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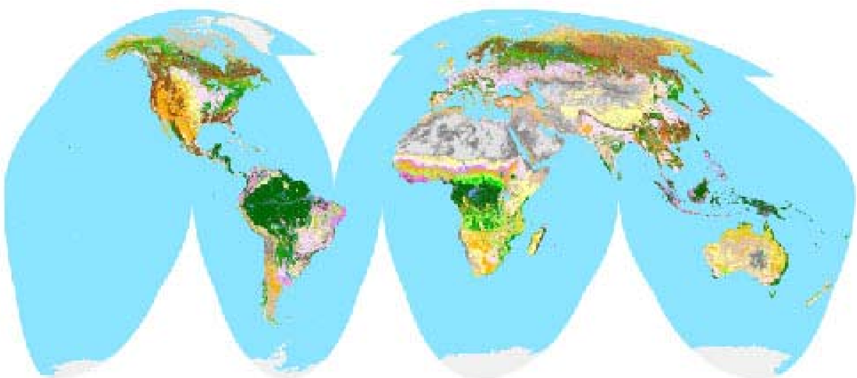

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# European capacity for monitoring and assimilating space-based climate change observations - status and prospects

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## Contents

# 1 Executive Summary

## 1.1 Overall conclusions

Europe's scientific community, in conjunction with the EC, EEA, ESA, EUMETSAT, ECMWF, EUMETNET and Member States Institutions have proven capacity for *climate monitoring* to determine the prevailing climate of any given region and to measure rates at which variables such as temperature and rainfall change. Europe has the capacity for *climate prediction* to determine the future state of the climate system years and decades ahead. Our monitoring and prediction work is supported by *climate research* to assure continued developments in the collection, archiving, analysis and application of climate data and information.

The accuracy and completeness of observations of the past and current state of the atmosphere, ocean and terrestrial components affect the accuracy of climate monitoring and prediction. Over the last decade the UN-sponsored Global Climate Observing System (GCOS) has established scientific requirements for systematic climate observations needed to characterize the state of the global climate system and its variability, to monitor the forcing of the climate system, help determine the causes of climate change, improve climate change prediction and to assess impacts, adaptations, risk and vulnerability.

Translating capacity and potential into operational services can occur by securing a stable financial platform. Sustained funding would strengthen observational networks (the space segment making measurements, plus processing, product generation and quality control) enabling the consistent generation of Fundamental Climate Data Records (FCDRs), which are essential for the derivation of Essential Climate Variables (ECVs). It would support reanalysis and assimilation schemes needed to turn these data into policy relevant information. It would promote the design and construction of information management systems and promote effective use of climate information and prediction services in climate-sensitive policy sectors.

The need for full access to standardised data for climate services provisioning Europe's governments, public and scientific community with climate information is extremely high. This was underscored at the 3rd World Climate Conference, held in August 2009, and is already expressed in the UNFCCC, the Convention's Protocol as well as studies such as the Stern Review. Existing capacities and networking in Europe provide a solid foundation, however the climate monitoring objectives will not be met without increased computing power for this distributed skills-base and a move away from the current dependence on research funding.

## 1.2 Key discussion points

1) European climate monitoring and prediction services would provide much needed but currently missing information for climate-sensitive policy sectors including health, transport and energy, insurance, civil protection, agriculture, forestry, fisheries, tourism, development-cooperation, and maritime planning. Climate information would support policy definition and implementation, help in fund allocation and prioritisation, meet mandatory reporting requirements and form part of public alarm systems protecting both our own citizens and those of partner countries.

2) The Global Climate Observing System has identified 44 essential climate variables as the minimum needed to provide reliable climate information. Peer-review of each variable by the international scientific community has established specifications, such as frequency and scale of observation as well as accuracy and acceptable levels of uncertainty. At least 31 of the ECVs can be measured from space such that they meet these specifications.

3) Europe has proven capacity in space hardware development and construction, processing algorithm development and generation of ECVs. The European satellites flying today, along with systems already commissioned provide the *potential* to generate around 29 of the ECVs. Current commitments (including the ESA Climate Change Initiative, EUMETSAT Satellite Application Facilities, ECMWF ERA reanalysis, some EC Framework Programme research projects and the GMES Services) support end-to-end production of around 40% of these over the next five to ten years – but long-term guarantees for operational production still have to be secured.

4) Participation in International programmes including the Committee on Earth Observation Satellites (CEOS) and the Group on Earth Observations (GEO) provide a framework for calibration, inter-comparison and benchmarking of European ECVs with others, along with task-sharing so complete provision of all 44 ECVs becomes possible.

5) Europe has world-leading capabilities in the reanalysis of climate data and assimilation of these and other observations to provide analysis of climate and climate change.

6) Unfortunately ECV production, reanalysis and assimilation activities in Europe are based on research funding or are performed on the margins of routine operations by satellite operators or by numerical weather prediction (NWP) services.

7) Joint Programme implementation is an imperative; to fill gaps, avoid overlaps and ensure that the existing disparate elements of a "European Climate Infrastructure" are formally recognised as such. Existing efforts, by the European Commission, ESA, EUMETSAT and others need to be connected, strengthened and sustained.

8) Increased computing resources (computational/storage, bandwidth and skilled personnel) are needed to ensure that coupled Earth System models can be run, and that the spatial and temporal resolution of these can be improved). The improvements should build on established skills centres; for example around the framework being put in place by the World Meteorological Organisation (WMO). A centralised facility is not needed, but substantial and sustained funding is required to reinforce a number of large installations and to provide the necessary communication and networking infrastructure.

9) Europe has the scientific and technical skills to provide full access to standardized data for climate but the current reliance on research budgets and ad-hoc "envelope" programmes for funding limit activities to test cases and demonstrator projects. The lack of a stable financial platform, analogous to that underpinning Numerical weather

prediction is a fundamental block to reliably generating products for operational users.

10) Because activities are funded from many sources the overall amount is difficult to establish. A dedicated study is urgently needed to identify the current levels of public expenditure on climate information provision. This would provide a basis for estimating budget levels needed to secure operational climate information services in Europe.

11) Because funding is not provided from an operational budget line Europe is unable to make the move from research to operations. We are in the unacceptable position of having to de-scope planned activities, even where these are essential and based on proven world-class science. This underplays European scientific capacity, is a severe handicap to joint implementation and makes it impossible for a climate service to deliver sustained information, as required in any legal or operational setting.

# 2 Introduction & rationale

## 2.1 Background

In June 2008, the French Presidency of the EU proposed the creation of a European Centre for Research into Climate Change and its impact. Such a centre would combine human and technical resources in order to provide appropriate computing capability to support the development of improved climate change simulations on global, regional and local scales as well as the development of homogeneous long-term series of climate data, organise a network of climate change experts and centres in Europe, and prepare a European multidisciplinary programme of research into the impacts of climate change. At the informal meeting of ministers responsible for space in Kourou, French Guiana on 21-22 July 2008, the MS highlighted the importance of the contribution of satellite-based climate change monitoring and related research activities. The majority of MS reacted with caution to the initiative proposed in the French Presidency discussion paper. Instead they highlighted the importance of making better use of existing European and national resources and infrastructures by strengthening cooperation and networking. It was agreed to conduct a study to assess in-depth the need for a new instrument in this field as well as possible solutions taking into account existing capacities and resources in Europe.

Eventually, a resolution on "Space and Climate Change" of the 5th Space Council (a concomitant meeting of the European Union (EU) Competitiveness Council and the European Space Agency (ESA) Ministerial Council) was adopted on 26th September. This "INVITES the commission to conduct a study to assess the needs for full access to standardised data and for increased computing power, and the means to fulfil them taking into account existing capacities and networking in Europe".

Further, it "CALLS for the scientific community, in conjunction with the EC, ESA and EUMETSAT (European Organisation for the Exploitation of Meteorological Satellites), to define how the range of GMES (Global Monitoring for Environment and Security) services and European space observation archives can contribute most effectively to the provision of data including Essential Climate Variables (ECVs) for scientific research".

The Competitiveness Council Resolution of 2nd December 2008 additionally "Invites the commission to foster the implementation of the GMES climate change monitoring to support the related European Union policies".

To respond to the above questions the Commission has undertaken to a) evaluate the status quo and future plans for the provision of climate data and b) identify what actions are required to build on existing and planned capacities to secure a dependable and comprehensive information source for climate data. Given that the initial request came from Space Council and is headed "Space and Climate Change", the Commission response, to which this report provides the scientific background, focuses primarily but not exclusively, on space-based Climate data sources. Taking its' key from the second part of the resolution it also further focuses on ECVs and the Fundamental Climate Data Records (FCDR) underpinning them, although again not exclusively where scientific consensus is that other variables, such as soil organic carbon, are of similar importance. Finally this report embraces both pan-European and national activities and has undergone a thorough external review.

The study behind the report was commissioned by ENTR and undertaken by the Joint Research Centre (JRC), following initial inter-service discussions between DGs ENTR, RTD, ENV, INFSO and the JRC. The study comprised a preliminary analysis by the JRC, followed by a high-level workshop with the participants listed in the acknowledgements. A draft-report containing the preliminary analysis, the contributions from the workshop participants and consensus of the workshop was subsequently presented to the policy directorates general of the European Commission, the GMES Advisory Council and the ECs Inter Service Group on climate change and space: feedback from these three processes has been incorporated into this final version of the report.

## 2.2 What is required and what is currently available

The need for full access to standardised data for climate services provisioning Europe's governments, public and scientific community with climate information is extremely high. This has been underscored at the 3rd World Climate Conference held in August 2009, and is already expressed in the UNFCCC (United Nations Framework Convention on Climate Change), the Convention's Protocol and studies such as the Stern Review.

### 2.2.1 What is Required?

Climate services include *climate monitoring* to determine the prevailing climate of any given region and to measure rates of change of variables such as temperature and rainfall; *climate prediction* to determine the future state of the climate system years and decades ahead; supported by *climate research* to assure continued developments in the collection, archiving, analysis and application of climate data.

Climate affects so many aspects of our day-to-day lives that analysis of needs by policy sector results in a huge list; everything from likely changes in wind-shear occurrence for airport developments to sea level rises for flood defences or likely energy needs for heating and cooling urban areas[1]. Although specific policy sectors call for specific answers, climate information is needed in the policy cycle at four key points - Policy definition; Management and scenario building; Reporting requirements; Alarm function.

*Policy definition* has to be based on accurate scientific information. How rapidly are changes occurring? What are the uncertainties in the measurements? How reliable are the forecasts, scenarios and speculations? Key policy decisions have to be made on the basis of science-based information. This is true for both sectoral policy users (such as health, environment, transport and energy) and for conditioning EU "Climate Change" policy itself. If the EU moves to a higher % use of biofuels what are the consequences for agricultural production patterns in both the EU and our trading partners? Should the EU support the inclusion of reduced emissions from deforestation and degradation in any future agreement? Pertinent answers to these sorts of questions would be significantly enhanced by quality information services using the best models, the best computing and the best observations.

*Management and scenario building* will be improved as informed choices are made from accurate assessments of current and future climates for any given region. How

[1] Manton, M.J., et al., 2009, Observation Needs for Climate Services and Research, White Paper presented at the session on Observation Needs for Climate Information, Prediction and Application at the 3rd World Climate Conference (WCC-3) held in Geneva, Switzerland 31st August to 4th September 2009

should funds be allocated? What should be given priority? How successful was any given project? Fund allocation processes and prioritisation needs to consider climatic change. For example road building needs to account for the rainfall and temperature extremes they are going to encounter, irrigation systems need to know how much water will be available and when, immunisation schemes need to account for changes in disease vectors. Post-project audit and evaluation also benefits from reliable climate information – Do the forest protection schemes put in place still enhance the world's carbon sinks?

*Reporting requirements* are already part of the policy and climate change landscape. Mandatory reporting on elements such as greenhouse gas emissions, carbon sinks, biodiversity protection schemes etc. are very much part of Multilateral Environmental Agreements, and observations underpin such reporting. Strategy Papers and Environmental Profiles have to be prepared as part of governmental development-assistance programmes. These increasingly need to take climate change into account, especially where adaptation measures are being proposed.

*Alarm functions* are an increasing feature of public policy. Forest fire forecasting systems or flood and drought forecasting systems are pertinent to the EU and to our development-assistance partners around the world. The security of our own food supply and those of our partners are highly dependent on climate. Other dimensions of security, such as access to water are also affected by climate. The international community is increasingly putting sanctions and controls in place and verification is critical for these whether targeted such as rights to water supplies or more general such as the carbon trading instruments linked to the UNFCCC. Observations are a fundamental part of successful alarm functions.

Potential DG clients of the climate data services, whether directly or indirectly, via their use in driving improved assessments of climate change include Education and Culture (EAC), Humanitarian Aid (ECHO), Enterprise and Industry (ENTR), Environment (ENV), Regional policy (REGIO), External cooperation programmes (RELEX, AIDCO, DEV), Energy and transport (TREN), agriculture (AGRI), Health (SANCO), Maritime affairs and fisheries (MARE), and Research (INFSO, RTD and JRC).

### 2.2.2 What is Currently Available?

At present a wide range of agencies and funding initiatives support the provision of ECVs and the landscape is complex, but rich and capable. In addition to the ESA, EUMETSAT and GMES service projects who were explicitly identified by Space Council, additional stake holders include: the European agencies ECMWF (European Centre for Medium Range Weather Forecasting), the EEA (European Environment Agency) and EUMETNET (Network of European Meteorological Services); national meteorological and climate centres (e.g. DKRZ/MPIM, Hadley Centre, CNRM, UK National Centre for Earth Observation etc); National Space Agencies and Earth Observation Centres. Within the research sector relevant EU projects funded under the Framework Programs include GEOMON, ENSEMBLES, CLAVIER, CECILIA etc., while within the Commission, DGs actively working in or supporting climate change research, include RTD, ENTR, INFSO, ENV & JRC.

Europe has proven capacity in space hardware development/construction, processing algorithm development and partly operational generation of a subset of ECVs. It should be noted however that the provision of ECV data and the underlying FCDRs in Europe is incidental to the core missions of many of the participants and not yet comprehensive.

Part of the European climate observing capacity has been put in place by EUMETSAT based both on data from operational satellite systems and data from research and development satellite systems of ESA. The driver for the current operational activities of EUMETSAT is support for weather prediction as well as supporting EUMETSAT's mandate for climate monitoring. "Operational" is the key here as it means EUMETSAT must maintain a continuing series of satellites with a guaranteed replacement policy, in contrast to ESA's mandate for technology development as a research and development agency. Nevertheless, the derivation of FCDRs is performed on the margins of EUMETSAT routine operations. The derivation of the FCDRs is best done at the source, i.e. by the instrument operator, while continuity predicates the systematic cross-calibration of instruments providing the same type of measurements in going from research missions like the ERS/Scatterometer to the operational ASCAT observations. The main motivation for the work is hence to develop a sustained operational capability for the derivation of FCDRs and Thematic Climate Data Records (TCDRs) in support of the development of ECVs.

Similarly, developments in the assimilation of direct observations in numerical weather prediction (NWP) models are driven by the need for better weather forecasts. The value of reanalysis utilising the developments in assimilation for NWP, is that it creates a homogeneous and dynamically consistent time-series of many parameters of the global Earth System, providing the ideal framework for the generation of consistent ECV records. Currently reanalyses have either been seen as one-off projects, or piggyback on the core NWP activities of ECMWF & National Weather services.

Separate from mission continuity and overlap, agencies have also given increased emphasis to the calibration of instruments and the inter-comparison of sensors between satellites. The development of the Global Space-based Inter-Calibration System (GSICS), jointly between the WMO Space Programme, CGMS and the Committee for Earth Observation Satellites (CEOS) Working Group on Calibration and Validation (WGCV), is expected to meet many of these needs. GSICS is designed to ensure the generation of well-calibrated FCDRs. Maintaining archives of the basic data records and metadata from past and current missions and reprocessing of datasets is also being given increasing attention in many agencies. For example, ESA member states are subscribing to a programme aimed at implementation of ECVs from their past and future missions. EUMETSAT, in conjunction with other agencies and WMO, has been supporting the SCOPE-CM initiative (Sustained Coordinated Processing of Environmental Satellite Data for Climate Monitoring, formerly referred to as 'R/SSC-CM'), with a focus on the generation of long-term ECV products. Many agencies are undertaking a range of reprocessing activities, although attention to ensuring common product benchmarks between the activities of different agencies is sometimes inadequate.

## 2.3 The International Dimension

Europe is not alone in focusing effort on addressing the topics dealt with in the present report. Many of these contributions are eloquently summarised in the recent Progress Report of the 2004 Global Climate Observing System (GCOS) Implementation (published in August 2009)[2]. These contributions range from complementary national programs by the United States and Japan amongst others, to coordinated international initiatives within CEOS and WMO. The GCOS progress report summarises the international progress made by the space agencies in response to the 2004 GCOS Implementation Plan[3] and its Satellite Supplement[4], much of which is detailed in the CEOS implementation plan[5] which contains coordinated response of the agencies to meet the overall GCOS objectives. For example, specific steps have been taken to provide access by all nations to all satellite products. Since 2004, there have also been some setbacks in ensuring mission continuity, but remedial action by space agencies has been prompt to fill expected gaps between satellite missions. Current plans still have some possible future gaps, but these have been identified by the space agencies and they are looking at ways of avoiding them. The report does however note that progress in the less-developed regions of the world in implementing the GCOS objectives has to date been less that satisfactory.

It is evident that the various national and international stakeholders are heavily dependent on one another to achieve global availability of the required datasets. In the context of the current report, however, we focus on the European contribution, with the understanding that this European contribution is be one of many that are required to fulfil the objective of long-term sustained observations by GCOS and forms part of the European contribution to the Global Earth Observation System of Systems (GEOSS). Climate is one of the Societal Benefit Area (SBA) recognised by the Group on Earth Observation (GEO). Maintaining strong international cooperation through entities such as GEO, CEOS and WMO, and doing so with a common voice, will thus be of paramount importance.

GEO has identified strategic targets for the Climate SBA to be accomplished before 2015. These should "Achieve effective and sustained operation of the global climate observing system and reliable delivery of the climate information needed for predicting, mitigating and adapting to climate variability and change, including for better understanding of the global carbon cycle."

To achieve this GEO proposes specific tasks by 2015, which include: Achieving a high level performance of all components of GCOS, including ensuring availability of all ECVs needed by WCRP, IPCC and UNFCCC, and the use of these in contributing to an improved modelling and prediction of climate. Access to all the observational data needed for climate monitoring and services in support of adaptation to climate variability and change should also be demonstrated. GEO is also asking for the development of a comprehensive global carbon observation and analysis system to support monitoring based decision-making and related to environment treaty obligations.

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[2] http://www.wmo.int/pages/prog/gcos/Publications/gcos-129.pdf.

[3] http://www.wmo.int/pages/prog/gcos/Publications/gcos-92.pdf

[4] http://www.wmo.int/pages/prog/gcos/Publications/gcos-107.pdf

[5] http://www.ceos.org/images/PDFs/CEOSResponse_1010A.pdf

# 3 Structure of the analysis

The structure of the analysis is dictated by the issues raised by the Space and Competitiveness Council resolutions:

- What standardised data are needed for climate studies,
- What data are currently available and will become available from whom in relation to the needs defined above (i.e. a gap analysis)
- What additional infrastructure and in particular computing power is needed to fill the gaps identified above and provide an operational service that provides the required climate data.
- What is the best means of putting this infrastructure in place (a distributed networks or centralisation).
- How better to co-ordinate among the existing players using in particular GMES.

The report addresses each of these issues in turn. The consensus from the initial inter-service discussions which was affirmed by the workshop was that the Essential Climate Variables defined by GCOS were the minimum set of data that could be considered and these are discussed in section 4; The detailed gap analysis is presented in tabular form in section 8; Section 5 analyses the European capacity according to maturity, differentiating between sustained operational capacity (Envelope Missions/EUMETSAT), non-operationally funded repetitive capacity (both ESA, EU & national research) and research funded new capacity for variables not covered in 1&2 above. Section 6 introduces needs for additional infrastructure in order to fill the gaps described above. These infrastructure requirements are expressed in terms of additional CPU, storage, bandwidth and expertise, and also whether these needs can be met by expanding existing facilities rather than new-build and the relative merits of distributed and centralised solutions. Finally section 7 discusses the co-ordination and governance issues and how to overcome them.

# 4 Essential Climate Data and Fundamental Data Records

## 4.1 The GCOS ECVs

A key commitment in the UNFCCC is related to systematic observation and development of data archives over the long-term related to the climate system. The Global Climate Observing System established in 1992 has become the recognised mechanism for facilitating this commitment. GCOS has issued two Adequacy Reports to the UNFCCC on the global climate observing systems. Its second report in 2003[6] GCOS established a list of ECVs that are both feasible to measure and have a high impact on the UNFCCC requirements and detailed basic principles that climate monitoring should adhere to in order to be effective (see below). This was followed by the implementation plans and progress reports referred to in 2.3. Consequently, needs in terms of space data products are internationally well defined and scientifically agreed. The missing part is how to provide an inter-variable wise consistent set of ECVs.

The GCOS ECVs are thus the consensus view from the international scientific community on what constitutes an indispensable climate data set. The Implementation Plan and its recommendations on resolution, accuracy, precision etc. have been extensively reviewed and revised by the science community through open review and dedicated workshops with the Intergovernmental Panel on Climate Change.

Both the inter-service group and the workshop experts recommended using the existing GCOS list precisely because it is so well defined. It was also recognised however, that the current ECVs were not the sole type of climate observation required. They are the absolute minimum and will need augmenting in second-generation climate information systems. Nevertheless, the ECVs are internationally accepted and are prerequisites to the production of other thematic indicators; a strategy of core data provision is entirely in keeping with strategy of the GMES services.

While observations of ECVs characterise past climate, studies[7] indicate that in the short-term (10-20 years), the biggest contribution to uncertainty in climate scenarios is the uncertainty in initial conditions i.e. the uncertainties in the *current* observations of ECVs. The 10-20 year time frame is critical for adaptation to climate change; robust estimate of climate change in the short-term also require complete observations of ECVs today.

In its report to COP-12 in 2006[8], CEOS provided a response by space agencies regarding the adequacy of past, present, and future satellite measurements. In the report CEOS identified what can be achieved by better coordination of existing and future capabilities as well as improvements requiring additional resources. The report was intended to initiate action and assist the Parties in advising and commenting on the agencies' planning. 59 individual actions were identified in order to address the requirements expressed by GCOS and these represent the basis of the implementation plan for the Climate Societal Benefit Area. These actions were grouped into three

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[6] http://www.wmo.int/pages/prog/gcos/Publications/gcos-82_2AR.pdf

[7] Cox, P.M., and Stephenson, D.B. (2007): A changing climate for prediction, Science, 317, pp 207-208.

[8] http://www.ceos.org/images/PDFs/ceos_ipdraft_nov2007.pdf

priority levels, thus reflecting the 2, 6 and 10 year targets in the GEOSS implementation plan.

### 4.2 The GCOS principles of good monitoring for climate change

A complete set of principles was adopted by the Congress of the World Meteorological Organization (WMO) through Resolution 9 (Cg-XIV) in May 2003; agreed by CEOS at its 17th Plenary in November 2003; and adopted by the Conference of the Parties (COP) through decision 11/CP.9 at COP-9 in December 2003.). These provide the framework by which standardisation of climate data produced by different agencies can be achieved.

### 4.3 Space based monitoring of ECVs/FDRs.

Table 1 indicates which of the 44 ECVs are capable of being monitored from space (these are in **bold** and additionally ***italics*** if there is uncertainty between nomenclature in the ECV table and in GCOS report 82.

| Domain | Essential Climate Variables |
|---|---|
| **Atmospheric** (over land, sea and ice) | **Surface: Air temperature, Precipitation**, ***Air pressure, Surface radiation budget,*** **Wind speed and direction, Water vapour.**<br>**Upper-air: Earth radiation budget (including solar irradiance)**, **Upper-air temperature (including MSU radiances)**, **Wind speed and direction, Water vapour, Cloud properties.**<br>**Composition: Carbon dioxide, Methane, Ozone, Other long-lived greenhouse gases[9], Aerosol properties.** |
| **Oceanic** | **Surface: Sea-surface temperature,** ***Sea-surface salinity,*** **Sea level, Sea state, Sea ice,** Current, **Ocean colour (for biological activity),** Carbon dioxide partial pressure.<br>**Sub-surface:** Temperature, Salinity, Current, Nutrients, Carbon, Ocean tracers, Phytoplankton. |
| **Terrestrial[10]** | River discharge, Water extraction/use, Ground water volumes, ***Lake & Reservoir levels and volumes***, **Snow cover & Snow water equivalent, Glaciers and ice cap extents and volumes,** Permafrost and seasonally-frozen ground, **Albedo,** ***Land cover (including vegetation type), Fraction of absorbed photosynthetically active radiation (fAPAR), Leaf area index (LAI), Biomass, Fire disturbance, Soil moisture (complete unsaturated zone)[11].*** |

**Table 1. ECVs by domain (indicating in bold those that can be measured from space).**

[9] Including nitrous oxide ($N_2O$), chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride ($SF_6$), and perfluorocarbons (PFCs).
[10] Includes runoff ($m^3 s^{-1}$), ground water extraction rates ($m^3 yr^{-1}$) and location, snow cover extent ($km^2$) and duration, snow depth (cm), glacier/ice cap inventory and mass balance ($kg\ m^{-2} yr^{-1}$), glacier length (m), ice sheet mass balance ($kg\ m^{-2} yr^{-1}$) and extent ($km^2$), permafrost extent ($km^2$), temperature profiles and active layer thickness, above ground biomass (t/ha), burnt area (ha), date and location of active fire, burn efficiency (%vegetation burned/unit area).
[11] Recognized as an emerging Essential Climate Variable (not part of the 44).

Note that the total of 31 space-based ECVs includes sub categories (e.g. fire disturbance includes fire detection, fire radiative power and burnt area). Those ECVs that cannot currently be measured from space are underlined.

The extensive table in section 8 of this report provides detail of Europe's contributions to the above. The European satellites flying today, along with systems already commissioned provide the *potential* to generate around 29 of the space-based ECVs. Current commitments (including the ESA Climate Change Initiative, EUMETSAT Satellite Application Facilities, ECMWF ERA reanalysis, some EC Framework Programme research projects and the GMES Services) support end-to-end production of around 40% of these over the next five to ten years – but long-term guarantees for operational production still have to be secured.

### 4.4 Non-space ECVs

The ECVs that cannot be monitored from Space at present are predominantly associated with the hydrological cycle - surface and sub-surface oceanic properties, or properties of the terrestrial component of the water cycle. For the oceanic ECVs *in-situ* measurements and monitoring are coordinated by GOOS and for the terrestrial ECVs by GTOS.

For the surface atmospheric ECVs, routine *in-situ* meteorological measurements provide additional capacity and ground-truthing for many of the measurements. Exchange of these data is organised globally by the World Meteorological Organisation (WMO). The dedicated GTS (Global Telecommunications System) network of WMO is currently being replaced by the larger, open WMO Information System (WIS) which will support the WMO Integrated Global Observing System (WIGOS). WIGOS will provide for the exchange of all required information produced within the various WMO observing systems, and WMO components of co-sponsored systems (e.g. GAW, GCOS, GOOS, GTOS, etc.), not just the surface observations.

Within Europe the processing of these *in-situ* meteorological data into high quality climate data and products is undertaken by the European Climate Support Network of EUMETNET, a network of 24 National Meteorological Services. EUMETNET members have agreed a policy of free and open access to these data.

Observations of atmospheric composition are also made at the surface under a wide range of national and international activities. GCOS recognises the WMO Global Atmosphere Watch (GAW) Ozone networks as its Baseline Total Ozone and Column Ozone Networks and will do likewise for the integrated global aerosol and $CO_2$ and GHG measurement networks in the future.

Within GMES, the European Environment Agency (EEA) has responsibility for co-ordination of data from the surface *in-situ* observations networks. The EEA has agreed with the European Commission that this role will initially be undertaken by creating a project team within EEA. The project will build capacity to coordinate in-situ data for GMES services by re-using the existing networks and capacities, as well as demonstrating results through 'quick wins' as proof of concept for the overall approach.

# 5 Current capabilities of an European ECV monitoring system

Who does what, for what period and to what standard in relation to the GCOS requirements Space is presented in Table 5 (section 8) for each of the ECVs that can be measured from. The following sections describe the capabilities for ECVs of existing and planned operational/Envelope mission based services and the capacities of non-operationally funded activities.

## 5.1 Capabilities of the Envelope Missions

### 5.1.1 Earth Explorers

In the mid-1990s, ESA started to develop a new approach to Earth Observation. Previously, satellites had been either operational satellites for meteorology, or research satellites, funded through individual programmes, with numerous instruments that enabled a range of different, and often non-related investigations. Under the new approach, the scientific questions to be addressed are the starting point for the definition of satellite missions and are the drivers for all requirements to be fulfilled by the missions. This was the philosophy implemented in ESA's Living Planet Programme, whereby the Earth Explorers were to become the primary Earth-science missions.

The science and research element of the Living Planet Programme was laid out in the document ESA SP-1227 based on a description of the Earth System by four themes: the Earth's interior, the physical climate, the geosphere and biosphere, and the atmosphere and marine environment with particular emphasis on the anthropogenic impact. The strategy for the issues to be addressed was expressed in the form of candidate missions that were defined through consultation with the scientific community. These missions covered a broad range of issues in Earth science.

The programmatic implementation of the strategy was formulated in the Earth Observation Envelope Programme, which consists of the Earth Explorer component and the Development and Exploitation component. Satellite missions were divided into Core and Opportunity missions, where the former are larger missions and the latter smaller missions that are scientifically led by the proposing team. For both types of missions, the user-driven approach was a fundamental principle.

More recently the scientific strategy for the Envelope programme has been set out in ESA Special Publication SP-1304 "The Changing Earth". Developed in consultation with the European science community, including a three-day seminar attended by nearly three hundred leading Earth scientists, the document was written by the ESA Science Advisory Committee (ESAC). It sets out the current understanding of Earth system science, the relevance of Earth observations from satellite and the priorities for research as a guide to the development of future Explorer missions.

The first of the Earth Explorer missions, the Gravity field and steady-state Ocean Circulation Experiment (GOCE) was launched 17$^{th}$ March 2009 and is now beginning to deliver its scientific data. It is aimed at understanding the solid Earth and providing the most accurate reference observations for unifying height systems across the Earth. In the context of climate, its most important output will be the best available geoid, essentially the precise shape of the Earth, or in the case of oceans the shape of the free ocean surface when at rest. Comparing the ocean surface at rest with the time-varying measurement of ocean surface available from satellite altimeters, will provide for the first time measurements of the mean ocean circulation around the Earth. The associated oceanic circulation of heat energy and momentum and exchange between the oceans and the atmosphere are critical measurements for climate.

Later in 2009 two further Explorer missions will be launched, SMOS (Soil Moisture and Ocean Salinity) which carries a passive L-band radiometer and will measure, as its name implies, two more of the most critical and most poorly known measurements related to climate, and Cryosat-2. This will carry sophisticated altimeter which will provide novel measurements of the cryosphere, notably of the thickness and extent of sea-ice in the Arctic which is of particular importance in regulating fluxes between the ocean and the atmosphere and of the changing status of the major ice sheets on Greenland and in the Antarctic. Three other Explorer missions have been selected and are under development: ADM-Aeolus, which will for the first time measure the three dimensional wind field in clear air, important both for numerical weather prediction and for understanding atmospheric circulation; SWARM, a constellation of three satellites in different orbits which will measure the Earth's changing magnetic field and its interaction with the immediate terrestrial environment; and finally EarthCARE, a complex mission comprising a cloud radar (developed by Japan), a cloud lidar and imaging instruments which will provide key measurements for the understanding of the role of clouds and aerosols in climate forcing, again providing information vital to one of the least well understood aspects of the terrestrial climate system.

In addition to the first six Explorer missions above, a seventh is currently under development with three candidates for final selection: BIOMASS, a long-wavelength radar which will provide, *inter alia*, the best measurements of standing carbon in tropical forests critical for any implementation of carbon accounting systems; PREMIER, which will provide information on the chemistry and dynamics of the upper troposphere and the lower stratosphere, and the interactions between them; and COreH2O, a dual frequency radar which will make unique measurements of the hydrology of the cryosphere, again almost a closed book at present in terms of our understanding of climate. All three missions are currently being pursued for a final selection in 2011.

All six Earth Explorer missions, and the three candidates studied for the seventh Explorer, will provide unique measurements of aspects of the Earth system crucial to our understanding of climate and to the development of relevant ECVs. A detailed indication of where each of the Earth Explorer missions and of where other ESA missions will contribute to the development of ECVs is summarised briefly in table 2.

### 5.1.2 Operational meteorological Services (MSG/MTG & METOP)

Operational Meteorological Satellite services in Europe are the responsibility of EUMETSAT an intergovernmental organisation founded in 1986. The mission of EUMETSAT is to "deliver weather and climate-related satellite data, images and products – 24 hours a day, 365 days a year". This information is supplied to the 22 member and 8 co-operating states, as well as the European Centre for Medium Range Weather Forecasting (ECMWF) and other users world-wide. In EUMETSAT, the member states are nominally represented by the heads of the national weather service.

| | | | ERS-1 (1991) | | | | | ERS-2 (1995) | | | | | | Envisat (2002) | | | | | | | | Earth Explorer | | | | | Sentinels | | | | | Eumetsat | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ECV | Measurement | Radar Altimeter | ATSR-1 | SAR Wave Mode | SAR Image Mode | Scatterometer | Radar Altimeter | ATSR-2 | SAR Wave Mode | SAR Image Mode | Scatterometer | GOME | Radar Altimeter | AATSR | MERIS | ASAR Wave Mode | ASAR Image Mode | Schiamachy | MIPAS | GOMOS | GOCE (2008) | SMOS (2009) | Cryosat (2009) | ADM/AEOLEUS (2009) | EarthCARE (2012) | Sentinel 1 (2012) | Sentinel 2 (2012) | Sentinel 3 (2012) | Sentinel 4 | Sentinel 5 | MSG (2002) | GOME-2 (2006) | IASI (2006) | ASCATT (2006) | Topex/JASON (1991) | SPOT - VGT (1998) | SPOT - HRV (1986) | Landsat (1972) | AVHRR (1981) | DMSP - SSMI (1987) | MODIS (1999) | SeaWIFS (1997) | Geosat Follow-on (1998) | OMI (2004) | TOMS (1978) | Aquarius (2010) | Radarsat (1995) | JERS/ ALOS (1991/2006) | Other Missions | Count |
| OCEAN | O.2 | Sea level and variability of its global mean | ● | | | | | ● | | | | | | ● | | | | | | | | ● | | ● | | | | | ● | | | | | | | ● | | | | | | | | ● | | | | | | | 8 |
| | O.3 | Sea surface temperature | | ● | | | | | ● | | | | | | ● | | | | | | | | | | | | | | ● | | | ● | | | | | | | | ● | | ● | | | | | | | | | 7 |
| | O.4 | Ocean colour and oceanic chlorophyll-a concentration | | | | | | | | | | | | | | ● | | | | | | | | | | | | | ● | | | | | | | | | | | | | ● | ● | | | | | | | | 4 |
| | O.5 | Wave height & other measures of sea state | ● | | ● | | | ● | | ● | | | | ● | | | ● | | | | | • | | ● | | | ● | | ● | | | | | | | ● | | | | | | | | ● | | | | | | | 12 |
| | O.6 | Measurement of changes in sea-surface salinity | | | | | | | | | | | | | | | | | | | | • | ● | | | | | | | | | | | | | | | | | | | | | | | | ● | | | | 3 |
| | O.1 | Sea-ice concentration | | | | • | | | | | • | | | | | | | • | | | | | | | | | • | | | | | | | | | | | | | | • | | | | | | | • | • | | 7 |
| LAND | T.1 | Lakes | • | • | | • | | • | • | | • | | | • | • | • | | • | | | | | | | | | • | • | • | | | | | | | • | | • | • | • | | • | • | | | | | • | • | | 21 |
| | T.2 | Glaciers and Ice Caps | • | | | • | | • | | | • | | | • | | | | • | | | | ● | | ● | | | • | | • | | | | | | | | | | | | | | | | | | | • | • | | 12 |
| | T.5 | Maps of land cover type, for detection of land cover change | | | | | | | ● | | | | | | ● | ● | | | | | | | | | | | | ● | ● | | | | | | | | ● | ● | • | ● | | ● | ● | | | | | | | | 11 |
| | T.6 | Maps of fAPAR | | | | | | | ● | | | | | | ● | ● | | | | | | | | | | | | | ● | | | | | | | | ● | | | ● | | ● | ● | | | | | | | | 8 |
| | T.7 | Maps of Leaf Area Index | | | | | | | ● | | | | | | ● | ● | | | | | | | | | | | | | ● | | | | | | | | ● | | | ● | | ● | ● | | | | | | | | 8 |
| | T.8 | Global, above ground forest biomass & forest biomass change | | | | • | | | | | | • | | | | | | • | | | | | | | | | • | | | | | | | | | | | | | | | | | | | | | • | ● | | 6 |
| | T.9 | Burnt area, active fire maps and fire radiated power | | • | | | | | ● | | | | | | ● | ● | | | | | | | | | | | | | ● | | | | | | | | ● | | | ● | | ● | ● | | | | | | | ● | 10 |
| | T.10 | Research towards global near-surface soil moisture map | | | | | • | | | | | • | | | | | | • | | | | | ● | | | | | | | | | | | | • | | | | | | | | | | | | | | | • | 6 |
| | T.3 | Snow areal extent | | • | | • | • | | • | | • | • | | | • | • | | • | | | | | | | | | • | | • | | | | | | | | ● | | | ● | • | ● | • | | | | | | | | 16 |
| | T.4 | Directional hemispherical (black sky) albedo | | | | | | | ● | | | | | | ● | ● | | | | | | | | | | | | | ● | | | ● | | | | | ● | | | ● | | ● | | | | | | | | ● | 9 |
| ATMOSPHERE | A.4 | Cloud properties | | ● | | | | | ● | | | | ● | | ● | ● | | | ● | ● | | | | | | ● | | | | ● | ● | ● | ● | | | | | | | | | | | | | | | | | • | 13 |
| | A.7 | Profiles and total columns of ozone | | | | | | | | | | | ● | | | | | | ● | ● | ● | | | | | | | | | | | | ● | | | | | | | | | | | | ● | ● | | | | ● | 8 |
| | A.8 | Aerosol Optical depth and other aerosol properties | | | | | | | ● | | | | ● | | ● | ● | | | ● | ● | ● | | | | • | ● | | | ● | ● | ● | ● | ● | | | | | | | | | ● | | | | • | | | | ● | 17 |
| | A.9 | Distribution of greenhouse gases, such as CO2 and CH4 | | | | | | | | | | | | | | | | | ● | ● | | | | | • | | | | | ● | ● | | | ● | | | | | | | | | | | | | | | | ● | 7 |
| | A.10 | Upper-air Wind | | | | | | | | | | | | | | | | | | | | | | | ● | | | | | | | | | | | | | | | | | | | | | | | | | | 1 |
| | | | 4 | 5 | 1 | 5 | 2 | 4 | 10 | 1 | 4 | 3 | 3 | 4 | 10 | 10 | 1 | 6 | 4 | 4 | 2 | 4 | 2 | 3 | 3 | 2 | 6 | 2 | 13 | 3 | 3 | 4 | 3 | 1 | 1 | 3 | 6 | 2 | 2 | 8 | 2 | 10 | 7 | 2 | 1 | 2 | 1 | 4 | 4 | 7 | |

**Table 2. How ESA and other European missions contribute to ECV**

To achieve this mission EUMETSAT has established, maintains and exploits European systems of operational meteorological satellites. This is a long-term commitment for which EUMETSAT has a very close relationship with ESA. ESA was fundamental in starting EUMETSAT and continues to make major steps in mission development and procurement. ESA's technological developments in the 1970s and 80 decades led to the establishment of EUMETSAT. Today the cooperation is very close with ESA being the development Agency for new missions and capabilities, and EUMETSAT being the operational Agency.

| **Meteosat** | **Operation** | **Instruments (temporal & spatial resolution)** | | | | |
|---|---|---|---|---|---|---|
| Metsosat 2 – Meteosat 7 | 1981 -2013 | HRV 30min, 2.5km | 3 channel MVIRI 30min,5km | | | |
| Meteosat 8 – Meteosat 11 (MSG) | 2002 -2018 | HRV channel 15min,1km | 12 channel SEVERI: MVIRI+9ne w 15min,3km | 2 band GERB 5min, 40km | | |
| Meteosat 12 – Meteosat 15 (MTG) | 2015 - 2025 | 4 channel HRFI 2min,0.5-1km) | 15 channel scanner: SEVIRI+3ne w 10min,1-2km | Lightnin g Imagery | IR c.f. IASI | UV-VIS Imagery c.f. GOME & SCIAMACHY |

**Table 3. Payloads of the three generations of METEOSAT**

It is a synergistic relationship, where original capacity of EUMETSAT instruments is maintained and improved from generation to generation with the addition of instruments or measurement techniques initially developed on other ESA Missions or European national efforts are added to successive generations of EUMETSAT satellites as shown by the payloads of Meteosat, Meteosat Second generation (MSG) and Meteosat Third Generation (MTG) above. It should however be noted that currently a GERB-like instrument is not foreseen for MTG.

Meteosat, MSG and MTG are a family of geostationary satellites providing continuous cover. The image window is shown in Figure 1.

EUMETSAT also operates the European Polar System (EPS) family of 3 METOP polar-orbiting satellites that will be operational for at least the 2006 – 2020 timeframe. EPS is the European contribution to a joint European-US satellite system, called the Initial Joint Polar-Orbiting Operational Satellite System (IJPS). This is an agreement between EUMETSAT and the United States of America's National Oceanic and Atmospheric Administration (NOAA). The terms of this partnership were firstestablished through an agreement concluded in 1998. To develop EPS there are also cooperative agreements with the European Space Agency (ESA) and with Centre National d'Etudes Spatiales (CNES).

Both NOAA & EUMETSAT satellites carry identical AVHRR/3 and the ATOVS suite consisting of AMSU-A, HIRS/4 and MHS and thus continue the longest climate data set from any satellite system. In addition, the Metop satellites carry a set of European sensors, IASI, ASCAT, GOME-2 and GRAS. Finally, JASON a joint effort with NASA & CNES carrying Poseidon-3 Altimeter continuous data record from 1992 Poseidon, onwards plus AMR radiometer.

An important part of the EUMETSAT assets is the distributed ground segment, using the central facilities in Darmstadt which produces many operational meteorological products and a network of seven Satellite Application Facilities (SAFs) which take advantage of specialized expertise in Member

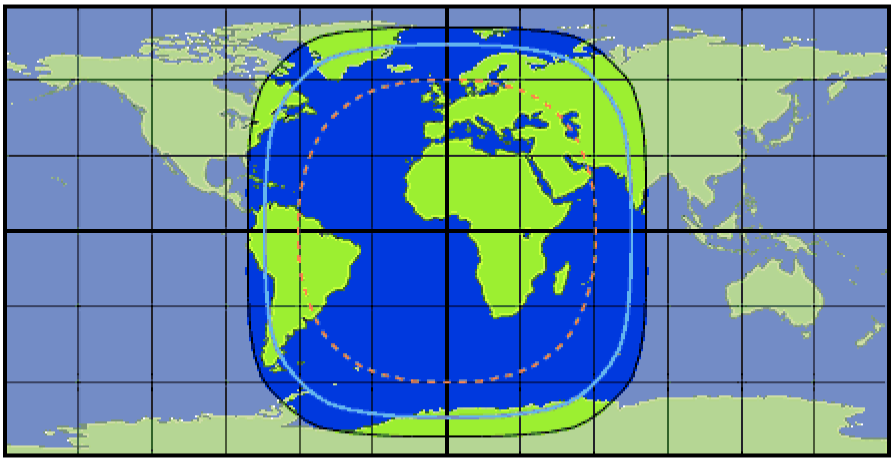


**Figure 1. Image window for METEOSAT geostationary satellites.**

States to produce additional products and undertake research into new ones. Each SAF is led by the National Meteorological Service (NMS) of a EUMETSAT Member State in association with a consortium of EUMETSAT Member States and Cooperating States, government bodies and research institutes. The lead NMS is responsible for the management of each complete SAF project. The research, data and services provided by the SAFs complement the standard meteorological products delivered by EUMETSAT's central facilities in Darmstadt, Germany. EUMETSAT supervises and coordinates the overall activities of the SAF network and the integration of the SAFs into the various operations within the EUMETSAT Application Ground Segment. And thus ensures that services are delivered in the most reliable and cost-effective way

With respect to the support to climate monitoring, the derivation of the FCDRs will increasingly be performed at EUMETSAT Central Facilities, whereas the derivation of a significant part of the TCDRs would fall into the responsibilities of the respective SAFs.

There are currently seven SAFs providing products and services on an operational basis:

- Support to Nowcasting and Very Short Range Forecasting (NWC SAF)
- Ocean and Sea Ice (OSI SAF)
- Climate Monitoring (CM SAF)
- Numerical Weather Prediction (NWP SAF)
- Land Surface Analysis (LSA SAF)
- Ozone and Atmospheric Chemistry Monitoring (O3M SAF)
- GRAS Meteorology (GRAS SAF)

In addition an eighth SAF, the SAF on Support to Operational Hydrology and Water Management, is under development and planned to become operational in 2011.

With respect to climate monitoring it should be noted that the EUMETSAT Climate Monitoring Satellite Application Facility (CMSAF) entered its operational phase in February 2007, and the funding has been secured until 2012. The CMSAF operationally generates cloud products, radiation products (surface fluxes, surface albedo, top of the atmosphere radiation fluxes) and global water vapour products.

One of the pilot projects within the SCOPE-CM initiative addresses the sustained generation of VIS/IR AVHRR cloud products for climate.

Together EUMETSAT satellites and ground segments have the potential capacity to deliver products addressing 26 of the 44 GCOS ECVs listed in table 4 with a combination of continuous high temporal resolution measurements over Europe & Africa and global observations with a repeat cycle of 1-3 days.

| | | | |
|---|---|---|---|
| **Atmospheric Surface** | **Air temperature** | EUMETSAT (OP) | 79W-79E, 81S-81N, hourly, 3 km |
| | **Precipitation** | EUMETSAT (OP) | 79W-79E, 81S-81N, hourly, 3 km |
| | **Surface radiation budget** | CM SAF (OP) | 79W-79E, 81S-81N, monthly, 15 km |
| | **Wind speed and direction** | EUMETSAT (OP) | 79W-79E, 81S-81N, hourly, 3 km<br>Global, daily, 12.5 km |
| | **Water vapour** | EUMETSAT (OP) | Global, daily, 5 km, |
| | **Pressure** | GRAS SAF (dev) | Global, c 600 profiles per day |
| **Atmospheric Upper-Air** | **Earth radiation budget** | CM SAF (OP) | 79W-79E, 81S-81N, monthly, 15 km |
| | **Upper Air Temperature** | EUMETSAT (OP)<br>GRAS SAF (dev) | 79W-79E, 81S-81N, hourly, 3 km<br>Global, c 600 profiles per day |
| | **Wind Speed and Direction** | EUMETSAT (OP)<br>CM SAF (OP) | 79W-79E, 81S-81N, hourly, 3 km<br>Global, daily, 12.5 km |
| | **Water Vapour** | EUMETSAT (OP)<br>CM SAF (OP) | 79W-79E, 81S-81N, hourly, 3 km<br>Global, daily, 12.5 km |
| | **Cloud Properties** (fractional cover, cloud type, cloud top temperature, pressure & height, optical thickness, cloud phase, cloud water path) | EUMETSAT (OP)<br>CM SAF (OP) | 79W-79E, 81S-81N, hourly, 3 km<br>60W-60E, 30-80N, daily, 15 km |
| **Atmospheric Composition** | **Carbon dioxide** | No-one at present | Not applicable |
| | **Methane** | No-one at present | Not applicable |
| | **Ozone** (column) | EUMETSAT (OP)<br>O3M SAF (OP) | 79W-79E, 81S-81N, hourly, 3 km<br>Global, daily, 80 x 40 km |
| | **Ozone** (profile) | O3M SAF (pre-OP) | Global, daily, 640 x 80 km |
| | **Other long-lived greenhouse gases** | No-one at present | Not applicable |
| | **Aerosol properties** | EUMETSAT (DEV)<br>O3M SAF (dev) | 79W-79E, 81S-81N, hourly, 3 km<br>Global, daily, 80 x 40 km |

| | | | |
|---|---|---|---|
| **Oceanic Surface** | **SST** | OSI SAF (OP) | Global, 12 hour, 1 km |
| | **Sea level** | No-one at present | Not applicable |
| | **Sea State** | OSI SAF (OP) | Global, 15 min, 12.5 km, |
| | **Sea Ice** | OSI SAF (OP) | Global, daily, 10 km |
| **Terrestrial** | **Snow Cover** | LSA SAF (OP) | 79W-79E, 81S-81N, daily, 3 km |
| | **Albedo** | LSA SAF (pre-OP) | 90W-90E, 40S-90N, daily, 3 km |
| | **LAI** | LSA SAF (OP) | 90W-90E, 40S-90N, daily, 3 km |
| | **faPAR** | LSA SAF(OP) | 90W-90E, 40S-90N, daily, 3 km |
| | **Fire disturbance** | EUMETSAT (OP) | 79W-79E, 81S-81N, 15 min, 3 km |
| | **Soil Moisture** | EUMETSAT (pre-OP) | Global, 12.5 km |

**Table 4. Data products from EUMETSAT and the SAFs which may contribute to ECVs**

20 of these products are produced operationally, those labelled (OP) in parentheses. For three of them (Carbon Dioxide, Methane, Other long-lived GHGs and Sea Level), it would be possible to derive observations from the existing sensors, but no dedicated ground segments has yet been put in place due to resource limitations. The derivation of Carbon Dioxide is under development, the remainder are at the pre-operational or development stage.

EUMETSAT present capacity provides products across the categories of ECVs that are also essential for weather prediction. EUMETSAT has the data and the capability to generate products for four other ECVs where there is not yet an established ground segment in place but the resources are not yet approved by its Member States.

#### **5.1.3** Capabilities for ECV monitoring with ENVISAT and ERS

Following the development of the geostationary Meteosat series of satellites the first polar orbiting mission to be developed by ESA was ERS-1, launched in 1991 and followed by an improved version ERS-2 in 1995. The most important of the EA environmental missions has however been Envisat, which was launched in 2002.

The ERS-1 payload comprised an active Microwave Instrument which operated as both scatterometer and Synthetic Aperture Radar (the first civilian SAR to be flown since the short-lived SeaSat US mission of 1978), together with a thermal imaging radiometer provided by the UK to measure sea surface temperature and a radar altimeter with ancillary measurements, related to, for example, precise positioning. This was followed by ERS-2 that improved the imaging radiometer to include measurements in the visible and near infrared of particular relevance to the terrestrial biosphere and embarked a wholly new instrument, GOME, which provided detailed measurements of the distribution of Ozone in the Earth's atmosphere. The GOME instrument has subsequently been included in the payload of the EUMETSAT Metop mission series (as has the ERS-based scatterometer) in order to provide long time series of measurements – excellent examples of the transition from research to operations of particular series of measurements.

The measurements of the Earth system provided by the ERS missions were continued and extended with the launch of Envisat in 2002. Still fully operational despite its initial intended lifetime of 5 years, Envisat carries an extended range of some ten instruments which measure all components of the Earth system, from the solid Earth to the upper atmosphere. The capabilities of ERS and Envisat to provide ECVs are summarised in Table 1.

#### 5.1.4 Capabilities of ESA GMES Sentinels

The ESA Sentinels constitute the first series of operational satellites for GMES; the GMES space component will use new as well as existing space assets. ESA is currently undertaking the development of five Sentinels mission families scheduled to be launched from 2011 onwards:

**Sentinel-1**: Focusing on synthetic aperture radar (SAR) applications
**Sentinel-2**: Providing high-resolution (10-20m) optical observation for GMES land and emergency services
**Sentinel-3**: Providing optical and microwave observation for GMES operational marine and land services

Sentinel-4 and Sentinel-5 are foreseen for later deployment to address primarily atmospheric chemistry monitoring requirements. It is envisaged that these will be implemented as additional payloads, developed by ESA, to carried by the EUMETSAT Third Generation Meteosat (Geostationary) and post- EPS (polar orbiting) mission series. A precursor mission for Sentinel-5 (S5P) is being developed by ESA in conjunction with the Netherlands, following on the success of the OMI instrument provided by the Netherlands to the NASA Aura mission. The Sentinel-5 precursor will help to provide measurements of atmospheric composition during the period after the foreseen end of life of Envisat and before the first flight of the Sentinel-5 payload on board post-EPS.

The Sentinels represent an important step in the development of research-to-operational capacity for delivering critical ECVs. They are the first non-meteorological operational series of dedicated Earth observation missions, of long duration, with guaranteed continuity and backup, providing long-term data streams that will be critical to the provision of ECVs to the climate community. Although the Sentinels will deliver data for understanding and monitoring other specific aspects of the earth system and for operational environmental services, their contribution to climate modelling, adaptation, mitigation and attribution will be unique.

Each Sentinel mission is based on a constellation of two satellites in the same orbital plane, a configuration that fulfils GMES' revisit and coverage requirements and provides a robust and affordable operational service. Individual satellite lifetimes are specified as seven years, with consumables allowing mission extension up to 12 years. The life-cycle of the space segment is planned to be in the order of 15-20 years.

The strategy for Sentinel procurement and replacement over this period is still under development. The first 2 satellites have been secured, but four to five satellites of each type are needed for the desired level of GMES robustness. The GMES Sentinels Flight Operations Control Centre (FOCC; also referred to as Mission Operations Centre) is being established at ESOC, Darmstadt, Germany.

All five Sentinels will provide data critical to the long-term measurement of ECVs (see Table 2 for a summary). Sentinel-1 will provide inputs to climate modelling through ECVs related to sea ice (extent, concentration, boundaries) and land ice (through glacier mass balance by interferometry), to ocean parameters such as wave characteristics and surface winds and to land cover characteristics, especially the extent and state of standing forests of particular importance to carbon accounting. Sentinel-2 will provide routine global imagery at high repeat cycles over a wide range of spectral channels, and will be of particular importance in assessing changes in land cover at the local to regional scale, including deforestation and changes in land use, and, coupled with Sentinel-3, assessing the physical state of terrestrial vegetation on regional to global scales.

Of particular interest for the observations of ECVs is the Sentinel-3 mission. The objectives for a series of satellites comprising the GMES Sentinel-3 mission encompass the commitment to consistent, long-term collection of remotely sensed marine and land data, of uniform quality, for operational ocean state analysis, forecasting and service provision, in the context of Global Monitoring for Environment and Security (GMES). A comprehensive measurement system facilitating global ocean and land observations is required to provide input data for advanced numerical forecasting models. For the remote sensing variables the following set of observational requirements have been established:

- Sea surface topography (SSH) and, significant wave height (SWH) over the global ocean to an accuracy and precision exceeding that of Envisat RA-2.
- Sea surface temperature (SST) determined globally to an equivalent accuracy and precision as that presently achieved by AATSR (i.e. <0.3 K), at a spatial resolution of 1 km.
- Visible and Thermal Infrared radiances ("Ocean Colour") for oceanic and coastal waters, determined to an equivalent level of accuracy and precision as MERIS data with complete Earth coverage in 2 to 3 days, and co-registered with SST measurements.
- Visible, Near Infrared, Short-Wave Infrared, and Thermal Infrared radiances ("Land Colour") for land surface, with complete Earth coverage in 1 to 2 days, with products equivalent to those derived from MERIS, AATSR and Spot VGT, together with those from their combination.

Essential operational requirements of the Sentinel-3 mission concept are:

- High inclination polar orbit, to achieve near-complete global coverage.
- Optical instrumentation requires a sun-synchronous orbit with a descending node equatorial crossing time in order to both complement existing platform observations and to mitigate sun glint, morning haze and cloud-cover impact.
- Complete global coverage from optical instrumentation every 1 to 3 days.
- Near-real-time data processing and delivery of all processed products for operational users.
- Continuous flow of data of at least the same quality as delivered by Envisat and a program duration of 20 years.
- Launch of 1st satellite in 2012 timeframe (with a series of platform to meet observational requirements and requirements for robust, continuous operational data provision).

### 5.1.5 Capacity based on GMES R&D funding with a perspective for sustainability

GMES is at the moment mainly paid from FP7 Space theme resources, but the roadmap includes initial non-research funds in 2011-13 (50 m€/year) and a proper dedicated finance as an EU programme (gradually growing to 500m€/year) from 2014 onwards.

The GMES governance is in the process of being developed. The aim of GMES is therefore to coordinate and sometimes consolidate European efforts for Earth observation both in space and with *in-situ* infrastructures in Europe, also with regard to the participation in the international arena.

The GMES services are financed by public funds and their outputs will be considered as public goods. For this reason, the data policy for the GMES services will be based on the principle of full and open access. GMES is a major EU contribution to GEO/GEOSS and will therefore also be compatible with GEO data sharing principles. The GMES observation infrastructure will draw upon existing capacities in Europe. For space observations, these include research and operational missions provided by ESA, EUMETSAT as well as the EU Member States.

#### 5.1.5.1 GMES service products being demonstrated

Under its GMES initiative, the European Community is putting in place operational services that will be capable of producing long term, consistent data sets for climate derived from observations and their reanalysis. These services will require a sustainable infrastructure regarding both the relevant *in-situ* and satellite observations. A European Commission communication outlining the programmatic approach was published in November 2008[12]. The GMES services were originally developed through large R&D projects under the EU's 6th (FP6: MERSEA, GEOLAND, GEMS)) and demonstrated under the 7th framework programme (FP7: MyOcean, GEOLAND2, MACC) that seek to utilize existing capacities in Europe and promote their cooperation. Truly operational services sufficiently enhanced, to produce climate quality data are expected to be available from 2011-14 onwards,

The GMES Services are arranged on the basis of earth components, namely land, ocean ("marine") and atmosphere. Climate is a cross-cutting theme for these services: Currently, ECVs are included in the scope of the marine and atmosphere services and will be addressed in the course of a global service development for the land monitoring service.

The atmosphere service addresses the themes climate forcing, air quality and UV radiation and will *inter alia* provide for the delivery of data services related to greenhouse gases, reactive gases and aerosols based on a global and a European ensemble model. A primary focus will be to provide information in areas where little or none is available today, e.g., gridded fields of atmospheric composition. This encompasses providing the atmospheric composition ECVs from a modelling system, based on satellite input. *In-situ* observations are not yet assimilated.

The marine service provides better information on the 3-D state and dynamics of the global ocean through global and European sea basin scale oceanographic models. Observational data sets from *in-situ* and space are analysed in state of the art models. It will also seek to establish an accurate long-term record of the ocean for climate purposes.

The global component of the land service will provide information on terrestrial ECVs, natural $CO_2$ stocks and budgets as well as fire impact due to biomass burning, together with the atmosphere service.

The current demonstration services are funded in the FP7 R&D projects Geoland2, MyOcean and MACC respectively for the Land, Marine and Atmosphere GMES services. These projects started between September 2008 and June 2009. They have a lifetime of about three years, but they are expected to be continued either with GMES Initial Operations or FP7 Space financing to bridge the interim before the fully operational phase in the GMES programme starts in 2014.

#### 5.1.5.2 GMES services for climate change are developing

On top of the GMES Earth compartment services, global and European reanalysis efforts are planned. They shall help to address problems of inhomogeneity and provide consistent time series of climate observations. In addition to producing consistent climate variable information, services for past and predicted impact statistics and their cost estimation are envisaged. Projected impacts, based on climate change models and scenarios in particular are important to help develop cost-effective and appropriate climate change adaptation actions. The climate change extensions to GMES will have to be developed and sustained by making additional resources available.

With regard to (climate-relevant) *in-situ* data required by GMES, the services will rely on data observed by public bodies in the EU Member States, at the moment often obtained in the frame of research activities or as contributions to international networks, and data exchange in the frame of international networks e.g., through the GEOSS.

To consolidate the European efforts for the purpose of operational services, the EU will be mainly focused on a better coordination within Europe, on the filling of existing gaps in observation capacities as well as encouraging a transfer of priority networks to operational status and their enhancement to

[12] CEC 2008, Commission of the European Communities communication Global Monitoring for Environment and Security (GMES): we care for a safer planet. COM (2008) 748 final, 12th November 2008.

support the production of data of sufficient quality where necessary. For a future operational GMES program, planning activities will have to address which observation infrastructures and climate modelling activities will receive support from European Union resources. The criteria will depend on the available resources. GMES operational costs are to be evaluated in the period 2009-2010.

Moreover, it should also be noted here that the EC Directorate General Research though its Framework Programme enables the development of projects which may be undoubtedly be considered precursors to the modelling components of an operational service, and which should make significant use of FCDRs and ECVs produced. In particular, there have been numerous research projects on climate change modelling, as well as research on impacts and defining cost- effective adaptation options. Over the last 3 Framework Programme DG RTD has funded a large number of projects which specific address these topics. It is therefore of paramount importance that in the development of the relevant GMES services attention should be paid that they build on tools and products developed in these projects preferably transferring them into an operational context. This will avoid duplication of effort and will ensure a better use of the available resources.

## 5.2 Capacity based on non-operational funding

### 5.2.1 ESA Climate change initiative

The ESA Climate Change Initiative aims to provide consistent long-term global records of the 'Essential Climate Variables' that are required by the Global Climate Observing System (GCOS). The proposed initiative will concentrate a major dedicated effort, in order to provide an adequate, comprehensive, and timely response to the extremely challenging set of requirements for (highly stable) long-term satellite-based products for climate, that have been addressed to Space Agencies via GCOS and CEOS

This program will focus on those climate variables (such as greenhouse gas concentrations, sea-ice and snow extent, fire disturbance) for which ESA satellite data sets (30 years of archives, ERS, Envisat and future Earth Explorer and Sentinel missions) will make a major contribution to complement that of international partner space agencies. Whilst the Earth Explorer and Sentinel missions may differ in scope, the nature of requirement, epoch of observation, policy-relevance and competences needed, are highly complementary with respect to each other, and will together constitute a major European contribution to the global response to climate change.

The Climate Change Initiative will build on Europe's substantial expertise in processing, generating, and exploiting global data sets. It will guarantee the availability of this space-based information for the future, in a form readily usable by scientific communities and government bodies. By enabling earth observation and climate scientists in Europe to focus their collective efforts on this critical issue during the 2009-15 timeframe, this new initiative will pave the way for future operational support to climate policies from the GMES system.

The long-term preservation of data from Earth observation missions, operated and acquired by ESA, is of paramount importance for the monitoring of long-term global trends with regard to many environmental parameters. A comprehensive approach to the achievement of this objective will be proposed at the next ESA Ministerial Council planned for 2011. Until then, and in preparation, a provisional solution is proposed for the next three years, including the archiving of the data and the evolution of data processing and data access systems in cooperation with national space agencies and other data owners.

An indication of the ECVs which are of highest priority in relation to ESA data sets and which ESA-developed missions will contribute to the delivery of each ECV is summarised in table 2.

### 5.2.2 National Initiatives & Research Capabilities

The French Space Agency (CNES) leads or participates in several Satellite Programmes having applications in the domains of environment and security:

- Mini-satellite CALIPSO (in collaboration with USA) and micro-satellite PARASOL, for a better understanding of the impact of clouds and aerosols on climate.
- Micro-satellite DEMETER, for a better detection of earthquakes and volcanic eruptions.
- IASI (in collaboration with EUMETSAT), for better meteorological forecast.
- Mini-satellite JASON (in collaboration with USA), for a better monitoring of oceans' height.
- SMOS (in collaboration with ESA and Spain), for determining soil moisture and Ocean Salinity.
- VENµS (Vegetation and Environment Monitoring on a new Micro-Satellite, in collaboration with the Israeli Space Agency), for monitoring the evolution of vegetation in pre-defined areas.
- SPOT 6 and SPOT7 Visible imaging (in collaboration with Belgium & Sweden)
- VEGETATION on SPOT

An additional multi-national endeavour is the SCIAMACHY mission. SCIAMACHY is an atmospheric sensor aboard the European satellite ENVISAT. It was launched in March 2002 as a joint project of Germany, the Netherlands and Belgium. It measures atmospheric absorption in spectral bands from the ultraviolet to the near infrared (240 nm - 2380 nm), providing knowledge about the composition, dynamics and radiation balance of the atmosphere. Moreover, aerosols, cloud properties and surface reflection can be retrieved.

SCIAMACHY is an imaging spectrometer comprising a mirror system, a sun diffusor, a telescope, a spectrometer, a calibration unit and thermal and electronic subsystems. SCIAMACHY performs measurements in nadir, limb, and solar/lunar occultation geometry. From these measurements total column amounts and stratospheric profiles of a multitude of atmospheric constituents are retrieved on a global scale. The observations of trace gases are performed simultaneously and globally. Limitations occur on the night side of the orbit (eclipse mode), where the sun does not illuminate the atmosphere and, consequently, no reflected and backscattered solar radiation can be measured. In this mode, a sequence of eclipse observations (e.g. air glow, biomass burning) is possible. Global coverage is obtained in three days.

RapidEye & Terra-SAR (DLR), COSMO-SkyMed (ASI) & DMC (UK) can also potentially contribute to selected ECVs.

A fundamental aspect of all of these missions is that whilst the Envelope Missions provide the long term systematic observations that are required for climate monitoring, exploratory/science missions allow us to advance the state of the art in the capability of new techniques to observe the earth system. Technological advancement benefits the public and private sectors and guarantees that European satellite engineering competence remains at the cutting edge. Furthermore, the development of these innovative sensing systems will also stimulate scientific research on both the development of products and algorithms as well as on the resulting applications making use of the new datasets. Ultimately we should not jeopardize the science/exploratory mission.

### 5.2.3 Reanalyses

Much of the data flows and products of observational services described above service assimilation in Numerical Weather prediction models. Data assimilation combines information from multiple sources: Observations; A short-range "background" forecast that carries forward the information extracted from prior observations; Error statistics and Dynamical and physical relationships, to produce the "most probable" estimate of the atmospheric state (and some estimate of uncertainty). The development of data assimilation in numerical weather forecasting models has been the driver of much of the improvement in models in the last 15 years.

ECMWF forecast skill improvements since 1980 (Northern Hemisphere)

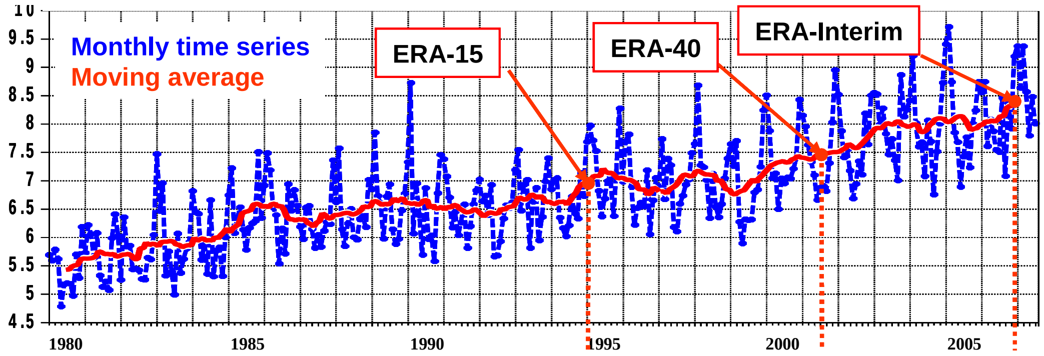


**Figure 2. ECMWF forecast skill improvements since 1980 (Northern Hemisphere).**

Reanalysis applies a fixed, modern data assimilation system to multi-year sets of observations to provide optimal physically consistent time series of climate variables. It is an inherent component of any system seeking to provide ECVs according to GCOS.

Some ECVS are intrinsic to global atmospheric reanalyses (upper air and surface wind, T, water vapour, etc). Reanalyses ensure the physical consistency between these ECVs and provide consistent 'best estimate' climate data sets for downstream applications.
Reanalyses can provide homogeneous "climate quality" atmospheric forcing to facilitate extraction of geophysical information from the satellite signals. Continued improvements in data assimilation techniques increases our understanding of the observations, improving bias estimates and providing feedback to the Earth Observation community on the quality of the data.

Globally ECMWF is at the forefront of developing data assimilation techniques and generating world class reanalysis products. The ERA-40 reanalysis datasets are widely used by the science community and have over 12,000 users. An example of its popularity is the fact that the paper "The ERA-40 re-analysis", published in 2005, has been identified by Thomson Reuters Scientific's /Essential Science Indicators/ as one of the most highly cited papers in the field of Geosciences, and has been designated as a "Current Classic" for February. However, ERA-40 used an ECMWF model version corresponding to the state of the art for NWP in 2000. Since the end of the ERA-40 project, many improvements to the model and assimilation system have taken place at ECMWF, and a new short global reanalysis called ERA-INTERIM, covering 1989 until today, has been produced, with the operational model version of 2006, With ERA-INTERIM, several weaknesses in ERA-40 have been corrected, such as a too intense meridional circulation in the stratosphere, an excessive rainfall over the tropical oceans, a flawed soil moisture budget over continents, etc. Since then, steady progress has continued in NWP and data assimilation, a significant volume of observations that were not available for previous reanalyses could be used thanks to the efforts of several organizations and international initiatives to recover and quality-control the older observation datasets, and last but not least, computing resources are growing with time, which will allow the production of future reanalyses at finer horizontal and vertical resolutions, with immediate effects on product quality and on the relevance of products for new applications. To date reanalyses have been supported as one-off projects, ERA-40 was funded by the EU, while ERA-INTERIM, which is now running in near real time, has been funded from ECMWF core funds in order to maintain a reanalysis capacity at ECMWF. There is a strong case for considering reanalysis capacity as part of any ECV production system, re-running the analyses on a regular basis as versions of models, data assimilation techniques and quality and availability of observations improve.

ERA-40 and ERA-INTERIM were not able to assimilate atmospheric trace composition observations, relying on calculated forcings of greenhouse gases and aerosols. The GMES projects GEMS and its successor MACC (precursor of the GMES Atmosphere service (GAS)) have been at the forefront of developing assimilation techniques for greenhouses gases, aerosols and reactive species, and a subsequent ECMWF reanalysis (ERA-75 from 1938 onwards) which is still in the planning stage could have some form of atmospheric chemistry assimilation scheme. ERA-75 would complement MACC in that MACC will include an element of reanalysis, but only for the current decade for which adequate satellite data exist to enable analysis of the global distributions of the key greenhouse and reactive gases and aerosols. ERA-75 would provide the much longer time series of meteorological conditions needed for study of multi-decadal trends, variability and extremes in essential climate variables related to atmospheric dynamics and thermodynamics.

Although complementary, ERA-75 and the MACC-GAS would be well placed to exploit a common infrastructure at ECMWF. Both would be based on the same underlying data assimilation software, technical improvement of which would be mutually beneficial, and delivery of services from ERA-75 could be provided through the mechanisms to be developed for the GAS.

Concurrently EUMETNET partners have also proposed a climate quality higher resolution regional reanalysis for Europe, that would be driven by ERA-75 at the boundaries and use national weather services high resolution regional models and statistical downscaling within Europe.

Europe needs to build on this expertise and extend the methodologies being developed in atmospheric reanalysis, not just to atmospheric composition, but also the whole Earth system.

## 6 Infrastructure to support European Climate Data production

Three elements of the ground segment infrastructure required to support an operational ECV service in Europe need to be considered: Network capacity, Processing and storage capacity and human resources to support and operate the infrastructure. In addition, developments in coupled Earth System models will require additional increases in all three, in order to improve the physics in the models as well as their spatial and temporal resolution, so that they can take full advantage of an operational ECV service.

In view of the French proposal, the need for and possible benefits of a centralised climate research centre also need to be considered. Finally key specific actions to support the component activities above that are the prerequisite for moving towards an operational ECV service in Europe are presented.

### 6.1 Network Capacity

The WMO Integrated Global Observing system WIGOS discussed in section 5 is a distributed network that is being designed to accommodate global needs for distribution of not just meteorological data as at present, but also all data from associated programs including GCOS. Within this framework European national meteorological agencies are already well advanced in their network design and provision and foresee a distributed structure as shown in Figure 3. The system relies on the internet rather than a dedicated network, so the continuing upgrade of the GEANT network to 10 GBit plus speeds will be beneficial to this. An increasingly important issue that also needs to be addressed is how to maintain secure system access to these high speed networks, without the security measures introducing ‘artificial’ bottle-necks in the network.

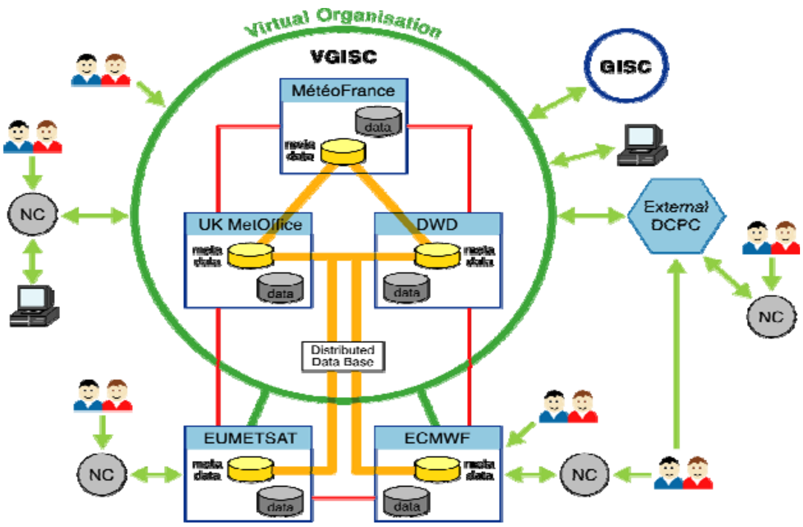


**Figure 3. Proposed design of the European Virtual Global Information Systems Centre of WIGOS.**

### 6.2 Computing and Storage Capacity

Examining the current solutions to providing processing and storage capacity for generating ECVs, whether the EUMETSAT SAFs, the ESA GMES Service Element partnerships or indeed the GMES services, they are all operated by consortia. In the

case of the first two, the consortia feature National Meteorological Services heavily. This is primarily for two purposes which together mean that it is difficult to envisage a dedicated centralised climate data and research centre being as efficient a use of resources as the Meteorological office dominated consortia model currently used.

- Meteorological services have a demand for much of the FCDR/ECV data for their operational forecasting. There is thus little or no additional cost to them acquiring and storing these same data to process as Essential Climate Variables. The same could not be said of a dedicated centralised climate data and research centre.

- Meteorological services are operational. Like any operational service they require backup processing capacity, in order to continue to run their forecasting models 24 hours a day 365 days a year, in the event of an outage of their primary computing facility. In some cases the backup capacity may be off-site but for many the back up is on-site and this spare is used for other research oriented work when not required for the operational service. ECMWF for instance operates 2 identical computers, one for forecasting jobs and the other is used for research, or reanalyses, when not needed. A dedicated centralised climate data and research centre would not have access to all this combined capacity.

Thus is almost certainly more efficient to build on processing and storage capacity at existing Meteorological service providers to provide the capacity for producing ECVs to GCOS standards and for climate change projections than to construct a dedicated centralised climate data and research centre.

### 6.3 Human Resources

Europe is not over resourced with high performance computing and satellite data processing experts or personnel qualified in ECV assimilation/research in general. The meteorological services employ already many such qualified personnel. Staffing a dedicated centralised climate data and research centre would not be easy, would be very expensive and would risk poaching existing staff from operational meteorological services. In the longer term, Europe needs to train more personnel in these fields.

### 6.4 A centralised versus a distributed solution

From the point of view of both computing and data storage capacity and human resources, a centralised climate data centre offers no added benefits, in comparison with enhancement of existing distributed facilities. Network enhancement initiatives from WMO and those of GEANT supported by DG INFSO explicitly recognise this. In the case of human resources, which are limited, developing a centralised facility would potentially involve a damaging drain loss of key personnel from existing facilities. The recommendation for providing the necessary infrastructure is through the co-ordinated enhancement of existing facilities.

### 6.5 Specific needs to move to an operational model

#### 6.5.1 Space Segment

Within the space segment, there is a need to ensure that Meteosat Third Generation continues to carry a GERB capability, together with a full range of IR and UV-VIS imagery sensors (IASI, GOME & SCIAMACHY) in order to observe all the atmospheric composition ECVs at the high temporal and spatial resolution possible from a geostationary satellite over the European/African window.

There is a further need to ensure that the Sentinel-5 precursor will provide continuity from ENVISAT to Sentinel-5, and subsequently there will be need to ensure continuity between the first Train of Sentinels and the follow on train for 2020 and beyond.

Finally, continued co-ordination between national space agencies & ESA will be needed to support the transfer of relevant sensor technologies from the ‘non-operational’ to operational/Envelope funded missions

#### 6.5.2 Ground Segment

A systematic upgrading of capacity at EUMETSAT and within the SAFs, is required to ensure the provision of products for all 26 ECVs that the EUMETSAT sensors can theoretically observe, to current GCOS standards, for the European/African window of METEOSAT. Global coverage with a repeat cycle of 1-3 days elsewhere should be an achievable target.

For the atmospheric composition ECVs – co-ordination between EUMETSAT, the SAFs and ESA via the climate change initiative to target atmospheric composition ECVs as a priority for the Climate Change Initiative. The objective should be twofold, further retrieval development and validation where necessary and reprocessing of the ESA back catalogue of data, and developing the supporting SAF consortia to support the implementation of similar imagery on MTG & the SENTINELS – SCIAMACHY in particular. In addition, the ESA Climate Change Initiative will need to be enhanced to ensure that that the ECV capacity developed within it can continue to be utilised.

GMES needs to ensure that all core services proposing ECV products will produce ECVs that are GCOS compliant.

Finally, in addition to the dedicated infrastructure developments to support the above, the implementation of WIS & WIGOS and opening the system to the developing European climate data infrastructure, need to be supported.

#### 6.5.3 Reanalysis

Reanalysis support to both ECMWF and EUMETNET is required to move reanalyses from one-off projects to routine operation, with a repeat time of c5 years.

#### 6.5.4 In-situ measurements

Regarding *in-situ* measurements and monitoring enhancements are needed in all domains (marine, land, atmosphere) as well as better access to data. Furthermore enhanced cooperation on climate change models and scenarios is also needed, which is important for achieving more cost-effective and appropriate climate change adaptation actions.

#### 6.5.5 Costs

Detailed costing of the above elements were beyond the scope of this current study, however they are needed. ECMWF has been able to give an estimate of the resources required to undertake a long term global reanalysis (ERA-75) via a ten-year collaborative programme, led by ECMWF. The computing resources correspond to circa 4% of ECMWF High Performance Computing Facility and of ECMWF Data Handling and Archiving Facility, with an estimated cost of 1 Million Euros per year, while the additional manpower (4 project team members at ECMWF, and 4 posts at partner institutions would be an additional 1 Million Euros per year.

#### 6.5.6 Summary

If all the above needs are addressed to exploit existing capabilities to the full then Europe would be able to produce 29 ECVs typically with global daily coverage, together with a capacity for sustained reanalaysis and assimilation of the data-sets.

Because activities are funded from many sources it has not been possible to establish the overall amount committed in the framework of this study. The individual elements have been identified but a dedicated study is urgently needed to identify the current levels of public expenditure on climate information provision they attract. This would provide a basis for estimating budget levels needed to secure operational climate information services in Europe.

Observations are only the start. These in turn are turned into essential climate variables. The ECVs are turned into policy relevant information through dedicated data assimilation schemes, information management systems take these, which are used to promote effective use of European climate information and prediction services in climate-sensitive policy sectors. These steps need to be undertaken by organisations with pan-European purview and operations profiles.

## 7 Initiatives to implement / facilitate the sustained monitoring of ECVs

Joint Programme implementation is an imperative; sustained co-ordination between all parties will be needed to fill gaps, avoid overlap and ensure that all elements of the infrastructure to support sustained delivery of high quality essential climate data in Europe are embraced. This will involve utilising European expertise from both national and multinational agencies. Domain-based approaches (atmosphere, ocean and land) should be superseded by an integrated approach supporting the retrieval of climate variables from dedicated assimilation schemes.

Multinational agencies that will have roles in these joint programmes include ESA, EUMETSAT and ECMWF. The EC will be expected to contribute to the sustained funding of ECV production activities by these agencies to meet the specific needs identified above and others. For this process to be more efficient the EC should have sustainable mechanisms for being represented and heard in the bodies that make both the scientific and technical and the administrative decisions taken by said agencies, namely their scientific and management councils. Whether these would be through the EC acquiring some form of observer status or membership of these agencies, or another means, is dependent upon legal discussions. A long-term sustainable climate observing system within Europe would benefit from closer ties between the EC and these agencies which could allow formal management input from *inter-alia* DG ENTR & scientific and technical input from *inter-alia* the JRC. GMES is developing the partnership framework to facilitate better cooperation and better sustained funding.

Europe has many of the scientific and technical skills to provide full access to standardized data for climate studies. The need is to maintain these data records and provide access to them over the long-term, but the current reliance on research budgets and ad-hoc programmes for funding limit many activities to test cases and demonstrator projects. The lack of a stable financial platform, analogous to that underpinning NWP is a fundamental block to reliably generating products for operational users.

Because funding is not provided from an operational budget line Europe is unable to make the move from research to operations. We are in the unacceptable position of having to de-scope planned activities, even where these are essential and based on proven world-class science. This underplays European scientific capacity, is a severe handicap to joint implementation and makes it impossible for a climate service to deliver sustained information, as required in any legal or operational setting.

Increased computing power (computational/storage, bandwidth and skilled personnel) is needed to ensure that coupled Earth System models can be run, and that the spatial and temporal resolution of these can be improved). Bandwidth improvements foreseen within GEANT will meet much of these needs provided that they can be utilised. For all aspects of computing power, not just bandwidth, this is an ongoing process, and regular upgrades will be necessary over the longer term. The improvements should build on established skills centres, particularly Meteorological Services and their partners. A centralised facility is not needed, but substantial funding is required to establish or reinforce a number of large installations, and to provide the necessary communication and networking infrastructure.

# 8 Gap analysis: Table 5

| Essential Climate Variable (mainly Space) | | | Fundamental Climate Data Record | GCOS Horiz. Res. Goal |
|---|---|---|---|---|
| Atmospheric | 1 | ***Precipitation*** | Passive microwave radiances, High frequency geostationary IR, Active radar (for calibration) | 100 km (1 km for extreme events) |
| | 2 | ***Earth Radiation Budget*** | Broadband radiances, Spectrally resolved solar irradiances, Geostationary multi-spectral imagery | 100 km |
| | 3 | ***Upper-air Temperature*** | Passive microwave radiances, GPS radio occultation, High spectral resolution IR radiances for re-analyses. | 100 km |
| | 4 | ***Upper-air Wind*** | VIS/IR imagery, Doppler wind lidar | 100 km |
| | 5 | ***Surface Wind Speed and Direction*** | Passive microwave radiances and scatterometry | 10 km |
| | 6 | ***Water Vapour*** | Passive microwave radiances, UV/VIS Radiances, IR imagery/soundings in 6.7um band, Microwave soundings in 183 GHz band | 10 - 50 km |
| | 7 | ***Cloud Properties*** | VIS/IR imagery, IR and microwave soundings | 99 - 100 km |
| | 8 | ***Carbon Dioxide*** | NIR/IR radiances | 10 - 250 km |
| | 9 | ***Methane*** | NIR/IR radiances | 10 - 50 km |
| | 10 | ***Other GHGs*** | NIR/IR radiances | |
| | 11 | ***Ozone (tropospheric)*** | UV/VIS radiances, IR/Microwave radiances | 5 - 50 km |
| | 12 | ***Ozone (stratospheric)*** | UV/VIS radiances, IR/Microwave radiances | 50 - 100 km |
| | 13 | ***Aerosol Properties*** | VIS/NIR /SWIR radiances | 1 – 10 km |
| | | | | |
| Oceanic | 14 | ***Sea-Surface Temperature*** | Single & multi-view IR and microwave imagery | 1 km |
| | 15 | ***Sea Level*** | Altimetry | 25 km |
| | 16 | ***Sea Ice*** | Passive Microwave imagery (DMSP, AMSRE), SAR, TIR & VIS imagery | 12 – 100 km |
| | 17 | ***Sea State*** | Altimetry, scatterometer, SAR | 25 km |
| | 18 | ***Ocean Salinity*** | Microwave radiances | 15 - 100 km |
| | 19 | ***Ocean Colour (IOP + Chl_a)*** | Multispectral VIS imagery | 1 km |
| | | | | |
| Terrestrial | 20 | ***Snow Cover (Extent, Snow Water Equivalent)*** | VIS/NIR/IR and passive microwave optical imagery | 100 m – 100 km |
| | 21 | ***Glaciers and Ice Caps*** | VIS/NIR/SWIR optical imagery, Altimetry | 30 m |
| | 22 | ***Permafrost and seasonally -frozen ground*** | - | 250 m |
| | 23 | ***River Discharge*** | Altimetry | 10 km |
| | 24 | ***Lake level/properties*** | VIS/NIR imagery radar imagery, Altimetry, IR imagery | 1 - 4 km |
| | 25 | ***Albedo*** | Multispectral and broadband imagery | 1 km |
| | 26 | ***Land Cover*** | multispectral VIS/NIR imagery | 250 m |
| | 27 | ***fAPAR*** | VIS/NIR imagery | 250 m |
| | 28 | ***Leaf Area Index*** | VIS/NIR imagery | 250 m |
| | 29 | ***Biomass*** | L Band / P Band SAR, Laser altimetry | 10 m |
| | 30 | ***Fire Disturbance*** | VIS/NIR/SWIR/TIR multispectral imagery | 250 m |
| | 31 | ***Soil Moisture (surface and root zone)*** | Active and Passive microwave (Scatterometer and SMOS) | 50km |

| Essential Climate Variable (mainly Space) | | EU Specific Horiz. Res (*current product*) | GCOS Vertical Resolution Goal | Historical time series length |
|---|---|---|---|---|
| Atmospheric | 1 | 10 km | - | 20-30 satellite (150 years in-situ) |
| | 2 | *15/45 km* | - | 20-30 satellite (150 years in-situ) |
| | 3 | 10 km | 100 m in troposphere, 2 km outside | 20-30 satellite (150 years in-situ) |
| | 4 | 10 km | 500 m | 20-30 satellite (150 years in-situ) |
| | 5 | 10 km | - | 20-30 satellite (150 years in-situ) |
| | 6 | 10 km | 100 m in troposphere, 2 km outside | 20-30 satellite (150 years in-situ) |
| | 7 | 15 km | - | 20-30 satellite (150 years in-situ) |
| | 8 | 10 - 100 km | 500 m – 1 km in troposphere, 1 – 2 km outside | 6/30 years |
| | 9 | 10 - 100 km | 2 km | 6 years |
| | 10 | - | - | 6 years |
| | 11 | - | 500 m | 6 years |
| | 12 | - | 500 m | 6 years |
| | 13 | - | 500 m | 6 years |
| | | | | |
| Oceanic | 14 | 1 km | - | 15 years |
| | 15 | - | - | 15 years |
| | 16 | 1km | - | 15 years |
| | 17 | 25 km | - | 15 years |
| | 18 | 25 km | 1 m upper, 2m deep ocean | 15 years |
| | 19 | 2 km | - | 15 years |
| | | | | |
| Terrestrial | 20 | *3/25 km* | - | 20 years |
| | 21 | - | - | - |
| | 22 | - | - | - |
| | 23 | - | - | - |
| | 24 | *1 km* | - | - |
| | 25 | 1 km | - | - |
| | 26 | 10 m | - | 20 years |
| | 27 | 1 km | - | 10 years |
| | 28 | 1 km | - | 10 years |
| | 29 | - | - | - |
| | 30 | 1 km | - | 0 years |
| | 31 | *25 km* | - | 0 years |

| Essential Climate Variable (mainly Space) | | Observation Cycle Goal | Absolute Accuracy Goal | Stability/drift |
|---|---|---|---|---|
| Atmospheric | 1 | 3 hr ( 10 min for extreme events) | individual events <0.1 mmhr-1, and less than 10% of monthly average. | 0.6% per decade |
| | 2 | 3 hr | 1 Wm-2 downwelling solar TOA, 5 Wm-2 outgoing TOA SW/LW | 1 Wm-2 per 5 years, 0.2 Wm-2 per decade |
| | 3 | 3 hr | 0.5 K | 0.05 K per decade (troposphere), 0.1 K per decade (stratosphere) |
| | 4 | 3 hr | 2 ms-1 | 2 ms-1 |
| | 5 | 1 hr | 10% (0.5 ms-1) | 0.1 ms-1 per decade |
| | 6 | 3 hr | 2% of local value, 1 % for column | 0.3% per decade |
| | 7 | 3 hr | Cloud cover 10%, Cloud top height 0.5 km, Cloud top temperature 0.3 K | - |
| | 8 | 3 hr | 1% (3ppm) | <1% |
| | 9 | 3 hr | 1% (20 ppb) | <1% |
| | 10 | - | - | - |
| | 11 | 3 hr | 10% | 1% |
| | 12 | 3 hr | 5% | 0.6% |
| | 13 | 1 day | 10% (0,01) | 5% per decade |
| | | | | |
| Oceanic | 14 | 3 hr | <0.25 K (ideal 0.1K) | at least 0.1K/decade (ideal req. 0.05K/decade) |
| | 15 | 1 day | 1 cm | 0.5 mm per decade |
| | 16 | 1 day | 5% | 5% per decade |
| | 17 | 3 hr | 10 cm | 5 cm per decade |
| | 18 | 1day (upper) - 1 week (surface) – 1 month (deep) | 0.001 (upper) - 0.05 (surface) psu | 0.05 psu per decade |
| | 19 | 1 day | 5% | 1% per decade |
| | | | | |
| Terrestrial | 20 | 1 day | 5% | - |
| | 21 | 1 year | 5% area, 10cm topography | 5% |
| | 22 | 1 day | 5% | - |
| | 23 | 1 day | 5% | - |
| | 24 | 1 month | 10 cm | 5% |
| | 25 | 1 day | 5-10% | - |
| | 26 | 1 year | 50 classes | - |
| | 27 | 1 day | 5% | - |
| | 28 | 1 day | 5% | - |
| | 29 | 1 year | 5t/ha | - |
| | 30 | 1 day | 5% | - |
| | 31 | 7 day | 5g/Kg | - |

| Essential Climate Variable (mainly Space) | | Lead EU Institutions | Contributing EU Institutions | GMES, ESA, EUMETSAT 'projects' (global, *limited area)* |
|---|---|---|---|---|
| Atmospheric | 1 | EUMETSAT | ECMWF | *CM SAF, Euro4M (EU area)* |
| | 2 | EUMETSAT, ESA | ECMWF | *Euro4M* |
| | 3 | EUMETSAT | ECMWF | *Euro4M* |
| | 4 | EUMETSAT/ESA | ECMWF | *Euro4M* |
| | 5 | EUMETSAT/ESA | KNMI, ECMWF | *Euro4M, OSI SAF, Monarch-A* |
| | 6 | EUMETSAT/ESA | ECMWF | MACC, *Euro4M, CM SAF* |
| | 7 | EUMETSAT/ESA | ECMWF | *Euro4M, CM SAF* |
| | 8 | ESA, EUMETSAT | ESRON, U BREMEN, LMD/CNRS, ECMWF | MACC, Carbones, *Monarch-A (arctic)* |
| | 9 | ESA, EUMETSAT | ESRON, BREMEN, LMD/CNRS, ECMWF | MACC |
| | 10 | ESA, EUMETSAT | ECMWF | MACC |
| | 11 | ESA/NIVR/EUMETSAT | ECMWF | MACC |
| | 12 | ESA/EUMETSAT | ECMWF | MACC |
| | 13 | ESA, CNES | ECMWF | MACC |
| | | | | |
| Oceanic | 14 | ESA, EUMETSAT | EEA,IFREMER, Met Office Hadley Centre | MyOcean, *OSI SAF, Euro4M, Monarch-A* |
| | 15 | ESA/CNES, EUMETSAT, EC | CLS | MyOcean, *Monarch-A* |
| | 16 | ESA, EUMETSAT | EUMETSAT/Met.no, ECMWF | MyOcean, *OSI SAF, Monarch-A* |
| | 17 | ESA/EUMETSAT, EC | EUMETSAT | MyOcean, *Monarch-A* |
| | 18 | ESA | IFREMER, ECMWF | MyOcean |
| | 19 | ESA, EC | JRC, PML, CNR, DLR | MyOcean, *Monarch-A* |
| | | | | |
| Terrestrial | 20 | ESA | EUMETSAT | *Euro4M, Land SAF, ECMWF* |
| | 21 | ESA | - | *Monarch-A (Arctic >65ºN)* |
| | 22 | - | - | *Monarch-A* |
| | 23 | - | - | *Monarch-A* |
| | 24 | ESA | - | *Geoland2 (Africa)* |
| | 25 | ESA, EUMETSAT | - | Geoland2, *Land SAF, ECMWF* |
| | 26 | ESA, CNES | - | *Geoland2* |
| | 27 | ESA | JRC, EUMETSAT, VITO | Geoland2, *Land SAF* |
| | 28 | ESA/EUMETSAT | - | Geoland2, *Land SAF, ECMWF* |
| | 29 | ESA | - | - |
| | 30 | ESA, EUMETSAT | - | Geoland2, *Land SAF, Monarch-A, ECMWF* |
| | 31 | ESA, EUMETSAT | EUMETSAT/ECMWF, ECMWF, H-SAF, Univ Vienna | Geoland2 |

| Essential Climate Variable (mainly Space) | | European Availability of Data | Use of non-EU datasets |
|---|---|---|---|
| Atmospheric | 1 | AMSU-A, MHS, Meteosat | SSM/I, SSMI/S |
| | 2 | GERB(MSG &MTG), EarthCare | CERES |
| | 3 | HIRS, AMSU, MHS, IASI, SSU, GRAS | AIRS, HIRS, AMSV |
| | 4 | METEOSAT, AVHRR, [*ADM*] | GOES, MTSAT |
| | 5 | ERS-1/2 SCAT, ASCAT | SEAWINDS |
| | 6 | HIRS, MHS, IASI, MERIS , GRAS, ATSR, GOME | SSM/I, AIRS, HIRS, AMSV-B |
| | 7 | METEOSAT, ATSR, AVHRR, Meris [*Sentinel-3: OLCI, SLSTR*] ; Earthcasre | AVHRR, GOES, MTSAT |
| | 8 | SCIAMACHY, IASI, Sentinel-5 | AIRS, GOSAT |
| | 9 | SCIAMACHY, IASI Sentinel-5 precursor, Sentinel-5 | GOSAT |
| | 10 | IASI, Sentinel-5 | - |
| | 11 | GOME-1, SCIAMACHY, GOME-2, OMI, IASI | - |
| | 12 | GOME-1, MIPAS, GOMOS, SCIAMACHY, OMI, IASI | - |
| | 13 | SCIAMACHY, AATSR, ATSR-2, MERIS, POLDER, PARASOL, MSG, Sentinel-3 SLSTR, OLCI, Earthcare | AVHRR,SAGE, TOMS, MODIS, MISR |
| | | | |
| Oceanic | 14 | ATSR-1, ATSR-2, AATSR, Sentinel-3 SLSTR, MSG, METOP | AVHRR, AMSR-E, TRMM-TMI, GOES, |
| | 15 | ERS/ENVISAT altimeter. Cryosat. Sentinel-3, JASON-2 | ERS/ENVISAT Altimeter, GOCE |
| | 16 | ERS/ENVISAT SAR, Cryosat2, RA, ASCAT, ERS-scat, MERIS, (A)ATSR, Sentinel-1, Sentinel-3 | AMSRE, SSM/I, SMMR, AVHRR, SeaWifs, Qscat, NSCAT |
| | 17 | ERS/ENVISAT SAR, Cryosat2, RA, ASCAT, ERS-scat, MERIS, (A)ATSR Sentinel-1, Sentinel-3 | RADARSAT, AMSRE, SSM/I, Qscat, NSCAT |
| | 18 | SMOS | Aquarius |
| | 19 | MERIS, Sentinel-3 OLCI | SeaWiFS, MODIS |
| | | | |
| Terrestrial | 20 | MSG. Envisat ASAR, Sentinel-1, Sentinel-3 OLCI | AVHRR |
| | 21 | ERS ENVISAT SAR, SPOT, Sentinel-1, Sentinel-2, ERS, ENVISAT Altimeter, Sentinel-3 RA | - |
| | 22 | - | - |
| | 23 | - | - |
| | 24 | ERS/ENVISAT/Sentinel-3 RAs, | - |
| | 25 | MSG, Meris, ATSR2, AATSR, Sentinel-3 OLCI | AVHRR |
| | 26 | MERIS, SPOT, Sentinel-2, Sentinel-3 OLCI, ATSR-2,AATSR,SLSTR, Sentinel-1, | - |
| | 27 | MERIS (300m-1.1km) , SEVIRI, VEGETATION, ATSR-2-AATSR-SLSTR,OLCI | SeaWiFS |
| | 28 | MSG, Vegetation, , Meris, ATSR-2-AATSR-SLSTR, OLCI | - |
| | 29 | [BIOMASS explorer: Phase-A study] | - |
| | 30 | MSG, ATSR-2, AATSR, MERIS, OLCI | - |
| | 31 | ERS Scatt, ASCAT, ASAR, Sentinel-1 | Scatterometer and Aquarius |

| Essential Climate Variable (mainly Space) | | Funding horizon commitment (20 years) - green, yellow, red, 2yr/cell | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 09-10 | 11-12 | 13-14 | 15-16 | 17-18 | 19-20 | 21-22 | 23-24 | 25-26 | 27-28 |
| Atmospheric | 1 | yellow | yellow | yellow | yellow | yellow | yellow | yellow | yellow | yellow | yellow |
| | 2 | green | green | green | green | green | red | red | red | red | red |
| | 3 | green | green | green | green | green | green | green | green | green | green |
| | 4 | yellow | yellow | green | green | yellow | yellow | yellow | yellow | yellow | yellow |
| | 5 | green | green | yellow | yellow | yellow | yellow | yellow | yellow | yellow | yellow |
| | 6 | green | green | green | green | green | green | green | green | green | green |
| | 7 | green | green | green | yellow | yellow | yellow | yellow | yellow | yellow | yellow |
| | 8 | green | green | green | green | green | yellow | yellow | yellow | yellow | yellow |
| | 9 | green | green | green | green | green | yellow | red | red | red | red |
| | 10 | green | green | green | green | green | yellow | red | red | red | red |
| | 11 | green | green | green | green | green | green | green | green | green | green |
| | 12 | green | green | green | green | green | green | green | green | green | green |
| | 13 | yellow | green | green | green | green | green | yellow | yellow | yellow | yellow |
| | | | | | | | | | | | |
| Oceanic | 14 | green | green | yellow | green | green | green | green | yellow | yellow | yellow |
| | 15 | yellow | yellow | yellow | yellow | yellow | yellow | red | red | red | red |
| | 16 | green | green | green | green | green | green | green | green | green | green |
| | 17 | yellow | yellow | yellow | yellow | yellow | yellow | red | red | red | red |
| | 18 | yellow | yellow | yellow | red | red | red | red | red | red | red |
| | 19 | green | yellow | yellow | green | green | green | green | green | green | green |
| | | | | | | | | | | | |
| Terrestrial | 20 | yellow | yellow | yellow | yellow | yellow | yellow | yellow | yellow | yellow | yellow |
| | 21 | yellow | yellow | yellow | yellow | yellow | red | red | red | red | red |
| | 22 | grey | grey | grey | grey | grey | grey | grey | grey | grey | grey |
| | 23 | yellow | yellow | yellow | yellow | yellow | yellow | red | red | red | red |
| | 24 | green | green | green | green | green | green | red | red | red | red |
| | 25 | green | green | green | green | green | green | green | green | green | green |
| | 26 | green | green | green | green | green | green | green | green | green | green |
| | 27 | yellow | yellow | yellow | yellow | yellow | yellow | yellow | yellow | yellow | yellow |
| | 28 | yellow | yellow | yellow | yellow | yellow | yellow | yellow | yellow | yellow | yellow |
| | 29 | yellow | yellow | yellow | yellow | yellow | yellow | yellow | yellow | yellow | yellow |
| | 30 | green | green | green | green | green | green | green | green | green | green |
| | 31 | yellow | green | green | green | yellow | yellow | yellow | yellow | yellow | yellow |

| Essential Climate Variable (mainly Space) | | Main areas of policy relevance | Contribution to International Initiatives - (GCOS/GEO in each) |
|---|---|---|---|
| Atmospheric | 1 | White Paper/European adaptation framework | GPCP |
| | 2 | - | WCRP |
| | 3 | - | WCRP |
| | 4 | - | CGMS IWWS |
| | 5 | White Paper/European adaptation framework | NOAA ? |
| | 6 | - | WCRP |
| | 7 | - | ISCCP, WCRP |
| | 8 | UNFCCC | - |
| | 9 | UNFCCC | - |
| | 10 | - | - |
| | 11 | UNFCCC, Air Quality | - |
| | 12 | UNFCCC, Montreal Protocol | - |
| | 13 | UNFCCC, Air Quality | - |
| | | | |
| Oceanic | 14 | UNFCCC, Seasonal and decadal forecasting, operational meterology and oceanography | WMO, GEO, JCOMM |
| | 15 | UNFCCC,White Paper/European adaptation framework | Wide ranging |
| | 16 | UNFCCC, Seasonal and decadal forecasting, operational meterology and oceanography | JCOMM, WMO/IMO (GMDSS Arctic and antarctic Met Area responsibility) |
| | 17 | UNFCCC, GMDSS in Arctic and Antarctic | WMO/IMO (GMDSS Arctic and antarctic Met Area responsibility) |
| | 18 | UNFCCC | Potentially many but immature at present. |
| | 19 | UNFCCC | CEOS Virtual Constellation |
| | | | |
| Terrestrial | 20 | - | - |
| | 21 | - | - |
| | 22 | - | - |
| | 23 | - | - |
| | 24 | - | - |
| | 25 | - | - |
| | 26 | - | - |
| | 27 | UNFCCC, EEA | GEO RE-analysis (Task ****) |
| | 28 | - | - |
| | 29 | - | - |
| | 30 | - | - |
| | 31 | - | - |

| Essential Climate Variable (mainly Space) | | Additional Notes (incl. institutional issues, data acess, human aspects) |
|---|---|---|
| Atmospheric | 1 | |
| | 2 | |
| | 3 | |
| | 4 | |
| | 5 | |
| | 6 | |
| | 7 | |
| | 8 | temporal stability of retrievals most important property for inverse modelling of emissions |
| | 9 | temporal stability of retrievals most important property for inverse modelling of emissions |
| | 10 | |
| | 11 | |
| | 12 | |
| | 13 | Better aerosol products than AOD needed as 20-80% of AOD water vapour effect. |
| | | |
| Oceanic | 14 | Coordinated by GHRSST (international community consensus) and GCOS SST/SI working group (smalled group dedicated largely to in situ and some satellite data). Needs good sea ice. |
| | 15 | Extreme water levels need to be established to a common datum. |
| | 16 | Needs to be linked to other processing activities. RADAR is essential. Long term data set is limited due to ice obseravations being scarse. |
| | 17 | Need better in situ data. Needs to be coupled to surface wind and sea state activities |
| | 18 | Space segment is new. Rely on parameterisations and models of salinity. |
| | 19 | global coastal regions are poorly addressed so far |
| | | |
| Terrestrial | 20 | |
| | 21 | |
| | 22 | |
| | 23 | |
| | 24 | |
| | 25 | |
| | 26 | |
| | 27 | concern about data gap following ENVISAT, inconsistency in terminology and definitions |
| | 28 | |
| | 29 | |
| | 30 | |
| | 31 | |

The goals for horizontal resolution, vertical resolution, observation cycle and absolute accuracy are synthesised from detailed information provided by the GCOS observation panels (http://192.91.247.60/sat2/aspscripts/UserBT.asp?AFF_SHORT_NAME=GCOS).

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## 10 Glossary

| | |
|---|---|
| AATSR | Advanced Along Track Scanning Radiometer |
| ADM-Aeolus | Atmospheric Dynamics Mission |
| AMR | Advanced Microwave Radiometer |
| AMSU | Advanced Microwave Sounding Unit |
| ASCAT | Advanced Scatterometer |
| ASI | Agenzia Spaziale Italiana |
| ATOVS | Advanced TIROS Operational Vertical Sounder |
| AVHRR | Advanced Very High Resolution Radiometer |
| BIOMASS | Candidate ESA Explorer mission to make Global Measurements of Forest Biomass |
| CALIPSO | Cloud Aerosol Lidar Infrared Pathfinder Satellite Observations |
| CECILIA | Central and Eastern Europe Climate Change Impact and Vulnerability Assessment |
| CEOS | Committee on Earth Observation Satellites |
| CFCs | Chlorofluorocarbons |
| CGMS | Coordination Group for Meteorological Satellites |
| CLAVIER | Climate Change and Variability: Impact on Central and Eastern Europe |
| CM SAF | Climate Monitoring Satellite Application Facility |
| CNES | Centre National d'Etudes Spatiales |
| CNRM | Centre National de Recherches Meteorologiques |
| $CO_2$ | Carbon Dioxide |
| COP | Conference of the Parties (to UNFCCC). |
| CoReH2O | Candidate ESA Explorer mission to make detailed observations of key snow, ice and water cycle characteristics |
| Cryosat-2 | ESA Ice Mission |
| DEMETER | Detection of Electro-Magnetic Emissions Transmitted from Earthquake Regions |
| DEV | Development |
| DG AGRI | Directorate General Agriculture and Rural Development |
| DG AIDCO | Directorate General EuropeAid |
| DG DEV | Directorate General Development |
| DG EAC | Directorate General Education and Culture |
| DG ENTR | Directorate General Enterprise and Industry |
| DG ENV | Directorate General Environment |
| DG INFSO | Directorate General Information Society and Media |
| DG MARE | Directorate General Maritime Affairs and Fisheries |
| DG REGIO | Directorate General Regional Policy |
| DG RELEX | Directorate General External Relations |
| DG RTD | Directorate General Research |
| DG TREN | Directorate General Energy and Transport |
| DG SANCO | Directorate General Health and Consumers |
| DKRZ | Deutsches Klimarechenzentrum |
| DLR | Deutsches Zentrum für Luft- und Raumfahrt |
| DMC | Disaster Monitoring Constellation |
| EarthCARE | ESA/JAXA Cloud and Aerosol Mission |
| EC | European Commission |
| ECHO | Directorate General Humanitarian-Aid |
| ECV | Essential Climate Variable |
| ECMWF | European Centre for Medium Range Weather Forecasting |
| EEA | European Environment Agency |
| ENSEMBLES | Ensemble Based Predictions of Climate Change and their Impacts |
| Envisat | Environmental Satellite |
| EPS | European Polar System |

| | |
|---|---|
| ERA | European Re-analysis |
| ERS | European Remote Sensing Satellite |
| ESA | European Space Agency |
| ESAC | ESA Science Advisory Committee |
| ESOC | European Space Operations Centre |
| EU | European Union |
| EUMETNET | The Network of European Meteorological Services |
| EUMETSAT | European organization for the exploitation of Meteorological Satellites |
| fAPAR | Fraction of Absorbed Photosynthetically Active Radiation |
| FCDR | Fundamental Climate Data Record |
| FOCC | Flight Operations Control Centre |
| FP6 | 6th Framework Program |
| FP7 | 7th Framework Program |
| GAW | Global Atmosphere Watch |
| GCOS | Global Climate Observing System |
| GEANT | Multi-gigabit European research and education network and associated services |
| GEO | Group on Earth Observation |
| GEOLAND | Integrated GMES project on Land Cover and Vegetation |
| GEOMON | Global Earth Observation and Monitoring of the Atmosphere |
| GEOSS | Global Earth Observation System of Systems |
| GEMS | Global and regional Earth-system (Atmosphere) Monitoring using Satellite and in-situ data (GEMS) |
| GERB | Geostationary Earth Radiation Budget |
| GHG | Greenhouse Gases |
| GMES | Global Monitoring for Environment and Security |
| GOCE | Gravity field and steady-state Ocean Circulation Explorer |
| GOME | Global Ozone Monitoring Experiment |
| GOOS | Global Ocean Observing System |
| GRAS | Global Navigation Satellite Systems Radio Occultation Receiver for Atmospheric Sounding |
| GRAS SAF | GRAS Satellite Application Facility |
| GSICS | Global Space-based Inter-Calibration System |
| GTOS | Global Terrestrial Observing System |
| GTS | Global Telecommunications System |
| HCFCs | Hydrochlorofluorocarbons |
| HFCs | Hydrofluorocarbons |
| HIRS | High Resolution Infrared Radiation Sounder |
| IASI | Infrared Atmospheric Sounding Interferometer |
| IPCC | Intergovernmental Panel on Climate Change |
| IJPS | Initial Joint Polar-Orbiting Operational Satellite System |
| IR | Infrared |
| JASON | CNES/NASA Ocean Altimetry Mission |
| JRC | Directorate General Joint Research Centre |
| LAI | Leaf Area Index |
| LSA SAF | Land Surface Analysis Satellite Application Facility |
| MACC | Monitoring Atmospheric Composition and Climate |
| MERIS | Medium Resolution Imaging Spectrometer |
| MERSEA | Marine Environment and Security for the European Area |
| MetOp | Meteorological Operational Satellite |
| MHS | Microwave Humidity Sounder |
| MIPAS | Mitchelson Interferometer for Passive Atmospheric Sounding |
| MPIM | Max-Planck-Institut für Meteorologie |

| | |
|---|---|
| MS | Member States |
| MSG | Meteosat Second Generation |
| MSU | Microwave Sounding Unit |
| MTG | Meteosat Third Generation |
| MyOcean | GMES Marine Core Service Implementation Project |
| $N_2O$ | Nitrous Oxide |
| NASA | National Aeronautics and Space Administration |
| NMS | National Meteorological Service |
| NOAA | National Oceanic and Atmopheric Administration |
| NWC SAF | Nowcasting and Very Short Range Forecasting Satellite Application Facility |
| NWP | Numerical Weather Prediction |
| NWP SAF | Numerical Weather Prediction Satellite Application Facility |
| O3M SAF | Ozone and Atmospheric Chemistry Monitoring Satellite Application Facility |
| OP | Operational |
| OSI SAF | Ocean and Sea Ice Satellite Application Facility |
| PARASOL | Polarization and Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar |
| PFCs | Perfluorocarbons |
| Pre-OP | Pre-Operational |
| PREMIER | Candidate ESA Explorer mission to understand atmospheric processes linking trace gases, radiation, chemistry and climate |
| QA/QC | Quality Assurance/Quality Control |
| R&D | Research and Development |
| RA | Radar Altimeter |
| R/SSC-CM | Regional / Specialized Satellite Centres for Climate Monitoring |
| SAF | Satellite Application Facility |
| SAR | Synthetic Aperture Radar |
| SBA | Societal Benefit Area |
| SCIAMACHY | Scanning Imaging Absorption Spectrometer for Atmospheric Chartography |
| SCOPE-CM | Sustained Coordinated Processing of Environmental Satellite Data for Climate Monitoring |
| $SF_6$ | Sulphur hexafluoride |
| SIT | Strategic Implementation Team |
| SMOS | Soil Moisture and Ocean Salinity |
| SPOT | Satellite Pour l'Observation de la Terre |
| SSH | Sea Surface Height |
| SWARM | ESA Magnetic Field Mission |
| SWH | Significant Wave Height |
| TCDR | Thematic Climate Data Record |
| TIROS | Television and Infrared Observational Satellite |
| UNFCCC | United Nations Framework Convention on Climate Change |
| VEGETATION | Instrument to study the Vegetation Cover at regional and Global Scale |
| VENμS | Vegetation and Environment monitoring on a New Micro-Satellite |
| VIS | Visible |
| WCRP | World Climate Research Program |
| WGCV | Working Group on Calibration and Validation |
| WIS | WMO Information System |
| WIGOS | WMO Integrated Global Observing System |
| WMO | World Meteorological Organisation |

European Commission

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**Abstract**

This report, which is based on the findings of a workshop at Ispra in March 2009, provides the scientific background to a forthcoming Commission response to the Space and Competitiveness councils requests that the commission assess the needs for full access to standardised climate change data, the means to provide these data and together with ESA, EUMETSAT and the scientific community define how GMES services can contribute effectively to providing these data. The report therefore focuses primarily, but not exclusively, on space-based Climate data sources.

Standardised climate data are needed for climate monitoring, prediction and research, while climate information informs the policy cycle at four key points - Policy definition; Management and scenario building; Reporting requirements; Alarm functions.

The workshop identified the 44 Essential Climate Variables defined by GCOS as the minimum set of standardised climate data that the commission should be considering and a gap analysis for the provision of these observations was undertaken. In addition European capacity is analysed according to maturity, differentiating between sustained operational capacity (Envelope Missions/EUMETSAT), non-operationally funded repetitive capacity and additional infrastructure needs in order to fill the gaps are identified. Finally the report discusses co-ordination and governance issues and how to overcome them. The key findings and recommendations are contained in an executive summary.

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