, ECMWF is shifting the focus from predicting fire danger (a measure of landscape flammability) to forecasting fire activity.

This progress has been made possible by utilising ECMWF's model infrastructure and initiating the development of a fire model within its physics-based framework, known as SPARKY. The introduction of high-resolution fire activity forecasts (up to 1 km), which incorporate not only weather conditions but also fuel status and human presence, expands our current capability for early detection of fires on a global scale. This advancement could position the Copernicus Programme at the forefront of fire forecasting in the years to come, contributing to building resilience against the escalating threat of extreme fire events in a warming climate.

10 https://forest-fire.emergency.copernicus.eu/

CONCLUSION AND FUTURE WORK

The initial phase of CAMS and C3S has delivered significant value in atmospheric and climate monitoring, firmly establishing both services as globally recognised and authoritative sources of environmental information. Over the past decade, these services have evolved from research initiatives into fully operational programmes that provide critical support for scientific research, policymaking, and commercial applications.

On 22 July, 2021, ECMWF signed a new Contribution Agreement with the European Commission to continue implementing the EU-funded C3S and CAMS for the next seven years. During this Phase 2 (2021–2028), Copernicus is building on this solid foundation by incorporating cutting-edge advancements in Earth system monitoring, high-resolution reanalyses, artificial intelligence (AI) integration, and enhanced user engagement.

> “ THE CO_2 MONITORING AND VERIFICATION SUPPORT CAPACITY WITHIN CAMS WILL PROVIDE NEAR-REAL-TIME ASSESSMENTS OF ANTHROPOGENIC CO_2 AND CH_4 EMISSIONS.”

A key component of this evolution is the development of the CO_2 Monitoring and Verification Support (CO2MVS) capacity within CAMS, which will provide near-real-time, observation-based assessments of anthropogenic CO_2 and CH_4 emissions. This capability will leverage data from Sentinel-5P, the upcoming CO_2M mission, and other contributing satellites to monitor emissions at finer spatial and temporal scales, supporting both national greenhouse gas (GHG) inventories and international climate agreements such as the Paris Agreement and the European Green Deal. This marks a transformative step in atmospheric monitoring, shifting from emissions estimates based on statistical inventories to direct, observation-based tracking of GHG emissions. Figure 11 represents the timeline for the implementation of this new service element of CAMS. This initiative fits in and will be an important contributor to a wider global initiative called the Global Greenhouse Gas Watch (G3W) being set up by the WMO.

On the climate side, C3S is preparing the next-generation ERA6 reanalysis, which will provide even greater accuracy, resolution, and coverage. This coupled Earth system reanalysis will integrate data from the atmosphere, ocean, land, and cryosphere to improve long-term climate assessments and inform adaptation strategies. By providing detailed reconstructions of past climate conditions, ERA6 will support risk assessments in critical areas such as water resource management, food security, and infrastructure planning.

Alongside ERA6, the planned EAC5 reanalysis for atmospheric composition will offer enhanced insights into long-term trends in air pollutants and greenhouse gases, further strengthening the link between climate services and policy-relevant air quality monitoring.

To better serve the evolving needs of EU Member States, the Copernicus Programme is expanding its National Collaboration Programme. This initiative allows individual countries to tailor Copernicus data products for national applications, facilitating the integration of Copernicus information with locally available datasets. The National Collaboration Programme enhances the synergy between Copernicus services and national climate adaptation efforts, supporting policy frameworks such as the EU Climate Law and the revised Ambient Air Quality Directives.

Looking beyond 2028, Copernicus services will continue to expand their role in global environmental governance. CAMS will refine its capabilities in air quality and emissions monitoring, improving the accuracy and timeliness of its forecasts while strengthening its contribution to European and international regulations. The service will maximise the impact of satellite data by integrating observations from new missions such as Sentinel-4, Sentinel-5, and CO_2M and by promoting the use of low-cost in situ sensor networks in data-sparse regions. C3S, on the other hand, will enhance its support for climate resilience by contributing to providing an operational framework for climate projections. For example, brokering access to climate forcings and scenarios could feed into projections streams produced by, for instance, the Destination Earth (DestinE) initiative which aims to create digital twins of the Earth (Sandu, 2024), enabling interactive, high-resolution climate simulations that will provide decision-makers with dynamic insights into future climate risks.

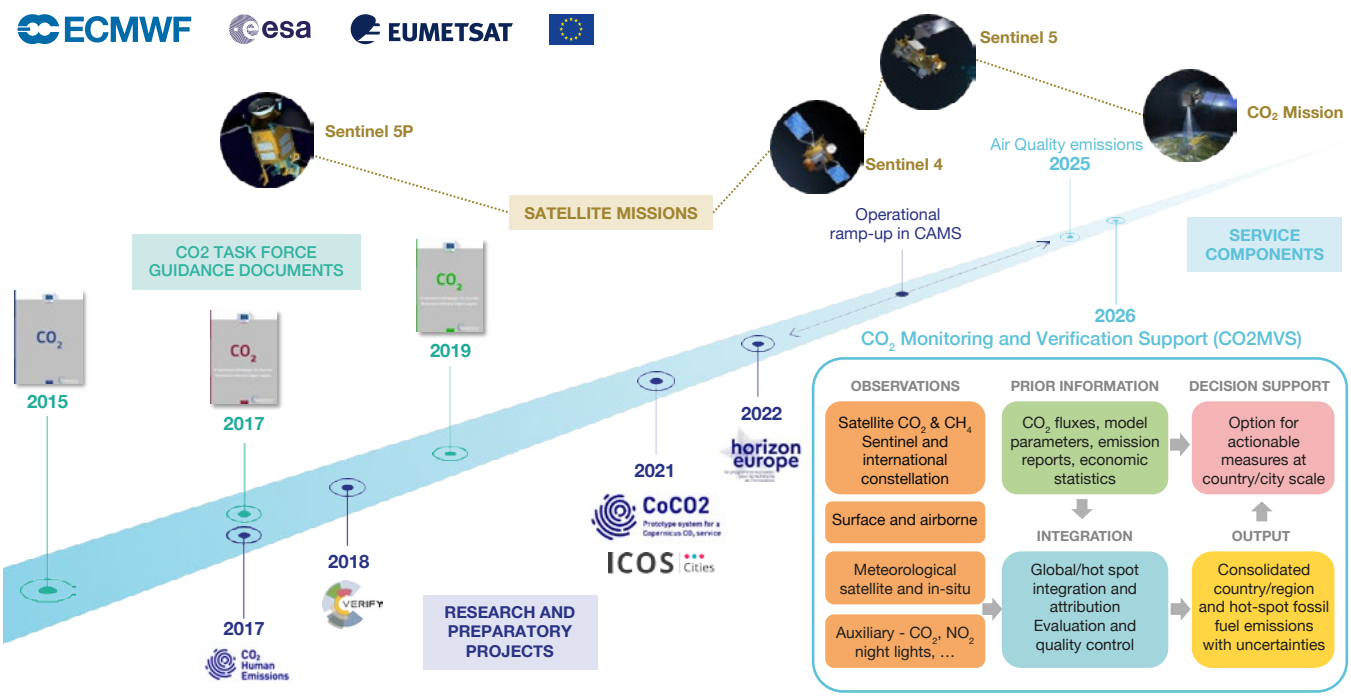


Figure 11: Timeline for the implementation of the Copernicus anthropogenic greenhouse gas emissions monitoring and verification support capacity. The scoping of this new element of CAMS, implemented by ECMWF, started in 2015 with reports from a CO2 Monitoring Task Force from the European Commission. Supported by dedicated research projects within Horizon 2020 and Horizon Europe, the science and methodologies have been developed and are now being implemented as part of CAMS. In parallel, the space segment is being ramped up by ESA and EUMETSAT through the Sentinel-5P, Sentinel-4, Sentinel-5 and CO2M missions. The overall structure of the envisaged integrated system that combines observations and prior information with modelling capacities at global and local scale is also shown (in the box).

AI and machine learning will play a crucial role in the next phase of Copernicus services. CAMS and C3S are already integrating AI-based techniques to improve data processing, uncertainty quantification, and model downscaling. These innovations will allow Copernicus to provide more accurate, localised forecasts while reducing computational costs and latency. The expansion of AI-driven services will also enhance climate risk assessments and facilitate more precise monitoring of extreme weather events, which are becoming increasingly frequent due to climate change.

Another critical aspect of the future evolution of Copernicus services is their growing economic and societal impact. Climate variability and atmospheric composition are increasingly influencing decision-making in energy production, finance, agriculture, and disaster management. C3S's seasonal forecasts and ERA5-derived climate risk assessments are already supporting renewable energy companies, including the wind energy sector in optimising production and grid stability. Similarly, insurers are using Copernicus data to assess climate risks and structure innovative financial products that mitigate economic losses from extreme weather events.

The next decade will see CAMS and C3S expand their user-driven portfolios within their operational frameworks, focusing on increased automation, enhanced timeliness, and improved accessibility of their services. The ambition is not only to sustain the current level of service but also to expand capabilities in areas such as air quality monitoring, emissions verification, and climate projection operationalisation. Copernicus 3.0 will aim to integrate near-real-time environmental intelligence, providing rapid-response capabilities for managing climate and air quality crises, such as wildfires, industrial accidents, and extreme weather events.

Equally, ECMWF intends to continue and expand its capabilities in early warning for floods and fire risks in support of CEMS with the JRC.

As climate change becomes an increasingly urgent global challenge, Copernicus services will continue to play a crucial role in climate action, risk mitigation and adaptation strategies. The planned enhancements in reanalysis, forecasting, and emissions tracking will provide policymakers, scientists, and businesses with even more powerful tools to tackle environmental challenges and drive sustainable transformation. Through ongoing innovation and collaboration, Copernicus services will ensure that Europe remains at the forefront of climate and atmospheric science, helping societies worldwide navigate an era of unprecedented environmental change.

CONTRIBUTORS

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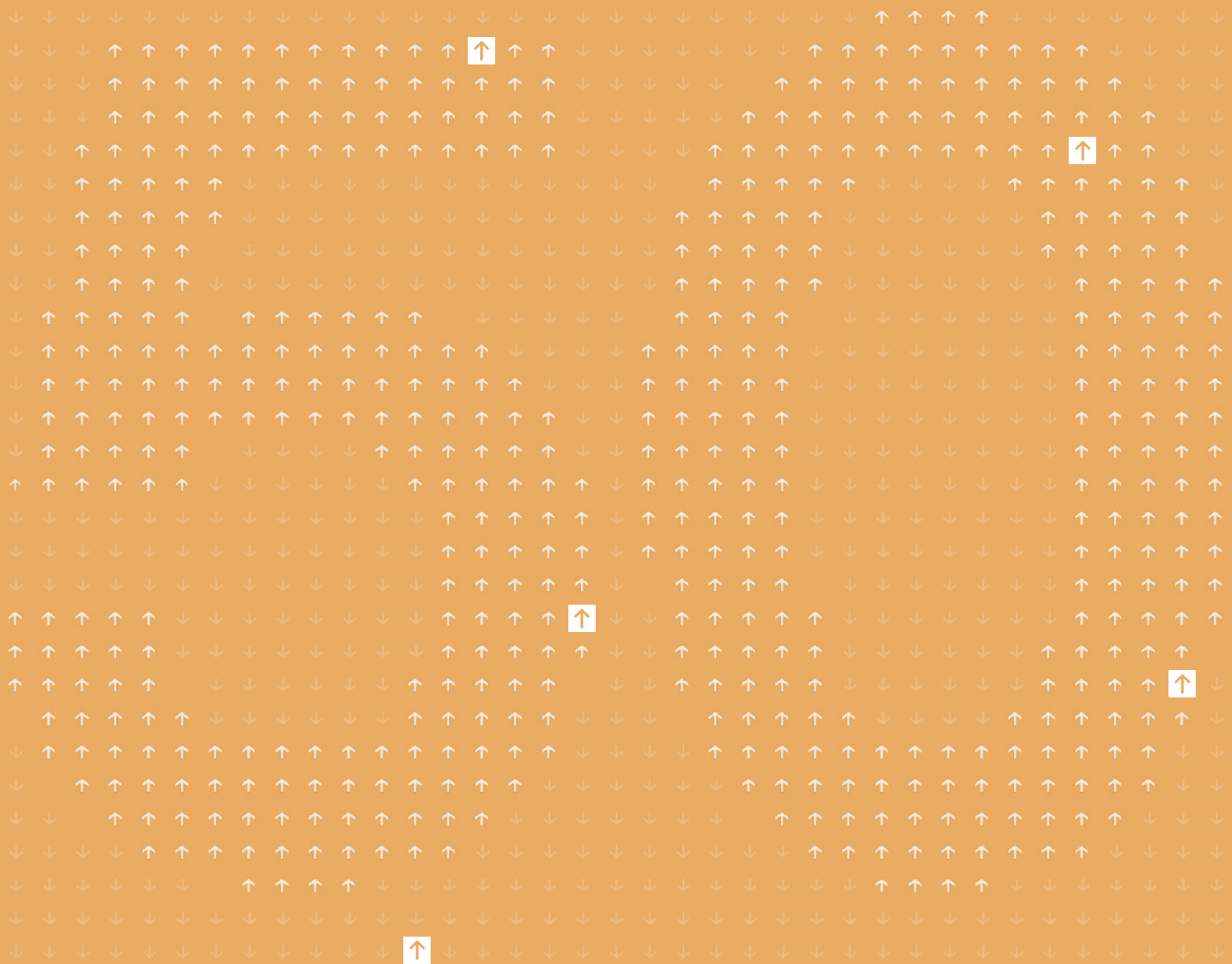

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