Copernicus: the European Earth Observation programme

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Copernicus, probably the world's most ambitious environmental satellite programme to date, is the European effort, building on the research and development investments in Earth observation over several decades, to create an operational system capable of collecting a comprehensive set of parameters to help us check the health of our planet, and identify, respond and adapt to global phenomena like climate change.

This long-term commitment started in May 1998 when a group of experts and Space Agencies representatives met in Baveno, Italy, and initiated the creation of an operational environmental monitoring programme so that Europe could play a major role in handling worldwide environmental and climate issues.

The overall programme is led by the European Union (EU), represented by the European Commission (EC), with the European Space Agency (ESA) as main partner and coordinator of the space component, along with the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), and the European Environment Agency (EEA), the European Centre for Medium-Range Weather Forecast (ECMWF) and other European institutions as entrusted entities for the core services.

The Copernicus Space Component includes dedicated satellites called Sentinels, which are being developed specifically to meet the Earth Observation needs of the Copernicus users. The six Sentinel satellite families include high-resolution multi-spectral cameras, radar imaging systems as well as specialised sensors for the measurements of sea/land topography, atmospheric composition and surface temperature:

- **Sentinel-1**: comprises a C-band SAR sensor to provide a high revisit time all-weather day-and-night supply of radar imagery and ensures continuity of ERS/Envisat SAR data. It supports services related to the monitoring of Arctic sea-ice extent, routine sea-ice mapping, surveillance of the marine environment including oil-spill monitoring and ship detection for maritime security, monitoring of land-surface for motion risks and mapping to support humanitarian aid and crisis relief actions. The first spacecraft was launched in 2014 and the second one in 2016, leading to an average revisit time of 6-day worldwide with the two-satellite constellation.
- **Sentinel-2**: comprises a high spatial resolution multi-spectral (13 bands) optical sensor, to provide continuity of SPOT- and Landsat-type data for services related to, for example, land management by European and national institutes, the agricultural industry and forestry, as

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well as disaster control and humanitarian relief operations. The first unit was launched in 2015 followed by its twin in 2017, ensuring a 5-day revisit time over continental land surfaces with the two-satellite constellation.

- **Sentinel-3**: comprises a suite of instruments to measure different parameters like sea-surface topography, sea- and land-surface temperature as well as high-spectral-resolution optical imagery of land and ocean surfaces (also known as ocean colour for the latter), with high accuracy and reliability in support of ocean analysis and forecasting systems and for environmental and climate monitoring. The two spacecraft, ensuring the different required revisit times for the different observations with the two-satellite constellation, were launched in 2016 and 2018.
- **Sentinel-4/-5**: this mission will use data at high temporal and spectral resolution from two imaging spectrometer instruments to be embarked on EUMETSAT satellites (Meteosat Third Generation and MetOp-SG satellites, at geostationary and polar orbits respectively), together with the data of other instruments on such satellites, in order to derive products for services to monitor air quality, stratospheric ozone, solar radiation and climate. A Sentinel-5 precursor mission was also developed and launched in 2017 in order to fill the gap in atmospheric composition sensing after Envisat's end of life.
- **Sentinel-6/Jason-CS**: will carry a radar altimeter to provide high-accuracy observations of the topography of the global ocean in order to provide continuity with the Jason series of ocean topography satellites. This information is essential for the continued monitoring of changes in global sea level, a key indicator of climate change, and also contributes to operational oceanography. The first satellite – Sentinel 6 Michael Freilich – is planned to be launched in November 2020, with the second to follow in 2025.

These space-based observations are also complemented by the so-called Contributing Missions, i.e. missions owned by national agencies or commercial entities which make some of their data, complementary to that from the Sentinels, available to Copernicus. Furthermore, an integrated Ground Segment ensures access to Sentinels and Contributing Missions data and completes the Space Component, which is co-funded by ESA and the EU. ESA, as coordinator and system architect of the CSC, develops, launches and operates the Sentinel satellites with EUMETSAT as partner.

The European Commission, acting on behalf of the EU, is in charge of leading the programme overall, including the space component, the In-Situ Component and the Services. The In-situ Component, under the coordination of the EEA, is composed of atmospheric and Earth based monitoring systems, and based on established networks and programmes at European and international levels.

Figure 1. Overview of the current Sentinels family with main applications. Credits: ESA.

Figure 2. This mosaic of cloud-free images from the Copernicus Sentinel-3A satellite spans the entire continent of Europe and more. This image is made up of scenes captured between 1 March 2017 and 30 July 2017, demonstrating the dryness experienced in regions including Spain, Italy and Turkey. Credits: Contains modified Copernicus Sentinel data (2017), processed by Sinergise/ESA, CC BY-SA 3.0 IGO.

The wealth of data from the Copernicus satellites, along with some in-situ data, feeds a range of value-added information services. The Services Component covers six thematic domains: ocean, land, atmosphere, emergency response, climate change and security which allow public and private users to use Copernicus data to tackle a wide range of societal challenges:

- The **Copernicus Land Monitoring Service** provides geographical information on land cover and its changes, land use, vegetation state, water cycle and earth surface energy variables to a broad range of users in Europe and across the world. It supports applications like spatial and urban planning, forest management, water management, agriculture and food security, nature conservation and restoration, rural development, ecosystem accounting and mitigation/adaptation to climate change. It is jointly implemented by the EEA and the EC Directorate General Joint Research Centre (JRC) and has been operational since 2012.
- The **Copernicus Marine Environment Monitoring Service** provides regular and systematic reference information on the physical and biogeochemical state, variability and dynamics of the ocean and marine ecosystems for the global ocean and the European regional seas. The observations and forecasts produced by the service support all marine applications, including: marine safety, marine resources, coastal and marine environment, weather, seasonal forecasting and climate. The implementation of this service has been, in 2014, entrusted to Mercator Ocean International and is operational since 2015.
- The **Copernicus Atmosphere Monitoring Service** provides continuous data and information on atmospheric composition and supports many applications in a variety of domains including health, environmental monitoring, renewable energies, meteorology and climatology. It focuses on five main areas: air quality and atmospheric composition, ozone layer and ultra-violet radiation, emissions and surface fluxes, solar radiation and climate forcing. The implementation of this service has been, in 2014, entrusted to the ECMWF (European Centre for Medium-Range Weather Forecast) and is operational since 2015.
- The **Copernicus Climate Change Service** supports society by providing authoritative

Figure 3. The city of Valencia is visible in the centre of the image, acquired by Sentinel-2 on 9 August 2017, flanked by the Mediterranean Sea on one side and overlooked by the mountains of Sierra Calderona to the north. Just 10 km south of the city, this true-colour image shows us the Albufera freshwater lagoon in green. Separated by a narrow strip of coastline featuring sand dunes and Mediterranean pine forest, three canals connect the lagoon and surrounding wetlands with the sea. Credits: Contains modified Copernicus Sentinel data (2017), processed by ESA, CC BY-SA 3.0 IGO.

information about the past, present and future climate in Europe and the rest of the world. Its mission is to support adaptation and mitigation policies of the EU by providing consistent and authoritative information about climate change. It is implemented by the ECMWF on behalf of the EC and is operational since 2018.

- The **Copernicus Emergency Management Service** provides all actors involved in the management of natural disasters, man-made emergency situations, and humanitarian crises (mainly Civil Protection Authorities and Humanitarian Aid Agencies) with timely and accurate maps and early-warning geo-spatial information derived from satellite remote sensing and completed by available in situ or open data sources. The service has been operational since 2012 and it is implemented by the EC DG JRC.

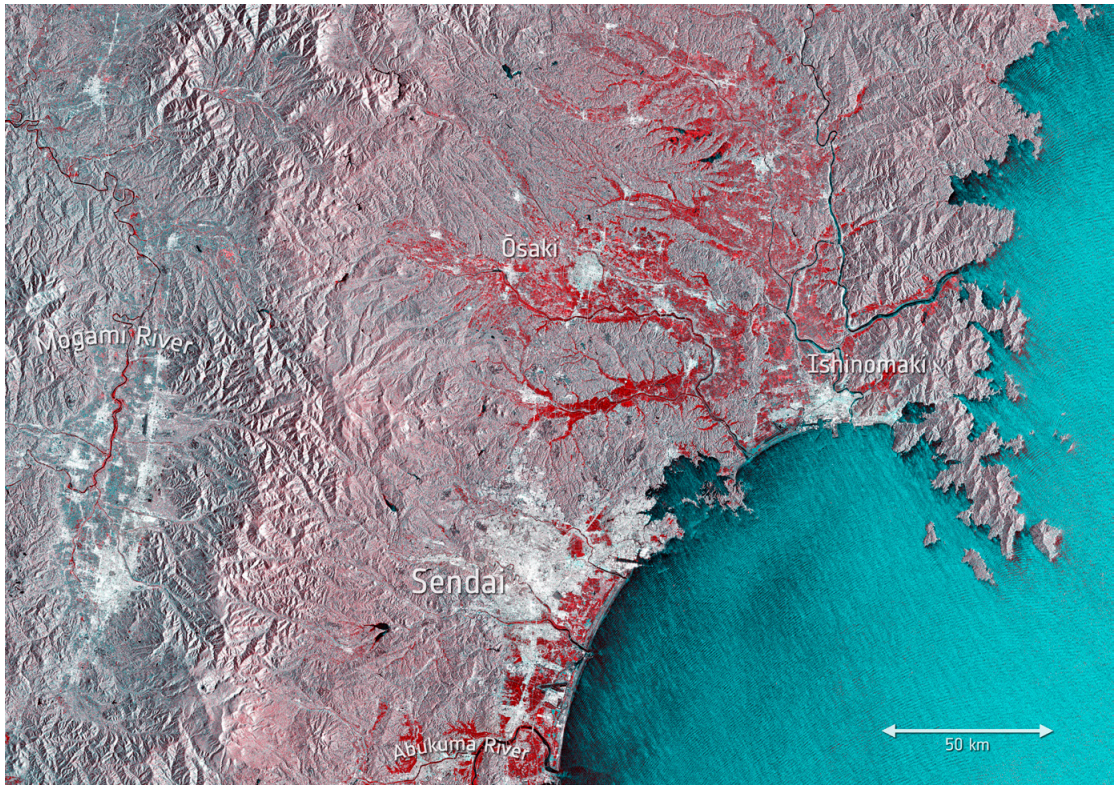


Figure 4. This image shows the extent of flooding on Japanese main island of Honshu, north east of Tokyo. Captured by the Copernicus Sentinel-1 mission, the floods are visible in red around the cities of Sendai and Ishinomaki on 12 October 2019. Credits: Contains modified Copernicus Sentinel data (2019), processed by ESA, CC BY-SA 3.0 IGO.

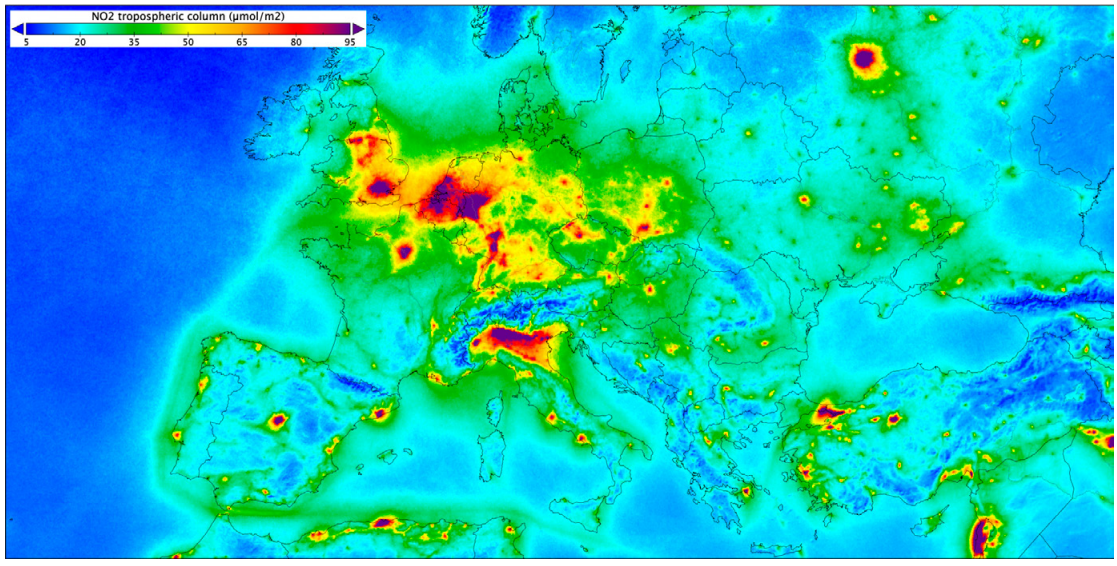


Figure 5. Based on measurements gathered by the Copernicus Sentinel-5P mission between April 2018 and March 2019, the image shows nitrogen dioxide over Europe. Nitrogen dioxide pollutes the air mainly as a result of traffic and the combustion of fossil fuel in industrial processes. It has a significant impact on human health, contributing particularly to respiratory problems. Credits: Contains modified Copernicus Sentinel data (2019), processed by ESA, CC BY-SA 3.0 IGO.

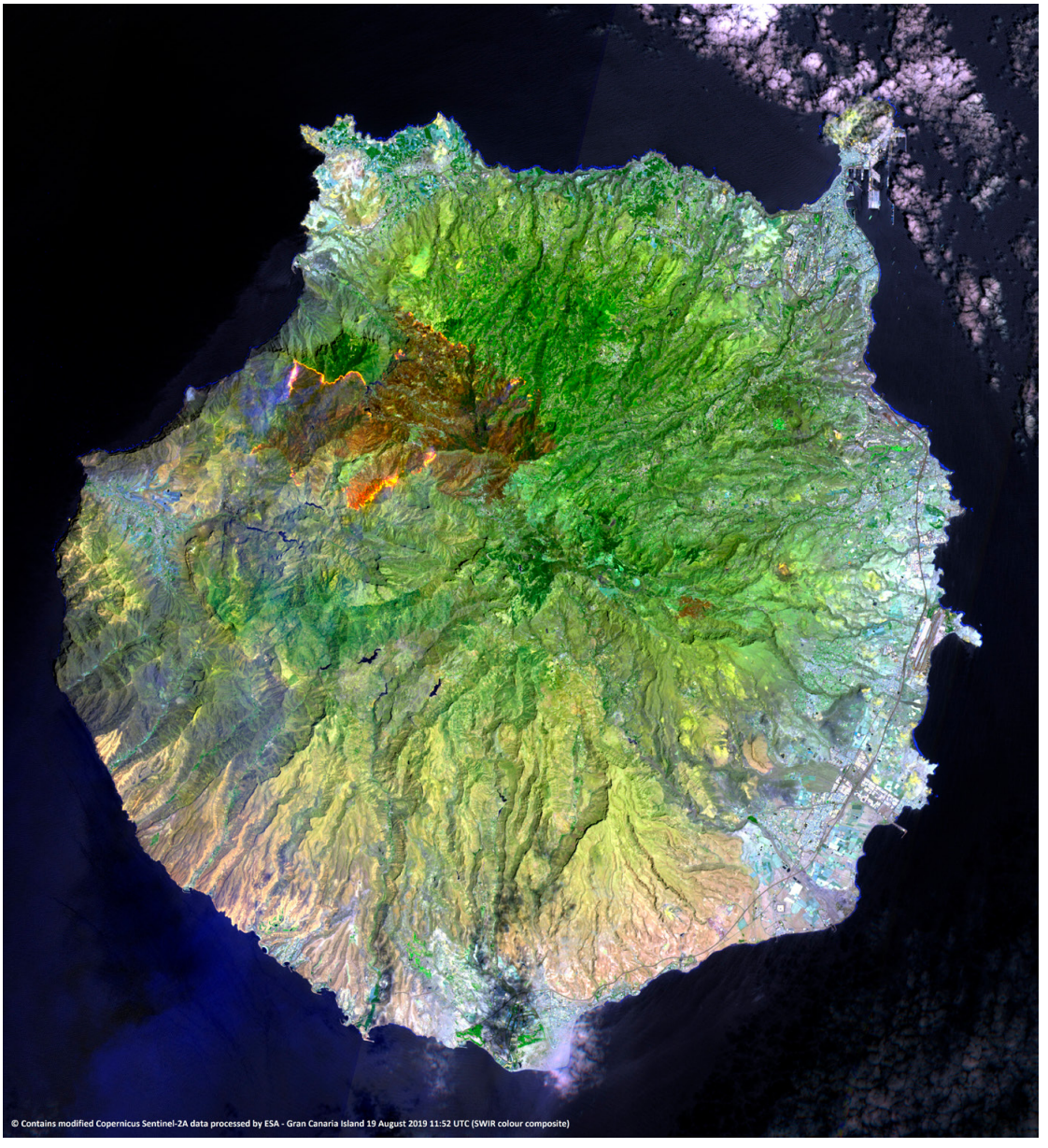


Figure 6. An unprecedented wildfire ripped through the island of Gran Canaria, one of Spanish Canary Islands off the northwest coast of Africa. The wildfire, which started on Saturday 17 August, has now started to subside after engulfing around 10 000 hectares of land, leading to the evacuation of over 9000 people. This false colour image, captured on 19 August, was created using the shortwave infrared bands from the Copernicus Sentinel-2's instrument, and allows us to clearly see the fires on the ground in bright orange. Burn scars are visible in dark brown. These bands also allow us to see through smoke but not clouds. Credits: contains modified Copernicus Sentinel data (2019), processed by ESA, CC BY-SA 3.0 IGO.

- The **Copernicus service for Security applications** aims to support EU policies by providing information in response to Europe's security challenges. It improves crisis prevention, preparedness and response in three key areas: Border surveillance, entrusted to FRONTEX (European Border and Coast Guard Agency) in 2015, Maritime surveillance, entrusted to EMSA (European Maritime Safety Agency) in 2015, and Support to EU External Action, entrusted to the European Satellite Centre (EU SatCen) in 2016.

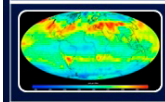
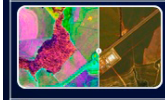
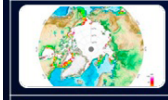
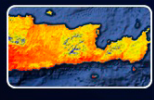
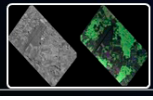
Sentinels High Priority Candidate Missions		Applications
	CO2M: Anthropogenic CO_2 Monitoring	Climate change (causes)
	CHIME: Copernicus HyperSpectral Imaging Mission for the Environment	Services for food security, agriculture management, soil and mineral resources
	CIMR: Copernicus Imaging Microwave Radiometer	Sea surface temperature, sea ice concentration & extent, sea surface salinity, soil moisture
	LSTM: Copernicus Land Surface Temperature Monitoring	Thermal Infrared observations over land & coastal regions for Agriculture & Urban management services
	CRISTAL: Copernicus PolaR Ice & Snow Topographic Altimeter	Climate change (effects), e.g. sea-ice thickness and snow depth, surface elevation and changes of glaciers
	ROSE-L: Radar Observing System for Europe L-band SAR	Forests, Agriculture and high-resolution monitoring of Arctic & Cryosphere, services in Disasters & Geohazards monitoring

Figure 7. Overview of the 6 future Copernicus High Priority Candidate Missions and main applications. Credits: ESA.

The launch of the first dedicated satellite, Sentinel-1A, in 2014, marked the beginning of the Copernicus operational phase. Access to Copernicus Sentinel data is governed by the Sentinel data policy, adopted in 2013, which ensures full, free and open access, thus seeking to stimulate downstream value-added EO-related business. All this data is made available globally through data hubs managed by ESA. Also, since mid-2018, the EC DIAS (Data and Information Access Service) initiative, managed by ESA and EUMETSAT, has allowed several commercial consortia to set up cloud processing platforms, which make access to Copernicus data far easier in order to boost the creation of new business models based on Earth Observation.

With the current configuration, an uninterrupted delivery of Copernicus data to users is guaranteed until at least 2035. In the meantime, Copernicus is evolving to respond to the dynamics of the EU policies' priorities and to the new societal needs and challenges requiring new observations. During the last two years, new user and observation requirements, supported by an observation gap analysis, have been identified. This has led to the investigation and design of new domains/techniques in an effort to provide long-term continuity and enhancements of current observational data on one side (i.e. Sentinels Next Generation), and also to complete the initial needs with innovative missions to tackle emerging and urgent needs for new types of observations (i.e. Sentinels High Priority Candidate Missions). The future Copernicus satellite missions will include greenhouse gases emissions tracking, polar ice/ocean microwave imaging radiometry and interferometric altimetry, thermal infrared imaging, soil moisture, surface deformation and hyper-spectral land imaging.

The Copernicus programme, with seven Sentinel satellites and over 40 contributing missions in orbit and many others to arrive in the future, with more than 350000 self-registered Sentinel data users on the EU/ESA Copernicus data portal and billions of indirect users of geospatial information apps using Copernicus, and delivering tens of terabytes of daily operational data and information services openly and freely in a wide range of environmental areas, is giving new insights into the state of the land, sea and air. It provides policymakers, scientists, businesses and the public with accurate and timely information on the status of our planet Earth. And with the future evolution of the programme it will help us check the 'pulse' of our planet for the decades to come.