

THE ESA CLIMATE CHANGE INITIATIVE

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prepared by/ <i>préparé par</i>	Stephen Plummer
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T A B L E O F C O N T E N T S

1	SCOPE	1
2	INTRODUCTION	1
3	THE ESA CLIMATE CHANGE INITIATIVE	2
4	INTERNATIONAL COORDINATION MECHANISMS	6
5	IMPLEMENTATION	7
6	THE FIRST STEPS IN THE CCI.....	9
7	PROGRAMME OUTPUTS	11

1 SCOPE

The purpose of this document is to provide an easy to read description of the ESA programme on Global Monitoring of Essential Climate Variables – better known as the “Climate Change Initiative” (CCI).

The intended audience is anyone, anywhere in the world, who wants to know about, get involved, or cooperate with, the ESA CCI.

The document is organized as follows:

Section 2: Rationale for and importance of the Programme.

Section 3: Explanation of the Programme, its organisation and objectives

Section 4: International context and interface with other major international efforts

Section 5: Presents the three-phase implementation plan for the six year period

Section 6: Details the first steps in the implementation of the Programme

Section 7: Identifies the key programmatic deliverables for the six year period

2 INTRODUCTION

Climate change is arguably the greatest challenge facing mankind in the twenty-first century. Its importance has been recognised in recent reports from the IPCC and from UNFCCC, and the overwhelming economic consequences are set out in the Stern Report (2007). These documents have served to secure the commitment of ESA Member States, both informally and formally through international agreements such as the UNFCCC, to actions which seek to minimise and mitigate the effects of climate change on their citizens and beyond their boundaries. As a consequence, action to predict, now-cast, monitor, mitigate and manage change is now a national, European and global imperative.

Observations from space provide unique information which greatly assists the successful understanding and management of climate change. It is increasingly clear that these observations are critical, but as yet there is not, as in for example the case of meteorology, a co-ordinated sustained programme which will ensure they are available to all. In addition, the nature of the problem requires that such data are adequately preserved over long periods of time, ensuring a reliable long term record. Over the course of the last few years a robust and formalised dialogue between the bodies with responsibility for the specification of climate observations and space agencies has led to a coherent set of requirement, agreed globally.

The first IPCC Assessment Report in 1990 was instrumental in paving the way for the adoption of the UN Framework Convention on Climate Change (UNFCCC) in 1992. A key commitment in the UNFCCC is related to systematic observation and development of data archives related to the climate system. **The Global Climate Observing System (GCOS, also established 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, and in its second report in 2003 GCOS established a list of Essential Climate Variables (ECV) that are both feasible and have a high impact on the UNFCCC requirements. In 2004 GCOS issued the “Implementation Plan for the Global Observing System for Climate in support of the UNFCCC”, where also GMES and GEO were considered, and in 2006 the document “Systematic Observation Requirements for Satellite-based Products for Climate”, where specific requirements to satellite products are put forward and based on this the CEOS developed the “CEOS Implementation Plan for Space-based observations for GEOSS” under ESA’s leadership. The needs in terms of space data products are thus internationally well defined and scientifically agreed. **The missing part is how to provide a consistent set of ECVs.**

3 THE ESA CLIMATE CHANGE INITIATIVE

To respond to this need the European Space Agency (ESA) has initiated a new programme, Global Monitoring of Essential Climate Variables, (known for convenience as the ESA Climate Change Initiative) 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. It is exclusively concerned with addressing the explicit needs of UNFCCC. Most of the effort will be focussed on activities related to ESA historical archives, and the contributions forthcoming ESA research (Earth Explorer e.g. GOCE, SMOS, Cryosat-2) missions will make to the ECVs but **a very important component in this process is to ensure international collaboration and thus achieve global consistency in ECV product generation.**

The initiative will implement a programme of work which ensures that the responsibilities and capabilities of ESA member states in addressing issues of climate change can be undertaken on a scale commensurate with the problem. It is based on the delivery of climate variables derived from **satellite data sets (not just ESA but all sources via international collaboration)** and includes all aspects of their availability including data acquisition, calibration and validation, long term algorithm maintenance, data curation, reprocessing as necessary, all within the context of an internationally agreed set of priorities.

Figure 1 below shows the schematic of the flow of the climate information system, as basic research feeds into applied and operational research and the development of climate services.

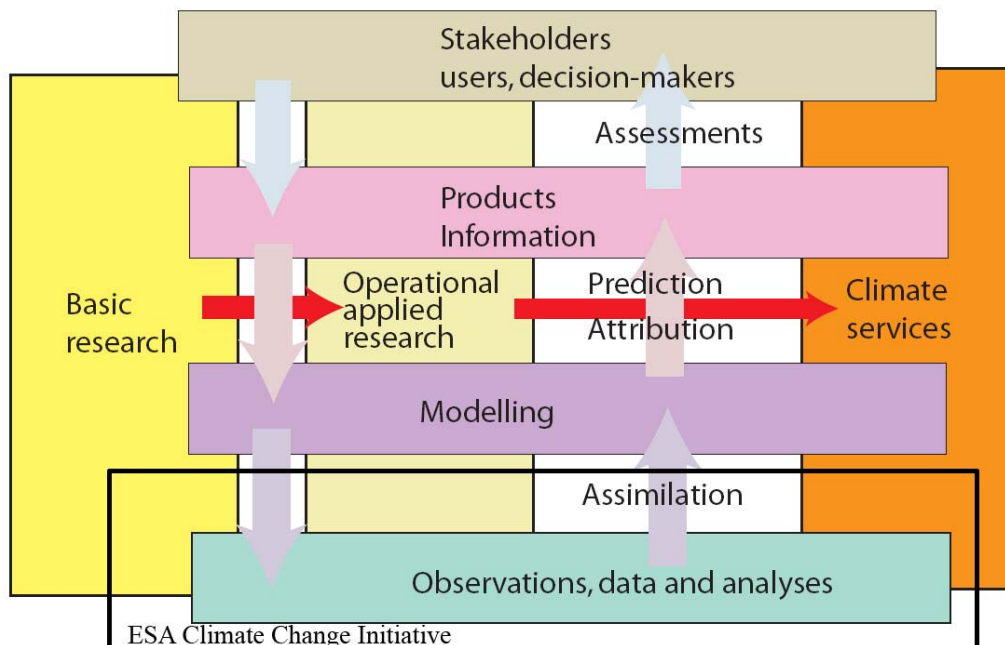


Figure 1: The climate information system (from K. Trenberth: *Observational needs for climate prediction and adaptation, WMO Bulletin 57(1), January 2008*) and the position of the ESA Climate Change Initiative within it.

The system is built on the climate observing system that includes the analysis and assimilation of data in models to produce fields for initializing and testing, the use of models for attribution and prediction and complete information assessment and assembly into products for dissemination to users. The users in turn provide feedback on their needs and mechanisms for improving the information content and type. **The frame at the bottom of the Figure 1 locates the ESA Climate Change Initiative within this framework.**

The ESA programme will bring together European expertise covering the full range of scientific, technical and development specializations available within the European Earth Observation community, and will establish lasting and transparent access for global climate scientific and operational communities to its results. **The essential feature of the programme will be to implement a coherent and continuous suite of actions that encompasses all steps necessary for the systematic generation of relevant ECVs, and ensures their regular updating on timescales corresponding to the increasingly urgent needs of the international climate change community.** In this context it can be noted that the quadri-annual IPCC process, drawing primarily upon peer reviewed published results, implies much more frequent updating and reanalysis than would result from a 'best effort' approach.

The programme objectives will be achieved by five main activities:

- 1) Gathering, collating and preserving the long-term time series in ESA's distributed archives.
- 2) (Re-)Processing periodically the basic EO-data sets from each individual mission and applying the most up-to-date algorithms and cal/val corrections
- 3) Integrating the calibrated data sets derived from individual contributing EO mission and sensors to constitute the most comprehensive and well-characterized global long term records possible for each ECV
- 4) Assessing the trends and consistency of the ECV records in the context of climate models and assimilation schemes
- 5) Developing improved models and algorithms for production of the required variables from emerging data sources, consistent with the long term record

Although actions in each of the five areas are being carried out by individual actors within Europe, many important scientific and technical challenges that call for significant long-term actions on the part of the Earth Observation community have been identified via UNFCCC. **Moreover, there is presently no single programmatic framework that unifies all such activities within Europe, or ensures their continuous implementation at the scale and consistency necessary to meet UNFCCC needs.**

The ESA programme aims to establish such a framework and its most important role will be to implement active feedback between each of the five steps identified above. **It will focus on those ECVs for which data from ESA missions, and relevant national missions, are of particular importance.** It will be closely coordinated with, and can potentially support, related actions on other ECVs, such as those for which meteorological missions are the primary source. **This will move from the present static situation of ad-hoc or isolated fixed-term projects, to a long-term cyclical process of systematic updating, regeneration and reanalysis** of the underlying fundamental data records, and the production of fully up to date, complete and consistent records of the relevant Essential Climate Variables.

It is essential to recognise that no single data set from any single EO mission or space agency is sufficient to constitute, independently of other data sources, all data required for a complete ECV: Merging from different sensors and sources, is a critical step in the generation of a complete ECV. Thus the tasks go far beyond recovery and reprocessing of data from existing archives. There is a need for integration of disparate data sources into reliable, tested, validated products based on improved and updated algorithms with attention constantly paid to their reliability and consistency. **The products must also be designed to allow easy and intelligent access by the climate community for integration into their models.** In turn these models will need to become much more data-driven as the critical need for political decisions in future will be shorter term scenario development, together with local now-casting capacity to allow nations to anticipate and address regional impacts of change.

Each ECV plays a specific role in the understanding of the climate system. No scientific analysis indicates one ECV to be more or less important than another.

Thus any significant improvements that CCI can achieve on the consistency, stability and availability of global satellite data products, for any of the ECVs in its scope, will be a substantial element of the CEOS response to GCOS.

For the Climate Change Initiative ESA has the benefit of authoritative advice from an independent Climate Science Advisory Board (CSAB) which includes representatives from GCOS, GTOS, IPCC, WCRP, JCOMM and ECMWF. This is to ensure the programme has full collaboration at international level and to provide mechanisms for critical feedback to ESA from the many communities with an interest in climate research. This process should strengthen the use of Earth observations and enhance, in particular, the current and future value of ESA Earth observation missions, for understanding and responding to climate change.

ESA member states have established a set of criteria for prioritising CCI activities:

- Significance of the response to GCOS requirements and to scientific priorities of international climate research and modelling communities.
- Availability and accessibility of suitable long time-series of adequately stable, calibrated satellite observations from which to constitute baseline data and derive ECV products.
- Relative importance, uniqueness and complementarity of ESA EO mission data in the context of the coordinated international response to GCOS.
- Maturity of the methodology and algorithms related to one or more ECVs.
- Capitalizing on established European excellence in generating and delivering high quality global EO data products.
- Effective engagement of complementary scientific expertise, and technical capabilities from participating states, to achieve a coherent European effort for GCOS, by efficient use of resources available to this programme.
- Prospects for transiting capabilities developed under this programme to an operational context for future regular updating and continuous availability of ECVs.

The need to adopt an integrated approach, encompassing all ECVs, is of paramount importance and the CCI programme will be implemented in a manner that facilitates structured integration between different scientific disciplines and specialist communities.

Integration will be sought at several levels:

1. **Within ECV Project teams:** By including appropriate specialist modelling groups (e.g., vegetation, carbon cycle, water cycle modelling) to guide the detailed definition requirements and trade-offs, and to independently validate and evaluate the output data products and provide the necessary feedback.
2. **Across ECVs** (i.e. between CCI projects): By mutual review of specifications, data definitions, reference data sets, data output products, and by participation in validation of each others products: [e.g., between SST and Sea Ice project teams, or between Cloud, Aerosol and Land Cover teams etc.]

3. **Across programmes:** By ensuring coordination with relevant on-going projects, inside Europe (e.g., funded nationally. by EC or by EUMETSAT) and outside of Europe (e.g., NASA, NOAA, JAXA) – taking the CEOS implementation plan as the coordination framework. e.g., CCI could fund European teams to implement and participate in cross-validation activities with (independently funded) non-European teams.
4. **Across communities:** Recognizing that there are a limited number of major climate modelling centres in Europe who have an integrated approach (and need) of all the ECVs, the executive will establish a dedicated Climate Modellers User Forum for this programme.

4 INTERNATIONAL COORDINATION MECHANISMS

The international framework for this programme is well established and the success of this programme will depend critically on ensuring that programme activities respond to needs and priorities identified within this framework, and contribute effectively to the collective effort of international partners to meet agreed common objectives. The Programme will therefore make use of existing coordination mechanisms as follows:

- **Coordination with GCOS**

As prime source of requirements for Global Climate Observations on behalf of UNFCCC, GCOS represents the high level user of this programme. The Agency supports the GCOS consultative and review processes both bi-laterally and via CEOS. The Programme will be implemented to ensure close consultation with the GCOS secretariat and its scientific panels throughout its implementation.

- **Coordination with International Climate Research Programmes**

The Climate Science Advisory Body will constitute the primary mechanism for coordination with the International Climate Research Programmes in association with GCOS.

- **International Coordination via CEOS and GEO**

CEOS Agencies are implementing a common action plan, in conjunction with GEO responding to the formal requirements of GCOS. This new ESA programme will enable organizations from participating states to contribute substantially to the CEOS implementation plan. All activities carried out under the ESA CCI will be coordinated with ESA's international partners via the CEOS implementation plan.

- **Bilateral coordination with partner Space Agencies**

The Agency maintains long-term bi-lateral coordination with its major space partners. Key partners in respect of this programme include EUMETSAT, NASA, NOAA, JAXA, USGS, CNES, DLR, ASI and CSA, all of whom operate EO missions or hold EO archives that

may contribute to the programme. Effective bi-lateral communication and coordination with these key partners throughout its life-cycle is a prerogative of the programme.

- **Coordination with EC Research Programmes**

EC Research programmes provide significant opportunities and resources for collaborative European research projects on climate and environment. These programmes support research activities on climate re-analysis, modelling and prediction that can benefit from ECV data products. These programmes can potentially also support complementary research on topics such as in-situ observations and ECVs that are outside CCI scope. The CCI programme will therefore make full use of existing bi-lateral cooperation mechanisms with the relevant EC services, notably DG-Enterprise and Industry for GMES, and DG-Research for Climate and Environment, to ensure coordinated action within Europe.

- **Coordination with National Climate Research Programmes**

The Executive will liaise with national climate research programmes in association with, and in support to, PB-EO delegations.

- **Dialogue with individual user organizations**

ESA has well-established mechanisms for dialogue and consultation with scientific users of Earth Observation data from all over the world. This programme will primarily serve scientific organizations that are active in climate modelling and research using existing channels to establish the appropriate user dialogue and feedback. In particular, the ESA staff responsible for managing the programme will maintain an open dialogue with individual scientific organizations that are interested in participating and exploiting its results.

Every effort will be made to contribute to relevant scientific forums organized by the climate research community, at National, European and International level, to promote awareness and engagement in this programme.

Of particular note are the initiatives of ESA, EC and EUMETSAT, within the context of the European Space Policy, to mutually coordinate European activities related to earth observation and climate change, especially those of relevance for GMES. The underlying goal is to ensure that member obtain maximum societal benefits from their individual and collective investments in EO and climate related observation and analysis capabilities, past, present and future.

5 IMPLEMENTATION

CCI activities will be progressively built up, and contracted, in three major phases, during the six years of the programme.

- **Phase 1: Scientific user consultation and detailed specifications** (2009 onwards)
- **Phase 2: Systems development and data products generation** (2010 onwards)
- **Phase 3: Assessment, Assimilation and Feedback** (2011 onwards)

Phase 1: Scientific user consultation and detailed specifications

- establish formal consultation mechanisms with the climate science programmes, including setting up of the Climate Science Advisory Body
- learn the lessons from analysis and assimilation of existing global data products
- establish data access, Cal/Val and reprocessing requirements specific to ECVs
- establish detailed data product, algorithm, and system performance specifications
- initiate detailed requirements engineering and algorithm developments for ECVs
- initiate data gathering and re-processing activities

Phase 2 Systems development and data product generation

- implement a series of high performance production systems for ECV generation
- verify the correct implementation of selected retrieval algorithms and data models
- initiate generation of large-scale long term ECV global data products
- characterise & validate products before issue to the climate modelling community

Phase 3: Assessment, Assimilation and feedback

- Trends assessment of all data products generated
- Comparison with independent sources including in-situ
- Use for initialization and evaluation of climate models
- Identification of anomalies, biases, discontinuities, and cal/val improvements

Phase 1 activities will generate results (specifications) that are required as inputs for starting Phase 2 (development and production). These activities will be implemented via contracts led and executed by the relevant science community, with support from industry as appropriate. They are expected to peak during years 2-3 of the programme. These activities will continue thereafter, at a reduced level, throughout the programme, to support cyclical reprocessing, updating and improvement of the ECV data products.

Phase 2 activities are expected to be mainly implemented by industry and major data processing centres. These will respond strictly to scientific specifications established during phase 1. Science teams will be directly involved in the associated contracts to ensure the integrity of the systems implementation and to assure the validity of all data products generated, before any are released to the climate research communities. Phase 2 activities are expected to peak during years 3 and 4 of the programme. They will continue thereafter to assure upgrading of systems and cyclical reprocessing, based on extended data availability, improved cal/val and processing algorithms.

Phase 3 activities, are expected to be carried out by the end users of the ECV data products, i.e. the climate and modelling research communities. These activities will support them to exploit the ECV data products generated, and to provide the feedback that will drive successive re-processing cycles. In order for this to occur on a large scale during the second half of the programme, preparatory actions to develop appropriate software tools and to draw on the experience of assimilating existing large-scale data products (e.g. GLOBCOVER, GLOBCOLOUR and others) will be initiated during phase 1.

Since the (GCOS) user requirement is for continuously updating long-term time series of climate observations, it is understood that activities initiated via this programme should continue after programme completion. All actors within the programme will therefore be required to work towards this long-term objective. No assumption is made at this stage about the funding sources or programmatic framework that would secure this continuity.

6 THE FIRST STEPS IN THE CCI

To firmly establish the scientific cogency of the programme, and mobilize the multi-disciplinary scientific expertise available within all participating states, 11 ECVs have been chosen to be addressed in the first phase of the programme. These were selected, on the basis of the prioritisation criteria, such that they:

- Encompass a representative (although not complete) set of variables for the ocean, terrestrial and atmospheric domains.
- Cover important (but not all) elements of the carbon cycle and the water cycle.
- Address major factors of uncertainty in climate radiative forcing and feedback
- Include the most rapidly changing elements of the climate system

The first 11 ECVs selected for the ESA CCI are:

- Sea-level
- Sea Surface Temperature
- Sea Ice
- Ocean Colour
- Land Cover

- Fire Disturbance
- Glaciers and Ice Caps
- Cloud Properties
- Aerosol Properties
- Ozone
- Greenhouse Gases (CO₂, CH₄)

This, however, does not preclude future activity on the remaining 10 ECVs within the scope of the CCI. Moreover, forerunner developments relevant for such ECVs are continuing within other the ESA programmes and the launch of the first three Earth Explorer missions in 2009-10 will stimulate major advances in the observations and maturity of methods for several ECVs that are not addressed above.

For completeness some on-going activities relevant for each of the ECVs not in the first eleven are indicated below:

- **Sea-State**

RA SWH and Wind will be addressed as by-products of the CCI activity on Sea Level

- **Ocean Surface Salinity**

CCI activities on ocean salinity will be defined after the successful launch, commissioning and cal/val of SMOS

- **LAI and f_{APAR}**

Further deliberations amongst scientific community will be pursued before starting a specific action within the CCI

- **Snow**

Due time will be allowed for the recently initiated GlobSnow project to yield first results, before a dedicated action is undertaken within the CCI

- **Albedo**

The GlobAlbedo project was launched in 2009 and dedicated action with CCI will be deferred until results are available from this project.

- **Lake Levels**

Algorithm developments on the estimations of lake (and river) levels with Altimeter observations are on-going at ESA. CCI actions to improve the Radar Altimeter observations for sea-level and sea-ice ECVs will indirectly benefit this ECV.

- **Biomass**

A SAR biomass airborne measurement campaign is underway in context of the candidate Biomass Explorer mission. Several research projects on Polarimetric InSAR methods for biomass retrieval are on-going. The decision to initiate further research activity on this topic will be deferred to a later stage of CCI.

- **Soil Moisture**

CCI activities on soil moisture will be defined after the successful launch, commissioning and cal/val of SMOS

- **Upper air winds**

CCI activities on this ECV will be deferred until the successful launch commissioning and cal/val of the ADM-Aeoleus.

The first steps of CCI are designed to create scientific impetus and facilitate timely, cooperative, and consistent contributions to the IPCC process. They will mobilize complementary expertise from research groups in participating states, to address diverse aspects of the climate system in an integrated fashion. These activities are intended to lay the basis for **subsequent programme actions that will address more operational aspects**, including **industrial system developments** and **operational sustainability**.

7 PROGRAMME OUTPUTS

The programme shall, ***in full compliance with the GCOS Climate Monitoring Implementation Principles***, deliver the following outputs:

- Frequently reprocessed and improved measurements of ***Essential Climate Variables***: as specified by GCOS, in the form of long-term time-series of suitably calibrated, validated, and scientifically characterized global, gridded, stable, consistent, satellite-based data products, derived from the fundamental climate data records (FCDRs) held by ESA and, as appropriate partner, Space Agencies, as required by the climate modelling and science communities, generated with high performance processing systems, each validated by the relevant science and modelling communities.
- ***Complete and consistent FCDRs*** from ESA EO archives along with supporting metadata, for each ECV
- ***Regularly re-processed data products*** from ESA and Third Party Missions, according to the needs of the user community for corresponding ECVs
- ***Cal/Val results, and metadata***, for all FCDRs preserved by ESA
- ***Formal technical specifications of high-level EO data products***, based on the complete (multi-mission) FCDRs, for each ECV
- ***New, improved and validated algorithms*** to meet, or approach, the specific performance requirements for each ECV
- ***Validated, data processing software packages***, implementing the specified algorithms
- ***Highly performant operational processing systems (SW & HW)***, each capable of ingesting the global, historical data sets from all missions in the FCDRs of a single ECV and (re)generating the required, high-level, global, gridded, EO data products for each ECV, with high throughput
- ***Output from International Organizations Forums participation***, as part of the Cal/Val, standardization, reprocessing agreed procedures
- ***Coordinated strategy for long-term EO data preservation and access***, exploiting at the maximum extent the standards for harmonised access among other relevant

- **Data toolboxes** that enable climate modellers easily to assimilate and evaluate the delivered EO data products for their climate re-analysis.
- **Specifications for improved global climate monitoring systems** (to GCOS)
- **Assessments of optimal performance requirements** for future Earth Observation missions to support climate monitoring
- **Documentation** on all FCDRs, ECVs, Cal/Val, and systems generated through this Programme
- **Scientific reports on the validation of all products** generated, and recommendations for future algorithm developments to meet the GCOS performance requirements
- **Educational and communication materials**, derived from EO data, to support the climate change UNFCCC process
- Technical reports to support ESA Member States **complying with the UNFCCC reporting requirements** for systematic global observations of climate