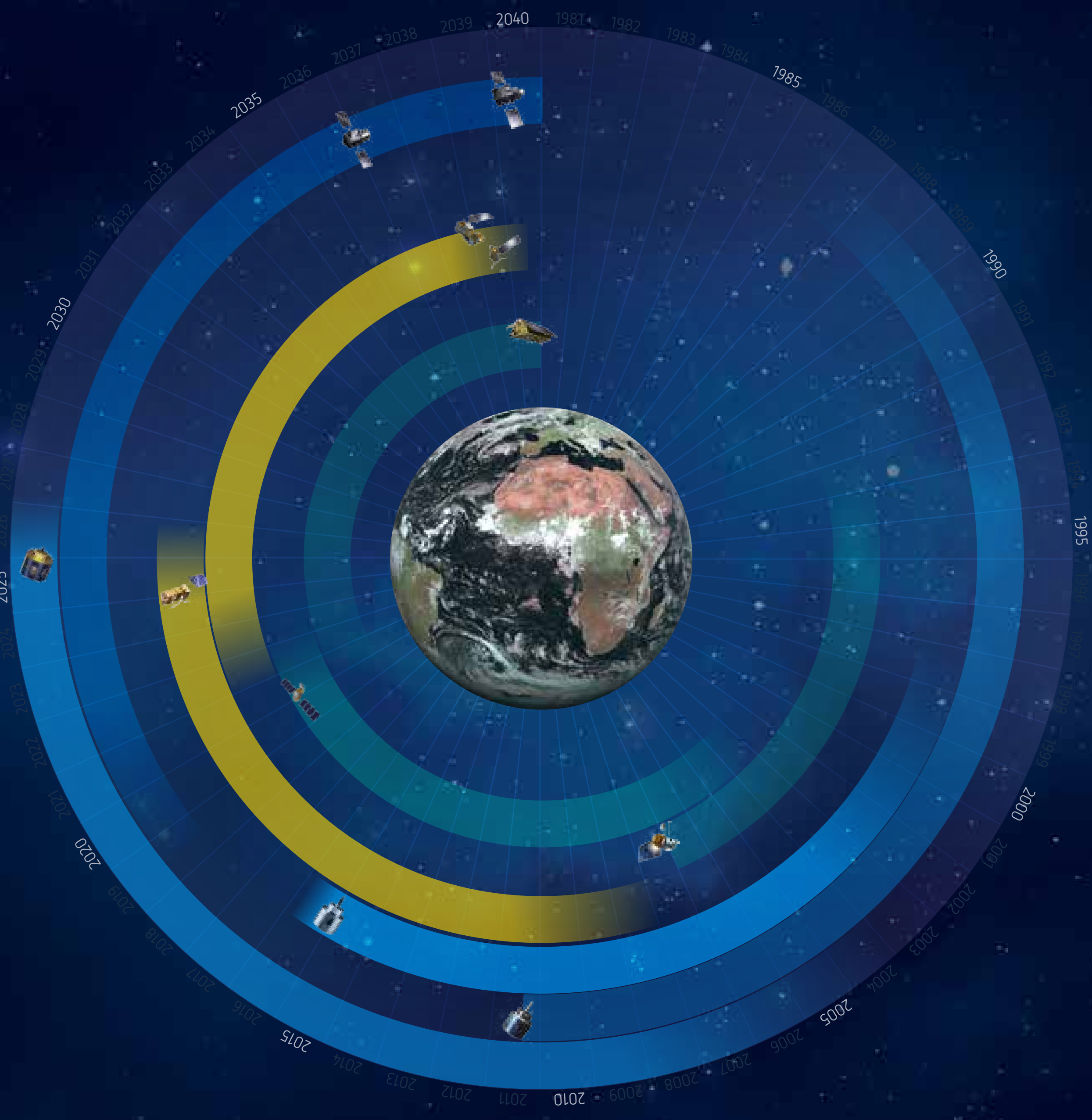
CLIMATE@EUMETSAT

FROM WEATHER TO CLIMATE



MONITORING WEATHER AND CLIMATE FROM SPACE

EUMETSAT

CLIMATE CHANGE – A REALITY AND A GLOBAL CHALLENGE

The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) reveals new evidence of climate change

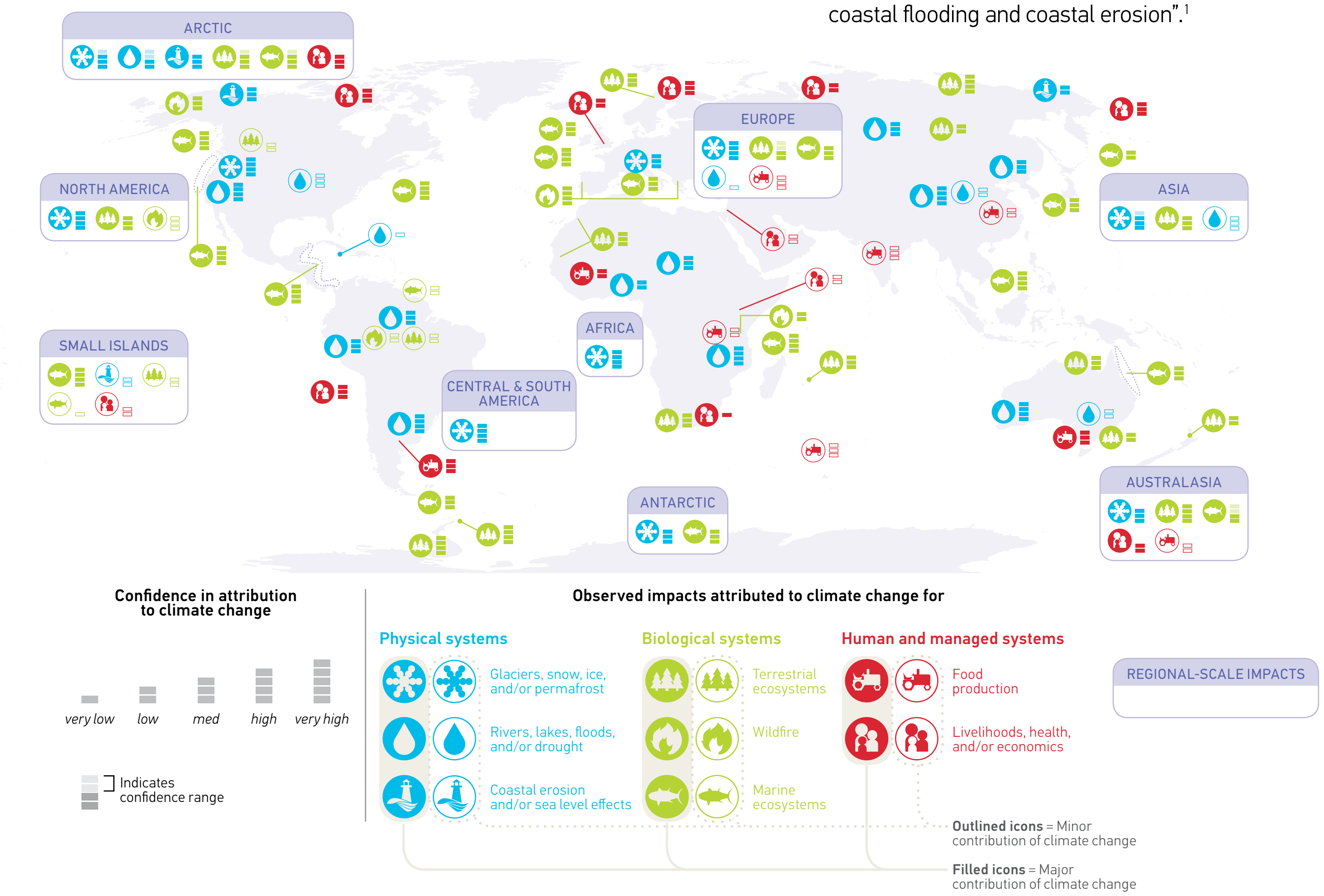
Observed impacts and confidence in attribution to climate change (from IPCC report [1])

"Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and oceans have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased".[1]

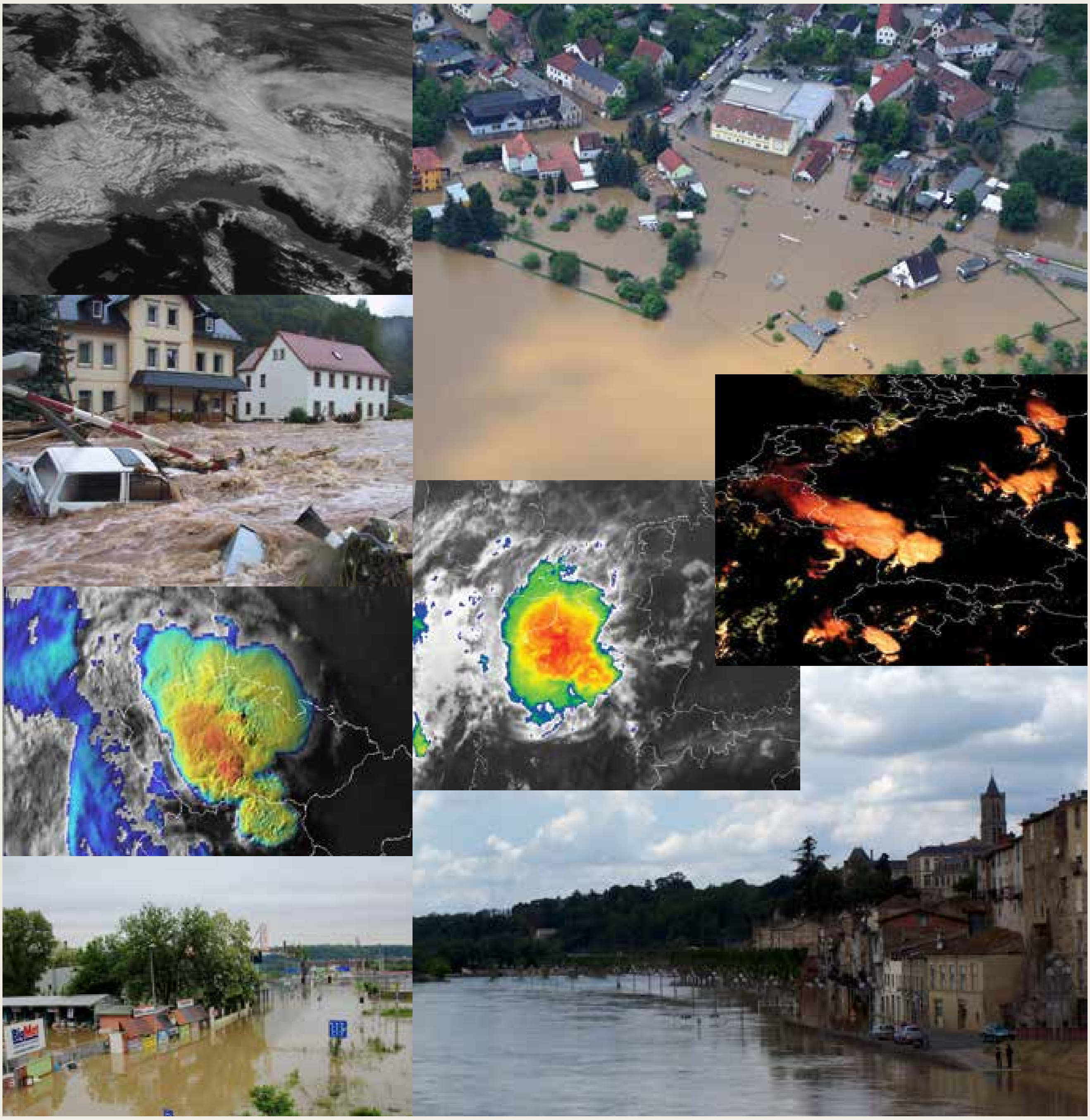
Changes in the Earth's energy balance, which are resulting from the increase in greenhouse gases are already disturbing global winds and rainfall patterns. Also, the number of extreme weather events doubled in the past three decades. The increase in frequency or intensity of heat waves, droughts, floods, cyclones and wildfires has clearly revealed the vulnerability of ecosystems as well as human populations in the affected regions.

Socio-economic consequences materialise in the form of disrupted food production and water supply, damage to infrastructure and settlements as well as health issues, for example through heat-related mortality or water-borne illnesses.

Europe will not be spared. According to IPCC, the southern areas, in particular, will experience droughts coinciding with a significantly increased demand for water for irrigation, industry and domestic use. In combination with wildfires threatening whole regions, this will affect agriculture and major industries like tourism. At the same time, Central and Northern Europe will experience more and more severe flooding. This is in addition to rising sea levels, which result in "coastal systems and low-lying areas increasingly experiencing adverse impacts such as submergence, coastal flooding and coastal erosion".[1]



[1] Climate Change 2013, The Physical Science Basis, Summary for Policymakers



As climate change already is a reality, the risk needs to be managed through suitable adaptation policies. These include strengthening preparedness by further improving early warning systems for high impact weather events - to which EUMETSAT meteorological satellites provide key observational inputs - the introduction of coastal defences and other flood protection infrastructure, as well as the revision of habitation planning.

On the other hand, mitigation policies remain crucial to contain emissions and the magnitude of climate change in the long term.

Also, they offer the potential for economic “green” growth: In Europe, more than 3.5 million people work in the green sector. Between 1999 and 2008, this sector created 180,000 jobs per year, of which most were retained even during the worst years of the economic crisis.

Adaptation and mitigation policies involve substantial public and private investments. Therefore, they need to be based on information concerning ongoing and future climate change established on solid scientific foundations.

Centennial floods in Europe in 2002 and 2013

THE GLOBAL FRAMEWORK FOR CLIMATE SERVICES

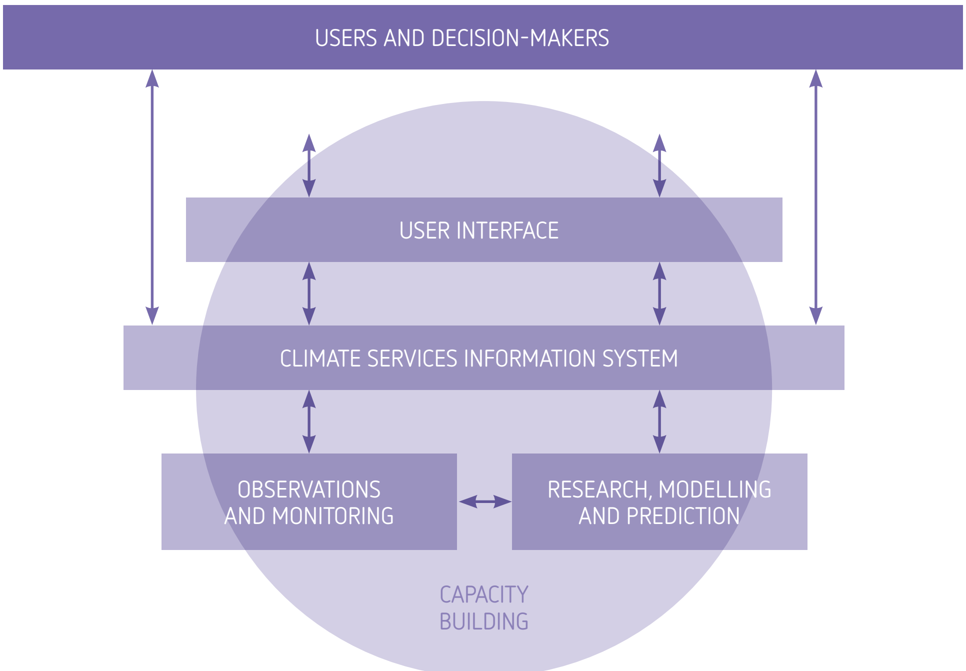
A global response to the need for climate information for decision making

To develop the required climate information services, the third World Climate Conference (WCC3, Geneva, 2009) established the Global Framework for Climate Services (GFCS). The GFCS is designed to improve the quality, quantity and availability of science-based climate information being developed by researchers and service providers and to bridge the gap between this information and the practical needs of end-users.

The GFCS is organised in five functional pillars. "Observations and monitoring" and "research, modelling and prediction" provide the foundation for the framework for delivering observations, data and model outputs from which the research community and service providers can extract an extensive set of climate products and information. The "climate services information system" routinely generates and exchanges these climate data, products and information. The "user interface" layer transforms them into tailored information required by specific adaptation projects, whilst promoting the development of new services in response to user needs. The "capacity building" pillar aims at upgrading the climate service capacities of developing countries in support of their adaptation strategies.

The GFCS targets development of climate services in support of four initial climate-sensitive sectors - agriculture and food security, disaster risk reduction, health and water resources management. "Climate-smart" decisions will, for example, improve food security and health care, enhance water resources management, to which energy is expected to be added, and reduce the impact of natural hazards. In these areas, "the seamless delivery of weather and climate services from the long- to short-term timescales is critical to ensure effective and consistent use of information for various real-world decision-making contexts".[2]

The five functional components (pillars) of the GFCS (source: WMO)



[2] Arame Tall, What do we mean by Climate Services, WMO, Special Bulletin, Volume 62 2013, Special Issue – GFCS Intergovernmental Board on Climate Services

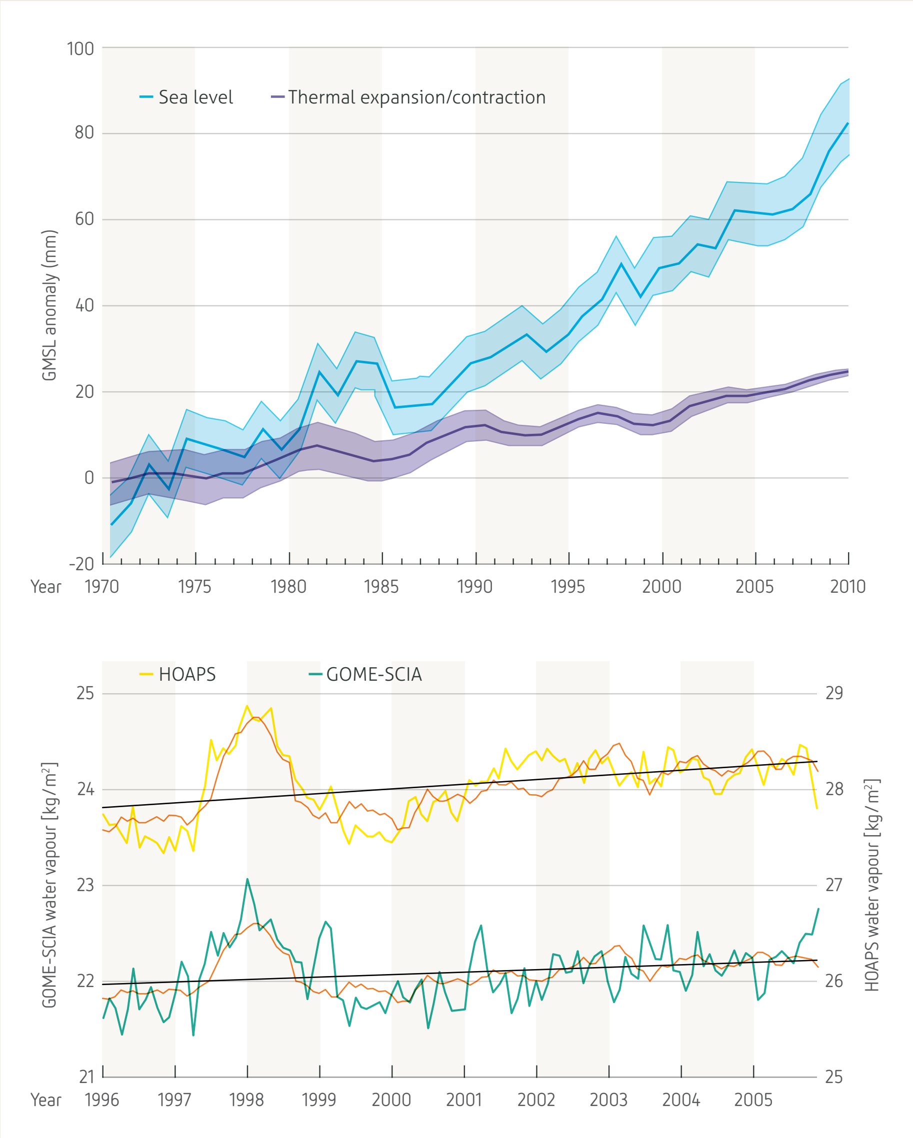
THE ESSENTIAL CONTRIBUTION OF OBSERVATIONS

Observations are crucial for the detection and assessment of climate change and for the validation of Earth system models used to produce predictions and projections addressing future climate

The need for observations is formally addressed through the United Nations Framework Convention on Climate Change (UNFCCC) which has charged the Global Climate Observing System (GCOS) with the responsibility for defining requirements for observations relevant to climate change, both *in-situ* and space-based. GCOS works with partners to establish requirements and to ensure the sustained provision of reliable physical, chemical and biological observations and data records, building on relevant observing systems.

Thus, GCOS has identified a set of geophysical variables, called Essential Climate Variables (ECV), which need to be observed to obtain the required evidence of climate change and support climate research and emerging climate information services. ECVs, such as wind vectors, sea level and albedo, are grouped into three categories: atmospheric, terrestrial and oceanic.

In view of the relatively slow dynamics of climate change, observations of ECVs have to be accurate, well-calibrated and homogeneous, to form the time-series spanning decades referred to as Climate Data Records (CDRs). The longest CDRs are used to distinguish the climate trends from shorter-term climate variability. CDRs can be used alone to analyse climate variability and change, or be ingested by numerical Earth system models used to reconstruct ("reanalyse") consistent climate records of a broader range of ECVs.



Global trends for sea level[3] and water vapour[4], as inferred from observations

[3] Rhein, M. et al. in Climate Change 2013 - The Physical Science Basis: Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. (eds T.F. Stocker et al.) 255-315 (Cambridge University Press, 2013)

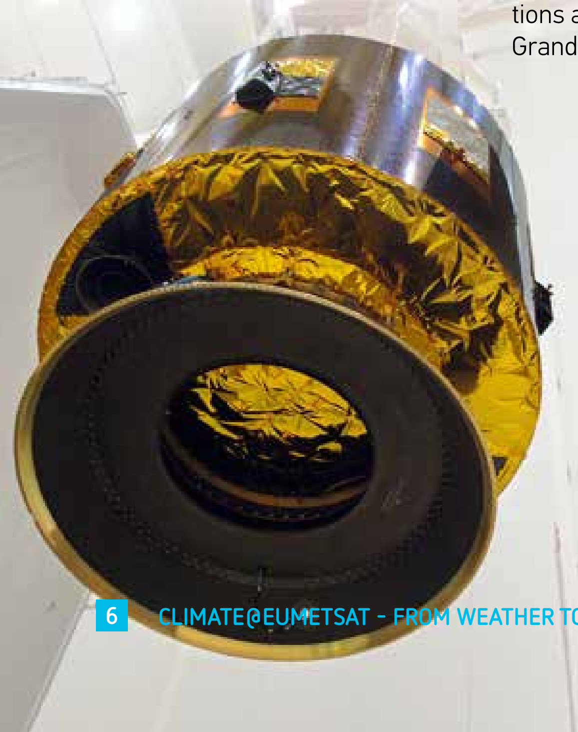
[4] Mieruch, S. et al. Comparison of decadal global water vapor changes derived from independent satellite time series, J. Geophys. Res. Atmos., 119, doi:10.1002/2014JD021588 (2014)

OBSERVATIONS FROM SPACE: THE VISION OF EUMETSAT

With their global and repetitive observations, satellites provide a unique insight on climate change, and the longest climate records from space are those already accumulated by operational meteorological satellites

In general, Climate Data Records for ECVs are derived from a combination of satellite and *in-situ* observations, with satellite observations making a significant contribution for a majority of ECVs. The GCOS implementation plan acknowledges that "...satellites are expected to become an increasingly important means of obtaining observations globally for comparing climate variability and change over different parts of the Earth. Therefore, a system of satellites and satellite sensors...implemented and operated in a manner that ensures the long-term accuracy, stability and homogeneity of the data is a high priority."

More recently, in October 2014, the conference on "Climate Research and Earth Observations from Space: Climate Information for Decision Making" jointly organised by EUMETSAT and the World Climate Research Programme, stressed that "there is an unequivocal need for sustained long-term space-based observing systems provided by operational satellites". The conference also established that "combining multi-sensor/satellite operational and research missions should be considered to address science questions across multiple (climate research) Grand Science Challenges."



THE VISION OF EUMETSAT

This was already the vision of EUMETSAT Member States when they agreed that the initial mandate of the organisation to "establish, maintain and exploit European systems of meteorological satellites" be extended to "contribute to the operational monitoring of the climate and the detection of global climatic changes". This was in recognition that:

- modern meteorology, like climate monitoring, requires observations of more than the atmosphere, which means in practice measurements of a great number of atmospheric, oceanic and terrestrial ECVs;
- the operational multi-satellite programmes of EUMETSAT and their committed continuation over the next decades are a unique asset for climate monitoring, already building an archive of more than 35 years of Meteosat data;
- the very existence of EUMETSAT as an organisation, along with its ground infrastructure and scientific and technical know-how, guarantees cost efficient contributions to climate change monitoring.

In 2000, the EUMETSAT Convention of 1986 was revised accordingly. The amended Convention also created the possibility to add optional programmes to the mandatory Meteosat and EUMETSAT Polar System programmes, to deliver additional observations of relevance for climate change monitoring. Not surprisingly, the first EUMETSAT optional programmes were contributions to the Jason-2 and Jason-3 high precision altimeter missions dedicated to the monitoring of ocean circulation and mean sea-level.

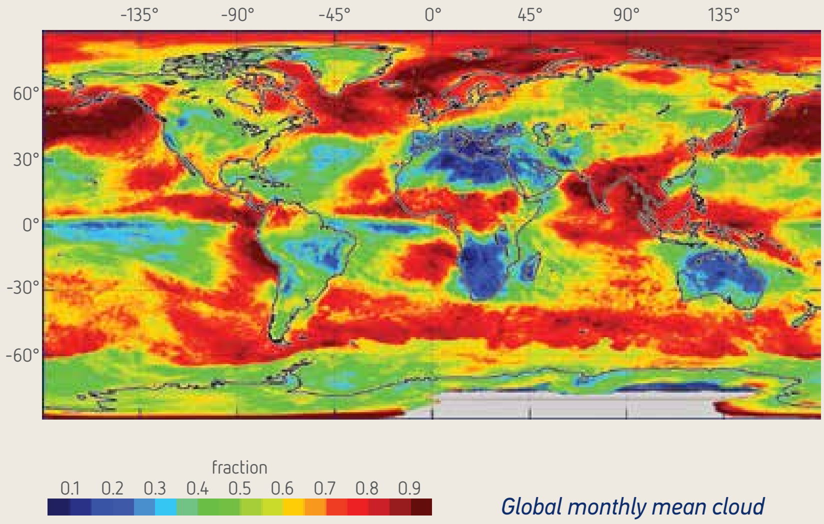
THE ROLE OF EUMETSAT: FROM SPACE-BASED OBSERVATIONS TO CLIMATE RECORDS

Climate monitoring is addressed across all EUMETSAT activities, from operations to the planning of future satellite systems, and involves specific scientific and technical efforts for the re-calibration of historical data and the extraction of climate records

In practice, EUMETSAT implements its climate monitoring mission through the following activities:

- delivering advanced multi-satellite programmes providing the operational perspective and long-term commitment required for climate monitoring;
- maintaining a unique archive of decades of space-based observations of the atmosphere, ocean and land surfaces;
- producing consistent Climate Data Records through re-calibration of space-based observations and reprocessing of the long series of physical and geophysical products thereof;
- cooperating with the scientific community to validate Climate Data Records and stimulate their use within the Global Framework for Climate Services;
- ensuring easy access to a broad range of well-documented Climate Data Records;
- supporting the European Union in the definition and implementation of its Copernicus Climate Change Service (C3S);
- supporting climate-related capacity building initiatives, especially in Africa.

Thus, the EUMETSAT Climate Monitoring activities are of particular relevance for three of the GFCS pillars. Those are "Observations and Monitoring", through the provision of sustained observing systems, the "Climate Services Information System" through the routine generation and exchange of climate data records, and "Capacity Building". Across all activities, EUMETSAT interacts with the research, modelling and prediction communities as well as the users of climate information, as a partner in projects contributing to the "User Interface" layer.



Global monthly mean cloud fractional coverage for July 2007 extracted from an AVHRR Climate Data Record covering the period 1982-2009 (source: CM SAF)

The overall framework for the climate engagement of EUMETSAT is the Climate Monitoring Implementation Plan approved by its Council. This plan prioritises climate-related efforts, provides an overview of committed and planned activities and identifies relevant frameworks and opportunities for international cooperation.

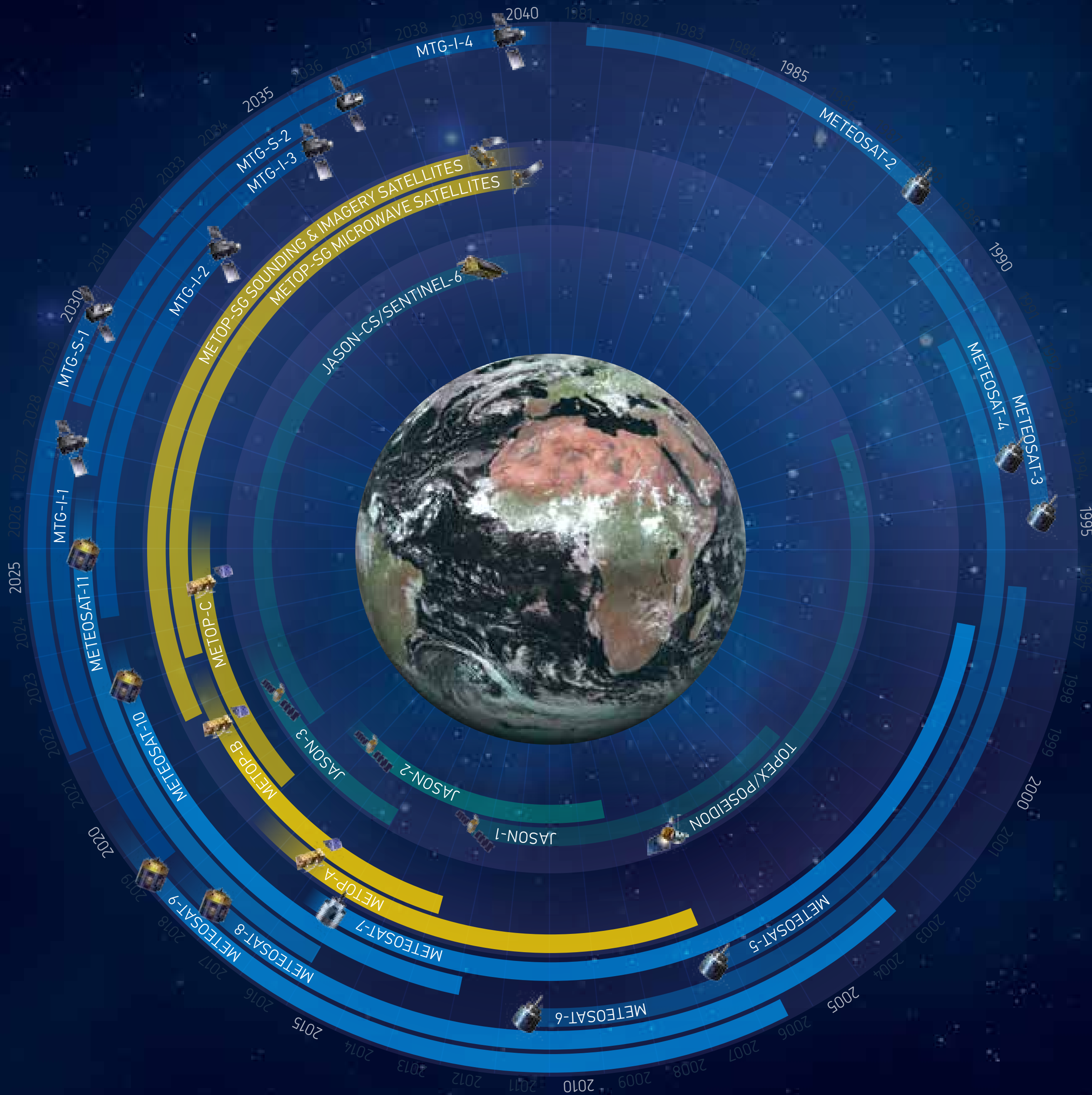
EUMETSAT climate monitoring activities involve its Central Facilities in Darmstadt and the network of Satellite Application Facilities (SAF) distributed across its Member States, with a leading role assigned to the Climate Monitoring SAF (CM SAF). They rely on the archiving and data processing infrastructure available at EUMETSAT headquarters and the SAFs.

EUMETSAT

DELIVERING LONG-TERM MULTI-SATELLITE PROGRAMMES

As a user-governed operational agency, EUMETSAT is committed to ensuring continuity of the observations and data services required by its Member States for forecasting high impact weather. This commitment is also an asset for climate monitoring.

Both observations and services are vital to the safety of life, property and infra-structure and also for the weather-sensitive sectors of the economy. In order to avoid interruptions of critical data services, long term multi-satellite programmes are needed. This requires backup assets available in orbit and on the ground, as well as planned overlap between spacecraft in a series and successive generations of spacecraft. For this reason, each generation of Meteosat and EUMETSAT polar-orbiting satellites typically covers two decades of observations, based on a series of three to four identical satellites.

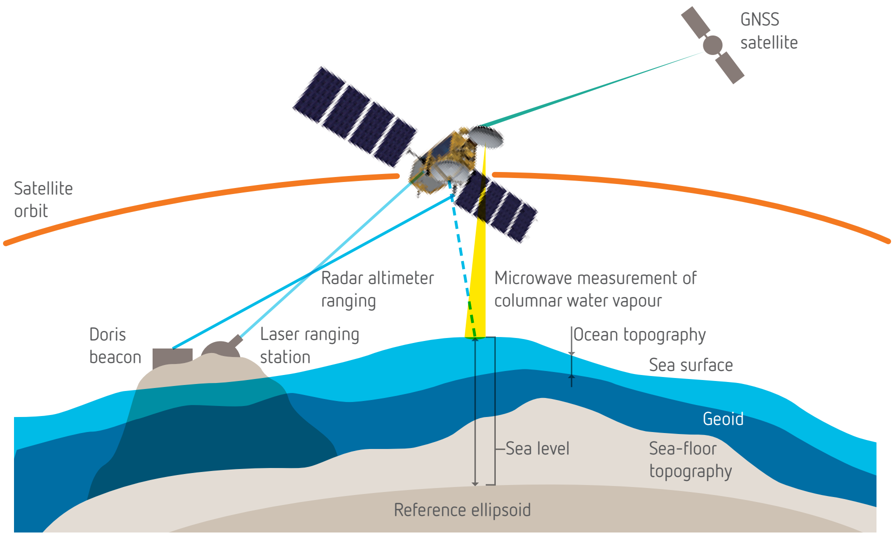


CONTINUITY AND INNOVATION

From a climate monitoring perspective, identical satellites support the delivery of long time series of consistent and homogeneous data across one generation of satellites. Also, this approach takes advantage of cross-calibration during the parallel operations of successive satellites, thus fulfilling or exceeding the GCOS requirements for sensor overlap in time.

Likewise, observation capabilities are continued with improvements from one generation to the next, such that the same physical parameters and ECVs can be extracted across generations of satellites, over many decades. Also, to ensure continuity of data records delivered by each type of sensor, EUMETSAT, when defining requirements for a new generation satellite system, follows GCOS Climate Monitoring Principles and guidelines whenever possible. The emphasis here is on sensor stability and calibration requirements.

Moreover, improvements of observation capabilities offer new opportunities for climate monitoring. For instance, the innovative Flexible Combined Imager on board the future Meteosat Third Generation (MTG) satellites will provide higher resolution thermal imagery with radiometric performances suitable to the observation of hot targets, to improve fire detection capabilities. This will increase the quality of climate-relevant products such as fire radiative energy and power. Also, the new Lightning Imager will help to assess the effects our changing climate has on thunderstorm activity over the tropical Atlantic and Indian oceans and the possible impact on long haul flights over these areas. Likewise, the combined use of observations from co-orbiting infrared hyperspectral sounders (IRS on MTG and IASI-NG on Metop-SG) and the Copernicus sounders (Sentinel-4 on MTG and Sentinel-5 on Metop-SG), will provide access to climate records of a broader range of atmospheric chemical compounds and greenhouse gases (ozone, CO, CH_4, etc.) that are ECVs. Advanced optical and microwave imagers, to be flown on the Metop-SG satellites, will monitor cirrus clouds and provide more detailed data on cloud and aerosol properties, surface temperature, albedo, precipitation and sea ice.



The principle of altimeter measurement of sea level

EUMETSAT SATELLITES DELIVER REFERENCE MEASUREMENTS FOR CLIMATE MONITORING

An important element of EUMETSAT's current satellite programmes are missions and instruments that are already designed or optimised for climate monitoring.

For instance, the radio occultation instruments (GRAS) flown on the Metop satellites, provide self-calibrated measurements of high-resolution vertical temperature profiles. These are suitable to assess the consistency of the expected warming in the troposphere and cooling in the stratosphere and are used to improve climate models.

Likewise, the Infrared Atmospheric Sounding Interferometer (IASI) flown aboard the Metop satellites since 2006 serves as a highly stable reference for cross calibrating imagery and soundings from less accurate multi-spectral infrared instruments.

Last but not least, the Jason-2/-3 high precision ocean altimeter mission, where EUMETSAT is involved in partnership with CNES, NOAA and NASA, is also a climate-dedicated mission monitoring mean sea level trends, as a key indicator of climate change. Following Topex/Poseidon and Jason-1, these ocean satellites expand an unsurpassed climate record initiated in 1992, which the future Sentinel-6/Jason-CS mission is expected to grow further until 2030.

RE-CALIBRATING INSTRUMENT DATA AND PRODUCING FUNDAMENTAL CLIMATE DATA RECORDS

As part of a pan European effort to bring the emerging climate services to operational maturity, EUMETSAT develops recalibration and reprocessing methods and extracts Climate Data Records from its archives

Jörg Schulz
Climate Services Product Manager
EUMETSAT

"Exploiting the more than 30 years long time series of data from meteorological satellites for climate research and services requires a dedicated effort to recalibrate and reprocess the data records."

RE-CALIBRATING ORIGINAL INSTRUMENT DATA

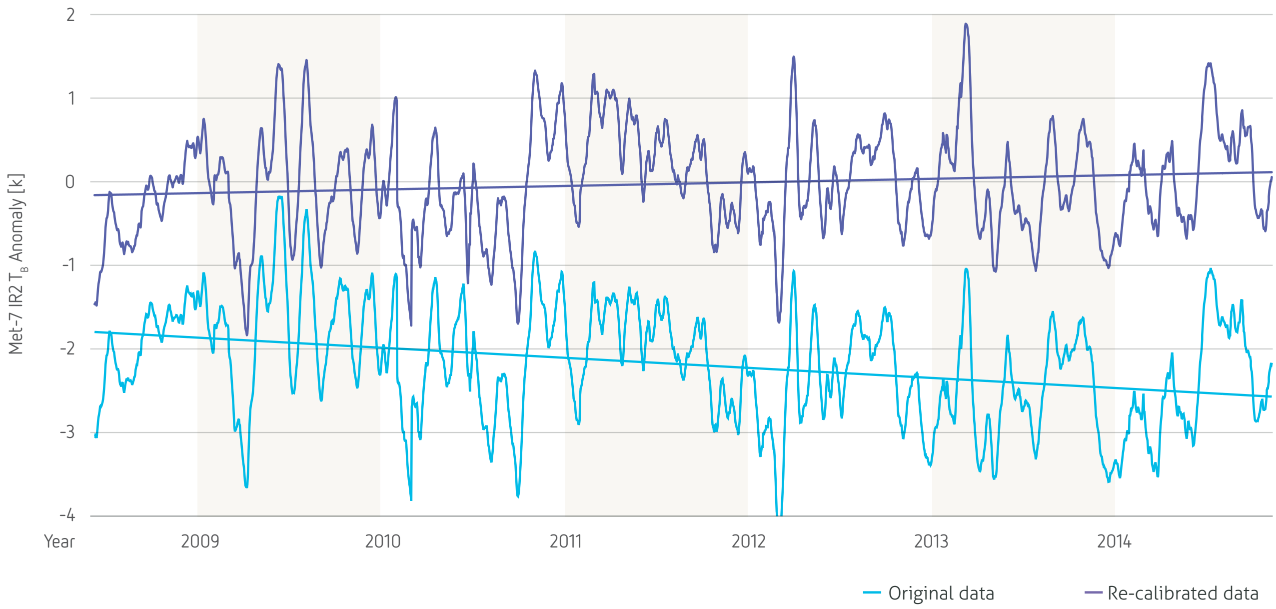
In order to produce Climate Data Records (CDR) of the highest possible quality, EUMETSAT develops methods to improve the archived original data. This is needed for historical missions such as Meteosat, which have been designed to monitor weather and not climate, hence without very accurate calibration mechanisms.

As a matter of fact, each instrument in a series has individual characteristics, some of which can even drift, and the calibration methods used during operations evolve throughout an instrument's lifetime or from one satellite to the next. Therefore, a simple agglomeration of data in time would show jumps and artificial trends, rendering the data useless for climate change analysis.

It is fortunately possible to improve the quality of individual mission data *a posteriori* by re-assessing the pre-launch characterisation and calibration data for each instrument and correcting well-characterised instrument anomalies. In some cases, data can also be recalibrated using external ground-based calibration systems and/or natural reference targets.

Moreover, time series from several successive instruments can be homogenised to the data of the best instrument in a series, using the periods of overlap of observations from one particular instrument with others, or cross-calibrated against data from an external, highly stable reference instrument like the IASI infrared spectrometer. Techniques for propagating the achieved cross-calibration backwards to previous instruments need then to be used, after having assessed the stability of their output data over time.

Time series of Meteosat-7 thermal infrared observations (residuals from average) computed from original data and from re-calibrated data. Recalibration eliminates the known drift of the onboard calibration system and provides insight into climate variability.

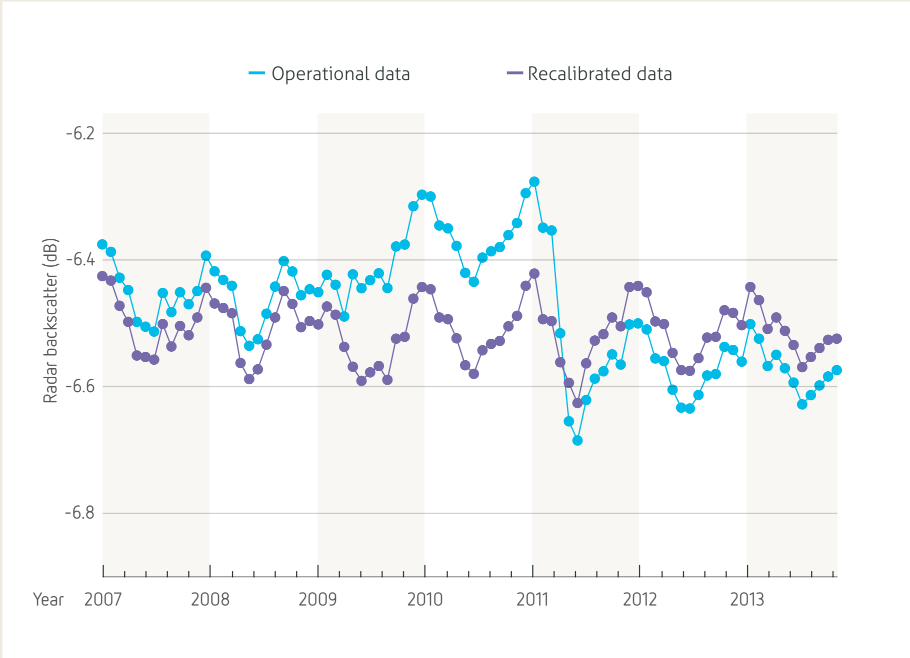


PRODUCING FUNDAMENTAL CLIMATE DATA RECORDS (FCDR)

Once the recalibration process has been completed, instrument measurements can be reprocessed to extract basic physical parameters (e.g. reflectance, radiance, radar backscatter) and to produce long time series known as Fundamental Climate Data Records (FCDR). This needs to be based on the best algorithm available as a result of continuous improvement of the algorithm used for extracting operational products over the lifetime of a multi-satellite programme. In addition, metadata need to be appended to FCDRs to capture information on quality control and uncertainties assessed through validation against independent reference data.

FCDRs form the prerequisite material from which series of geophysical parameters, i.e. ECVs, can be re-processed using again the best available algorithms. For instance, the main physical parameter extracted from self-calibrated observations of the occultation of GNSS signals by the atmosphere is the bending angle, which characterises the refraction of the GNSS signal through its path in the atmosphere, from the emitting GNSS satellite to the GRAS receiver embarked on Metop. The bending angle relates to the density of the atmosphere and hence to temperature and moisture, such that vertical profiles of both parameters can be retrieved from profiles of the bending angle.

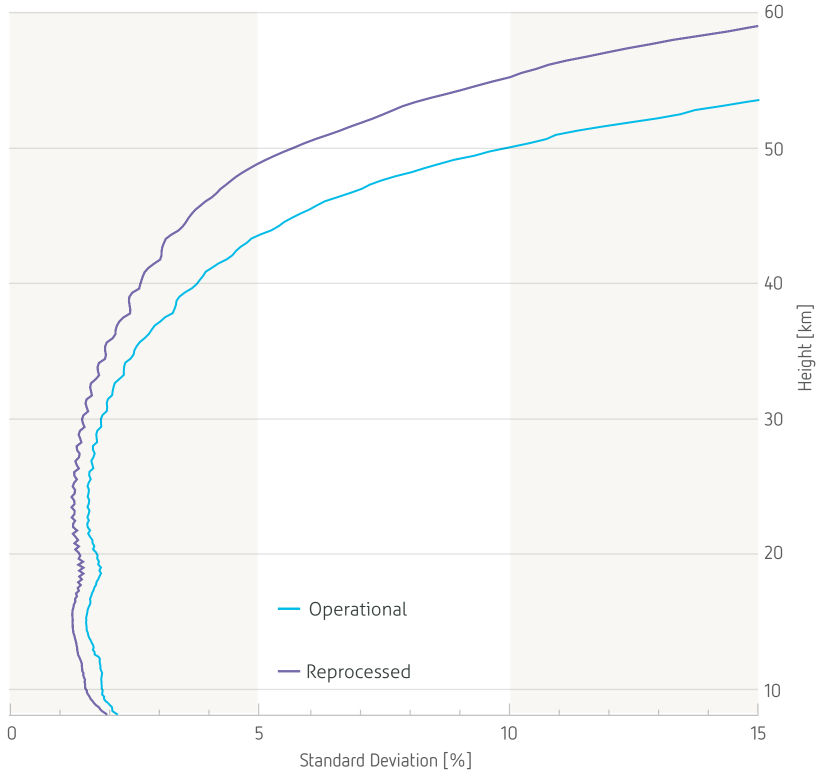
Production and continuous improvement of FCDRs are therefore a top priority for EUMETSAT. This demands in-depth understanding of instruments, rescuing calibration and characterisation data, algorithmic research and complex validation techniques.



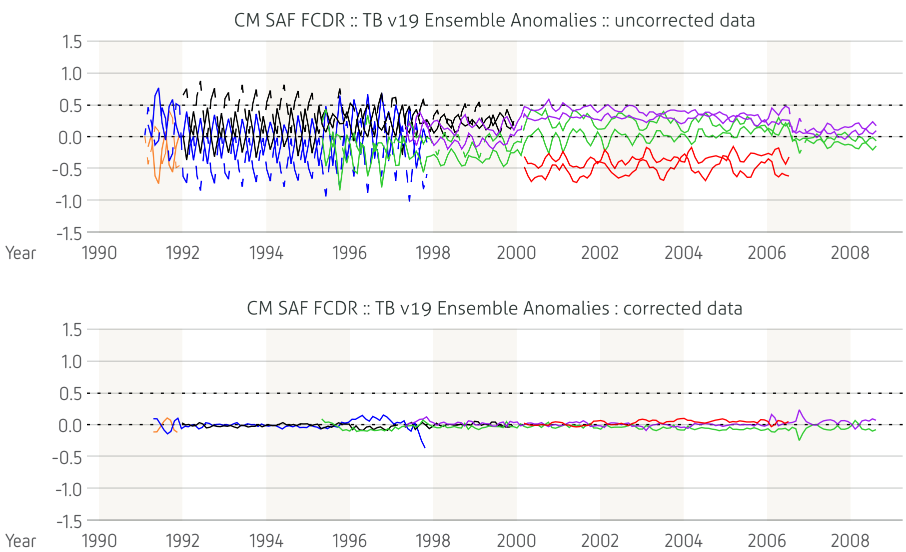
Radar backscatter signature of the tropical rainforest measured by ASCAT real time products (blue) and products recalibrated against ground transponder data (purple). Recalibration eliminates drifts and jumps in the time series, which now reflects only the natural variations of the backscatter of the forest canopy.

EUMETSAT

RE-CALIBRATING INSTRUMENT DATA AND PRODUCING FUNDAMENTAL CLIMATE DATA RECORDS



Standard deviation (in %) of operational and reprocessed bending angles from GRAS compared to ECMWF operational forecasts, showing improved quality of reprocessed data at all vertical levels



In the case of GRAS Radio-Occultation (RO) observations, sophisticated algorithms based on geometrical optics and wave optics theory have been used to reprocess vertical profiles of bending angle and deliver a FCDR of the best possible accuracy.

This FCDR will be used by Met Office (UK) to assess the representation of temperatures in the upper troposphere and lower stratosphere by the latest version of the Hadley Centre climate model. Comparisons of model outputs with RO data are enabled by forward modelling of the RO bending angles from the temperature and moisture fields of the climate model. The results of this study will feed into the process of improving the climate model and will encourage the whole climate modelling community to use the RO CDR for the same purpose.

Another example is the 21-year (1987-2008) FCDR of microwave brightness temperature released by the EUMETSAT Climate Monitoring SAF based on the reprocessing of observations from the series of SSM/I imagers flown on the US defence meteorological satellites. The direct ingestion of this dataset in the global numerical weather prediction of the European Centre for Medium-range Weather Forecasts (ECMWF) will provide additional information on precipitation and moisture. It will thus help improve the representation of the water cycle over two decades of the ECMWF "reanalysis", which is critical for understanding key climate processes and low-frequency variability.

Time series of microwave temperature (residuals from average) prior to correction (upper panel) and after correction (lower panel). Daily means are shown. Colours indicate the different satellites over time. (source: CM SAF)

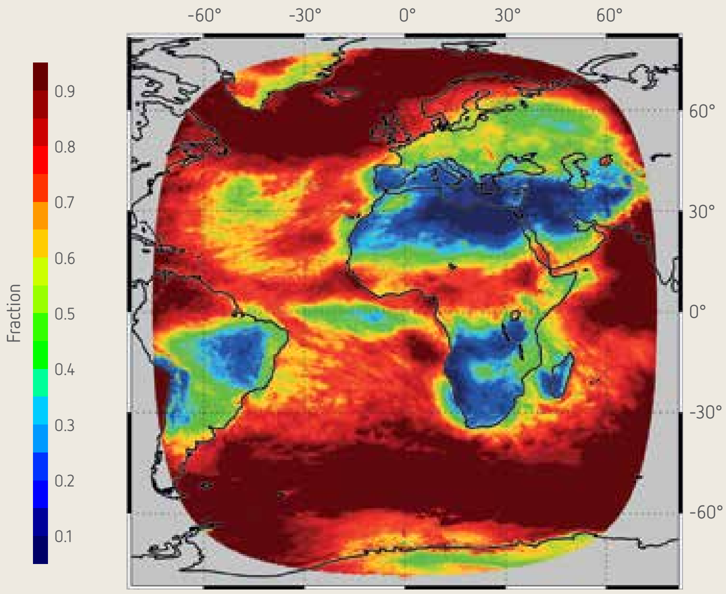
PRODUCING RECORDS OF ESSENTIAL CLIMATE VARIABLES

Climate records of essential climate variables are key inputs to climate research and services

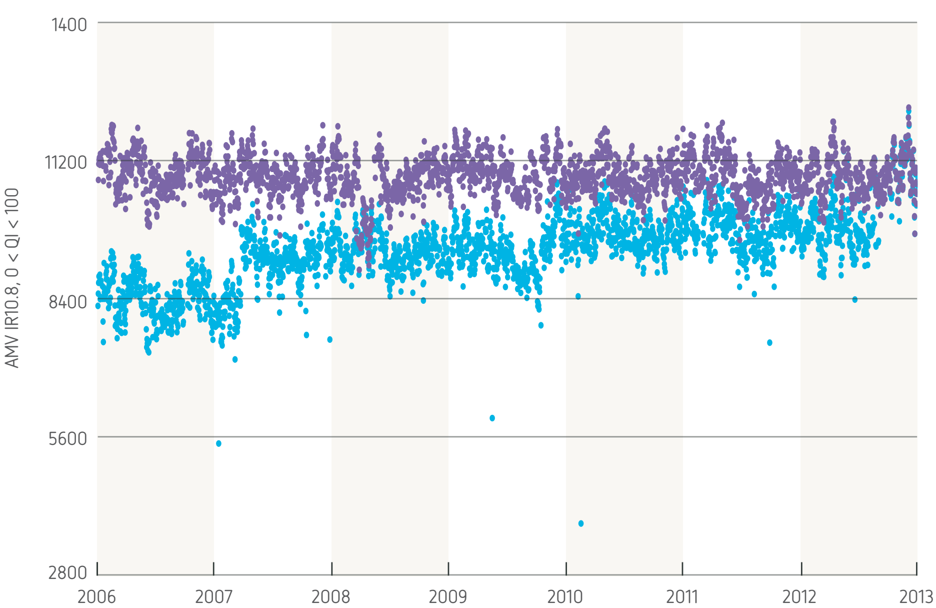
Homogeneous series of ECV parameters, such as wind, temperature, cloud parameters, wind or radiation budget, in turn constitute so-called Thematic Climate Data Records (TCDRs).

While EUMETSAT central facilities share the development of TCDRs with the SAF network, the downstream production of TCDRs is indeed a top priority for the SAFs.

The value reprocessing delivers for climate monitoring is illustrated by the improvement in terms of quality the TCDR for wind vectors in the atmosphere shows over the series of real-time operational products available in the EUMETSAT archive. These products are estimated from the displacement of clouds and moisture patterns observed every 15 minutes by the visible and infrared imagery of the Meteosat Second Generation satellites, since 2002.



Averaged cloud fraction (CFC) for July 2010 with a latitude-longitude sampling of 0.05 degree, extracted from a Meteosat Climate Data Record (source: CM SAF)[5]



Number of wind vector products extracted from Meteosat imagery with a quality index above 80%, for reprocessed (purple) and real time (blue) products in the period 2006-2013. Over the entire period, reprocessing brings the number of high quality products to the highest level achieved in real time (in 2013).

[5] Stengel, M., Kniffka, A., Meirink, J. F., Lockhoff, M., Tan, J., and Hollmann, R.: CLAAS: the CM SAF cloud property data set using SEVIRI, Atmos. Chem. Phys., 14, 4297-4311, doi:10.5194/acp-14-4297-2014, 2014

EUMETSAT

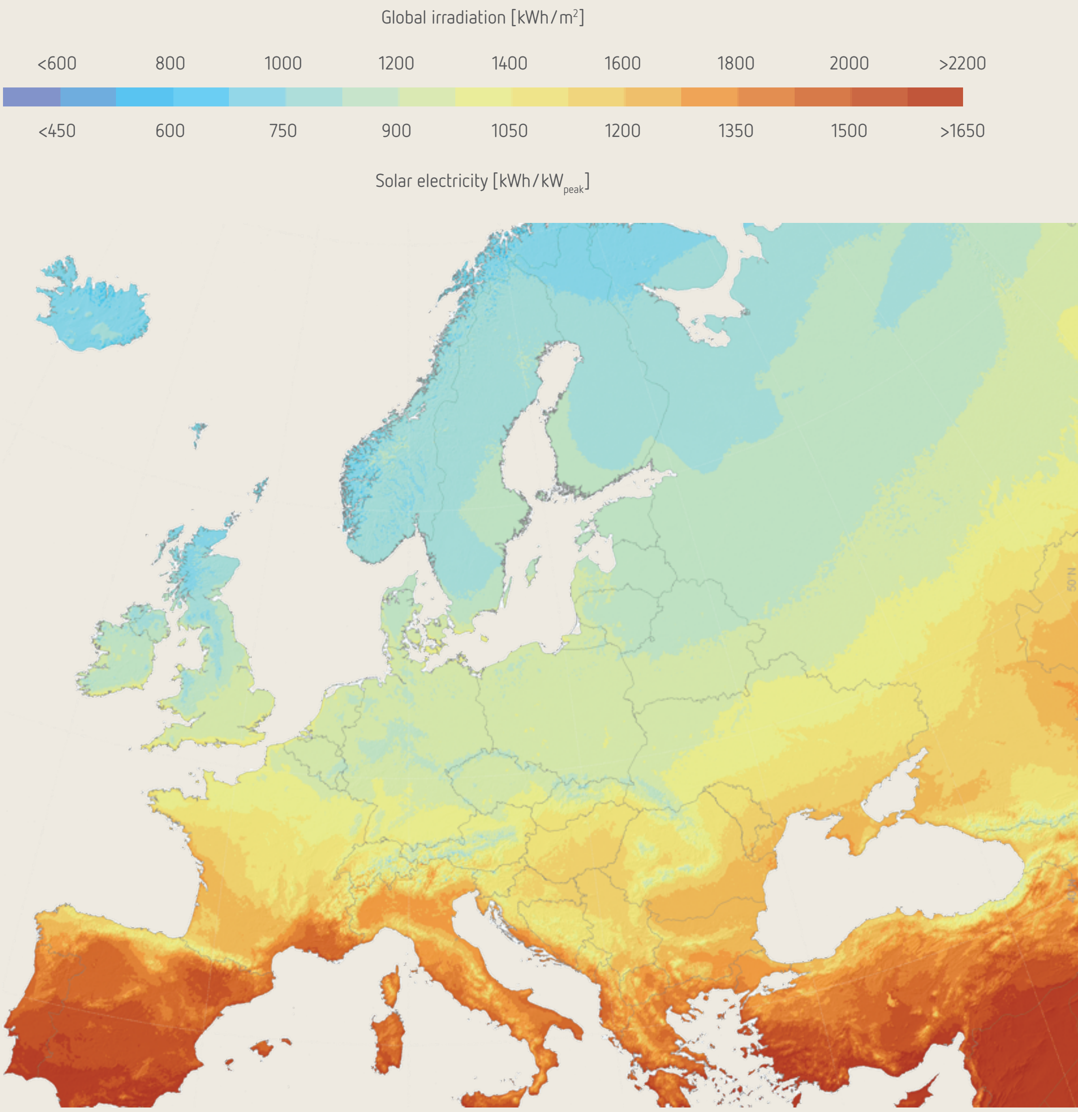
PRODUCING CLIMATE RECORDS FOR ESSENTIAL CLIMATE VARIABLES

The socio-economic benefits of EUMETSAT climate records is illustrated by the evaluation of photovoltaic electricity potential from Meteosat visible imagery

Martin Werscheck
Head of EUMETSAT Climate Monitoring Satellite Application Facility (CM SAF)
Deutscher Wetterdienst (DWD)

"The CM SAF develops, generates, archives and distributes sustained high-quality satellite-derived products of the energy & water cycle to monitor, understand and adapt to climate variability and climate change."

The expansion and the efficient use of renewable energy sources are essential for the mitigation of climate change through the reduction of greenhouse gas emissions. Effective planning, deployment and use of solar energy systems require information about the photovoltaic (PV) solar electricity potential of possible locations. The Joint Research Centre (JRC) of the European Commission infers this information over Europe, Africa and Asia from Meteosat CDRs of the solar surface irradiance (the solar resource) released by the CM SAF: maps of the photovoltaic electricity potential are produced by applying a transfer function to the solar resource, using a PV system simulator modelling the efficiency of such systems. JRC offers a web application for the estimation of solar electricity potential for a variety of sites and PV systems, which is widely used (~100 hits per day).[6]



Map of photovoltaic solar electricity potential based on Meteosat solar irradiance climatology (source: JRC with inputs from CM SAF)[7]

[6] http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php
[7] www.cmsaf.eu

UPGRADING IT INFRASTRUCTURE TO MEET THE CLIMATE CHALLENGE

Fast and frequent reprocessing of long series of observations using increasingly complex algorithms requires continuous improvement of IT infrastructure for accessing and processing large volumes of data

Algorithms used to extract Climate Data Records from archived data are becoming increasingly complex, involving more and more sophisticated representation of measurement physics for a given instrument, or combining information from different sensors and satellites. Thus, algorithmic research needs safe and flexible access to the data and software environment of the real-time operational satellite systems, while the continuous improvement of CDRs requires higher computer power for fast re-processing and quality analysis of large datasets.

Achieving this goal requires an increase in computer power of the IT infrastructure at EUMETSAT's central facilities, but also, for the sake of maximum efficiency and flexible usage, adopting the virtualisation of processing chains.

The IT infrastructure already uses cloud technologies and will be expanded with additional rapid disk access capacity to further facilitate direct, frequent and fast admission to large subsets of the data available in EUMETSAT's archives.

Virtualisation of processing chains has already been achieved for MSG in 2014 and will be performed for EPS/Metop in 2015-2016.

In addition, to facilitate reprocessing of increasingly large volumes of data in the future, EUMETSAT has imposed a more flexible architecture for the processing chains of the MTG and EPS-SG ground systems, based on processing frameworks hosting evolvable processing software.

COOPERATING WITH THE SCIENTIFIC COMMUNITY

EUMETSAT cooperates with the science community to validate Climate Data Records and stimulate their use in climate research and services

Dr Dick Dee
Head of ECMWF Reanalysis Section
Coordinator of the ERA-CLIM project

"Our long-standing cooperation with EUMETSAT on quality control and assimilation of satellite data into the ECMWF model has been a great asset for ERA-CLIM projects. It allows us to use the best possible reprocessed satellite data input for global climate reanalysis."

A key focus of the GFCS is on enabling "…. researchers and the producers and users of information to join forces to improve the quality and quantity of climate services worldwide". Therefore, EUMETSAT is involved in integrated research projects involving research institutes, service providers and end users to enhance the value of its own CDRs.

One goal is to develop standard methods to qualify the quality and maturity of Climate Data Records and their production from a user perspective, to eliminate possible barriers to their wide-spread use in climate research and by the Copernicus Climate Change Service (C3S).

Within the EU-funded CORE-CLIMAX project aimed at assessing the capability to establish a European capacity for the sustained production of CDRs, methods proposed by EUMETSAT have been en-dorsed by all key European providers of CDRs and are now systematically applied to qualify EUMETSAT's CDRs.

Another goal is to validate EUMETSAT's CDRs using independent reference measurements and to demonstrate their relevance for climate services. For this purpose, EUMETSAT is involved in the EU-funded ERA-CLIM "reanalysis" projects led by ECMWF, whereby space-based and conventional observations are ingested into numerical models of the coupled atmosphere-ocean-land-cryosphere system which can produce estimates of a much broader set of ECVs. The latest project, ERA-CLIM2, involves 15 European institutions and will produce a global, high-resolution reanalysis covering the last 100 years. EUMETSAT's contribution consists of improving its original sensor data records, 80% of which are suitable for ingestion by the models. Thus EUMETSAT's CDRs will enhance and be embedded in one of the most used datasets in geo-sciences, currently attracting more than 17,000 users in more than 100 countries.

Criteria proposed by EUMETSAT within the CORE-CLIMAX project to qualify the maturity of Climate Data Records and their production from a user perspective

IS THE SOFTWARE ROBUST AND MAINTAINABLE?

ARE THE DATA AND METHODS WELL DOCUMENTED?

HAS THE UNCERTAINTY OF THE DATA BEEN SYSTEMATICALLY ASSESSED?

ARE DATA WELL USED AND USER FEEDBACK TAKEN CARE OF?

Sofware readiness	Metadata	User documentation	Uncertainty characterisation	Public access, feedback and update	Usage
Are the codes compliant with standards, stable, portable and reproducible?	Do the metadata meet international standards and allow provenance tracking?	Are the formal documents and peer-reviewed papers up-to-date and public?	Are the uncertainties assessed systematically in a standard manner?	Are the data, source code and documents publicly available and regularly updated?	Are the data widely used in the scientific and decision- and policy-making communities?

EUMETSAT is engaged in a sustained dialogue with the World Climate Research Programme (WCRP)

The WCRP coordinates climate research worldwide through its core projects on climate variability (CLIVAR), the energy and water cycle (GEWEX), the cryosphere (CliC) and the stratosphere (SPARC). It also acts as an "umbrella" for the development of reanalyses and the evaluation of the climate models used in the IPCC assessment process.

EUMETSAT is engaged in a sustained dialogue with the WCRP, participating inter alia in its Data Advisory Council (WDAC) where all data issues are discussed.

In 2014, after the publication of the 5th IPCC Assessment Report, EUMETSAT and the WCRP organised a symposium on "Climate Research and Earth Observations from Space: Climate Information for Decision Making"[8] attracting more than 500 leading scientists from 50 countries.

The symposium discussed the need for and role of climate observations from space in relation to the six Grand Science Challenges of the WCRP: "clouds, circulation and climate sensitivity", "the changing water cycle ", "Cryosphere in a warming world", "Ocean circulation and Regional Sea level rise", "Prediction and attribution of extremes: from climate to weather", "Regional climate variability and change: enabling climate services".

The Symposium concluded that the broad range of priorities of the research community can only be addressed by international cooperation through the Architecture for Climate monitoring from Space.

In October 2014, the Climate Symposium, organised in Darmstadt by WCRP and EUMETSAT attracted over 500 leading scientists from 50 countries

[8] All information on the Climate Symposium, including live sessions, is available on www.theclimatesymposium.com

ENSURING EASY ACCESS TO CLIMATE DATA RECORDS

Easy and inexpensive access to a broad range of data, including Climate Data Records, is a key element of EUMETSAT's user service

This is particularly important when considering that the demand for delivery of climate information will significantly increase with the ongoing development of climate services.

Access to data and products available from EUMETSAT is provided via the Earth Observation Portal on the EUMETSAT's website. An online catalogue, the Product Navigator, facilitates the discovery of data and products, including the climate-relevant data. Information can then be ordered free of charge from the Data Centre and a user helpdesk is available to further facilitate the ordering process.

The EUMETSAT Data Centre hosts the unique archive ensuring the long-term preservation of data and products extracted from all EUMETSAT satellites, the Copernicus Sentinel missions operated by EUMETSAT on behalf of the European Union and some partner missions. The EUMETSAT archive is the repository for climate relevant datasets generated at the EUMETSAT headquarters and within the SAF network and offers one of Europe's largest collections of Earth observation data.

All data and products are made available in established formats containing complete information on how the climate-relevant data have been created. EUMETSAT is producing Climate Data Records in NetCDF and WMO BUFR formats, following international standards for metadata (Climate Forecast Convention) to enable the widest usage of its data records.

In addition, the websites of the SAF network – accessible from the EUMETSAT website – offer even more climate relevant information.

In future, CDRs will also be supplied with persistent unique identifiers, in particular the digital object identifier (doi) widely used by international science journals. This provides a reference which allows the user to quickly identify EUMETSAT CDRs, ensuring that the CDRs can easily be cited in the scientific literature.

The EUMETSAT Network of Satellite Application Facilities

NWC SAF
Support to Nowcasting and Very Short Range Forecasting
Led by Agencia Estatal de Meteorología, Spain

OSI SAF
Ocean and Sea Ice
Led by Météo France

CM SAF
Climate Monitoring
Led by Deutscher Wetterdienst, Germany

NWP SAF
Numerical Weather Prediction
Led by Met Office (UK)

LSA SAF
Land Surface Analysis
Led by Portuguese Meteorological Institute

O3M SAF
Ozone and Atmospheric Chemistry Monitoring
Led by Finnish Meteorological Institute

ROM SAF
Radio Occultation Meteorology
Led by Danish Meteorological Institute

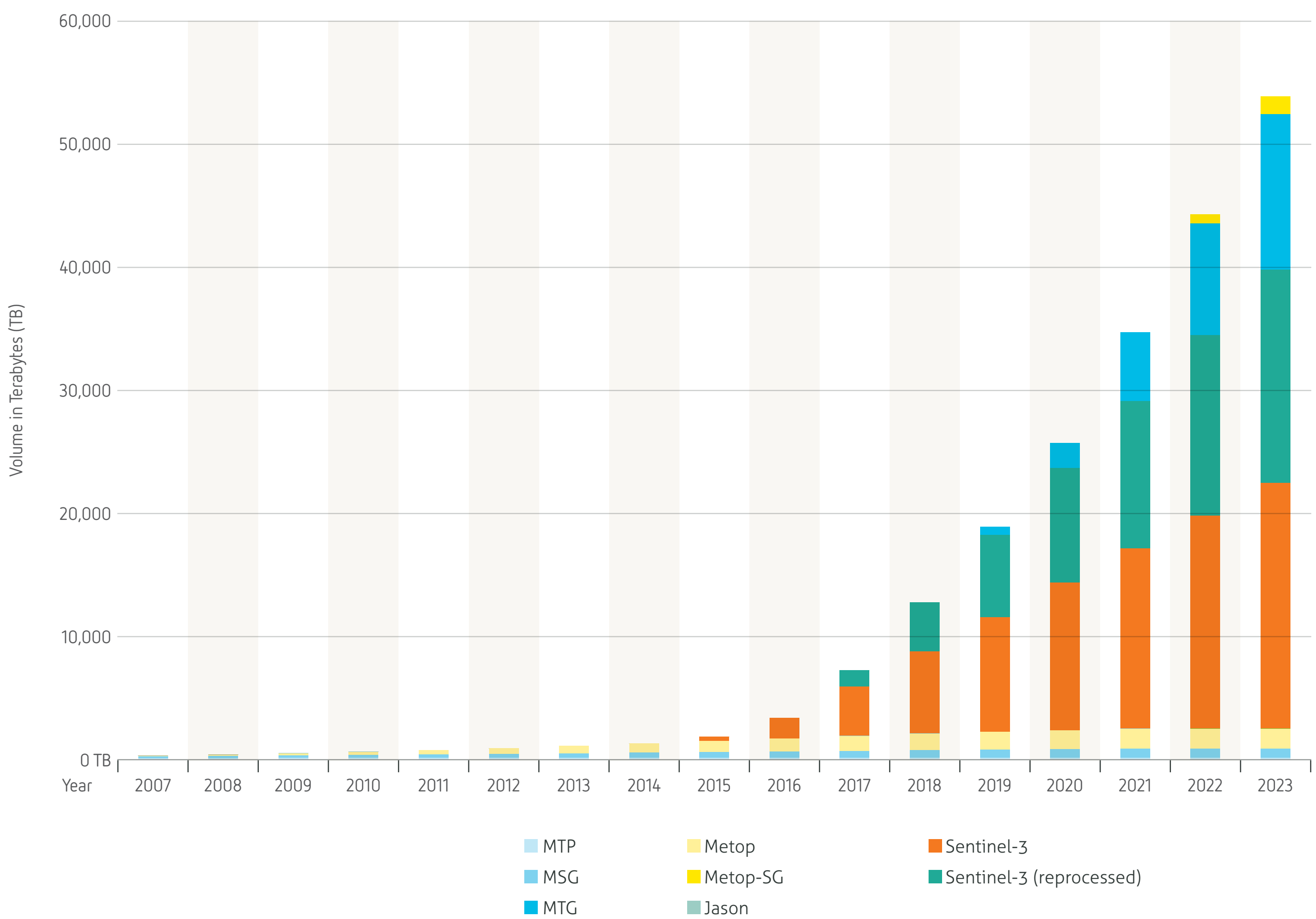
H SAF
Support to Operational Hydrology and Water Management
Led by Italian Meteorological Institute

A UNIQUE ARCHIVE FOR DATA PRESERVATION

With almost 35 years of data from operational meteorological satellites and a volume of 1.4 Petabytes (PB), the EUMETSAT archives host some of the world's longest data records collected by satellites and constitute an invaluable asset for climate monitoring and the understanding of climate change.

The new data library installed in 2014 will support the expansion of the archive in time and scope with data from future satellite systems, including Sentinel-3, MTG and EPS-SG expected to bring the total volume up to 40 PB by 2020. The scalability of the system will enable hosting up to 200 PB in the 2025 timeframe.

As part of its data preservation policy, EUMETSAT maintains three distinct copies of its archive, one being hosted outside its headquarters.



Planned evolution of the volume of the EUMETSAT archive

EUMETSAT

SUPPORTING THE EU COPERNICUS CLIMATE CHANGE SERVICE

The EU Copernicus Climate Change Service (C3S) "responds to environmental and societal challenges associated with climate variability and human-induced climate change."[9]

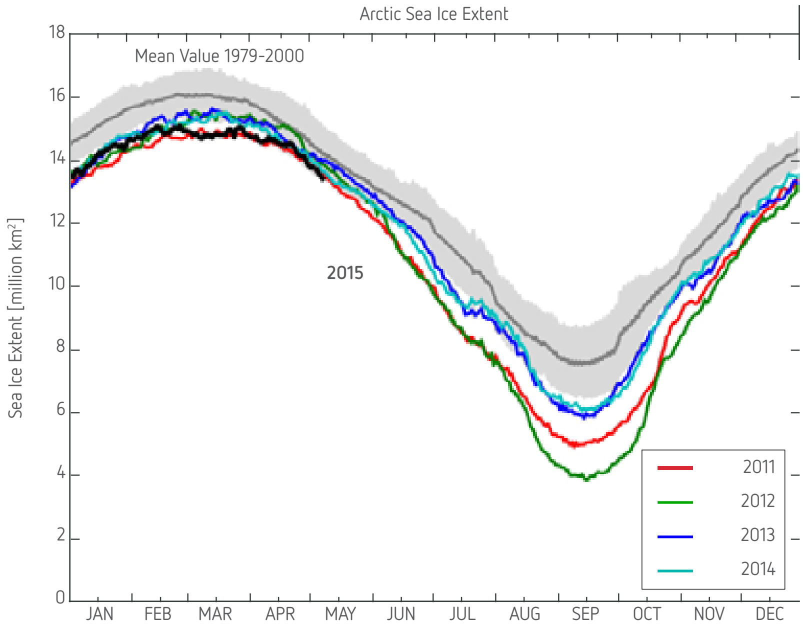
Mauro Facchini
Head of Copernicus Unit
DG GROW
European Commission

"The Copernicus Climate Change Service will give access to information for monitoring and predicting climate change and will help to support adaptation and mitigation strategies."

The C3S is one of the six services of Copernicus, the EU's flagship Earth observation programme, which aim to ensure operational monitoring of the atmosphere, oceans and continental surfaces to provide reliable, validated information services for a range of environmental and security applications.

The C3S is implemented by the European Centre for Medium-range Weather Forecasts (ECMWF). Relying on sustained observations - both from *in-situ* networks and satellites - and on Earth system modelling capabilities, the C3S will deliver a wealth of information on current climate change and future climate.

The annual cycle of Arctic sea ice extent in our changing climate: the grey line represents the average cycle in the period 1979-2009 and the shadow the variability around this average, while the coloured lines represent individual cycles in the years 2011 to 2014 (source: OSI SAF)



To do so, the C3S needs to capitalise on a series of observations from space. These include EUMETSAT's missions such as Jason-2/-3, Meteosat and EPS/Metop, and, in the future, the four dedicated Copernicus Sentinel missions operated by EUMETSAT on behalf of the EU to monitor the ocean (the Sentinel-3 and Sentinel-6 marine missions) and the atmospheric composition (Sentinel-4 and -5).

EUMETSAT's climate monitoring activities and existing know-how constitute an asset for the initial development of the C3S and are expected to expand with EUMETSAT's foreseen contribution to the C3S.

Dr. Jean-Noël Thépaut
Head of the Copernicus Climate Change Service
European Centre for Medium-range Weather Forecasts

"The service will combine observations of the climate system with the latest science to develop authoritative, quality-assured information about past, current and future states of the climate in Europe and worldwide."

[9] www.copernicus-climate.eu

SUPPORTING CLIMATE-RELATED CAPACITY BUILDING INITIATIVES

The regional implementation of the Global Framework for Climate Services is a political priority in Africa. EUMETSAT supports relevant capacity building initiatives established in cooperation between the African Union and the European Union.

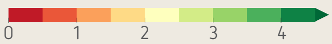
H.E. Rhoda Peace, African Union Commissioner for Rural Economy and Agriculture, and H.E. Edna Molewa, South African Minister of Environmental Affairs, signing a political statement confirming their commitment to the implementation of the GFCS in Africa and the Caribbean and Pacific regions, Benoni, 7 September 2014

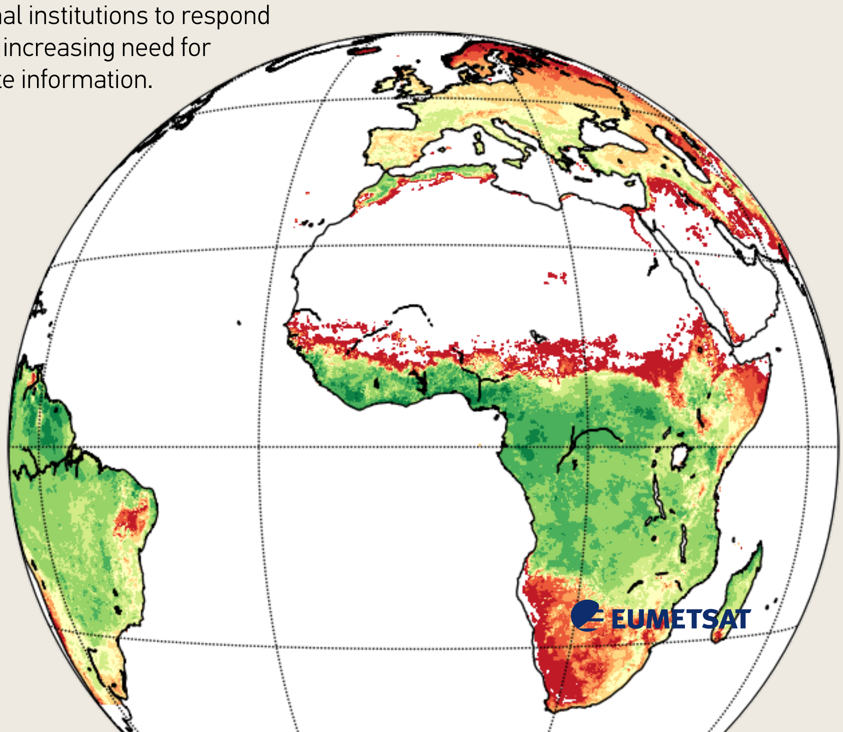
With the Addis Ababa Declaration of September 2012 and the Benoni Statement of September 2014, the African Regional policy institutions and the African, Carribbean, and Pacific Group of States (ACP) Secretariat called for the implementation of GFCS in Africa, Caribbean and Pacific and asked support from the European Union. These policy institutions consider that climate services are indispensable for decision makers and planners confronted with the adverse effects of climate change. This applies, but is not limited to water management, food security and disaster risks reduction and health.

Since 2002, EUMETSAT has provided continuous support to capacity building in Africa via a number of projects (PUMA in 2002-2006, AMESD in 2007-2013 and now MESA) funded by the European Development Fund (EDF) and carried out in partnership with the European Union, the African Union, the Regional Economic Communities, the ACP Secretariat and the World Meteorological Organization (WMO). Over the last 15 years, a unique pan-African infrastructure for access to satellite data and meteorological and environment monitoring and forecasting information has been established and maintained. With MESA, the infrastructure will further expand to include a network of around 500 stations of EUMETSAT's satellite broadcasting service - named EUMETCast - installed in 52 African countries and regional centres. EUMETSAT supports the setup and maintenance of this infrastructure, delivers satellite data and other information, and provides related training and support through cooperation with several training centres in Africa.

Within the on-going EDF-funded Monitoring of Environment and Security in Africa (MESA) project, which includes initial implementation of continental-wide climate services for disaster risk reduction, EUMETSAT supports the consolidation of the data access infrastructure and training. The engagement will enable African regional and national institutions to respond to the increasing need for climate information.

Monthly mean evapotranspiration at the surface for January 2001 extracted from a Meteosat Climate Data Record (source: CM SAF)





THE INTERNATIONAL DIMENSION: EUMETSAT IN GLOBAL PARTNERSHIPS

The full potential of space-based observations for climate change monitoring can only be realised and amplified through international cooperation. Therefore, all EUMETSAT climate activities are embedded in international cooperation frameworks.

THE GLOBAL CLIMATE OBSERVING SYSTEM

The Global Climate Observing System[10] (GCOS) programme provides the overall foundation through the assessment and formulation of requirements for climate monitoring from space. Those are captured in GCOS reference documents and reports, including the GCOS implementation plan and its satellite supplement. EUMETSAT is supporting GCOS in the assessment process, as well as the related efforts of the WMO space programme.

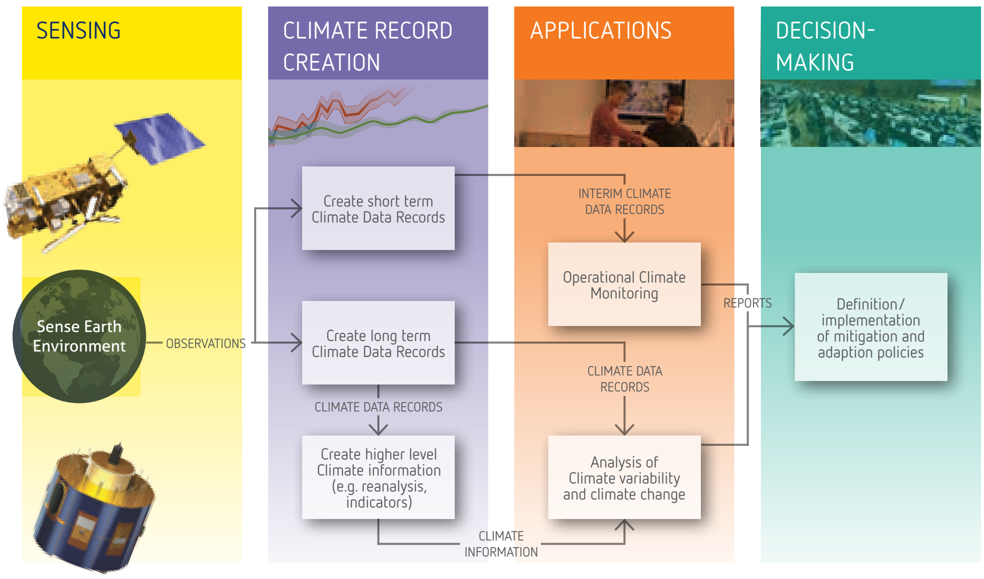
THE GLOBAL ARCHITECTURE FOR CLIMATE MONITORING FROM SPACE

No single country or agency can fulfil the full range of demanding requirements established by GCOS for space-based observations. Therefore, international cooperation is required across all operational and research space agencies to coordinate existing assets, promote their optimised combined use for climate monitoring and plan for future systems aimed at expanding Climate Data Records in time and scope and bridging identified gaps against GCOS requirements.

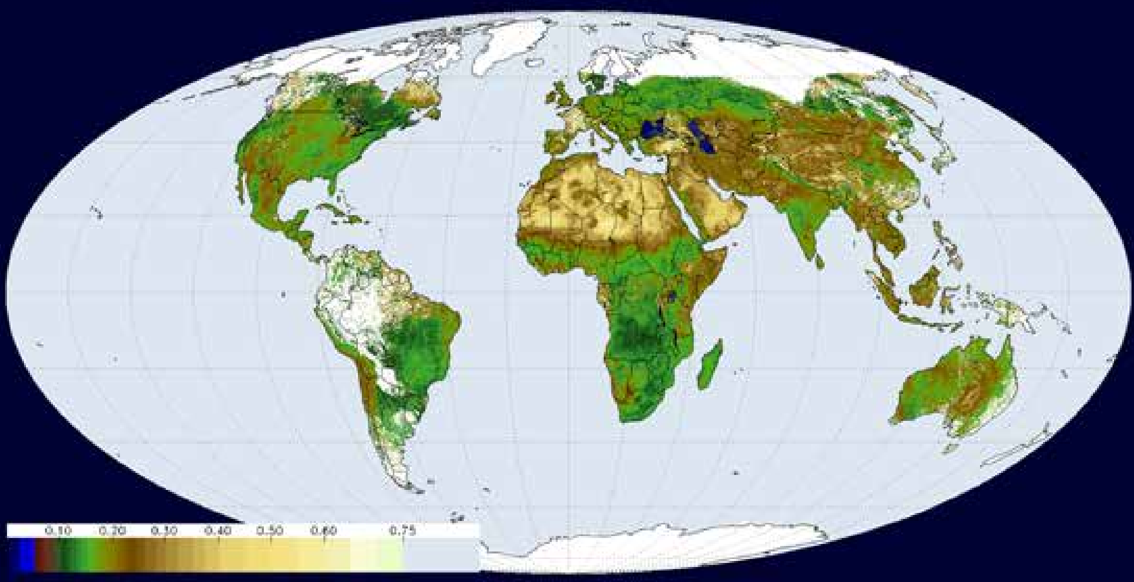
The overall framework for this international endeavour is called the 'Global Architecture for Climate Monitoring from Space' (GFCS). The Architecture was defined in 2013, following an initiative of WMO, Committee on Earth Observation Satellites (CEOS) and the Coordination Group for Meteorological Satellites (CGMS). It will constitute the space component of the "Observation and Monitoring" pillar of the GFCS, fulfilling GCOS requirements.

Functions and assets to be coordinated span all across the value adding chain. They include not only satellites, but also all ground systems necessary for archiving and preserving data and supporting their open exchange as well as granting access. Other essential elements include recalibration and cross-calibration, reprocessing, extraction and delivery of qualified Climate Data Records to the worldwide user community including decision makers.

Functional breakdown of the Architecture for Climate Monitoring from Space and support to decision making



[10] http://www.wmo.int/pages/prog/gcos/



In 2014, during the EUMETSAT chairmanship of CEOS, operational and research space agencies participating in CEOS and CGMS established a joint CEOS-CGMS working group on Climate to implement the Architecture.

This working group also involves the WMO and has three main objectives:

- Provision of a structured, comprehensive and accessible view as to which Climate Data Records are currently available from satellite missions of CEOS and CGMS members or their combination;

- Creation of the conditions for delivering further Climate Data Records. This includes multi-mission Climate Data Records, through best use of available data to fulfil GCOS requirements (e.g. by identifying and targeting cross-calibration or re-processing gaps/shortfalls);

- Optimisation of the planning of future satellite missions and constellations to expand existing and planned Climate Data Records, both in terms of coverage and record length and to address possible gaps with respect to GCOS requirements.

Under the first objective, a rolling inventory of existing and planned Climate Data Records of Essential Climate Variables has been established and will be consolidated to trace the CDRs of ECVs to contributing Fundamental CDRs and space missions.

Under the second objective, cooperative projects are ongoing to cross calibrate data from missions of CEOS and CGMS agencies and develop the sustained generation of improved and new Climate Data Records.

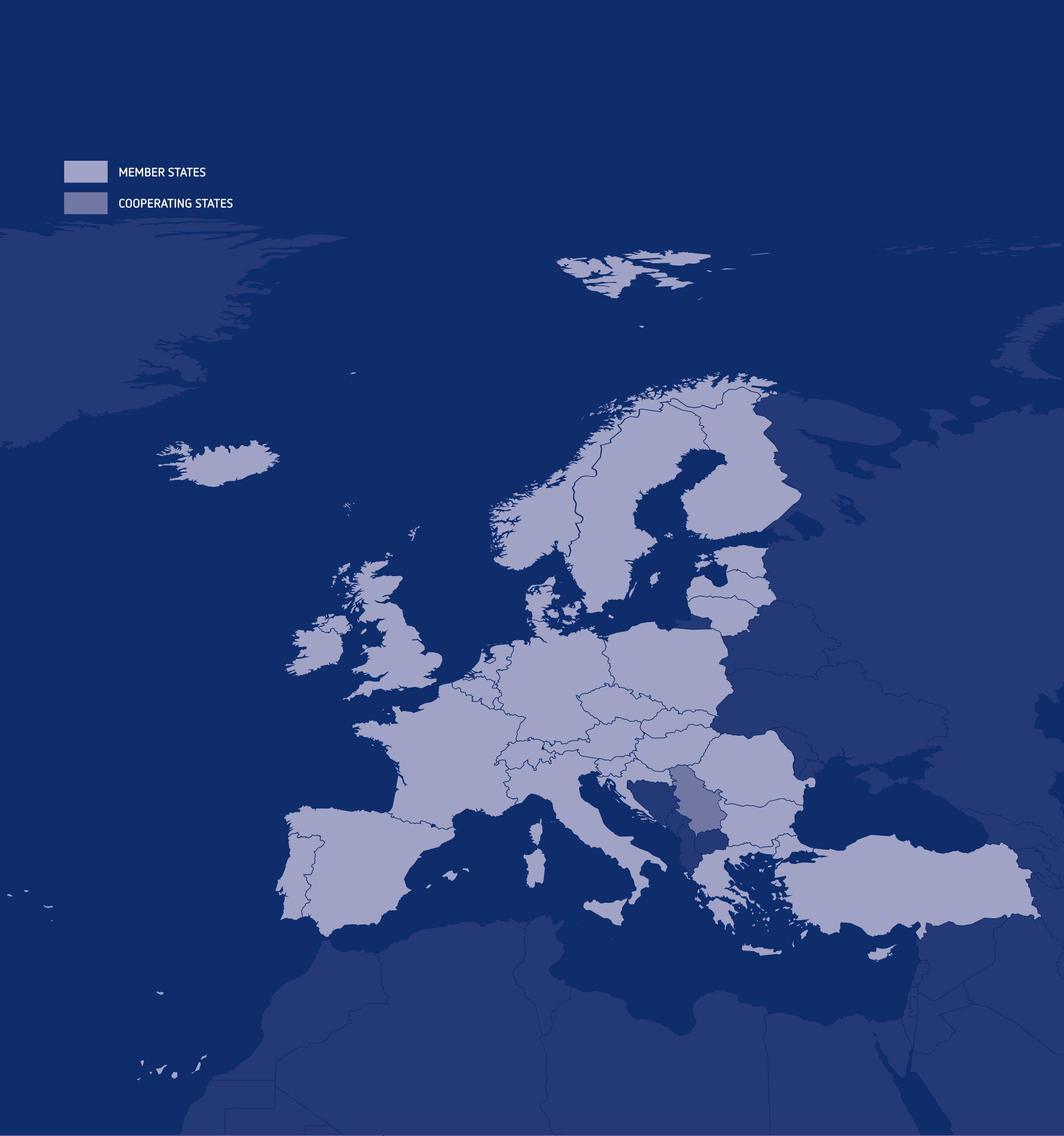
In this area, EUMETSAT participates in the WMO GSICS (Global Space-Based Inter-Calibration System) and SCOPE-CM (Sustained, Co-ordinated Processing of Environmental Satellite Data for Climate Monitoring) initiatives.

GSICS provides an international platform to develop standard methods and operational procedures to ensure quality and comparability of satellite measurements taken at different times and locations by a variety of missions and to produce and share calibration products. Downstream from GSICS, SCOPE-CM coordinates projects targeting the sustained generation of CDRs from satellite data.

EUMETSAT has supported GSICS since its initiation in 2005, hosts the secretariat of SCOPE-CM and is involved in several SCOPE-CM projects, through its central facilities and its SAF network.

Under the third objective, CEOS and CGMS agencies plan for future missions required to expand climate data records, capitalizing on the work of the CEOS virtual constellation.

Climatology of surface albedo established in the framework of the SCOPE-CM international project using historical data from the full "ring" of geostationary meteorological satellites (source: SCOPE-CM)



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Brochure: APP.03, V.1

MEMBER STATES

COOPERATING STATES

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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