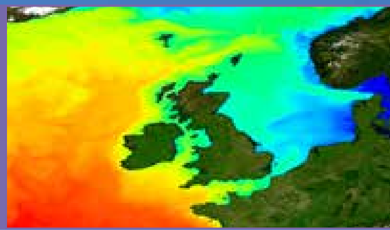
OPERATIONAL OCEANOGRAPHY @EUMETSAT

DELIVERING INTEGRATED MARINE OBSERVATIONS



MONITORING WEATHER AND CLIMATE FROM SPACE

EUMETSAT

COMMITTED TO THE DEVELOPMENT OF OPERATIONAL OCEANOGRAPHY

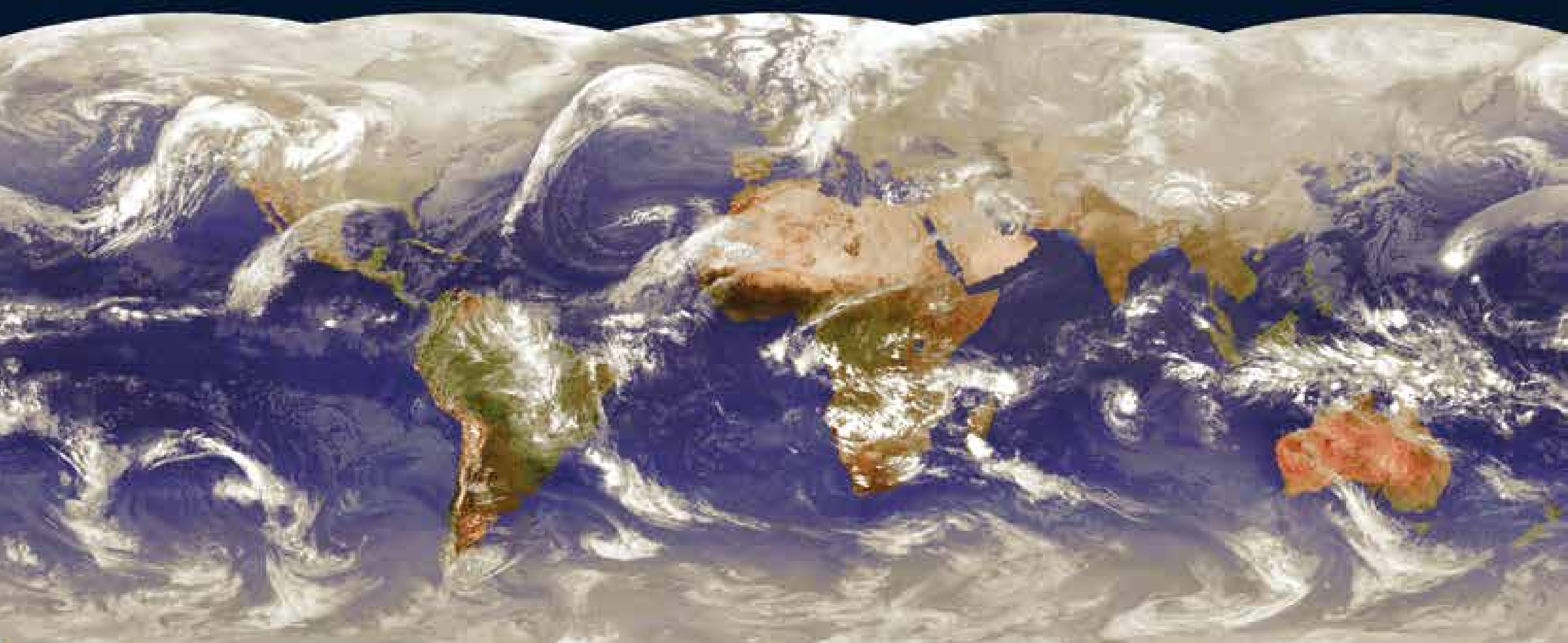
More than 70% of the Earth's surface is covered by oceans, which play a key part in shaping our weather and climate and are also a driver of the global economy

A recent European study estimated that if all economic activities that depend on the sea are counted, then the European Union's "blue" economy represents 5.4 million jobs and a gross added value of just under €500 billion per year. Whether it is shipping, fishing, offshore energy or coastal tourism, all marine economic activities are sensitive to the vagaries of ocean conditions, which is why reliable, up-to-date oceanographic data and forecasts are vital.

Operational oceanography, like operational meteorology, is about delivering relevant and reliable information services to citizens and decision-makers, about the past, current and future state of the seas and ocean, at global, basin and coastal scales. This encompasses systematic and long-term routine observations of the ocean and surface weather, real-time processing and distribution of data products, their ingestion into ocean models - or other systems exploited by service providers - and, ultimately, delivery of information services to users. In many cases, end-users expect both oceanographic and meteorological information, which calls for an integrated approach to observing systems and real-time data services.

As the global ocean is even more difficult to observe *in situ* than the atmosphere, the initial development of operational oceanography has largely been stimulated by the advent of ocean observing satellites, starting with infrared imagery from meteorological satellites. The major breakthrough was the development of satellite altimetry, in the 1980s, followed by more accurate observations of sea surface temperature (SST) and the first observations of ocean colour.

Today, satellites play a key role in operational oceanography because they provide continuous, long-term global observations of the physical and biological state of the ocean and of the atmospheric parameters (wind, radiative fluxes, and precipitation) that drive its variability. Satellites are indeed a unique source of highly accurate global measurements of sea state and ocean surface winds, sea level, SST, ocean colour and sea ice. The integration of their observations with equally indispensable *in situ* observations from buoys, ships, ARGO floats, etc., and ocean modelling opened up the possibility of ocean monitoring and forecasting at global, basin and coastal scales.



This possibility has now become a reality in Europe, thanks to the stimulus of the European Union Copernicus[1] flagship Earth Observation Programme, which has established the operational Copernicus Marine Environment Monitoring Service (CMEMS).

EUMETSAT has already been contributing to the development of operational oceanography through the delivery of a range of ocean products to the CMEMS and its user community. This includes data and products from the Jason-2 satellite - jointly exploited with NOAA[2] , CNES[3] and NASA[4] - from EUMETSAT's own Metop and Meteosat satellite series and from missions of its international partners. These products are extracted by EUMETSAT's central facilities in Darmstadt, Germany, its Satellite Application Facility on Ocean and Sea Ice (OSI SAF) and CNES's AVISO system, and are delivered in real time via the EUMETCast satellite broadcast service and offline via the EUMETSAT Earth Observation Portal.

This role is continuing to expand in the context of the EU Copernicus Programme and further cooperation with the United States. In partnership with CNES, NOAA and NASA, EUMETSAT is delivering data to Copernicus from the Jason-3 ocean altimetry satellite, the fourth in the series of US/European cooperative missions that together have built up a time series of global mean sea level that dates back to 1992. EUMETSAT is also developing the ground segment of the follow-up Sentinel-6/Jason-CS (Continuity of Service) mission implemented in partnership with ESA, NASA, NOAA, CNES and the EU.

The EU has also entrusted EUMETSAT with the task of exploiting, in cooperation with ESA, the Copernicus Sentinel-3 marine mission, and thus, after the launches of the Jason-3 and Sentinel-3A satellites in early 2016, EUMETSAT is now delivering, on behalf of the EU, a broader range of highly accurate ocean surface topography, sea surface temperature and ocean colour products from a constellation of ocean monitoring satellites composed of Sentinel-3 and Jason satellites. These data services will be enhanced in scope in 2017 when the second Sentinel-3 satellite is launched and further in 2021, when Sentinel-6/Jason-CS improves the capabilities of its Jason-3 precursor.

EUMETSAT exploits the Copernicus marine missions in synergy with its own missions to provide equal access to a unique, integrated marine data stream to all service providers and users in the EU and EUMETSAT Member States, through its EUMETCast real-time data broadcasting service and its Earth Observation Portal.

THE OCEAN AND SEA ICE SATELLITE APPLICATION FACILITY (OSI SAF)

The OSI SAF (http://www.osi-saf.org/) is one of eight thematic centres of excellence distributed across EUMETSAT Member States tasked to develop and deliver specific EUMETSAT satellite products and services.

Led by Météo-France, the OSI SAF involves Met.No (Norway), DMI (Denmark), Ifremer (France) and KNMI (the Netherlands). It delivers real-time and offline products including surface winds, sea surface temperature, radiative flux and sea ice products to the meteorological and oceanographic user communities.

[1] http://www.copernicus.eu/

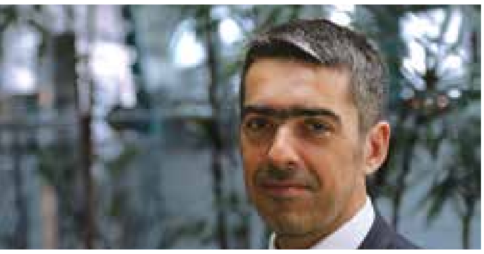
[2] National Oceanic and Atmospheric Administration

[3] Centre National d'Etudes Spatiales

[4] National Aeronautics and Space Administration

OPERATIONAL OCEANOGRAPHY IN EUROPE: THE COPERNICUS STIMULUS

The EU Copernicus Programme has brought the Copernicus Marine Environment Monitoring Service[5] (CMEMS) to operational status, as the backbone for the development of marine information services in Europe



Pierre Bahurel
Director General
Mercator Ocean

"By providing real-time and reprocessed ocean observations, EUMETSAT is a major contributor to the CMEMS. EUMETSAT data have a direct impact on service quality, as they are ingested into two-thirds of CMEMS observation products and into all our models. The development of our services will continue to depend on sea level, surface temperature, ocean colour and sea ice observations from the Jason-2 and -3, Metop, Meteosat, Sentinel-3 satellites and the future Sentinel-6."

The CMEMS provides regular and systematic reference information and forecasts on the state of the oceans and regional seas and will further develop operational oceanography in Europe. The service, which is operated by Mercator Ocean, caters for the operational needs of public and private users by providing open access to real-time information about the state of the oceans – temperature, currents, salinity, sea level, sea ice, winds, ocean optics, chemistry, biology and chlorophyll.

For this purpose, the CMEMS runs an ocean monitoring and forecasting system for the global ocean and six regional basins (North-East Atlantic, Atlantic - Iberian - Biscay - Irish, and the Arctic, Baltic, Mediterranean and Black seas), in support of the development of a broad range of applications. The system delivers ocean analyses and forecasts for the past, present and near future, based on the combined use of satellite and *in situ* observations and ocean modelling.

The CMEMS focuses on providing data in four key application areas:

MARINE RESOURCES

Real-time information is delivered for fish stock management and marine environment protection.

MARITIME SAFETY

CMEMS information is used for ship routing and safety at sea, surveillance, iceberg drift prediction, prevention of environmental risks, e.g. marine pollution.

COASTAL AND MARINE ENVIRONMENT

CMEMS information contributes to water quality monitoring and environmental impact assessment.

SEASONAL FORECASTING AND CLIMATE CHANGE

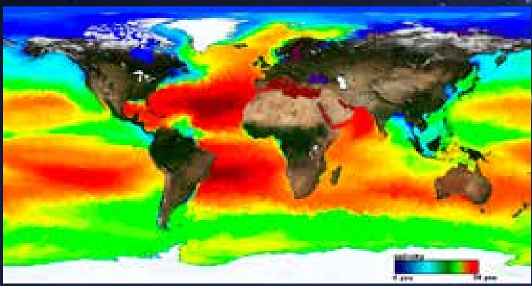
Sea level rise is monitored at global and regional scales to predict possible increases in coastal erosion and risks of flooding associated with storm surges. The CMEMS also provides inputs to seasonal forecasts delivered by the Copernicus Climate Chance Service[6] and information on phenomena such as El Niño and La Niña.

As one of the leading European operational providers of space-based observations of the ocean, EUMETSAT has been closely interlinked with the precursor MyOcean projects from the very beginning and this continues with the CMEMS, which relies on near-real-time and reprocessed observations from the Sentinel-3, Jason, Meteosat and Metop satellites.

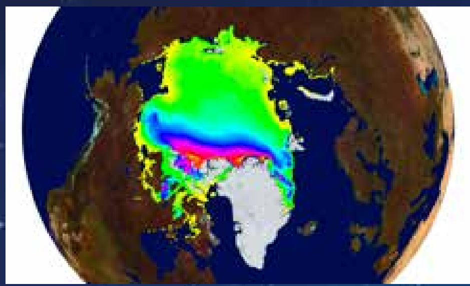
Since 2014, EUMETSAT and the CMEMS have established an Operations and Coordination Working Group addressing evolving data requirements of the CMEMS, feedback on all EUMETSAT data services including from third party missions, and coordination of training and outreach. Discussions also address comparisons between models and observations, data reprocessing requirements for climate monitoring, ocean reanalyses and joint approaches for quality assessment of Climate Data Records.

[5] *http://marine.copernicus.eu/*
[6] *http://climate.copernicus.eu/*

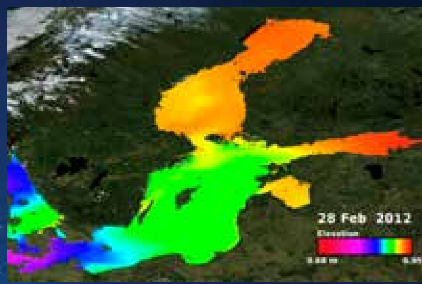
THE COPERNICUS MARINE SERVICE, A COMPREHENSIVE PORTFOLIO OF MARINE INFORMATION SERVICES



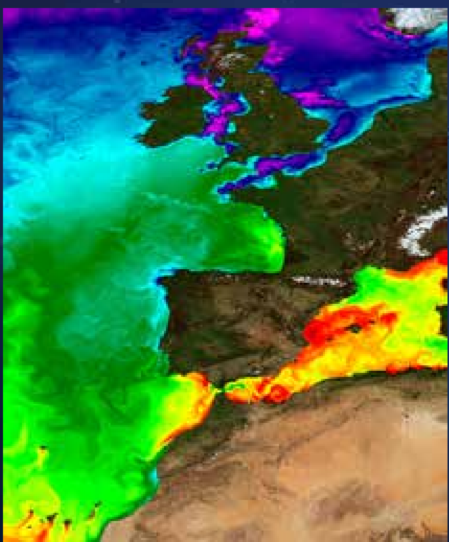
Global Ocean, Sea Surface Salinity, 2011



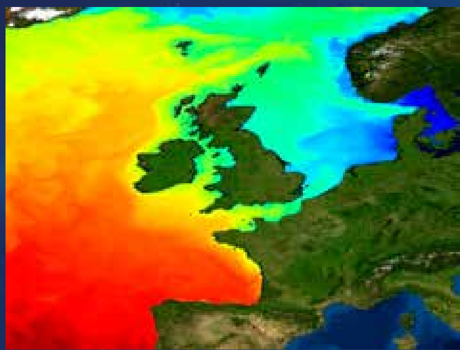
Arctic Ocean, Ice Thickness, January 2009



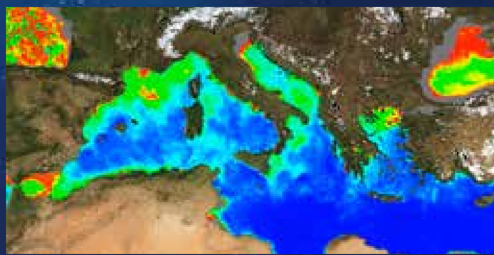
Baltic Sea, Sea Surface Height, 2010



Iberian-Biscay-Irish Ocean, Sea Surface Temperature, 2009



North West Shelf, Sea Surface Temperature, 2013



Mediterranean Sea, Ocean Colour, 2011

CMEMS SERVICE AREAS

1. GLOBAL OCEAN
2. ARCTIC OCEAN
3. BALTIC SEA
4. ATLANTIC-EUROPEAN NORTH WEST SHELF-OCEAN
5. ATLANTIC-IBERIAN BISCAY IRISH-OCEAN
6. MEDITERRANEAN SEA
7. BLACK SEA

European Union Programme

Copernicus
Europe's eyes on Earth

MERCATOR OCEAN
OCEAN FORECASTERS

EUMETSAT - A LONG-TERM OPERATIONAL PARTNER FOR COPERNICUS MARINE SERVICES AND USERS

EUMETSAT was created in 1986 as an intergovernmental organisation to establish, maintain and exploit operational systems of European meteorological satellites, starting with the first generation of Meteosat satellites

The Meteosat, Metop and Jason-2 satellites in orbit

Since its creation, the organisation has evolved into a user-governed operational space agency delivering a wide portfolio of satellite data and support services for monitoring the atmosphere, the ocean and the climate, based on long term, multi-satellite programmes. More than 25 years of successful cooperation with the European Space Agency, involving also a highly competitive European space industry, have made Europe the world leader in satellite meteorology.

With a second generation of Meteosat and the first EUMETSAT Polar System (EPS), EUMETSAT is also a trusted global partner for other operators of operational environmental satellites in the USA, China, India, Russia, Japan and South Korea, with which it coordinates satellite operations and exchanges data and expertise under the auspices of the World Meteorological Organization.

In 2000, the founding convention of EUMETSAT was revised to expand its mandate to climate monitoring and detection of climate change. This was in recognition that modern meteorology, like climate monitoring, requires more than observations of the atmosphere, and that the existence of EUMETSAT as an organisation along with its infrastructure and its long-term commitment were assets for cost efficient monitoring of climate from space. One goal was then to foster the synergies between spaced-based observations of weather, atmospheric composition, ocean and climate, and to encourage their best possible use by a broader range of user communities.

The new ruling Convention also opened the possibility for optional and third party programmes addressing requirements not fulfilled by the mandatory Meteosat and Metop series. Not surprisingly, the first two optional programmes were dedicated to oceanography and climate monitoring, covering EUMETSAT's participation in the Jason-2 and Jason-3 missions, both implemented in partnership with NOAA, CNES and NASA, with the support of the European Commission for Jason-3.

EUMETSAT AND COPERNICUS

Involved from the very beginning in the discussions which brought Copernicus into existence - starting with the Baveno Manifesto in 1998 - EUMETSAT has also invested in the programme's development phase, contributing in particular to the Copernicus-funded, ESA-led development of the Sentinel-3 ground segment, under the first third party programme approved by its ruling Council.

EUMETSAT also contributes to establishing the follow-on Sentinel-6/Jason-CS (Continuity of Service) cooperative mission, together with ESA, NASA, NOAA and the European Commission, under a dedicated Jason-CS optional programme approved in September 2015 by its Member States.

Planning for Meteosat, Metop, Jason and Sentinel-3 missions

The EUMETSAT Jason-CS programme covers the system activities, the development of the ground segment and co-funding of the second of the pair of Jason-CS satellites with the EU.

The main role of EUMETSAT in Copernicus is in the area of operations, data and support services, through the tasks entrusted by the European Union under the Agreement signed on 7 November 2014 with the European Commission.

After the successful launch of Sentinel-3A on 16 February 2016, EUMETSAT's role is to operate the satellite and deliver the marine mission on behalf of the EU, in cooperation with ESA. EUMETSAT is also delivering data to Copernicus from the Jason-3 ocean altimetry satellite, and will also exploit the follow-on Sentinel-6/Jason-CS satellites in the 2020-2035 timeframe. Thus EUMETSAT will deliver marine data and support services from a constellation of ocean monitoring satellites until 2035 - starting with Sentinel-3A and Jason-3, and continuing with up to four Sentinel-3 satellites and Sentinel-6/Jason-CS - and also from its own satellite missions.

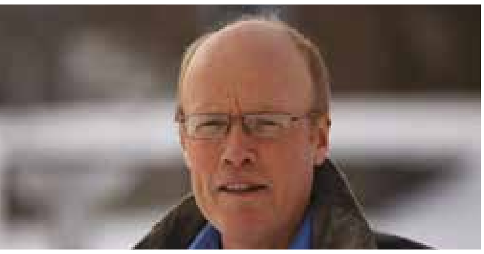
The long-term perspective is not only based on the Sentinel-3 and Sentinel-6/Jason-CS missions, but also on the committed continuation of the EUMETSAT Meteosat and EPS/Metop series until at least 2040. Following the launches of Meteosat-10 and Metop-B in 2012 and Meteosat-11 in 2015, the current generation will continue to deliver ocean data services until at least 2025, overlapping over a couple of years with the first satellites of the new Meteosat Third Generation (MTG) and EPS Second Generation (EPS-SG) systems, expected to be launched around 2020. Both new systems will deliver observations over two more decades, with enhanced ocean capabilities.

Signature of the Copernicus Agreement with the EU on 7 November 2014

The aim of EUMETSAT is to combine EUMETSAT's and the Copernicus marine missions to support the development of operational oceanography in Europe, in a true, multi-decadal operational perspective, in full synergy with meteorology. The ultimate goal is to offer all service providers and users in the Member States of the EU and EUMETSAT equal access to a multi-mission marine data stream, through existing EUMETSAT dissemination channels, in order to create the broadest possible range of opportunities.

EUMETSAT'S METOP SERIES: A CLOSE VIEW OF THE OCEAN SURFACE

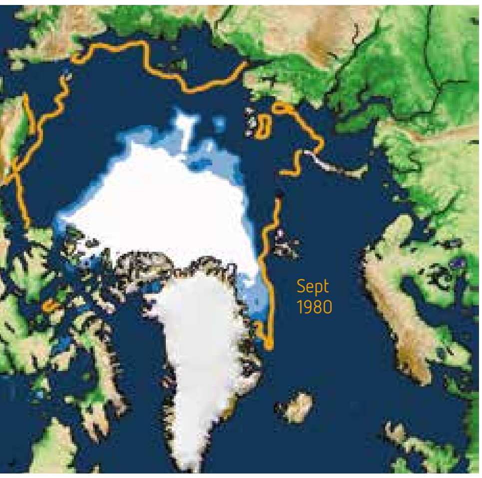
As part of the EUMETSAT Polar System, the Metop satellites provide global observations of sea surface wind, sea ice and sea surface temperature and collect *in situ* observations of the ocean through the ARGOS system



Lars Anders Breivik
Met.no

"We are using satellite data for ocean monitoring and in particular sea ice monitoring. We make daily high-resolution sea ice charts using Metop AVHRR data together with satellite radar data. These products are used for ship navigation, planning, and all kinds of activity close to the ice border."

Arctic minimum sea ice extent, 15 September 2012. Orange outline shows minimal extent in September 1980 (source: OSI SAF)



Launched sequentially, Metop-A, -B and -C operate at 817 km above the Earth in a sun-synchronous, mid-morning orbit. Metop-A, launched in 2006, has now exceeded its design lifetime, triggering the launch of Metop-B in 2012. Metop-C is scheduled for launch in October 2018. The Metop satellites will provide continuous data until at least 2025, at which time the Metop Second Generation satellites will have taken over for another two decades.

A GLOBAL OCEAN OBSERVATION CAPABILITY

The Metop satellites carry two main instruments relevant to operational oceanography:

- the Advanced Scatterometer (ASCAT) is a multi-beam C-band imaging radar measuring the radar signal backscattered by the ocean and ice surfaces, from which ocean surface wind and sea ice extent and type are extracted by the EUMETSAT SAF on Ocean and Sea Ice;

- the Advanced Very High Resolution Radiometer (AVHRR) is a visible and infrared imager with one-kilometre resolution - first flown on the NOAA TIROS-N satellite in 1978 - which is used to extract sea surface temperature products.

A third instrument, the Infrared Atmospheric Sounding Interferometer (IASI) is also used to extract sea surface temperature at lower resolution, and provides a highly accurate reference source for cross-calibrating geostationary thermal infrared imagery.

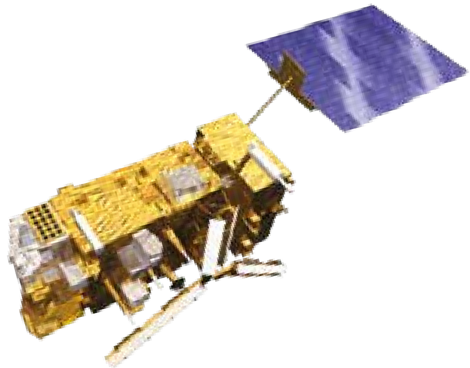
Global products from all Metop instruments are disseminated in real time to users worldwide.

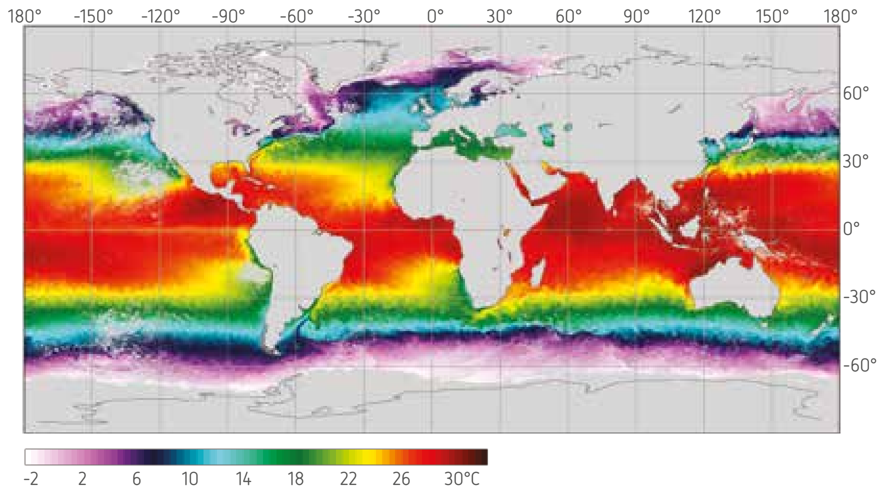
Global wind products are delivered in real time to users in two grids, with 12.5 km and 25 km sampling. The coastal product with 12.5 km sampling provides the most detailed information near the coasts, where winds are variable and high winds can generate large waves and storm surges.

Ocean surface wind data are used directly or assimilated by Numerical Weather Prediction (NWP) models which produce surface wind analyses and forecasts. These forecasts are in turn used to drive ocean models capable of forecasting sea state, storm surges, transport and dispersion of oil spills and wind-driven currents in the upper ocean. Forecasts of surface weather and ocean conditions are then used in combination to support navigation, offshore industries, marine renewable energy, fisheries, pollution control and coastal protection.

ASCAT measurements are also used to deliver crucial information on sea ice extent and type, to a range of applications, such as ship routing and climate research.

OSI SAF ASCAT 12.5 km winds (red), with a Meteosat infrared image and Numerical Weather Prediction model winds (blue)





Global sea surface temperature derived from Metop AVHRR observations - 10 day synthesis (source: OSI SAF)

The ARGOS receivers on board Metop are provided by the French Space Agency (CNES), as one of the main assets of the ARGOS system. They collect *in situ* observations of the three-dimensional ocean, acquired by buoys, profiling floats, etc., which, together with satellite observations, are vital input to ocean models and forecast services.

THE 2020-2040 PERSPECTIVE: EPS SECOND GENERATION

In the 2020-2040 timeframe, the EPS Second Generation system will simultaneously exploit two different and complementary satellites: a sounding and optical imaging Metop-SG-A satellite and a microwave imaging satellite, Metop-SG-B, both flying on the same mid-morning orbit as the current Metop satellites.

All ocean observation capabilities available on the current Metop satellites will be continued, enhanced and augmented.

The METImage advanced visible and infrared imager (on board Metop-SG-A) will have more spectral channels and better resolution (500 meters) than AVHRR, delivering higher resolution and more accurate sea surface temperature and sea ice data plus new ice parameters.

The SCA scatterometer (on board Metop-SG-B) will observe ocean surface backscatter, wind and sea ice at higher spatial resolution than ASCAT, and, thanks to the dual polarisation of one of its three antennas, will deliver accurate wind vector measurements even for very high speed winds.

ARGOS platforms in operation over the Atlantic Ocean and Mediterranean Sea, June 2015 (source: CLS)

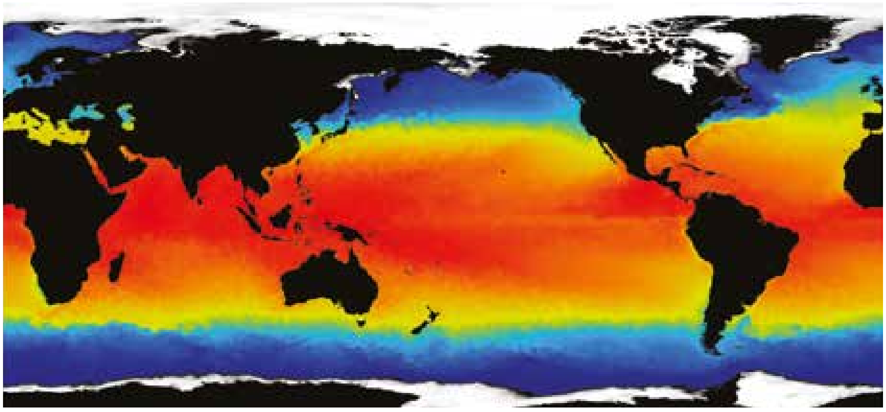
Also on Metop-SG-B, the MWI microwave imager will add a capability that is not available on the current Metop, to measure precipitation over the sea, an important component of the freshwater flux at the ocean surface, as well as sea ice concentration.

Finally, a fourth generation of ARGOS receiver will be embarked on Metop-SG-B.

Artist impression of Metop-SG satellites in orbit (source: ESA)

THE POTENTIAL OF THE GEOSTATIONARY ORBIT: METEOSAT

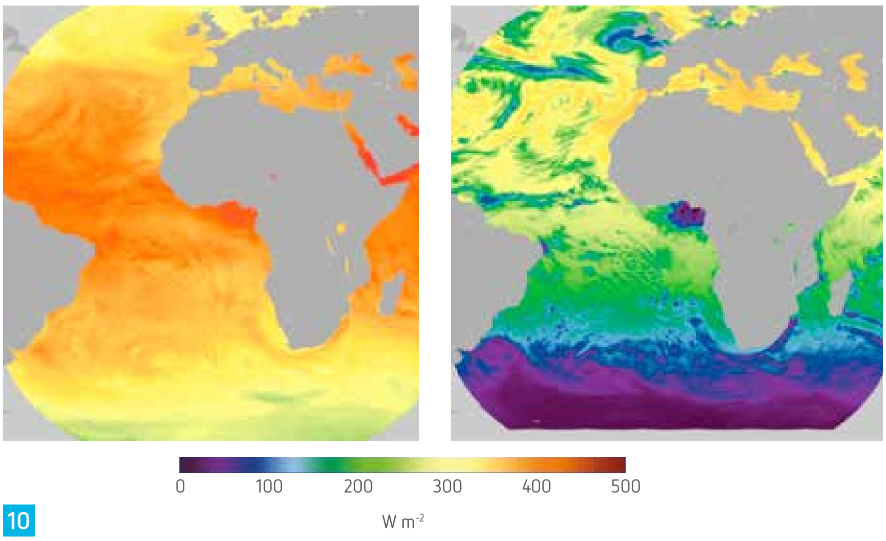
The geostationary orbit has a unique potential for operational oceanography in the open ocean and coastal zone, because it allows very frequent observations, every 5 to 15 minutes



High-resolution (~ 5 km) global daily analysis of the sea surface temperature including observations from Meteosat and polar orbiting satellites as produced by the Operational Sea Surface Temperature and Sea Ice Analysis (OSTIA) system

Incoming long wave (left) and solar (right) fluxes at the ocean surface (in W m^{-2}), integrated over 24 hours, as extracted from Metosat imagery for 14 June 2012 (source: OSI SAF)

Despite the lower spatial resolution achievable from 36,000 km above the Earth, the ability to collect very frequent observations is a distinct advantage. First, more cloud-free observations of sea surface temperature can be acquired, taking advantage of the fast movement of clouds, and, secondly, it is possible to estimate parameters such as the solar and radiative fluxes at the air-sea interface, which together with surface winds and precipitation, drive ocean circulation. Last but not least, the geostationary orbit is extremely promising for coastal oceanography, as only geostationary spacecraft can deliver observations at the high frequency required to sample the fast variability of coastal circulation.



EUMETSAT operates Meteosat Second Generation (MSG) as a two-satellite system, with one satellite making observations of the full Earth disk every 15 minutes, and the second scanning part of the North Atlantic Ocean, Europe and adjacent seas every five minutes.

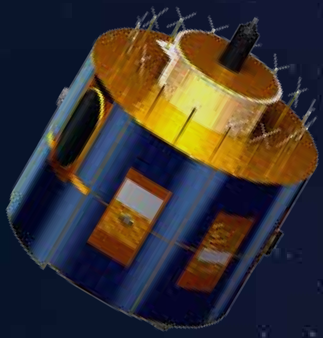
The MSG Spinning Enhanced Visible and Infrared Imager (SEVIRI) delivers fast imagery in 12 spectral channels, including thermal infrared channels that have a typical spatial resolution of 0.05 degrees (~5 km) over the Atlantic Ocean and the Mediterranean Sea.

SEA SURFACE TEMPERATURE

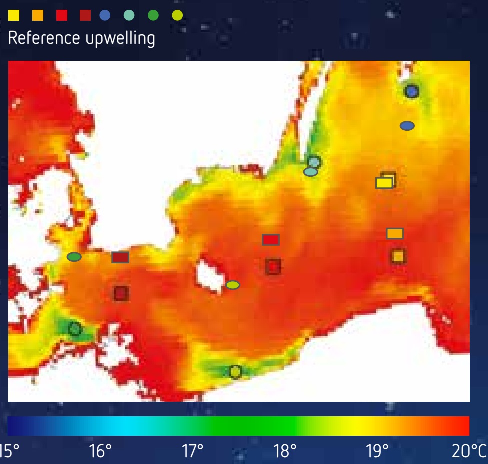
SST information is extracted every hour and can be combined with finer-scale but less frequent data from polar-orbiting satellites and *in situ* data to create operational, high resolution, multi-mission global SST products.

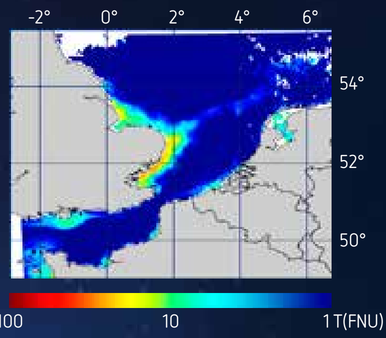
RADIATIVE AIR-SEA FLUXES

The frequent SEVIRI visible and infrared imagery, and the consequent possibility to observe the same pixel in cloudy and clear conditions at relatively short intervals, allows the estimation of the effect of clouds on incoming solar radiation, and the extraction of solar flux available at the air-sea interface to heat the upper layers of the ocean, an important parameter for operational oceanography. Likewise, based on modelling of the radiative properties of clouds in the infrared spectrum and on external information on the vertical profile of temperature in the troposphere, it is possible to extract estimates of incoming long wave fluxes. These parameters, together with the SST, document the three components of radiative fluxes at the air-sea interface.



Meteosat infrared imagery used to study coastal upwelling in the Baltic Sea , with cold sea surface temperature signatures depicted in green (left, source: IOPAS) and visible imagery used to detect total suspended matter (TSM) in turbid waters (right, Courtesy of G. Neukermans, RBINS/MUMM)

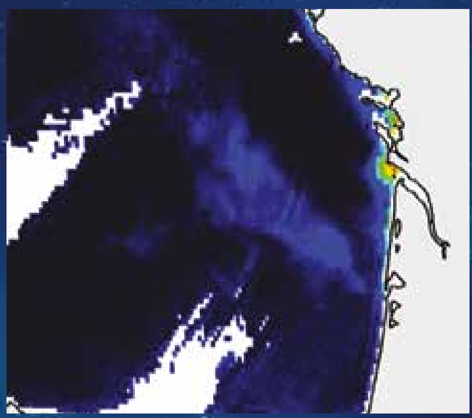




EXPLORING THE POTENTIAL OF METEOSAT FOR COASTAL OCEANOGRAPHY

The high frequency of Meteosat observations also enables scientists to observe daily variations in SST in coastal areas. For example, a recent research project has used resampled Meteosat imagery to map SST in coastal areas of the Baltic Sea to monitor coastal upwelling.

Likewise, although SEVIRI was not designed to observe ocean colour, studies in the southern North Sea have shown that its imagery can be used to map fast variations of total suspended matter (TSM) in turbid waters. This is of high interest in many coastal regions because of the link with sediment transport problems (dredging, dumping, and geomorphology) and due to the impact of TSM on the availability of light to coastal ecosystems. Other studies have demonstrated the capability to map algal blooms.



Algae (Coccolithophore) bloom extracted from a series of frequent (15 minutes) Meteosat images showing the value of accessing more cloud-free images, as clouds move across the Meteosat field of view.

THE 2020-2040 PERSPECTIVE: METEOSAT THIRD GENERATION

Meteosat Third Generation, currently under development with ESA, will be operated as a three-satellite system involving two different satellites, MTG-I for the enhanced imaging mission and MTG-S for the new sounding mission. The first MTG-I satellite is expected to be operational in 2020 and the first MTG-S will follow two years later.

The Flexible Combined Imager (FCI) embarked on the MTG-I satellites will image in 16 spectral channels at very high spatial resolutions, from 2 km to 0.5 km, and will continue the long time series of SST and flux products from the current Meteosat, with expected improvements due to more accurate, more frequent and higher resolution observations.

One MTG-I satellite will deliver full disk imagery every 10 minutes, while a second one will provide faster imagery, every 2.5 minutes, but over Europe and adjacent seas only.

The MTG-S satellite will carry an infrared sounding interferometer (IRS) operating at a horizontal resolution of four kilometres. It will deliver additional SST products at moderate resolution, benefiting from the excellent absolute infrared calibration of the instrument, and will significantly improve the accuracy of incoming long wave flux products through direct access to vertical profiles of temperature in the troposphere.

Artist impression of MTG satellites in orbit (source: ESA)

JASON-2/-3: THE REFERENCE MISSION FOR MONITORING OCEAN CIRCULATION AND MEAN SEA LEVEL

The Jason high precision ocean altimeter missions deliver reference measurements of sea surface height, an essential input to the ocean forecasting models used in operational oceanography, and monitors mean sea level variations in our changing climate

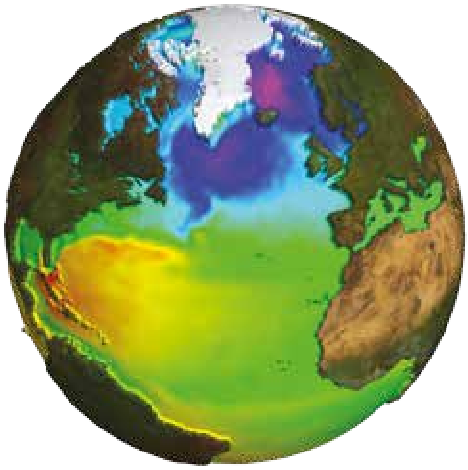
Anny Cazenave
Senior Scientist at the Laboratoire d'Etudes en Geophysique et Oceanographie Spatiale, Director for Earth Sciences at the International Space Science Institute

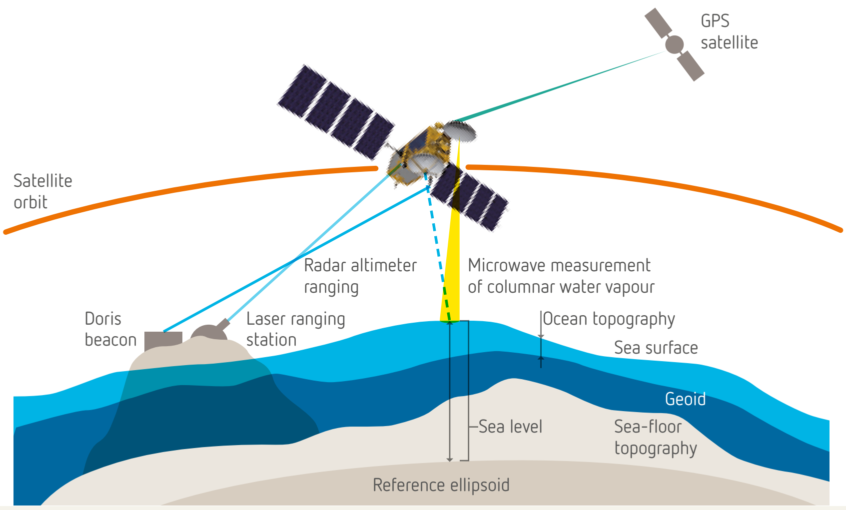
"Sea level is a key indicator of climate change as it integrates the response of several components of the climate system to continuing greenhouse gas emissions: i.e. ocean thermal expansion, glacier melting and ice mass loss from the Greenland and Antarctica ice sheets. Therefore, monitoring global mean sea level rise and its regional variations with the Jason altimeter satellite series is crucial for better understanding the response of the climate system to anthropogenic global warming and for validating climate models used for projecting future changes, especially in highly vulnerable, highly populated coastal regions."

Ocean altimetry satellites deliver one of the essential inputs to operational oceanography, as they capture, on a global scale, the signature at the ocean surface of the three-dimensional structure underneath, which cannot be resolved otherwise, due to the sparse distribution of *in situ* observations. In fact, observations of ocean surface topography are as important as observations of surface pressure in meteorology, and are used in advanced ocean models to forecast the three-dimensional ocean circulation, a major building block of any operational ocean information service.

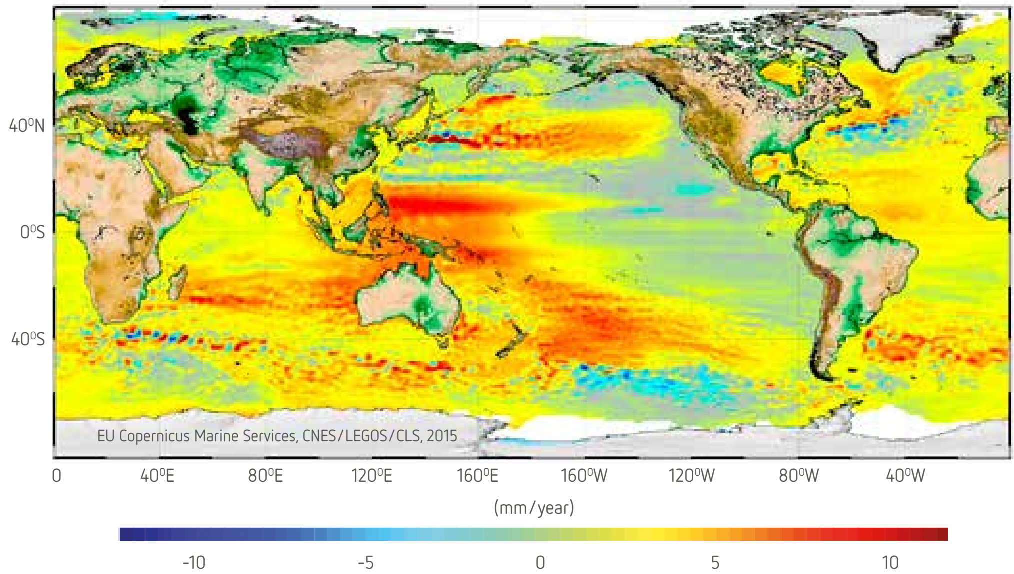
HOW OCEAN ALTIMETRY WORKS

The altimeter sends microwave pulses to the ocean surface and measures the time it takes for the signals to return. After correction of delays caused by the ionosphere and troposphere, using the dual frequency capability of the altimeter and water vapour measurements from a co-flying microwave radiometer, this data is then used to calculate the distance between the satellite and the surface of the ocean. Combining the result with the precise location of the spacecraft estimated using the DORIS, GPS and laser retro-reflector systems makes it possible to determine the topography of the ocean surface in a fixed geocentric referential, and to estimate sea state and surface wind speed as by-products.





Principle of altimeter measurement (bottom left), and sea surface height derived from ocean altimetry satellites plotted on a 3D globe (top)



Map of regional trends (1993 - 2015) of mean sea level extracted from Topex/Poseidon and Jason altimetry data (source: EU Copernicus Marine Services, CNES/LEGOS/CLS)

Estimates of mean sea level and its variations in space and time can also be derived from the most accurate altimeter measurements of sea surface height, like those of Jason-2/-3. This information is invaluable to shed light on a major impact of climate change and is also essential for adaption policies in coastal areas threatened by sea level rise.

The Jason satellites are the continuation of the existing successful cooperation between the USA and Europe on high-precision altimetry, involving EUMETSAT, NOAA, CNES and NASA.

Jason-3 was launched on 17 January 2016 to fulfil the Ocean Surface Topography Mission (OSTM), aimed at expanding the series of high-precision data initiated in 1992 by Topex-Poseidon and continued by the earlier Jason-1 and Jason-2 satellites. The Jason-3 satellite is the result of an international partnership between EUMETSAT, the French Space Agency (CNES), the US National Oceanic and Atmospheric Administration (NOAA), the US National Aeronautics and Space Administration (NASA), and the European Union, which funds European contributions to Jason-3 operations as part of its Copernicus Programme.

Orbiting at an altitude of 1,336 km on a dedicated non-synchronous orbit that avoids aliasing of low frequency signals by tidal signals, the Jason satellites provide the most accurate measurements of sea surface topography available for operational oceanography and sea level monitoring. Combining data from the CNES- and NASA-provided instruments, sea surface topography can be estimated to an unprecedented accuracy of a few centimetres.

Therefore, Jason data also provide the indispensable reference against which measurements of all other altimeter missions (e.g. SARAL, HY-2 and Sentinel-3) can be cross-calibrated, to ultimately form the bias-free multi-mission altimeter product ready for ingestion by CMEMS and other ocean models.

Mauro Facchini
Head of Copernicus Unit
DG GROW
European Commission

"Jason-3 is an important mission for Copernicus, being a reference for cross-calibration of other ocean altimeter missions including Sentinel-3, to generate global bias-free sea surface topography multi-mission products that can be assimilated into ocean models like those operated by the CMEMS."

EUMETSAT

JASON-2/-3: THE REFERENCE MISSION FOR MONITORING OCEAN CIRCULATION AND MEAN SEA LEVEL

Gerrit Burgers
Climate Researcher

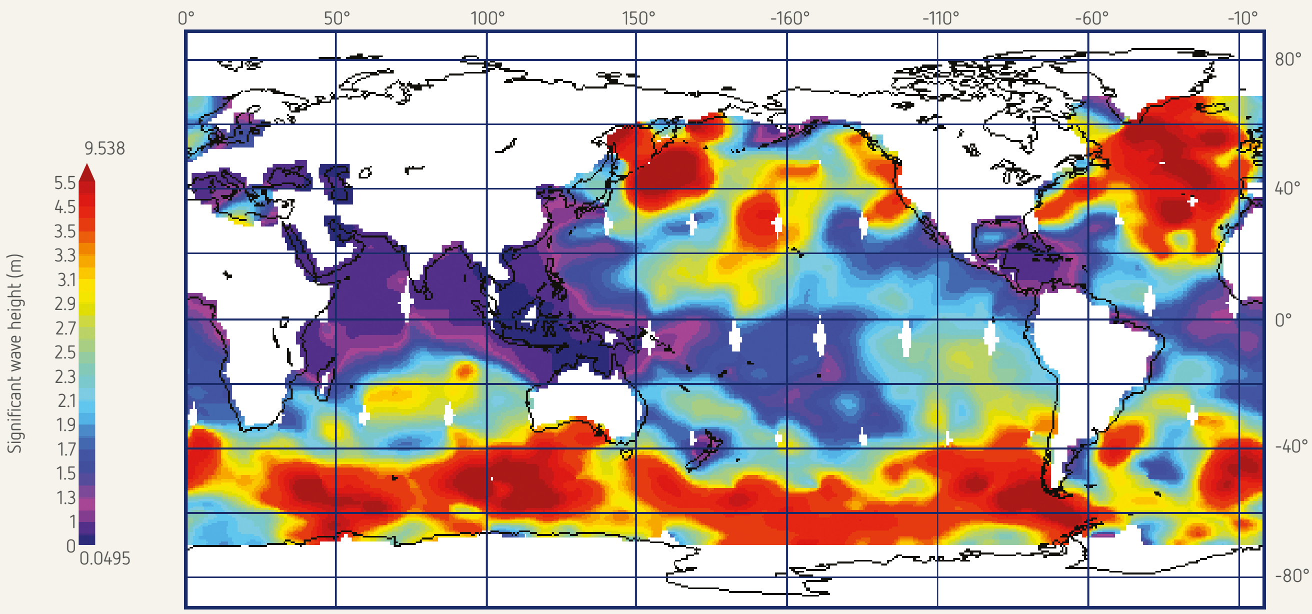
"The Dutch policy is to prevent flooding, now and in the future. This means detecting sea level trends along our coast amid large short-term fluctuations. Only the continuation of highly accurate sea level measurements from Jason will allow us to quantify sea level rise quickly, gaining precious time to respond."

EUMETSAT, CNES and NOAA process data from Jason-3, with EUMETSAT being responsible for data services to users of the EUMETSAT and EU Member States, on behalf of the EU Copernicus Programme. Data access in Europe is secured via the multi-mission infrastructure available at EUMETSAT and CNES, including EUMETSAT's EUMETCast real-time data dissemination system, Earth Observation Portal and archives, as well as CNES's AVISO data system.

The three main Jason-3 products are:

- the Operational Geophysical Data Record (OGDR) disseminated to users within three hours of observation, which includes estimates of significant wave height and wind speed every five minutes.
- the Interim Geophysical Data Record (IGDR) distributed within two days of observation and provides more accurate sea surface topography data. It is ingested by operational ocean prediction models and coupled atmosphere-ocean models used for seasonal forecast, or used directly for validation of previous ocean forecasts. NOAA also uses this product to extract tropical cyclone heat potential (TCHP) in support of cyclone monitoring.
- the Geophysical Data Record (GDR) made available within 60 days is the most accurate and complete product, including fully validated sea surface height data. It is used principally for ocean reanalysis and climate monitoring, in particular for climate model verification, sea level monitoring and climate change assessment, e.g. in the context of the International Panel for Climate Change (IPCC).

Global significant wave height map using data from ocean altimetry satellites (source: AVISO)



COPERNICUS SENTINEL-3 – KEEPING AN EYE ON THE OCEANS

EUMETSAT operates Sentinel-3, with support from ESA, and delivers the marine mission

Sentinel-3 satellite, artist's impression (source: ESA, J. Huart)

The main objective of the Sentinel-3 marine mission is to monitor sea surface temperature, ocean colour, as well as ocean surface topography, in conjunction with the Jason-3 (and later Sentinel-6/Jason-CS) reference altimeter missions.

The full implementation of the Sentinel-3 mission involves an operational system of two satellites to provide global data coverage and adequate revisit frequency. Sentinel-3A was launched in 2016, and will be joined by Sentinel-3B in 2017, and then Sentinel-3C and -3D will take over from 2021 onwards.

The satellites have a design lifetime of seven years and will fly on a sun-synchronous, polar orbit at an average altitude of 815 km, carrying the following instruments:

- The dual view, nine-channel Sea and Land Surface Temperature Radiometer (SLSTR) will continue and further improve the highly accurate measurements of sea surface temperature collected by the AATSR instruments flown on ERS and Envisat, with a spatial resolution of 500 m in the visible and shortwave infrared and 1 km in the thermal infrared;
- Observing in 21 narrow spectral bands of the visible and near infrared spectrum, the Ocean and Land Colour Instrument (OLCI) will continue and expand the medium-resolution measurements (300 m) of Envisat's MERIS instrument;
- The dual-frequency Synthetic Aperture Radar Altimeter (SRAL) will provide sea surface topography measurements in "SAR mode", i.e. with a resolution as high as 300 m along track. SRAL is supported by a microwave radiometer for atmospheric correction and a precise orbit determination package composed of a DORIS receiver, a Global Navigation Satellite System and a Laser Retroreflector.

The main marine products from the Sentinel-3 satellites are sea surface temperature, ocean topography, ocean colour, ocean-surface wave and sea ice products which will be ingested in a variety of models of the open ocean and coastal areas. Applications include ocean and marine forecasting, management of marine resources and ecosystems, monitoring of water quality and pollution, sea ice charting services and ship routing.

One of the first images from the Ocean and Land Colour Instrument onboard the Sentinel-3A satellite (3 March 2016).

EUMETSAT

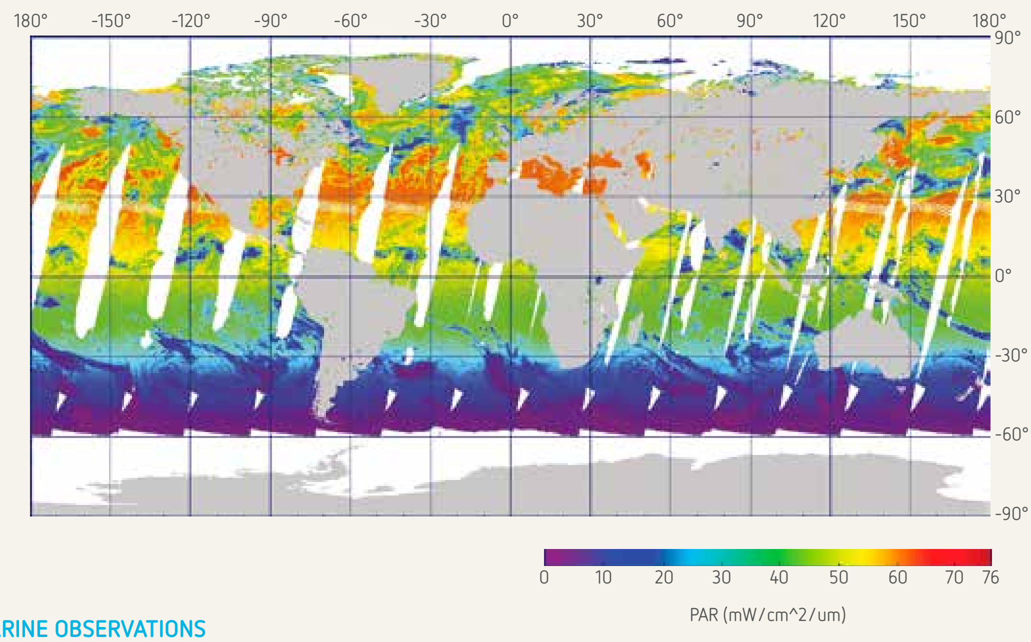
OPERATING SENTINEL-3 AND DELIVERING ITS MARINE MISSION

The SLTSR instrument provides high resolution sea surface temperature measurements and the SRAL is used to generate sea/lake surface height, significant wave height, surface wind speed and sea ice height and thickness.

Ocean colour measurements from OLCI provide global monitoring of chlorophyll-a - a proxy for phytoplankton biomass - used to estimate associated primary production. In the last decade, applications of satellite-derived ocean colour data have made important contributions to ocean biogeochemistry, physical oceanography, ecosystem assessment, fisheries oceanography and coastal management. OLCI ocean products include normalised water surface reflectance, chlorophyll-a concentration for open/coastal waters, total suspended matter (TSM), coloured detrital and dissolved material, photosynthetically available radiation (PAR), and aerosol optical depth over water.

The Sentinel-3 space and ground segments have been developed by ESA. EUMETSAT is the operator of the Sentinel-3 satellites, with the support of ESA, and is responsible for delivering the marine mission. To prepare for this role, EUMETSAT supported ESA in the development of the ground segment and preparation for operations, under a dedicated EUMETSAT third party programme funded by Copernicus.
The ground segment implemented at EUMETSAT premises includes the Flight Operations Segment required to control and exploit the Sentinel-3 satellites, and one instance of the Data Processing Ground Segment for processing their ocean observations and EUMETSAT multi-mission ground systems. EUMETSAT is delivering operational ocean data from Sentinel-3 and support services to Copernicus, based on a Copernicus Service Level Specification agreed with the European Commission.

Merged MERIS /SeaWIFS photosynthetically available radiation average, July 2003. PAR indicates the total energy available for photosynthesis, and is a key parameter for biological and ecological studies. (source: ESA)



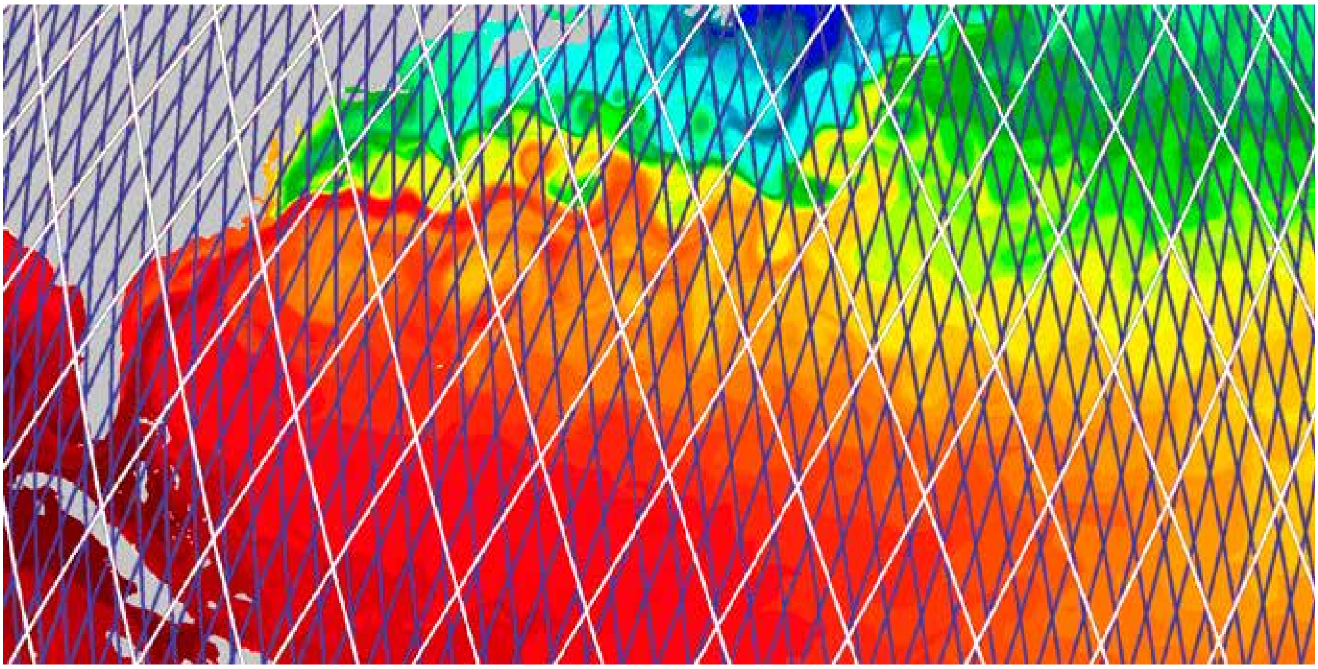
JASON-3/SENTINEL-6 AND SENTINEL-3: AN INTEGRATED COPERNICUS OCEAN ALTIMETRY CAPABILITY

Jason-3/Sentinel-6 and Sentinel-3 form the European backbone of an international virtual constellation of ocean altimeter missions

Monitoring sea surface topography and mean sea level in support of operational oceanography and climate monitoring requires a virtual constellation of altimeter missions, including one reference mission. Considering the narrow, nadir viewing beam of altimeters, a constellation of at least three satellites, with different orbits and repeat cycles, is needed to provide global coverage and to sample ocean variability at scales ranging from eddies, to large gyre currents, tropical oscillations like El Niño, and general circulation.

With the optimum combination of the Jason/Sentinel-6 reference altimeter missions and the altimeter mission of Sentinel-3, Europe, in cooperation with the United States, provides both the reference and the backbone of the virtual constellation expected to fulfil the requirements of operational oceanography and sea level monitoring in the next two decades.

The Jason satellites are required to cross-calibrate all observations from other altimeter satellites, and, on that basis, to produce a consistent, bias-free multi-mission sea surface topography product that can be ingested into ocean models like those run by CMEMS.
The satellites are equally essential to further expand the time series of mean sea level accumulated since 1992 as an invaluable climate data record, for use in climate services.



Sentinel-3 (in blue) and Jason-3/Sentinel-6/CS (white) orbital paths, superimposed on a CMEMS sea surface temperature image. The combination of cross-calibrated altimeter missions provides appropriate sampling of both the eddy circulation associated with gyre currents and ocean dynamics at the mid latitudes and of the faster large scale variations of the tropical ocean. (source: CMEMS)

JASON-3/SENTINEL-6 AND SENTINEL-3: AN INTEGRATED COPERNICUS OCEAN ALTIMETRY CAPABILITY

Remko Scharroo
Remote Sensing Scientist EUMETSAT

"After the launch of Jason-3 and Sentinel-3A in January-February 2016, we now have a full constellation of altimeter missions in orbit. After cross-calibration of these missions, we will monitor both the large scale signals like El Niño and the smaller scale eddies of the mid latitude ocean."

JASON-3

The Jason-3 programme is built on the same cooperation as Jason-2, involving EUMETSAT, NOAA, CNES and NASA. Jason-3 also involves the European Union, which funds the European operations through its Copernicus programme. ESA also contributes financially to the programme.

Jason-3 is a recurrent Jason-2 satellite, based on the same Proteus platform delivered by CNES and the same US and European instruments and provides sea surface height to an accuracy of better than four centimetres, every ten days, for a nominal lifetime of five years.

It has a key role as the reference mission against which Sentinel-3 and other altimeter mission data can be cross-calibrated. It is also the precursor to the Sentinel-6/Jason-CS (Continuity of Service) cooperative mission implemented by two successive Jason-CS satellites, which will take over from Jason-3 after 2020.

THE SENTINEL-6/JASON-CS MISSION

The Sentinel-6/Jason-CS cooperative mission will be implemented by two successive satellites and continue from 2020 to 2030 the high accuracy ocean surface topography measurements after Jason-3. Thus, with Jason-3, a Copernicus constellation of one Jason satellite and two Sentinel-3 satellites will be maintained in orbit from 2017 onwards, after the launch of Sentinel-3B.

Building on the heritage of previous Jason cooperation, the Sentinel-6/Jason-CS mission involves Europe, through EUMETSAT, ESA and the European Union, and the United States, through NASA and NOAA. Under the agreed sharing of responsibilities, EUMETSAT coordinates system activities, develops the ground segment and will exploit the European part of the system on behalf of the EU Copernicus programme.

The Jason-CS satellites are developed and procured by ESA and carry an evolution of the SRAL altimeter of Sentinel-3 that can be operated in a so-called interleaved mode, which can deliver simultaneously high resolution (300m along track) sea surface height measurements in SAR mode and the lower resolution measurements required to continue the reference Jason mission. The altimeter will be exploited together with a precision orbit determination and microwave radiometer package composed of US and European contributions.

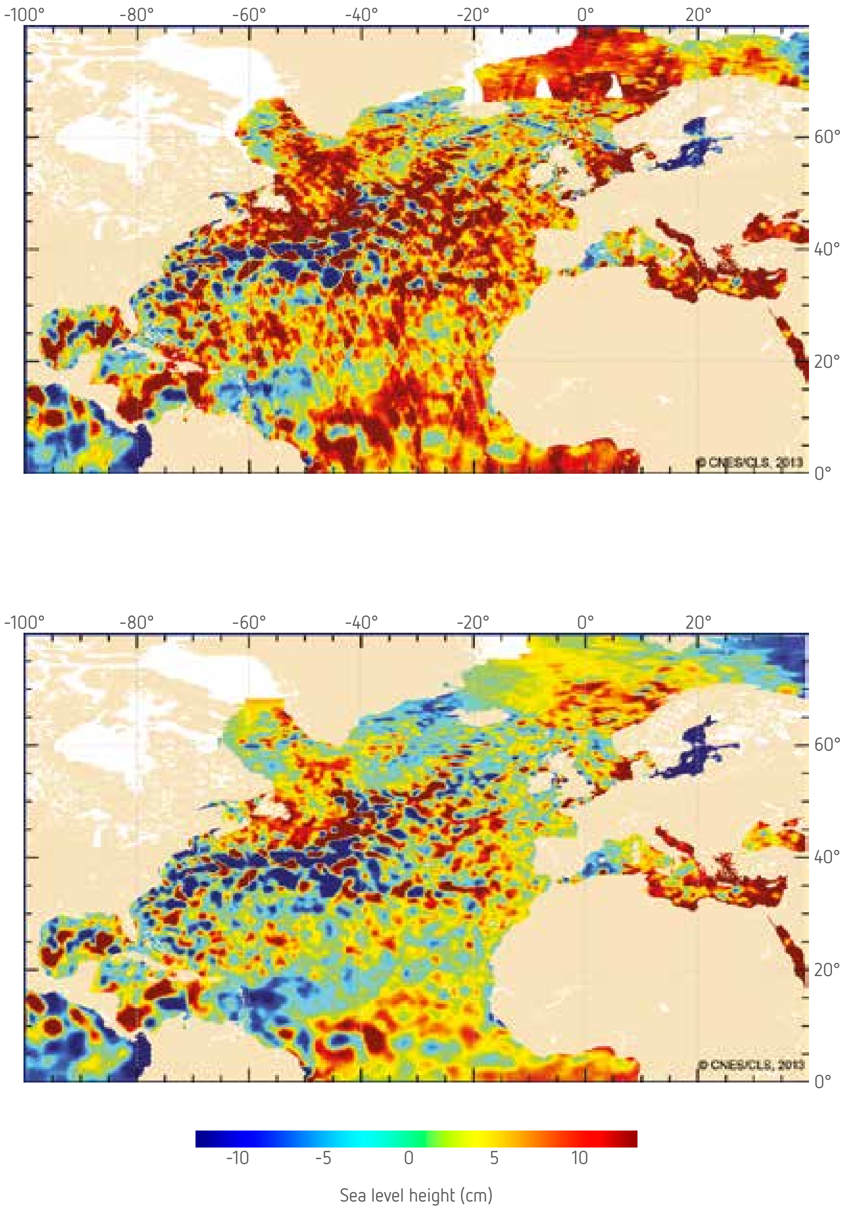
Jason-CS satellite, artist's impression (source: Airbus Defence and Space)

Thus, the Sentinel-6 mission, like Sentinel-3, will provide observations with higher resolution along track and even greater accuracy, whilst ensuring the required consistency with previous Topex/Poseidon and Jason Climate Data Records. The launch services for both spacecraft will be provided by the US, as for the previous Jason satellites.

The European contribution to the Sentinel-6/Jason-CS mission is implemented through the combination of an ESA optional programme, covering the development of the first satellite, a EUMETSAT optional programme covering in particular system activities, the development of a full ground segment and preparation for operations, and the EU Copernicus programme covering funding of operations and co-funding of the recurrent satellite with EUMETSAT.

A UNIFIED SYSTEM FOR AN INTEGRATED SERVICE

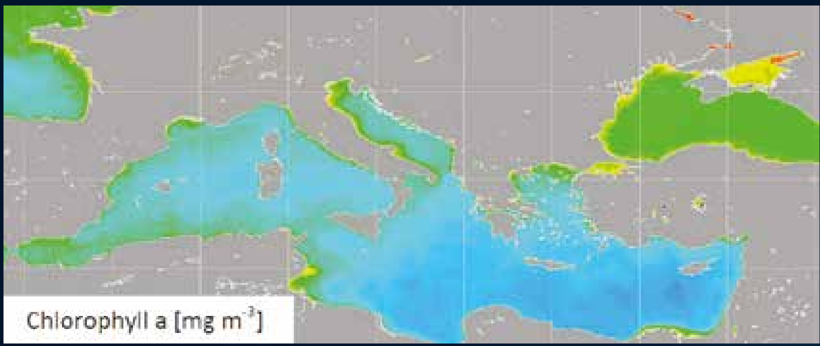
Under its optional Jason-CS programme, EUMETSAT develops the Sentinel-6 ground segment, re-using assets from the Sentinel-3 and EPS programmes and its multi-mission ground systems, to exploit Sentinel-3 and Sentinel-6 as a unified, cost-effective multi-mission system delivering a single marine data stream to users, including cross-calibrated multi-mission products.



Maps of sea level anomalies from altimetry satellites on 5 February, 2013. A map computed using Jason-2 and Cryosat missions without cross-calibration processing (top) compared to the same data cross-calibrated, with Jason-2 as reference mission (bottom). The use of a multi-mission cross-calibration process ensures that all data from all satellites provide consistent and accurate information allowing us to better retrieve ocean features and dynamics. (source: CLS)

THE BENEFITS OF EUMETSAT COOPERATION WITH OTHER SATELLITE OPERATORS

EUMETSAT exchanges data with other operators of operational satellites to offer additional opportunities for the development of operational oceanography in Europe and worldwide



New S-NPP VIIRS Ocean Colour products are now available on EUMETCast (source: NOAA)

Suomi-NPP satellite, artist's impression (source: NOAA)

This makes EUMETSAT data available worldwide, and enriches its ocean product portfolio, for the benefit of its Member States and Copernicus.

THE JOINT POLAR SYSTEM WITH THE UNITED STATES

EUMETSAT and NOAA have established an Initial Joint Polar System (IJPS) which is a truly integrated system of two operational polar-orbiting satellites flying on complementary orbits, including shared real-time data acquisition in the Arctic (Svalbard) and Antarctic (McMurdo), as well as exchange of data, products and related expertise.

Following the launch of the US Suomi National Polar Partnership (Suomi-NPP) satellite in October 2011, the IJPS is now composed of three satellites (Metop-A, Metop-B and Suomi-NPP) of the latest generation, with new observing capabilities from Suomi-NPP becoming available to EUMETSAT.

EUMETSAT disseminates meteorological products from Suomi-NPP to its Member States, and also provides sea surface temperature and ocean colour products from the Visible Infrared Imaging Radiometer Suite (VIIRS), in response to Copernicus requirements.

The successor to Suomi-NPP, JPSS-1 will be launched by NOAA on 2017 and EUMETSAT will launch Metop-C in 2018.

VIRTUAL CONSTELLATION AND DATA EXCHANGE WITH OTHER INTERNATIONAL PARTNERS

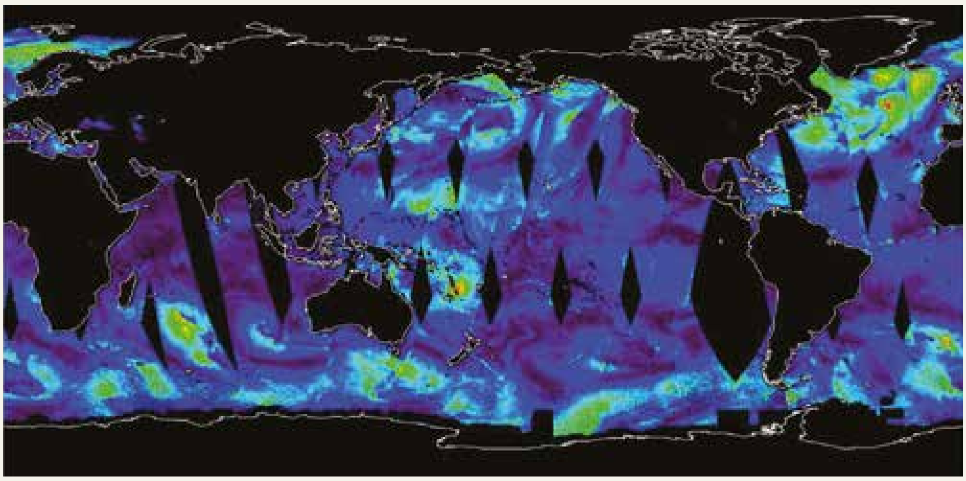
The Committee on Earth Observation Satellites (CEOS) has developed the concept of virtual constellations to coordinate missions that together meet a common set of requirements. EUMETSAT is involved in the constellations for Ocean Surface Topography, Ocean Colour Radiometry, Ocean Surface Vector Winds and Sea Surface Temperature.

To implement this concept, EUMETSAT has established cooperation with other operators of operational ocean satellites, in particular in China and India, to foster exchange of data and their use by the worldwide user communities.

As an example, EUMETSAT users have access to ocean surface topography measurements from the joint ISRO/CNES SARAL altimeter mission that was successfully launched on 25 February 2013 and is part of the Ocean Surface Topography virtual constellation. This will be one more input to the cross-calibrated multi-mission product used by CMEMS.

Another input is ocean surface wind vector, sea state, precipitation and all weather sea surface temperature products from the HY-2 series of China's State Ocean Administration (SOA), with which EUMETSAT signed a cooperation agreement in 2012.

Also, based on cooperation with NASA and JAXA (Japan Aerospace Exploration Agency) , EUMETSAT redistributes real time precipitation products from the Global Precipitation Mission (GPM) Core Observatory and the GCOM-W1 missions, as well as ocean surface wind products from the RapidScat mission implemented on the International Space Station and all weather sea surface temperature products from GCOM W1.



Ocean surface wind vector products available to EUMETSAT Member States since December 2014 from the Chinese State Ocean Administration's HY-2A satellite

DATA ACCESS: THE LAST NAUTICAL MILE TO THE USERS

Using its operational EUMETCast data broadcast service, EUMETSAT will provide equal access to all users in the EU and EUMETSAT Member States

For the delivery of products from the Copernicus Jason-3, Sentinel-3 and -6 missions as well as from its own and relevant third party missions, EUMETSAT makes optimal use of its existing multi-mission infrastructure, accessible through its Earth Observation portal and Product Navigator, connected to the EU Copernicus portal.

To meet demanding requirements in terms of timeliness as well as to deliver Copernicus data and products to all users in the EU and EUMETSAT Member States, EUMETSAT will rely primarily on its operational EUMETCast multicasting service. This service is based on European commercial telecommunication satellites and the latest Digital Video Broadcast (DVB-S2) standard.

Using technologies widely used for Digital TV broadcasting, EUMETCast delivers a wide range of meteorological and environmental satellite data to more than 4,500 users in Europe and Africa, with an average availability of 99.9 percent.

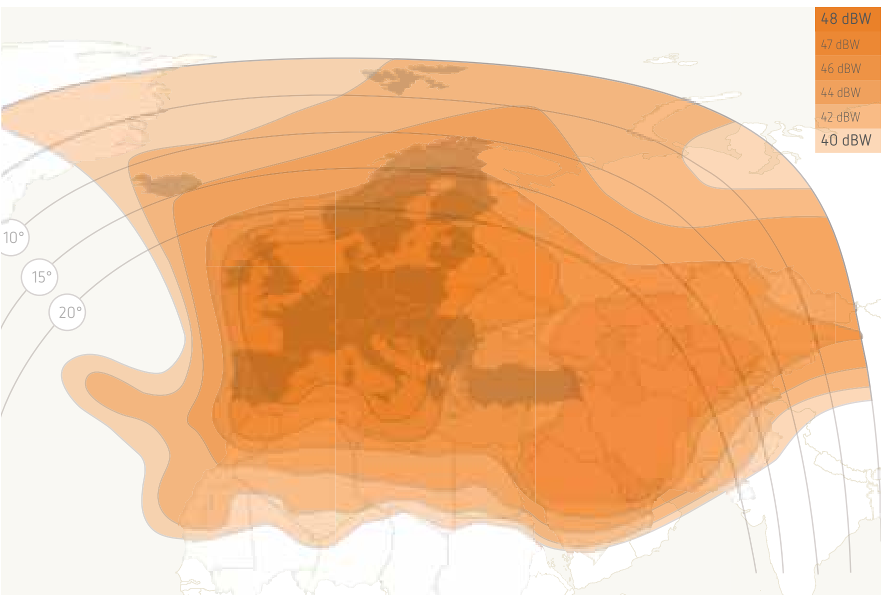
After the successful launch of Sentinel-3A, the highly scalable architecture of EUMETCast allows flexible Sentinel-3 data services (e.g. low or high volume, contents and formats) to an unlimited number of simultaneous users in the EU and EUMETSAT Member States, regardless of possible limitations of local communication infrastructures. Users only have to be equipped with a standard VSAT terminal costing less than two k€.

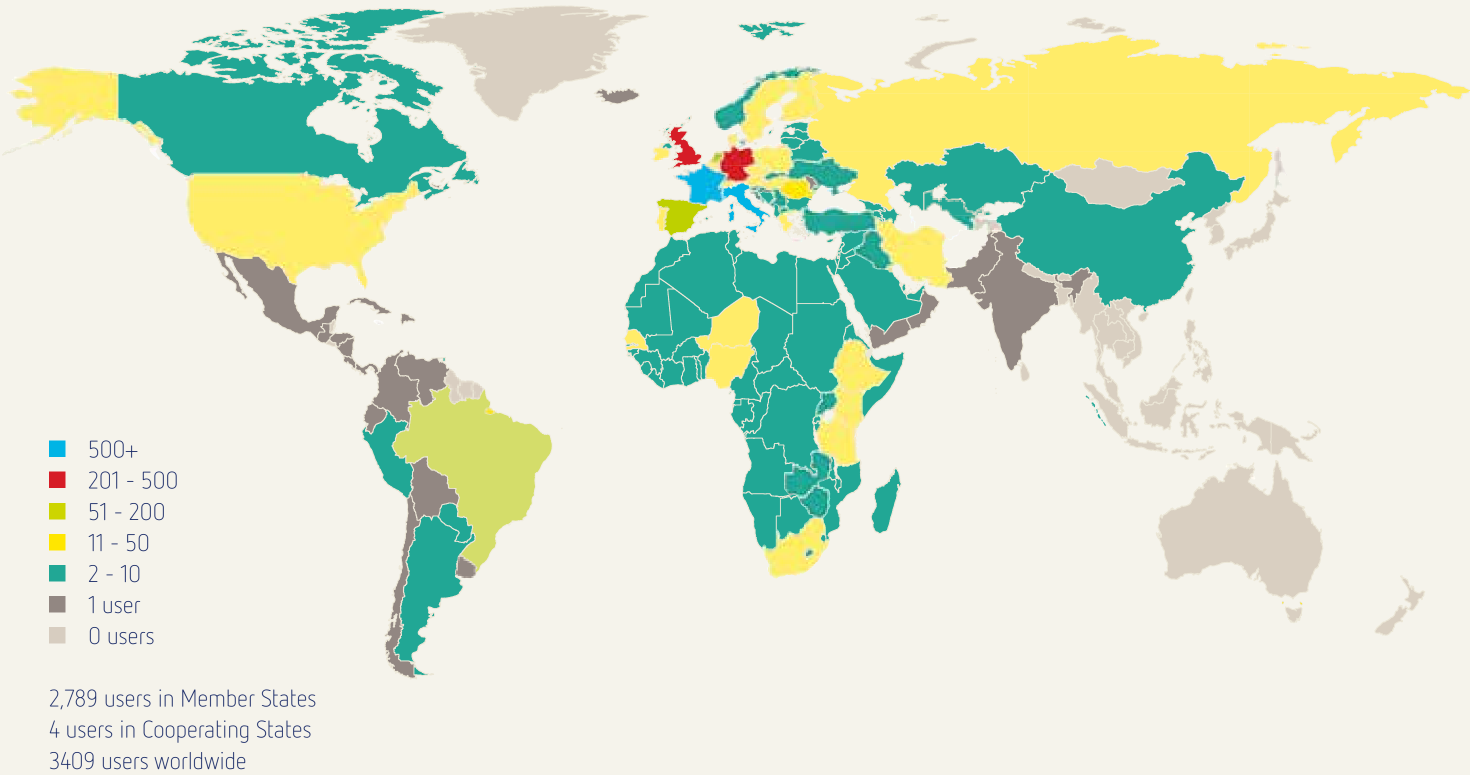
EUMETCast thus provides equal access opportunities for all Copernicus users in Europe, with possible extensions to Africa, through the existing EUMETCast-Africa service. Furthermore, EUMETCast users will receive an integrating stream of marine data to support the development of a broader range of real-time applications and downstream services.

As a complement to the EUMETCast satellite service, EUMETSAT has also developed EUMETCast Terrestrial for multicasting data via the academic infrastructure provided by GÉANT and national research network providers. To access the data via this service, users must be eligible to connect to the national research networks. EUMETCast Terrestrial can deliver high volumes of data to small user communities in Europe whenever dissemination by satellite is less appropriate, for example due to the limited number of users.

Sentinel-3 marine products will also be delivered online via the Sentinel-3 Online Data Access system accessible via the EUMETSAT Earth Observation Portal, while archived data will be accessible through EUMETSAT's Data Centre.

EUMETCast coverage over Europe, low-cost dish



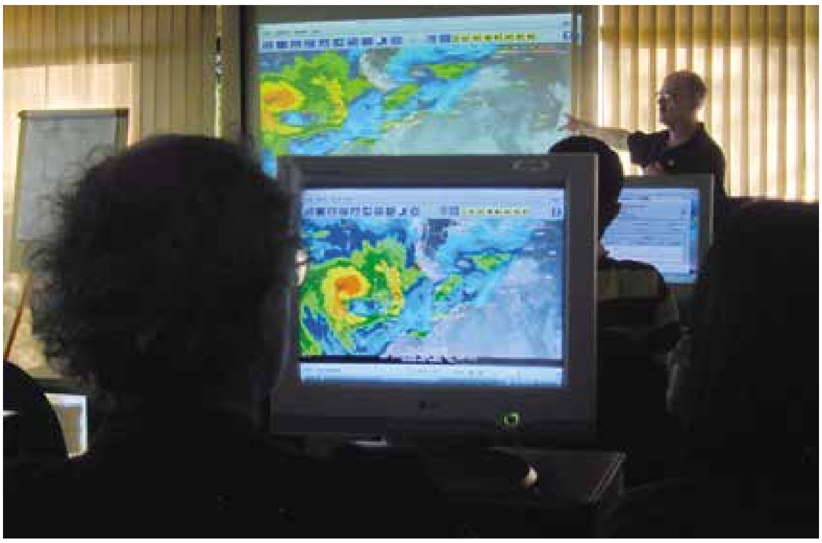


EUMETCast worldwide user distribution, December 2015

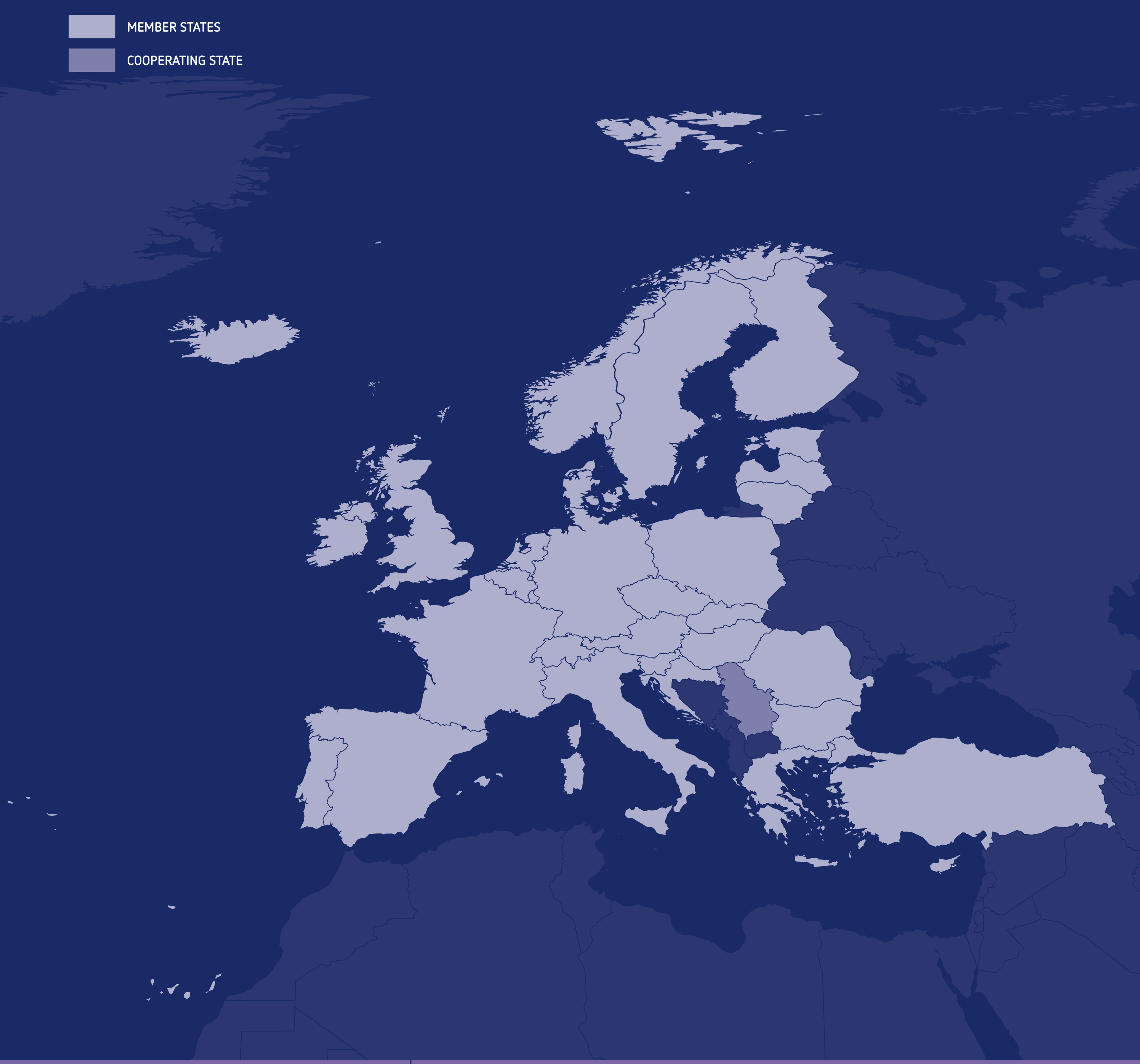
SUPPORTING USERS AND EXPANDING THE USER BASE

The full benefits of investment in advanced satellite systems can only be realised with appropriate support to user communities, including help desk services and training programmes. EUMETSAT therefore invests in these areas, together with EUMETNET and its Member States, and is one sponsor of the online training portal EUMETRAIN (www.eumetrain.org).

EUMETSAT has also organised training courses on the operational use of ocean surface wind and wave information from satellites by marine meteorologists in Europe, Africa and South America, and is working with Copernicus service providers and the EC on dedicated ocean training of interest to the marine community.



Marine training workshop on the use of satellite wind and wave products in South American waters, Brazil, 14-19 May 2012



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MEMBER STATES

COOPERATING STATE

EUMETSAT also has established cooperation agreements with organisations involved in meteorological satellite activities, including the National Meteorological Services of Canada, China, India, Japan, Russia, South Korea and USA

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