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DOCUMENT

Response by ESA to GCOS

Results of the Climate Change Initiative

Requirements Analysis

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Issue 3	Revision 2		
Reason for change	**Date**	**Pages**	**Paragraph(s)**
Change Climate Modelling Community to Climate Research where appropriate	25/07/2013	15 and 42	4.2 and 4.9

Table of contents:

1 SCOPE

This document is the ESA response to the Global Climate Observing System (GCOS) as a first result of the ESA Climate Change Initiative (CCI) launched in 2009. It was first published in 2011, and the present version is an update as of 31 May 2013. The CCI has been created to address the GCOS Essential Climate Variable (ECV) requirements for satellite datasets and derived products. In its initial phase, and to guide its path forward, the CCI completed a comprehensive analysis of user requirements for such datasets for 10 ECVs. ESA presents the results of this analysis as a significant contribution to GCOS and the international community. It has already been considered in updating the GCOS requirements and should be of wider use for CEOS agencies responding to GCOS.

The CCI requirements analysis is based on contributions by thirteen ECV-specific projects within the CCI and the ESA Strategic Initiative (StrIn) and by the CCI Climate Modelling User Group (listed in Appendix D). Parts of these documents (e.g. tables, figures) have been used in this report. In addition, general principles of CCI implementation were evaluated for their coherence with GCOS guidelines. All other references used in this report are listed in Appendix E and in the ECV-specific sections.

This document is organized as follows:

Section 2: Presents the background and context to the GCOS requirements and to the international response by space agencies

Section 3: Describes the background and status of the CCI, and its compliance with general GCOS guidelines

Section 4: Specifies the basis and motivation for the CCI requirements analysis

Section 5: Presents the results of the CCI requirements analysis

Section 6: Describes the work of the CCI Climate Modelling User Group and some of its results

Section 7 and 8: Provide a concluding analysis and concluding remarks

2 BACKGROUND AND INTERNATIONAL CONTEXT

2.1 GCOS Requirements and CEOS Response

The 2004 *Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC* (GCOS, 2004), the supplemental 2006 *Systematic Observation Requirements for Satellite-based Products for Climate* (‘Satellite Supplement’, ‘GCOS-107’; GCOS, 2006), and their updates respectively released in 2010 and 2011, capture the GCOS requirements for sustained, long-term, fundamental climate data records and derived products addressing the ECVs. These datasets are important information needed to meet observations-related priority needs expressed by the UNFCCC, the IPCC and the WCRP to:

- Characterize the state of the global climate system and its variability;

- Monitor the forcing of the climate system, including both natural and anthropogenic contributions;
- Support the attribution of the causes of climate change;
- Support the prediction of global climate change;
- Enable projection of global climate change information down to regional and local scales;
- Enable characterization of extreme events important in impact assessment and adaptation, and the assessment of risk and vulnerability.

In the GCOS documents[1], Earth observation satellites have been identified to make a significant contribution in observing 26 ECVs. As a consequence, and following a mandate by the UNFCCC Subsidiary Body on Scientific and Technological Advice, space agencies coordinated within CEOS have been responding to the needs formulated under GCOS auspices: a 2006 CEOS plan (CEOS, 2006) is guiding international space agency action in support of climate with the following strands of activity: systematic exploitation of archived data, calibration of sensors, validation of products, and planning of future climate-relevant missions. The latter has been guided by the GCOS Climate Monitoring Principles, which were endorsed by CEOS in 2003. Overall, satisfactory progress has been made on the CEOS plan (as shown in GCOS, 2009), and space agency coordination in the area of climate has further advanced, for example through establishment of the CEOS Working Group on Climate in 2010.

2.2 ESA Response to GCOS

ESA contributes in various ways to the different strands of activity identified in the CEOS response to GCOS. This report describes the response by ESA to GCOS through the CCI.

The ESA CCI was conceived to leverage long time series of archived satellite data, mainly from European missions, for generating climate datasets, in response to GCOS needs and in support of the UNFCCC, the IPCC, WCRP and international research and modelling groups. It therefore contributes significantly to the international CEOS response to GCOS. The CCI is coordinated with research programmes supported by the European Commission and European states, and is expected to underpin the establishment of climate services under the European GMES initiative.

The CCI was approved by ESA Member states at the Ministerial Council in November 2008 (as the ESA "Global Monitoring of Essential Climate Variables" programme). Its principal objective is "to realize the full potential of the long-term global Earth Observation archives that ESA together with its Member states have established over the last thirty years, as a significant and timely contribution to the ECV databases required by the UNFCCC" [CCI Statement of Work, ESA (2009)].

The CCI focuses on the exploitation of data records primarily, but not exclusively, from past ESA satellite missions, for the benefit of climate monitoring and climate research. It complements existing efforts in Europe (e.g. led by EUMETSAT through the CM SAF) and internationally (e.g. under the umbrella of SCOPE-CM) which both focus on datasets characterizing meteorological aspects of the climate system. The success of the CCI will be measured by the quality of its results (in short, climate-quality satellite-based ECV products), and its ability to establish lasting and

[1] Including the 2010 update of the GCOS Implementation Plan (GCOS, 2010b) and the subsequent 2011 Satellite Supplement (GCOS, 2011)

transparent access for global scientific and operational communities to these results. The CCI places strong emphasis on the generation of fully described, error-characterized, consistent satellite-based ECV products.

ESA, through the CCI, will do its utmost to meet the stringent requirements set in GCOS (2006, 2011), using archived satellite data. However, since the sources of those data include instruments built without climate specifications and before GCOS requirements were considered, **it cannot be expected that all ECV products generated in the CCI are compliant with GCOS requirements**.

A competitive tender for proposals to generate climate-quality products addressing a first set of eleven ECVs was released by ESA in the last quarter of 2009. Those eleven ECVs were:

- Atmosphere (4): Ozone, Clouds, Aerosols, Greenhouse gases (CO_2, CH_4)
- Oceans (4): Sea level, Sea surface temperature, Sea ice, Ocean colour
- Terrestrial (3): Land cover, Glaciers and ice caps, Fire disturbance.

An updated version of GCOS (2004) was published in 2010 (GCOS, 2010b) and a corresponding Satellite Supplement (GCOS, 2011) in December 2011. It is worth noting that the updating process of the Satellite Supplement benefited from initial findings of the CCI.

3 THE CCI CONTEXT

3.1 Programme Overview and Status

The first three-year phase of the CCI were science-led, mainly consisting of reviewing the state-of-the-art, gathering input data, and generating initial, validated ECV products. Based on this work, in a second three-year phase, the CCI anticipates the implementation of a prototype processing system, leading to sustained production of ECV datasets and broad user take-up, for example in data assimilation (Figure 1). A total of 95 M€ has been ascribed to the CCI (phases 1 and 2), including funding from the ESA Strategic Initiative (StrIn) as well as increased contributions at C-MIN 12.

As part of CCI phase I, between August and December 2010, ten ECV-specific projects were launched (hereafter: ECV_cci projects; see Table 1). The ECV_cci teams are consortia of between six and 15 European partner institutions, including academia, government agencies and system engineering companies (see Appendix B for details). Within each consortium, responsibilities have been assigned for: science lead, project management, Earth observation science expertise, climate research expertise, and system engineering.

During the first three years, the ECV_cci teams have worked in parallel on the following tasks: user requirements analysis and product specification; algorithm development, inter-comparison (“round robin”) and selection; prototyping a processing and archiving system; initial ECV product generation, including validation; and assessment of user take-up.

It has been the task of each team’s science leader (Table 1) to ensure the overall scientific integrity of the respective ECV_cci project throughout phase I. All CCI teams have significant involvement of past or current IPCC authors. The science leader will also ensure that each CCI project maintains effective working links to the appropriate international climate science programmes, such as GCOS and WCRP. Appendix C provides an overview of CCI project linkages to international programmes and working groups.

In addition to the ten ECV_cci teams, a CCI Climate Modelling User Group (CMUG) consisting of major European climate modelling centres has been set up (see section 6 for details). At all stages of the programme, its task is to provide a climate modelling perspective on the CCI, and to test datasets generated in the CCI within their models. CMUG also aims to provide an interface between the CCI and the international climate modelling community. The existence of CMUG emphasizes the important role of climate modelling as a primary user of CCI output.

A CCI project on sea ice was launched in the course of 2011, as well as projects dedicated to ice sheets and soil moisture, though funded under a different scheme. The possibility for more CCI projects at a later stage, focussing on other ECVs is tentatively envisaged for: upper-air winds, sea state, sea-surface salinity, FAPAR, LAI, albedo, biomass, lake levels, and snow cover.

Table 1: ESA CCI projects, science leaders and corresponding ECV product needs identified in GCOS-107 (GCOS, 2006) and GCOS-154 (GCOS, 2011).

CCI Project	Science Leader	GCOS-107 Product
Cloud	Deutscher Wetterdienst, Germany (*R. Hollmann*)	A.4
Ozone	BIRA-IASB, Belgium (*M. van Roozendael*)	A.7
Aerosol	DLR, Germany / FMI, Finland (*T. Holzer-Popp / G. De Leeuw*)	A.8
GHG	University of Bremen, Germany (*M. Buchwitz*)	A.9
Sea Level	LEGOS-CNES, France (*A. Cazenave*)	O.2
SST	University of Edinburgh, UK (*C. Merchant*)	O.3
Ocean Colour	Plymouth Marine Laboratory, UK (*S. Sathyendranath*)	O.4
Sea Ice*	Nansen Environmental and Remote Sensing Centre, Norway (*S. Sandven*)	O.5
Glaciers	University of Zurich, Switzerland (*F. Paul*)	T.2.1
Ice Sheets*	Danish Technical University, Denmark (*R. Forsberg)*	T.4
Land cover	Université Catholique de Louvain, Belgium (*P. Defourny*)	T.5.1
Fire	University of Alcala, Spain (*E. Chuvieco*)	T.9
Soil Moisture*	Vienna University of Technology, Wien, Austria (*W. Wagner*)	T.11
Climate Modelling User Group	UK Met Office Hadley Centre (*R. Saunders*)	-

* Shaded boxes denote CCI Projects initiated in 2011-2012.

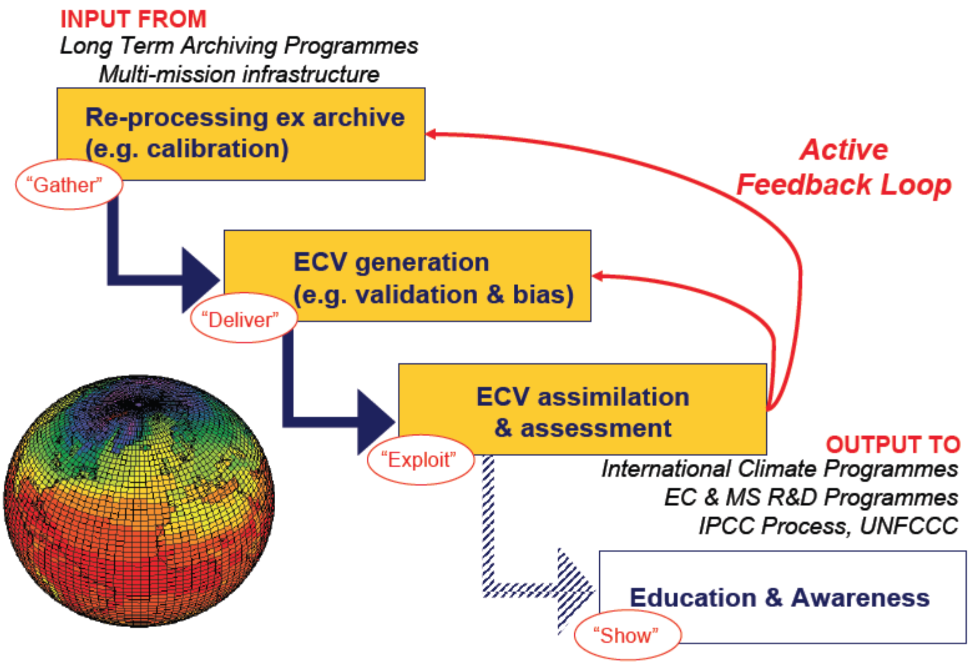

Figure 1: ESA Climate Change Initiative programme flow.

3.2 General GCOS Requirements addressed by the CCI

From the outset, the CCI has been systematically based on the requirements identified in GCOS-107. The CCI embraces many cross-cutting recommendations from this document (such as the need for sustained reprocessing of archived data, for consistent products, and for access to datasets), uses proposed terminology (such as 'FCDRs' and 'products'), and adopts the ECV-specific GCOS requirements on accuracy, stability etc. as a high-level target baseline.

The CCI projects have just generated their first climate datasets and products within the programme; it is therefore premature to assess their adherence to the generic *Guideline for the Generation of Datasets and Products Meeting GCOS Requirements* (GCOS-143; GCOS, 2010a). Nevertheless the CCI objectives and programmatic set-up take full account of the GCOS principles of transparency and traceability, to enable scientific judgment and user acceptance. The CCI statement of work, which is a mandatory guideline for all CCI projects, heeds the principles stated in GCOS (2010a) (see Table 2). The CCI also supports the intent of the joint May 2010 GCOS/WCRP letter[2] calling for strengthened collaboration in the generation and intercomparison of climate data records, by fostering the pan-European and international dialogue on the use of satellite data records for climate applications.

[2] http://www.wmo.int/pages/prog/gcos/documents/GCOS-WCRP_JointLetter_All.pdf (accessed 5 May 2011)

Table 2. Match-up of ESA CCI programmatic provisions with *Guideline to the Generation of Datasets and Products Meeting GCOS Requirements* (GCOS-143; GCOS, 2010a). References in () relate to the CCI Statement of Work (R-X: Recommendations; CR-X: Cardinal Requirements; ESA, 2009).

Need identified in the GCOS Guideline (GCOS-143)	Matching ESA CCI Provisions
1. Full description of all steps taken in the generation of FCDRs and ECV products, including algorithms used, specific FCDRs used, and characteristics and outcomes of validation activities	All related steps require full and openly accessible documentation (e.g. on requirements analysis, product specification, algorithm selection, validation and intercomparison), to be published on www.esa-cci.org (R-3).
2. Application of appropriate calibration/validation activities	Product validation is foreseen within the CCI, and outside, by independent science bodies and groups (R-3, R-7). Calibration and possible re-calibration of FCDRs as a result of CCI are under ESA responsibility.
3. Statement of expected accuracy, stability and resolution (time, space) of the product, including, where possible, a comparison with the GCOS requirements	The provision of full error characteristics for all products generated within the CCI is a key deliverable (CR-1, CR-2).
4. Assessment of long-term stability and homogeneity of the product	Within a research context, the most complete and consistent possible time series of ECV products should be produced and validated (CR-2).
5. Information on the scientific review process related to FCDR/product construction (including algorithm selection), FCDR/product quality and applications[3]	Results are to be published in peer-reviewed journals (R-4); algorithms are to match product needs identified in user requirements analysis (including consideration of GCOS requirements) (R-5, CR-1); intercomparison of algorithms fostered by round robin exercise (R-7).
6. Global coverage of FCDRs and products where possible	Multi-sensor global satellite data products will be generated, with a focus on, but not limited to, ESA satellite mission data (R-1, CR-2, Annexes to Statement of Work).
7. Version management of FCDRs and products, particularly in connection with improved algorithms and reprocessing	Version management of all datasets and products is recommended, e.g. through assignment of file tracking IDs and document version numbers (see CCI Project Guidelines

[3] This could be publications in peer-reviewed journals, or evaluations by independent, internationally-recognized science groups.

	DS-3).
8. Arrangements for access to the FCDRs, products and all documentation	The CCI will provide public information and documentation online at www.esa-cci.org; Datasets, products and their descriptors will also be made openly available when validated; long-term preservation and access to be addressed in specification of processing and archiving system prototype; CCI datasets follow the CF metadata convention.[4]
9. Timeliness of data release to the user community to enable monitoring activities	Open, explicit schedule for release of data and documents (section 4.8.2); Products to be publicly released as soon as validated by CCI teams (Task 4); Creation of a climate research data package will facilitate this process (Task 3).
10. Facility for user feedback	Several mechanisms to ensure timely and critical user feedback: the CCI climate modelling user group; CCI project-specific user groups; intercomparison of algorithms within each CCI project ("round robin"); encouragement to publish results in peer reviewed literature; www.esa-cci.org.
11. Application of a quantitative maturity index if possible	Maturity of existing algorithms will be assessed in the first year of each project (2011), through intercomparison and peer review (Task 2); CCI product validation and user assessment will occur at the end of the third year (2013; Task 4); application of a maturity index[5] may be considered as an option.
12. Publication of a summary (a webpage or a peer-reviewed article) documenting point-by-point the extent to which this guideline has been followed	Given implicitly by CCI provisions, including that (page 9) "each CCI project team will adhere to the GCOS guidelines for the generation of global satellite data products"; summary to be published online on CCI project pages and to be provided in future reports to GCOS.

[4] NetCDF Climate and Forecast (CF) Metadata Convention http://cf-pcmdi.llnl.gov/
[5] Such as for example the maturity index developed by NOAA (Bates and Barkstrom, 2006)

4 INTRODUCTION TO CCI REQUIREMENTS ANALYSIS

4.1 Overview

The development of ECV products by the CCI is, firstly, driven by the GCOS 'cardinal' requirements as given in GCOS-107 (GCOS, 2006) and now updated in GCOS-154 (GCOS, 2011). Secondly, the CCI is expected to make a difference in the generation and take-up of consistent, error-characterized global satellite climate records for a subset of ECVs; the programme therefore has to decide in which climate application areas its impact can be maximized.

This requires a thorough understanding of the state of climate science and up-to-date knowledge of climate-related requirements of satellite data users. The principles of transparency, traceability and consistency are especially important at this stage where the basis for later CCI implementation is established, and robust, well-founded choices have to be made. Finally, a trade-off is required between ambition and feasibility. All these points have now been addressed by the CCI.

The first CCI deliverable was a critical, science-based analysis of user requirements for ECV products in general (e.g. which accuracy, stability and spatio-temporal resolution of a regional sea level change map are needed to make best use of it for impact studies). The user requirements gathering exercise builds the basis for the specification, development and evaluation of the ECV products to be generated in the CCI.

Performed by all ECV_cci teams and the CMUG, the requirements analysis is based on GCOS-107 and a range of other detailed user requirements for climate datasets and ECV products. The result of collecting and discussing the requirements, and drawing conclusions (which ones can be addressed in the CCI? which ones cannot be addressed? which ones can be addressed elsewhere?) has led to (i) valuable feedback to GCOS (through this report, and through input to the 2011 update of GCOS-107) and to the broader community in setting requirements, (ii) detailed specification of planned ECV_cci products, and (iii) input to a science agenda emanating from the CCI.

The analysis included a critical review of the 'cardinal' user requirements formulated by GCOS (in GCOS-107); several methods for collecting community feedback were used. Updates of the GCOS satellite-specific requirements (such as the one in 2011) and the GCOS-led requirements definition process in general may wish to take those into account. The CCI requirements analysis will also inform European and CEOS-coordinated efforts in response to GCOS.

The second deliverable is a specification of the planned products to be generated within the CCI as a result of the user requirements analysis, based on rational, well-founded choices. Those also take into account the capabilities presently available (e.g. data archived by ESA, length of record, known sensor performance).

All ECV_cci projects and the Climate Modelling User Group were involved in this process, completed in the first half of 2011. The following sections summarize the main findings.

4.2 Status

Work on the CCI started between July and December 2010 with the kick-off of all approved ten initial CCI projects. All ECV_cci teams[6] collected, discussed, reviewed and analysed user requirements, and documented their findings in a 'User Requirements Document (URD)'[7]. They used a wide range of different sources for collecting user requirements, including:

- International references (e.g. IGOS Theme reports, WMO RRR database);
- International working groups (e.g. WCRP GEWEX);
- User surveys (workshops, interviews, online questionnaires);
- Climate modellers, including the CCI Climate Modelling User Group;
- CCI project-affiliated climate research groups;
- Scientific peer-reviewed literature.

Particular emphasis has been placed on analysing user requirements from a climate modelling perspective, although other climate applications identified by GCOS (e.g. use of satellite products for trend analysis, impact studies, emission inventories) also play an important role as 'customers' of the CCI and have been taken into account.

The user requirements analysis included an assessment of the error characteristics of ECV products (at CEOS data processing levels 2/3/4, see Appendix F) that are required to have maximum impact on the identified climate application area (e.g. to allow the detection of climate change impacts over and above natural variability). It also identified the FCDRs (at CEOS 'level 1') required by the ECV_cci project to achieve the quality, longevity and format of the envisaged ECV product.

The CCI requirements analysis addresses the following questions:

- To which extent are the GCOS requirements achievable with the currently available multi-satellite records?
- How mature (well-founded) are the gathered requirements?
- Which set of requirements can the CCI meet, with priority on maximizing the exploitation of ESA mission data and their impact on climate research?
- Which portions of the climate user community will be primarily addressed by the CCI project (e.g. those related to global climate models, trend analyses, impact studies, reanalyses etc.)?
- Which sets of requirements are better met by other organizations?
- Which requirements cannot be met, and why?

The answers have a direct bearing on the detailed ECV product specifications that are selected and further pursued in the CCI. The ECV_cci teams have made choices to that effect (documented in a 'Product Specification Document (PSD)'). For each FCDR and ECV_cci product, they provide detailed definitions of the geophysical parameters to be generated, error budgets, quality indicators, data formats and ancillary data used. Robustness of the choices made in the CCI is determined by:

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[7] All CCI documents for public use are available on the CCI homepage at http://www.esa-cci.org

- To what degree they are susceptible to change over time; and,
- To what degree users will benefit from the final, validated product.

It is acknowledged that in some cases the product specifications defined by the CCI projects will not reach the stringent GCOS requirements; however, the improved datasets and products are still expected to be of value for climate research as in many cases they will provide the first uncertainty estimates with their products. However, since the sources of those data are (mainly) European instruments, not necessarily built to observe ECVs over the long term, it is not surprising that the ECV products generated in the CCI will not meet all the GCOS requirements.

This document does not cover the crucial steps of product validation and documentation that are the basis for climate-quality ECV products, and their transparency, traceability and access (in line with GCOS, 2010a). Data management issues are also not covered. Those points were however addressed by all CCI projects during the first two years of the programme, with details given in mandatory (and openly published) reports on product validation, algorithm selection, and product use.

The Science Leader of each CCI project is the responsible focal point for all above-mentioned CCI outputs (Table 1). A summary of all planned ECV_cci products and their specifications in comparison to GCOS-107 requirements is given in Appendix A.

Where applicable, this report uses common terminology to discern the level of utility of requirements (in brackets the definition used in the WMO RRR database; WMO, 2011):

- **target** (or goal) as a maximum requirement (an "ideal value above which further improvement of the observation would not cause any significant improvement in performance for the application in question");
- **threshold** as a minimum requirement ("has to be met to ensure that data are useful. Below this minimum, the benefit derived does not compensate for the additional cost involved in using the observation. Threshold requirements for any given observing system cannot be stated in an absolute sense; assumptions have to be made concerning which other observing systems are likely to be available."); and,
- **breakthrough** as an intermediate requirement ("between 'threshold' and 'goal' which, if achieved, would result in a significant improvement for the targeted application.").

The report uses the CEOS definitions to describe datasets at different processing levels (see Appendix F).

4.3 Review and Feedback

Results of the CCI-led appraisal of climate user requirements are not final and will be updated as necessary, based on feedback from within the CCI and from the international community. Since it can be a difficult task for users to assess some of their future requirements, up to 5-10 years in advance, reviews by scientists (such as the international science groups identified in each CCI project, GCOS expert panels) relating to each user application will provide independent advice and thus ensure robustness of the conclusions. All related documents (URDs and PSDs) are available on the ECV-specific sections of the CCI website (www.esa-cci.org).

Product specifications as a result of the user requirements analysis will evolve as the CCI projects progress. The ECV_cci products (first released in late 2012-2013) are being made available for critical review by international peers, such as those listed in Appendix C. Interaction with modelling intercomparison exercises (such as CMIP5) and the IPCC is also expected to yield valuable feedback. Therefore, reviews of the decisions made at this stage are foreseen later in the CCI, using the feedback loops built into the programme (see Figure 1).

5 RESULTS OF CCI REQUIREMENTS ANALYSIS

5.1 Cloud_cci

Collection of Requirements

The Cloud_cci team gathered requirements for satellite-based cloud products set by international consensus and in peer-reviewed publications. It quoted requirements set by GCOS in GCOS-107 and the WMO RRR database (WMO, 2011), by WCRP (also in WMO RRR database), by Ohring *et al.* (2004) and by CCI CMUG. Requirements as set by Ohring *et al.* pose the biggest challenge, particularly on stability over time, since they aim at detecting decadal trends in heritage cloud datasets. Modellers place more emphasis on precision and spatio-temporal resolution, and their needs are discussed in detail by the team. Reference was also made to key publications in the field of satellite cloud climatology and climate modelling, although not all possible applications of cloud data (and associated requirements) for climate process studies could be captured.

Discussion, Conclusion, Traceability

The Cloud_cci project plans two sets of product families based on the optimal estimation approach, initially covering a three-year period: firstly, heritage multi-instrument products (based on AVHRR, MODIS and AATSR) aiming at an improvement of the existing long-term AVHRR record. Such products would provide the basis for an improved, fully error-characterized cloud climatology, allowing better assessment of cloud feedbacks and improved validation of model fields (beyond CCI phase I, processing of three decades of data is planned).

Secondly, combined retrieval of cloud properties from the ESA AATSR and MERIS sensors is foreseen within a community physical retrieval framework. Both product families cover cloud fractional coverage, cloud top height/temperature as well as liquid/ice water content. All products will be made available as monthly averages at 50km horizontal resolution, on the basis of sub-daily sampling (6-10 times daily).

In a compliance analysis, the Cloud_cci project took into account all results from the user requirements gathering exercise, but used the GCOS requirements as the primary reference. The team contrasted the envisaged products against GCOS requirements (see Table 9) – they are largely being met. Due to the measurement technique, some microphysical properties (e.g. cloud liquid and ice water path) can only be measured during daytime. Most of the WCRP requirements identified by the team can also be met. Cloud_cci targets generally do not meet modellers' requirements for high temporal (1-3 h), horizontal (10-30 km), and vertical resolution (~0.2 km), necessary to support of cloud process studies and model development (as expressed by CMUG). Interestingly, the WCRP requirements, although driven mostly by the climate modelling community, never asked for finer scale than 100km horizontal resolution (maybe due to their date – 1998).

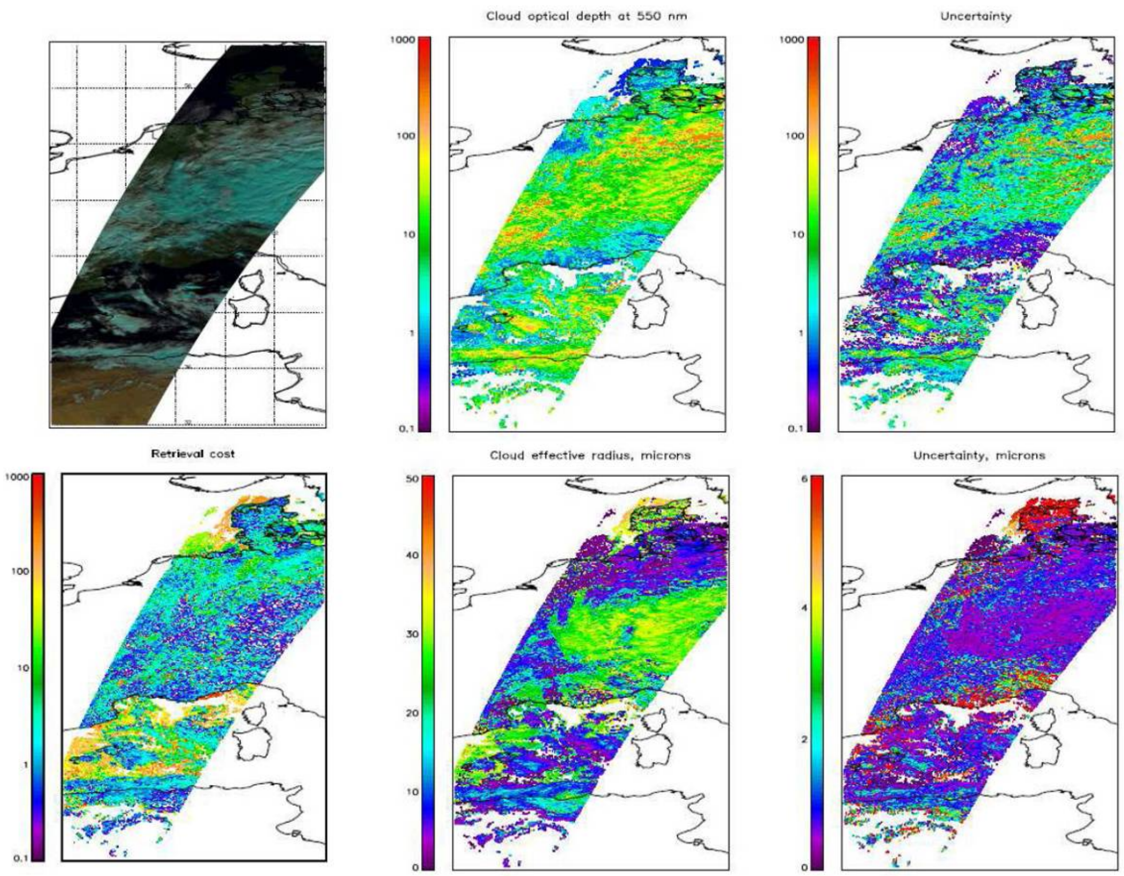

Figure 2: Example of cloud retrieval over Europe. Top from left to right: false colour image based on instrument swath (blue colour is indicative of ice cloud), cloud optical depth and error on the cloud optical depth. Bottom from left to right: retrieval cost, cloud effective radius and error on the effective radius.

Making available all instrument-resolution retrievals (CEOS 'level 2') of cloud properties needed for the core Cloud_cci products should in principle address many of the model developers' needs. This requires adequate post-processing to accommodate modellers' data formatting needs, and the Cloud_cci is taking steps toward that end. Such data would then be effectively available at ~6h temporal and 0.25-5 km spatial resolution, depending on the instrument.

The Cloud_cci project is identifying possible error sources in the cloud products it generates (see Figure 2 for examples), separating them into random and systematic errors. This is fully in line with GCOS guidelines for product generation. Random errors are inherent to the methodology (optimal estimation; Rodgers, 2000) and due to sampling, i.e. the uneven distribution of satellite retrievals in space and time. Systematic errors are due to calibration of the instruments, aggregation and interpolation of data, inherent to the retrieval method, among others.

Linkages

The Cloud_cci project collected cloud-related requirements from other ECV_cci project teams related to:

- Consistent error characteristics
- Common ancillary fields (e.g. ERA-40, ERA-Interim, surface albedo, vegetation, emissivity, ice (sea, land), SST)
- Common horizontal grids, definition of atmospheric layers
- Common terminology, formats, projections

A dialogue has been established mostly with CCI projects that use the same set of instruments as Cloud_cci: Aerosol_cci, SST_cci, Ocean_Colour_cci, Fire_cci, and Land_Cover_cci. Common goals of these projects are consistent cloud masks (critical cloud optical thickness) and correction of cloud radiative effects (e.g. shadows). However, stated requirements can only be met partly, mainly due to the time period covered by the other CCI projects compared with the three year period (2007-2009) for which the Cloud_cci cloud products will be available in phase I (see also Table 7).

Reference

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5.2 Ozone_cci

Collection of Requirements

The Ozone_cci project gathered existing user requirements from international consensus references, such as GCOS-107, WMO (2004) and the WMO RRR database (WMO, 2011a), as well as from the climate modelling community in the CCI CMUG. Views from climate researchers associated with the project (DLR, University of Cambridge) as well as results from the recent Scientific Assessment of Ozone Depletion (WMO, 2011b) were also taken into account. Both target and threshold requirements were considered important, the latter being achievable, based on experience current ozone data.

Discussion, Conclusion, Traceability

The most important objectives with respect to data products of the Ozone_cci project are to generate long-term datasets for (i) climate monitoring over a decadal timeframe, (ii) the investigation of trends and variability and their relationship to climate change and to the Montreal protocol, and (iii) improving process descriptions (e.g. ozone chemistry and atmospheric dynamics) in numerical models.

In relation to objectives (ii) and (iii), the planned work includes the use of three different chemistry-climate models (CCMs) developed by the project partners for investigating ozone-related processes and feedback mechanisms under a changing climate. These models are ozone-specific adaptions of global climate models and simulate short-term variations and long-term trends of the ozone content in the troposphere and stratosphere. CCMs will be used to evaluate the products generated in the Ozone_cci project. Conversely, Ozone_cci products will be used to establish a more robust benchmark for assessing the quality of the CCMs (WCRP, 2010). Improved CCMs will help simulate spatial structures and temporal behaviour of the ozone layer better, and further the understanding of processes in the upper-troposphere and stratosphere, e.g. variability in stratospheric water vapour.

The project team interpreted the GCOS horizontal/vertical data resolution requirements as being primarily driven by currently available CCMs. Ozone-related process scales vary strongly with altitude, and therefore, vertical resolution requirements are determined by the sampling required to resolving the selected phenomenon or process. Tropospheric ozone models have high horizontal resolution (<20km), whereas stratospheric models operate at lower resolutions (100-300 km).

In response to the user requirements, the Ozone_cci project plans two categories of products (see Table 10): a column integrated product (total ozone) and two vertically resolved products (limb and nadir sounded ozone profiles). The team made a useful separation of the product requirements by distinguishing between targets (ambition for the future) and thresholds (already achievable).

Total column ozone

In setting specifications for total ozone products, the team used scientific considerations as well as experience with available satellite measurements over the past 30 years. Such products provide the basis for the detection of interannual variability and of long-term trends (WMO, 2011b). To better understand regional and seasonal evolution of the distribution of ozone (see Figure 3), the project proposed that temporal resolution of global products should not be longer than ~3 days. This would allow the assessment of climatologically important meteorological blocking events and of regional changes of ozone amount. Such assessments require adequate spatial resolution in the order of 100-300 km. Many atmospheric models have rather coarse grids; therefore products with a resolution around 100 km globally would be needed, with 20 km a desirable target.

Stability requirements were established based on the following estimation: to detect a 6 DU/decade (2%) trend in a specific area where mean total ozone column value is 300 DU, target stability should be about half (1%) of the trend. This corresponds to the 0.6-1%/decade stability demanded by GCOS. To account for regional specifics, a distinction of requirements for geographical zones (tropics, mid-latitudes and polar regions) has been made. Initial products will use the GOME (for the period 1995-2010), SCIAMACHY and GOME-2 instruments (for a two-year period to be determined), along with independent validation datasets.

Ozone profile

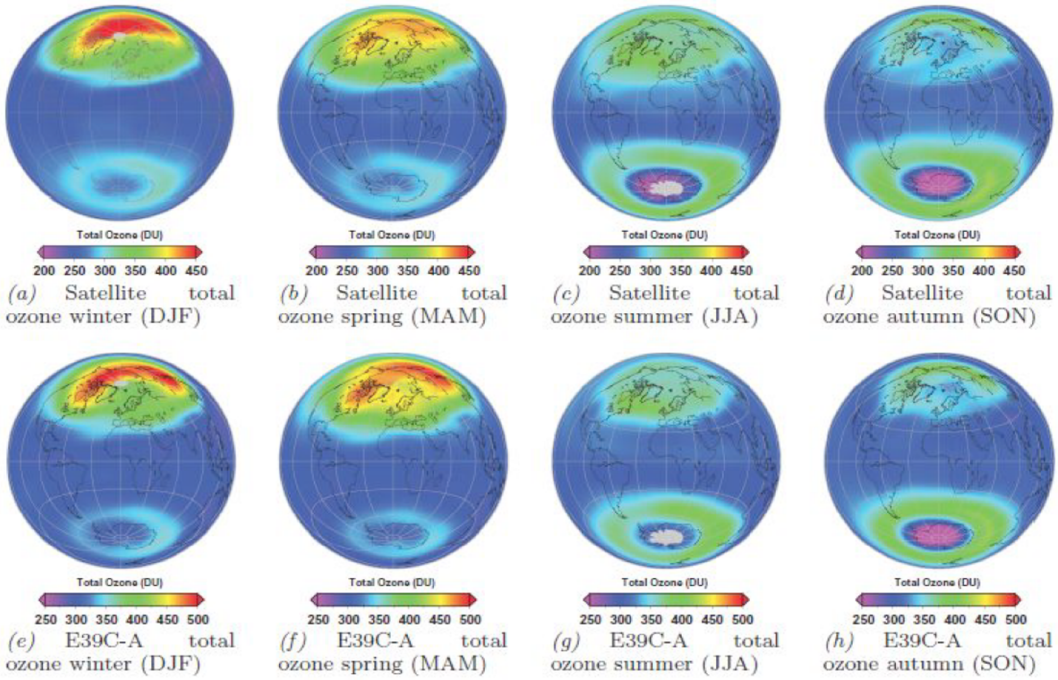
Requirements for ozone profile data are derived from the needs of different application areas (ozone seasonal cycles, interannual variability, evolution of ozone layer, trends) and scales of processes in different atmospheric regions (troposphere, upper troposphere/lower stratosphere (UTLS), stratosphere/middle atmosphere). For the purpose of this project, troposphere extends from the surface to the tropopause defined by an ozone concentration of 150 ppbv, the UTLS extends from about 5 to 25 km, and the middle atmosphere extends from about 25 to 60 km altitude. Limb-viewing instruments provide vertical profiles of from the upper troposphere to the top of the atmosphere, with vertical resolution depending mainly on the viewing geometry.

Product requirements reflect spatial and temporal resolution of the CCMs identified in the project for evaluation. As noted above, CCMs have typical horizontal resolutions of 200 km at the equator; therefore product horizontal resolution of 100-200 km (target-threshold) is planned. To adequately resolve vertical exchange phenomena, CCMs use vertical resolutions of ~1 km in the UTLS region and more relaxed resolutions elsewhere. The team considered a coarser vertical resolution (~3 km) of ozone profiles sufficient; higher vertical resolution (~1 km) should be aspired to wherever possible. In the UTLS region, products from limb sounders can provide such high vertical resolution (1-3 km). Coarser resolution products obtained from nadir sounders (3-6 km) will also be useful, given their very good horizontal coverage. Horizontal and temporal product resolutions of profile products are in line with the abovementioned requirements for total column products, for easier comparison and consistency checking.

The team proposed application-specific Ozone_cci product accuracies of 10% (8%; 8%) accuracy in the troposphere (in the UTLS; in the stratosphere). An accuracy of 20% (15%; 15%) was considered sufficient, considering the intrinsic variability of the dynamics in studies over short to interannual timescales. Regarding stability, requirements are defined for detecting ozone trends. The following assumptions were made: in order to detect an ozone trend in the stratosphere of 0.2 ppmv/decade (4%) in a region where the mean mixing ratio is 5 ppmv, stability needs to be a third of the trend, i.e. 1-3%/decade (target-threshold). Achieving this stability depends on the length of record available. These requirements are also given for the troposphere (column values) for consistency (see
Table 10). They are more relaxed than the GCOS stability requirement of 0.6%/decade.

For ozone profiles from nadir-viewing instruments, data from GOME, SCIAMACHY, GOME-2 and OMI will be used, most probably for the period 2008-2009, along with independent validation datasets. For ozone profile datasets from limb viewing instruments, the project will use measurements from SCIAMACHY, GOMOS, MIPAS and ACE-FTS over the same timeframe.

Figure 3: Comparison of seasonal variability of total ozone retrieved from satellites (top row) and obtained from a climate-chemistry model (bottom row) (Loyola et al., 2009).



Each ECV product generated by the project shall have an associated error bar, representing the 95% confidence interval (2-sigma). With a common error budget available for each single-source dataset, it will be possible to assign error bars to merged datasets derived from different instruments. The total error of such merged products is often unknown. The Ozone_cci is continuing to work with the international community (e.g. through WCRP SPARC, WMO GAW and NDACC) in order to find common ground in the characterization of data, error evaluation, and analysis.

The project also identified the need to make both CEOS 'level 2' (instrument resolution) and 'level 3' (gridded) products available, the former particularly for data assimilation. This agrees with the demands expressed by climate modellers within the CCI CMUG.

Linkages

The Ozone_cci project will explore linkages to the GHG_cci, SST_cci, and Land_Cover_cci projects, for example, to use ozone in atmospheric correction algorithms. It was also noted that projects such as Aerosol_cci should strive for generating products with spatial and temporal resolution similar to Ozone_cci, e.g. for smoothly assimilating aerosol datasets in CCMs.

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5.3 Aerosol_cci

The Aerosol_cci project aims to consolidate the available European expertise to better understand and improve existing aerosol retrieval methods, and move towards achieving the accuracy requirements set by GCOS. The project plans to focus on comparing aerosol variables (including aerosol optical depth; AOD) derived from a number of different sensors, using a range of retrieval algorithms over the full period of the data record. These activities have a clear orientation towards climate modeller and reanalysis needs. Continuation of records provided by non-European heritage sensors is a possibility at a later stage, but not the initial focus.

Collection of Requirements

The team made a clear distinction between the analysis of user requirements gathered, and specification of the products to be generated by the Aerosol_cci. For the former, the discussion below gives details. For the latter, only the aerosol variables to be addressed, their horizontal and vertical resolution and the sensors to be used were specified. Accuracy and stability of the planned products are to be established in the validation process.

Specifically, the project will identify instrument-specific, best practice approaches to retrieve aerosol properties from space. It also investigates the potential for merging complementary information from different instruments. A major element will be the detailed analysis of critical methods (e.g. cloud screening, surface reflectance parameterization, aerosol microphysical model) through intercomparison, validation and scientific discussion within the project team. The Aerosol_cci project will be concentrating on multi-mission algorithm development, testing, and reconciling differences for single test years (1997 and 2008) before applying these improved algorithms to the full mission time series. In a parallel step, the sources of aerosol retrieval uncertainty will be identified and their impact quantified, aiming at best-practice community retrieval algorithms.

The Aerosol_cci project performed a thorough and well-structured analysis of user requirements for aerosol ECV products. A useful interpretation of the FCDR definition adapted to the specifics of aerosol datasets was undertaken, pointing out the challenges in generating FCDRs due to differences (in sampling, resolution) of the various sensors. Requirements identified in GCOS-107 and by climate modellers in the CMUG were briefly reviewed. In addition, the AeroCOM (Aerosol Comparisons between Observations and Models) community and the European MACC (Monitoring Atmospheric Composition and Climate) project provided input in support of a range of climate applications. The AeroCOM project consists of groups involved in international aerosol satellite product intercomparisons for the validation of global aerosol climate models (Kinne *et al.*, 2006). Users associated with MACC and its predecessor projects, precursors to a European GMES Atmospheric Service (http://www.gmes-atmosphere.eu), provided needs related to data assimilation and reanalysis. Contributions to the requirements gathering exercise were also invited on the project website.

The team noted that although the IPCC Fourth Assessment Report 2007 widely recognizes the important role of satellite data to characterize the global effects of aerosols, for example on radiative forcing, much of the scientific analysis of aerosol impact on climate has been performed without using satellite-derived measurements of aerosol. Integration of the wealth of aerosol-related satellite datasets in a modelling framework for monitoring and prediction purposes has been addressed only recently, for example in the European PROMOTE/GEMS/MACC projects. In Aerosol_cci, close links to the climate modelling community were therefore being sought from the outset to ensure that modellers are provided with datasets tailored to their needs.

Discussion, Conclusion, Traceability

A range of user requirements for AOD and other aerosol parameters was discussed in the project, including those provided by GCOS. On a pixel basis, the GCOS target requirements were considered not attainable by any current satellite product. Requirements identified by climate modellers in the CCI CMUG largely match those by GCOS for AOD, but have higher temporal resolution (6 h versus 1 day). Climate modellers emphasized the need for better quantification of both aerosol direct and indirect cloud-related effects. Any improvement over the currently very basic aerosol climatologies prevailing in current climate models (essentially time-invariant two-dimensional fields and aerosol amount) was seen as a valuable step forward. Other users placed emphasis on consistent error characteristics of aerosol products and on the need to better quantify aerosol absorption properties in the atmosphere. MACC users emphasized the need for instrument-resolution aerosol retrievals for assimilation.

According to the Aerosol_cci requirements analysis, users required two main categories of aerosol products:

- Global products with daily time resolution. Horizontal resolution should be either 10x10 km^2 or 1° x 1°. Aerosol and cloud retrievals should be available for a period spanning at least 10 years (e.g. 2002 - 2011). Products for periods before the year 2002 should be linked and made comparable with appropriate error analysis; and,
- Instantaneous retrievals (at instrument resolution, CEOS 'level 2' in Appendix F), requested to drive the reanalysis of assimilation systems. Globally, 500-1000 retrievals per hour would have significant impact on the skill of these systems. Spatial averaging may be done in consultation with the users, such as the ECMWF, to limit the size of the data to be transferred.

Satellite variable (AERONET provides reference datasets)	Required accuracy at superpixel level of 10x10 km^2	Required accuracy at climate model grid level of 1°x1°	Required accuracy at regional level of 1000x1000 km^2
Aerosol optical depth at 550nm and other wavelengths	20% or 0.05	10% or 0.02	0.02
Fine mode fraction	20% or 0.1	20% or 0.1	0.1
Dust fraction	30% or 0.2	30% or 0.2	30% or 0.2
Absorption optical depth (computed from SSA and aerosol size)	20% or 0.05	20% or 0.02	0.02

Table 3: Scale-dependent accuracy requirements for aerosol parameters as identified in the Aerosol_cci requirements analysis (percentages refer to locally prevailing values).

Satellite variable (AERONET provides reference datasets)	Required monthly RMS month-to-month stability at regional level of 1000x1000 km^2	Required monthly RMS year-to-year stability at regional level of 1000x1000 km^2	Required monthly RMS decadal stability at regional level of 1000x1000 km^2
Aerosol optical depth at 550nm and other wavelengths	0.01	0.005	0.01
Fine mode fraction	0.05	0.05	0.05
Dust fraction	0.05	0.05	0.05
Absorption optical depth (computed from SSA and aerosol size)	0.002	0.005	0.005

Table 4: Time-dependent stability requirements for aerosol parameters as identified in the Aerosol_cci requirements analysis.

In extension to the GCOS requirements, the user requirements analysis recommended associating required accuracy and stability to resolution in time and space (see Table 3, Table 4). Three spatial scales and three temporal scales were considered useful here: “superpixel” level (10x10 km²), model grid level (1° x 1°) and regional level (1000x1000 km²). Higher accuracy could be attained at lower spatial resolutions, mainly since spatial averaging leads to smoothing of random errors. Desirable AOD target requirement of 0.02 almost matches the GCOS requirement of 0.01. Stability was not only specified over decadal scale, but also as intermonthly and interannual stability, emphasizing that it could only be determined regionally. The needed product stability for AOD almost matches the GCOS requirement (0.005-0.01 depending on timescale, compared to 0.005). It was derived by assuming a regional average AOD range over land between 0.1-0.5, and the necessity to detect at least a 5% trend of 0.1, i.e. 0.005.

Each product at instrument resolution (CEOS ‘level 2’) will include, as required by climate modellers and for data assimilation, pixel-wise error information derived via propagation of uncertainties due to input data and retrieval models. Pixel-wise error characterization also provides a highly valuable basis for establishing the accuracy of higher-level (averaged, CEOS ‘level 3/4') products, given the high variability of aerosols in time and space. Accuracy is (correctly) interpreted as including both random and systematic elements, which will be treated distinctly for all products.

In line with the overall CCI objective to generate satellite-based products for climate that are either competitive with, or complementary to, existing assets, the Aerosol_cci project plans a number of products to be generated within the Aerosol_cci project. They will address (see also Table 11):

- AOD at 440, 550, 670, 870 nm
- Fine mode fraction
- Dust fraction
- Aerosol absorption (both Single-Scattering Albedo (SSA) and Aerosol Absorption Index (AAI))
- Aerosol type probability (“climatology”)
- Stratospheric aerosol vertical profiles

AOD at four different wavelengths contains information on aerosol size distribution and, together with aerosol type, an indicator for fine and coarse (dust) mode fractions (AOD at 440 and 870 nm alone allows computation of the Angstrom parameter, a basic indicator of size). Consistency with existing AOD satellite climate datasets is ensured by delivering AOD at 550nm. Details on the size distribution (fine, dust fraction) allow identification of aerosol species and the ability to link them to source types (e.g. marine, continental, urban, biomass burning). They also inform the analysis of specific processes related to aerosol absorption, aerosols above clouds, and vertical profiles. Along with AOD(λ), a global climatology of aerosol type probability will be generated. New approaches will be pursued to characterize absorption AOD (related to SSA), which has been difficult to measure from space, but is critical to estimate the effects of aerosols on climate through absorbing constituents, such as black carbon.

The Aerosol_cci project will generate global products covering one full annual cycle of two reference years (1997 and 2008), recognizing that key satellite datasets exist concurrently for these years: for 2008, data from MERIS, AATSR, PARASOL, SCIAMACHY, GOMOS, OMI, AVHRR (on Metop) and GOME-2 will be used; for 1997, ATSR-2, GOME and POLDER data will be analysed. Additionally the full archive of ATSR-2 and AATSR data will be used to produce a 17 year global data set of AOD and Angstrom parameter from the best performing (A)ATSR algorithm. The products will include daily, monthly, seasonal and annual aggregated versions. All products at instrument resolution will include pixel-wise error information (both random and systematic errors). The Aerosol_cci project noted that the opportunity exists, at a later stage in the CCI and based on results from a reference year, for the formation of composite products from current observations, with some extension back in time using calibrated data from heritage instruments.

All products and their error characteristics will be validated globally against ground based Aeronet data, and supported by *in situ* aerosol composition measurements. Different validation approaches were discussed, and issues related to determining stability mentioned (Anderson *et al.*, 2005). The following factors were identified as main error sources: cloud detection and screening, surface treatment, and the aerosol models assumed in the retrievals.

Linkages

Collaboration with the Cloud_cci team (in investigating the aerosol-cloud indirect effect) and other projects (Ocean_Colour_cci, Land_Cover_cci, Fire_cci, Ozone_cci) will ensure the close interaction needed for generating consistent ECV products. These CCI projects use aerosol models for the corrections of aerosol-related radiance perturbation in the satellite data. They also use a similar family of sensors as does the Aerosol_cci project. Advice from the Ocean_Colour_cci and Land_Cover_cci projects is sought regarding ocean particle loading (chlorophyll-a, sediments) and surface reflectance functions, both needed as boundary conditions in aerosol retrievals.

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5.4 GHG_cci

Collection of Requirements

In its requirements analysis, the GHG_cci project cited GCOS and CMUG requirements and peer-reviewed publications using satellite-based CO_2 and CH_4 data for estimating regional fluxes. The team then focussed on what products were possible using current satellite capabilities. This resulted in a set of product requirements and specifications. The first opportunity to retrieve the total dry column of carbon dioxide and methane began with the launch of ENVISAT. GHG_cci therefore finds itself in a different situation compared to other CCI projects because existing products have a much shorter history, and the accuracy of retrieval algorithms is evolving. As a community consensus on best practices is yet to be established, the algorithm intercomparison phase – “round robin” – has been extended to two years. This phase will include studying differences between satellite retrievals and *in situ* validation data, and understanding the error characteristics of all datasets.

Discussion, Conclusion, Traceability

Two core products are planned in the GHG_cci, addressing the mixing ratio of CO_2 and CH_4 for regional surface flux applications. The products are given as (near-surface sensitive) column-averaged dry air mole fractions, in ppm (“XCO_2” and “XCH_4”). Both are derived from two sensors, the European SCIAMACHY on Envisat and the JAXA TANSO-FTS instrument on GOSAT. The standard CO_2 and CH_4 products from JAXA-NIES and from NASA (via the Atmospheric CO_2 observations from space programme, ACOS) are used for comparison. In addition, in upper layers, algorithms to derive vertical profiles or partial columns of CO_2/CH_4 from IR sounders (IASI, MIPAS) and other instruments (e.g. SCIAMACHY solar occultation mode) will be further developed. They have the potential to provide additional constraints to regional surface flux inverse modelling. It should be noted that all products are currently under active development.

Within the project, 9 years of SCIAMACHY and 3 years of TANSO-FTS measurements will be processed using a proxy algorithm. In addition, a minimum of one year overlapping data from the two instruments will be produced using a “full physics” algorithm (which allows simultaneous retrieval of CH_4, aerosol and cirrus properties).

The GHG_cci project considers the planned products consistent with GCOS needs, but not identical to them. For example, the accuracy requirements are more stringent (e.g. required XCO_2 relative accuracy is 0.5 ppm). Relative accuracy is seen as critically important as compared to absolute accuracy since even minor spatially coherent biases adversely affect the inversion (Bergamaschi *et al.*, 2009). The GCOS temporal resolution target (3 h) was considered unrealistic and cannot be met with the existing constellation of instruments (3-6 days revisit time). All planned GHG_cci products have associated target (goal), breakthrough and threshold requirements. Also, a useful distinction between random (“precision”) and systematic errors is made. Precision is specified both for analysed (averaged over time and space, e.g. 1000 x 1000 km^2, monthly averages) and for instantaneous retrievals at instrument resolution.

The results of this discussion are given in Table 12. Uncertainties are expressed in terms of 1-sigma and dependent on spatial averaging. Products are expected to meet these requirements over land. Over ocean, the low reflectivity of water in the spectral IR region used to retrieve the GHG columns typically results in lower signal levels (with some exceptions, e.g. sun-glint) and therefore larger noise. It is also stressed that product requirements are indicative and may depend on time, location, retrieval algorithm and sensor. The GHG_cci project will investigate how to reliably determine error correlations between the XCO_2 and XCH_4 values retrieved from individual ground-pixels.

Major challenges are to validate data products and assess their accuracy, establishing reliable error bars. Well-characterized *in situ* datasets, for example from the TCCON[8] network (ground-based high-resolution Fourier transform spectrometers which retrieve column-average mixing ratios of CO_2, CH_4 and other greenhouse gases), are sparsely distributed, currently with 13 sites worldwide.

[8] Total Carbon Column Observing Network: https://tccon-wiki.caltech.edu/

Figure 4 shows an example for intercomparing XCO_2 anomalies derived from satellite, ground-based remote sensing, and *in situ* measurements assimilated in a model-based analysis.

Linkages

In its work, the GHG_cci project will benefit from expertise provided by the Aerosol_cci and Cloud_cci teams to correct for atmospheric effects (cloud cover, aerosol scattering) affecting GHG products. In addition, expertise from the Land_Cover_cci and the Fire_cci will be useful in interpreting GHG results in terms of land cover type and burned area. There is overlap in the instruments used by GHG_cci with Ozone_cci (SCIAMACHY).

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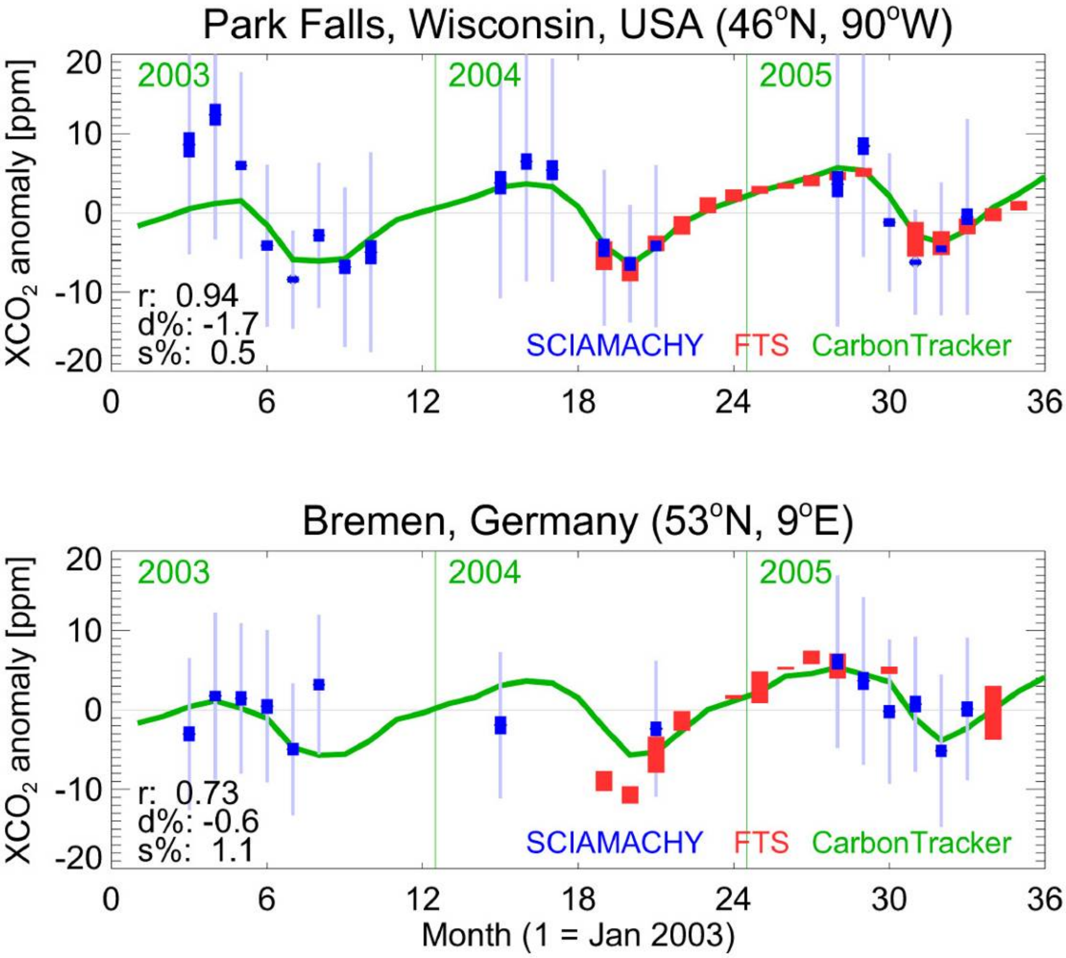

Figure 4: Comparison of anomalies of column-averaged dry air mole fraction of CO_2 derived from satellite (IUP SCIAMACHY WFMDv1.0 XCO_2 data product), ground-based remote sensing (TCCON FTS) and model-based analysis (NOAA CarbonTracker) for Park Falls, Wisconsin, USA (top) and Bremen, Germany (bottom). The panels also include error bars where available (Schneising *et al.*, 2008).

5.5 Sea_Level_cci

Collection of Requirements

The Sea_Level_cci project reviewed and synthesized user requirements from GCOS (GCOS-107), WCRP, WMO (in the RRR database; WMO, 2011a), and from climate modellers included in the CMUG. The project also gathered needs expressed by national and international agencies, individual research institutes, and academia, based on responses to a questionnaire and using the results of a comprehensive user requirements review undertaken recently in the context of the CEOS Ocean Surface Topography Constellation (CEOS, 2009). Different application areas for sea level products were identified, including ocean reanalysis, ocean model development and validation, and ocean model initialisation.

Discussion, Conclusion, Traceability

The Sea_Level_cci team considered the GCOS requirements (in GCOS-107) ambitious given the capabilities available, i.e. with respect to the performance of existing altimeters and the relatively short length of the existing altimetry-based sea-level climate record. The Sea_Level_cci therefore suggested to refine the GCOS requirements, in particular with a view to differentiate requirements for the ocean surface topography signal by climate application, such as (i) long-term global mean sea level trends, (ii) regional mean sea level signal (trends and variability), and (iii) mesoscale and coastal signal. A synthesis of user requirements is given in Table 5.

In contrast to the climate modelling community (in CMUG) which considered sea level data mainly relevant for model initialization, data assimilation and monitoring, the Sea_Level_cci team argued that sea level information was also useful for reanalyses and model development, and less so for model initialization. Requirements from the wider ocean topography community (CEOS, 2009) included monitoring of mean sea level to an accuracy of 1mm/year, and basin-scale accuracy of 1 cm consistent with GCOS-107. Differentiation between requirements for instrument-level products (along-track, CEOS 'level 2'; see Appendix F) and gridded products (CEOS 'level 3') was deemed necessary.

Table 5: Synthesis of sea level user requirements gathered by the Sea_Level_cci project

Variable/ Parameter	Horizontal Resolution	Temporal Resolution	Accuracy	Stability
Global mean sea level	50 km	10 days	2-4 mm (over orbital cycle)	<0.3 mm/yr (long-term drift precision) <0.5 mm/yr (on annual timescale)
Regional sea level	25 km	Weekly	1 cm (over grid mesh of 50-100 km)	<1 mm/yr (for grid mesh of 50-100 km)

The project further assessed the scientific limits of existing sea level data records, including a review of strengths, weaknesses and consistency of current best practices and algorithms used in generating sea level ECV products.

Based on these findings, the Sea_Level_cci team plans the following set of activities:

The project will focus on (i) full error characterization of datasets, (ii) improvement of algorithms, (iii) product consistency cross-checks in view of different algorithms and instruments. To this end, the team will evaluate more than sixty individual processing algorithms from the complete radar-altimeter data processing chain, and seek opportunities for improvement, mainly in the areas of instrument correction and geophysical correction. Error characterization depends on the product scale (global and regional, for the latter see Figure 5 as an example) and on the instruments used, and shall be provided for all variables in the ECV products generated by the project. The project will then generate multi-mission sea-surface height products from the altimeters on the Topex/Poseidon and Jason series, as well as ERS-1/2, Envisat and Cryosat-2 (i.e. from 1993 to present). It is expected that the requirements stated in Table 5 can be met by these products (see Table 13 for a summary).

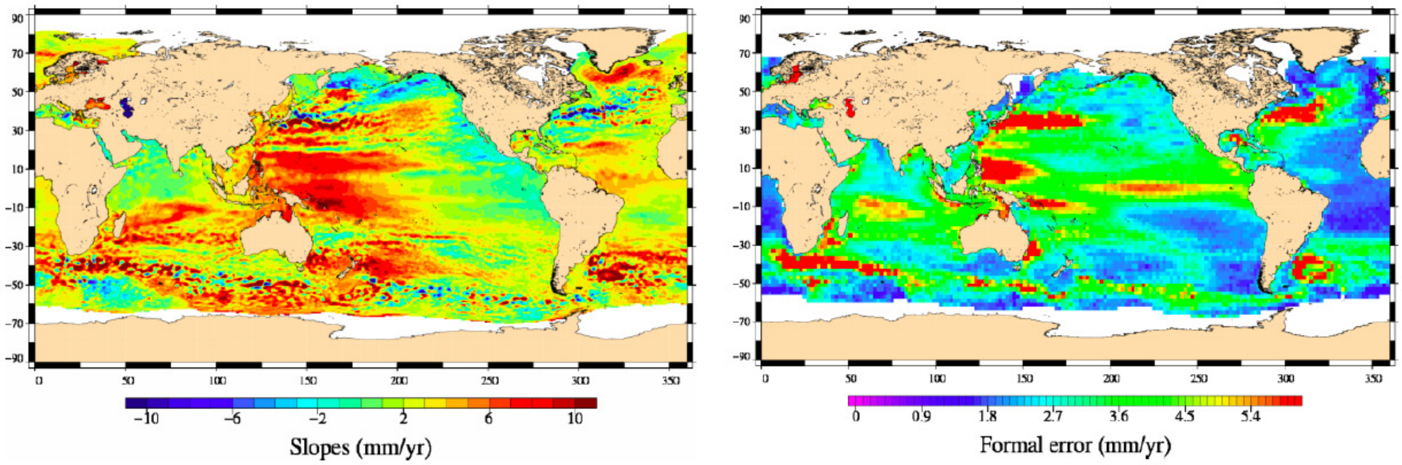

Figure 5: The Sea_Level_cci project plans to provide improved estimates of regional mean sea level trends (left panel) and associated uncertainties (right panel). Regional variations of sea level change depend inter alia on seasonal to interannual ocean variability. Trends in the left hand panel are calculated on a 2°x 2° grid (Prandi et al., 2010).

Linkages

The Sea_Level_cci started a fruitful dialogue with the climate modelling community (in CMUG) on the use of sea level datasets in model development and in reanalyses. The project also provided useful feedback to the updating of GCOS-107 requirements.

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5.6 SST_cci

Collection of Requirements

The SST_cci team comprehensively gathered requirements through a user survey, review of literature (including GCOS, IPCC, UNFCCC), information from other projects (MyOcean, GHRSST), discussion sessions as well as input from the CCI CMUG. About 110 respondents to the online survey represented a range of disciplines, including coastal oceanography, climate research, climate variability studies, regional modelling, and seasonal modelling. Synthesizing these different sources of input allowed the SST_cci team to identify key requirements that guided the specification of SST_cci products.

Discussion, Conclusion, Traceability

The SST_cci requirements analysis focussed on current and prospective needs, the full characterization of uncertainties (systematic errors, random errors, precision and stability), data coverage (global preferred by majority of users), length of record (>30 years preferred), reprocessing cycles (continuous versus once a year), and target, breakthrough and threshold requirements for spatial and temporal resolution of SST datasets. Many other details of user requirements were evaluated but are not presented here.

User survey responses revealed that climate users require future SST products to have smaller and better-quantified uncertainties. The survey assessed strengths and weaknesses in current SST datasets (see e.g. Figure 6) per climate application category (e.g. model evaluation, regional modelling, climate monitoring). It also identified inadequate characterisation of uncertainties as a problem of most datasets

'Skin' SST (up to ~20 μm depth) is most commonly required by respondents, followed by SSTs at depths roughly corresponding to the range of traditional *in situ* observations (20 cm and 5 m). Analyses with 10 km or finer resolution, and daily or more frequent temporal resolution find greatest use. For spatial resolution, responses indicated <1 km/0.1°/1° as target/breakthrough/threshold requirements (see Figure 7).

The most common requirements for SST data frequency at a location are monthly (threshold), daily (breakthrough) and 3 hourly (target). However, there are also significant numbers of respondents with more stringent requirements. For the majority of respondents, it is acceptable to use temporal averaging when building datasets, but it is not acceptable for a significant minority. SSTs are most commonly required at midnight, 6am, midday and 6pm local time; additional data at midpoints between those times are required by many, and SSTs at half-hour spacing would be used for some applications.

The analysis of user requirements further showed that target accuracy (mean discrepancy between measurements and validation values; 'bias' in CCI Guidelines) was on average 0.1/0.3°C (target/threshold), but with a strong minority requiring accuracies to 0.01°C and less. Most users would accept datasets with decadal stability of 0.1°C. All values refer to SST fields to be evaluated on a spatial scale of 100 km.

Another important aspect of the user requirement analysis is the need for SST products in areas with cloud cover or sea ice cover, in addition to clear open ocean areas. Since the majority of users required global data, SST beneath clouds is a requirement and determines the extent to which (cloud-penetrating) passive microwave radiances observed from space are included in the generation of SST products, in addition to infrared radiances. Sea ice was identified as another important additional field required for generating SST datasets.

In terms of data representation, the most common requirement is for CEOS 'level 4' (analysed) data, but a strong minority of respondents required CEOS 'level 2' (at instrument resolution) and CEOS 'level 3' (regridded) data.

	ATSR series	AVHRR Pathfinder V5	Other AVHRR	SEVIRI	AMSR-E	TMI	HadSST2	ICOADS	Other
Spatial resolution	9 : 0	17 : 2	14 : 0	1 : 0	6 : 5	5 : 3	13 : 16	4 : 11	3 : 2
	9 : 0	**16 : 3**	**14 : 0**	**1 : 0**	**5 : 6**	**5 : 5**	**10 : 22**	**3 : 13**	**3 : 2**
Spatial sampling	2 : 7	5 : 7	4 : 6	0 : 0	5 : 0	0 : 0	3 : 8	3 : 14	1 : 0
	2 : 7	**5 : 8**	**4 : 7**	**0 : 0**	**5 : 0**	**0 : 0**	**2 : 9**	**2 : 15**	**1 : 1**
Grid	2 : 0	10 : 0	6 : 0	0 : 0	3 : 0	4 : 1	19 : 3	6 : 0	4 : 0
	2 : 1	**10 : 1**	**6 : 1**	**0 : 1**	**3 : 1**	**4 : 2**	**18 : 6**	**5 : 2**	**4 : 0**
Frequency of observations	2 : 7	11 : 3	7 : 1	3 : 0	10 : 2	6 : 0	13 : 7	5 : 10	1 : 0
	2 : 8	**11 : 5**	**6 : 3**	**3 : 1**	**9 : 3**	**6 : 2**	**10 : 12**	**3 : 10**	**1 : 0**
Bias characteristics	7 : 0	3 : 3	0 : 4	0 : 0	2 : 5	0 : 1	3 : 4	0 : 5	0 : 1
	7 : 1	**3 : 4**	**0 : 5**	**0 : 0**	**2 : 6**	**0 : 1**	**3 : 4**	**0 : 5**	**0 : 1**
Precision of the data	9 : 0	6 : 0	5 : 1	1 : 0	3 : 1	3 : 0	6 : 6	2 : 1	0 : 0
	9 : 0	**5 : 2**	**5 : 2**	**1 : 0**	**3 : 2**	**3 : 1**	**6 : 7**	**2 : 2**	**0 : 1**
Stability of the data	4 : 0	5 : 1	3 : 1	0 : 0	3 : 0	0 : 0	13 : 2	4 : 3	1 : 0
	4 : 0	**5 : 2**	**3 : 2**	**0 : 1**	**3 : 2**	**0 : 2**	**12 : 3**	**4 : 3**	**1 : 0**
Well characterised uncertainties	2 : 0	3 : 4	1 : 4	0 : 0	1 : 3	1 : 2	6 : 7	1 : 4	0 : 2
	2 : 1	**3 : 5**	**1 : 5**	**0 : 0**	**1 : 4**	**1 : 2**	**5 : 9**	**0 : 5**	**0 : 3**
Depth that the SST corresponds to	4 : 1	3 : 2	4 : 1	0 : 1	3 : 2	1 : 1	2 : 5	2 : 2	0 : 0
	4 : 1	**3 : 3**	**4 : 1**	**0 : 1**	**3 : 2**	**1 : 1**	**2 : 5**	**2 : 2**	**0 : 0**
Format of the data files	5 : 0	5 : 2	5 : 1	2 : 0	8 : 0	4 : 0	21 : 4	10 : 1	2 : 1
	5 : 1	**5 : 3**	**5 : 2**	**2 : 1**	**8 : 1**	**4 : 1**	**20 : 6**	**10 : 1**	**2 : 1**
Timeliness of data delivery	5 : 0	7 : 2	6 : 1	1 : 0	7 : 0	3 : 0	10 : 3	1 : 0	2 : 0
	5 : 0	**7 : 2**	**6 : 1**	**1 : 0**	**7 : 0**	**3 : 0**	**9 : 4**	**1 : 1**	**2 : 0**
Reliability of the data delivery	4 : 1	4 : 1	4 : 1	1 : 1	3 : 1	2 : 1	8 : 1	4 : 1	1 : 0
	4 : 1	**4 : 1**	**4 : 1**	**1 : 1**	**3 : 1**	**2 : 1**	**8 : 2**	**4 : 2**	**1 : 0**
Length of the data record	1 : 5	12 : 5	6 : 3	0 : 2	1 : 5	0 : 5	35 : 2	23 : 2	1 : 1
	1 : 5	**12 : 6**	**6 : 3**	**0 : 3**	**1 : 5**	**0 : 6**	**35 : 2**	**23 : 2**	**1 : 1**
Reputation of the data	4 : 0	14 : 0	4 : 0	0 : 0	5 : 0	2 : 1	27 : 0	13 : 1	1 : 0
	4 : 0	**14 : 0**	**4 : 0**	**0 : 0**	**5 : 0**	**2 : 1**	**27 : 1**	**13 : 1**	**1 : 0**
Other	0 : 2	0 : 0	0 : 0	1 : 0	1 : 0	2 : 1	1 : 0	1 : 0	1 : 0
	0 : 2	**0 : 2**	**0 : 2**	**1 : 0**	**1 : 0**	**2 : 1**	**1 : 1**	**1 : 1**	**1 : 0**

Figure 6: Result of SST_cci user survey: Assessment of strengths and weaknesses for SST data on their original grid/swath/positions and averaged onto a grid (CEOS 'level 2' and 'level 3' data). Each column contains the responses for an individual dataset. Each row is for different aspects of the data that might be regarded as a strength or weakness. Each row is split into two: the top numbers and colours show strengths and weaknesses as viewed in the present day; the bottom numbers (in bold) and colours are how the strengths and weaknesses will be viewed in the future. The numbers give the number of times each aspect was selected (strengths: weaknesses). A box is coloured green if the ratio is greater than 2: 1, red if it is less than 1: 2, grey if it is between those numbers and white if there was no response for that dataset/category.

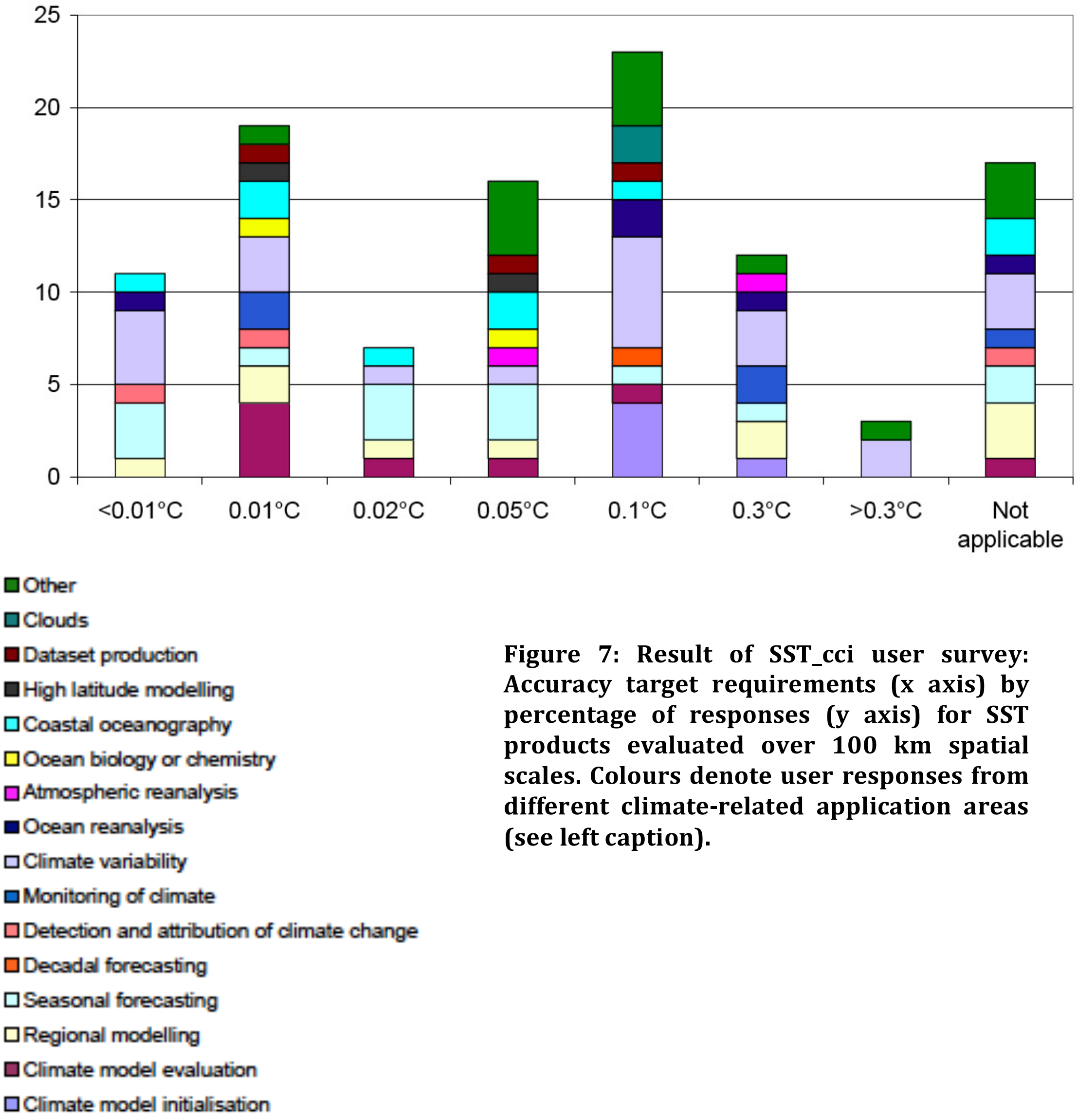

Figure 7: Result of SST_cci user survey: Accuracy target requirements (x axis) by percentage of responses (y axis) for SST products evaluated over 100 km spatial scales. Colours denote user responses from different climate-related application areas (see left caption).

In response to the requirements analysis, the SST_cci project intends to provide a significant improvement over the current state-of-the art, by developing algorithms tuned to requirements of the climate community, and by implementing a prototype system to generate climate quality SST data products. The project will develop and improve SST algorithms to exploit infrared (IR) time series (combined ATSR and AVHRR. Key improvements are expected in (i) new and improved optimal estimation techniques beyond those initiated by the AATSR Reprocessing for Climate (ARC) project (Merchant *et al.*, 2008), (ii) radiance bias correction with reference to ARC SSTs, (iii) better robustness of SST products with regard to aerosol effects, and (iv) mitigation of diurnal SST variability by adjustment of SST to a reference depth and time of day. A summary of planned SST_cci products is given in Table 14.

A multi-sensor approach, incorporating geostationary IR sensors and passive microwave sensors, will also be prototyped to provide a long (1991-2011) time series of consistent SST products. This will be applied to produce a merged climate quality SST analysis product based only on satellite data, which will be independently validated by the climate community. Particular emphasis will be placed on uncertainty characterization of SST retrievals, recognizing random (uncorrelated), pseudo-random (correlated on synoptic space-time scales), and systematic (correlated) components of the error (Merchant *et al.*, 2006).

Problems in high-latitudes will be addressed, including flagging issues for both passive microwave and IR sensors, and cloud-and-ice discrimination to avoid biased SSTs. All products will be error-characterized with uncertainty estimates built up from first principles, which will in turn be validated against uncertainties observed relative to independent reference *in situ* data.

The following datasets will be exploited, covering the period August 1991 to December 2010, using the (A)ATSR series and AVHRR in Global Area Coverage (GAC) mode. For an additional SST_cci product that will demonstrate the potential of using a broader set of SST-relevant sensors over a period of six months, SEVIRI, Metop, AMSR-E and TMI data will be used in addition to AATSR and AVHRR.

Linkages

The importance of linkages to other CCI projects has been identified and contact have been established (Cloud_cci, Ocean_Colour_cci, Sea_Level_cci, Aerosol_cci), for example for using consistent ancillary fields (clouds, sea ice), performing atmospheric corrections, using common FCDRs (aerosols), or investigating the benefits of co-analysis (ocean colour).

References

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Merchant C.J. D. Llewellyn-Jones, R.W. Saunders, N.A. Rayner, E.C. Kent, C.P. Old, D. Berry, A.R. Birks, T. Blackmore, G.K. Corlett, O. Embury, V.L. Jay, J. Kennedy, C.T. Mutlow, T.J. Nightingale, A.G. O'Carroll, M.J. Pritchard, J.J. Remedios, and S. Tett (2008): *Deriving a sea surface temperature record suitable for climate change research from the along-track scanning radiometers*, Advances in Space Research 41 (2008) 1-11.

5.7 Ocean_Colour_cci

Collection of Requirements

The Ocean_Colour_cci project gathered user requirements through a consultation meeting, a user survey, and by review of scientific literature and international planning documents. At the consultation meeting, application-specific requirements for ocean colour radiances and derived products for climate research and climate modelling were explored. The online survey addressed the requirements of the modelling community and those scientists who use ocean-colour data directly to monitor decadal scale variability in the marine ecosystem. 78 responses were received from about a 20/80 percent share of “modellers” and “Earth observation scientists”. Figure 8 shows the geographical distribution and Figure 9 the research areas of respondents. The document review included reports from climate modellers in the CCI CMUG, GCOS, WCRP (CLIVAR and

WGCM), IGBP (IMBER, AIMES) and ESSP (GCP). Overall, the Ocean_Colour_cci team took the broadest view possible on the current and potential uses of ocean-colour data in climate-related studies. The requirements analysis focussed on case 1 waters (open oceans).

Discussion, Conclusion, Traceability

As a result of gathering requirements, global-scale modellers confirmed chlorophyll-a concentration as the most useful ECV product, since this parameter sheds light on trends in marine ecosystems that impact air-sea fluxes of CO_2 and other radiatively important gases. Of particular interest is the detection of trends in the onset of spring bloom, and of climate-driven shifts and persistent changes in marine ecosystems. Datasets of five years' length would be considered useful, and 30 years or longer ideal.

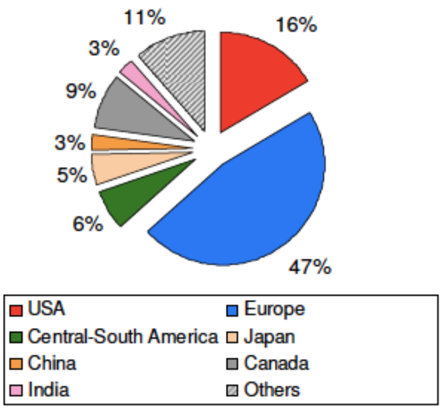

Figure 8: Responses to Ocean_Colour_cci user requirements survey, partitioned by geographic region (78 responses in total).

In terms of spatial and temporal resolution, the analysis revealed that requirements vary according to the type of model used. For example, spatial resolution requested by global models is 1°, whereas regional models require resolution in the 4-25 km range. The temporal resolution required is 1 month for global models and 1 day to 1 week for regional models. The timeliness of product delivery is typically not important for research models, whereas operational models require products within 1 day of data acquisition.

Most users considered complete pixel-by-pixel error specification of ocean colour datasets important. Error reduction was considered desirable, but there was lack of clarity on what might be feasible in the near term (3-5 years). Many users were also uncertain whether *in situ* measurements that could be used to validate satellite products had sufficient precision and accuracy to match some of the stated accuracy targets. Chlorophyll in the open ocean has a dynamic range of some five orders of magnitude: from about 0.01 mg m^{-3} to about 100 mg m^{-3}, and it was generally agreed that high accuracy was more important in the high chlorophyll range than at the low end.

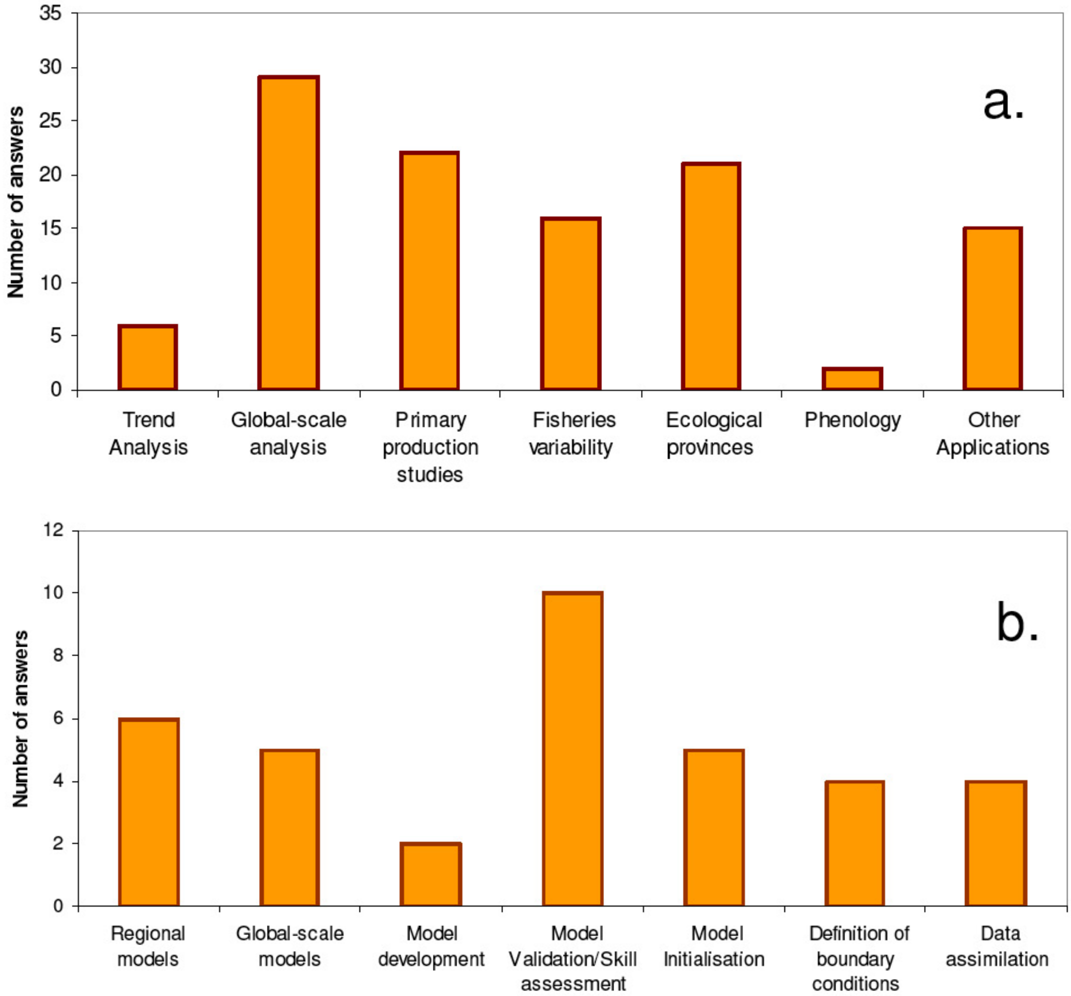

Figure 9: Ocean_Colour_cci project user requirements survey: Areas of research of (a) direct users of ocean colour products, and (b) climate modellers who responded to the survey.

Modellers at the consultation meeting reported that precision was less important than accuracy, but this contradicted with results from the user survey, which revealed the opposite. Regional modellers considered 30% accuracy in derived chlorophyll-a acceptable, whereas global modellers and "EO scientists" required <10% target accuracy. The average accuracy requirements for water-leaving radiance (nL_w) were also around 10% (5% is GCOS-107 target).

Stability was considered important for trend analyses, but no clear requirement could be established. The non-linear relationship between satellite signal and chlorophyll concentration, the high dynamic range in chlorophyll concentration and the log-normal distribution of chlorophyll in the ocean all combined make it difficult to establish the answer. Reference to Ohring *et al.* (2005) was made who recommends a stability of 1% in water-leaving radiance on the basis of detecting 20% of expected decadal trends.

As a long-term goal, users felt the need to have algorithms that work seamlessly across Case 1 and Case 2 waters. There was also interest in additional products from ocean colour that are currently emerging, such as information on particle size structure, phytoplankton functional types, and measures of concentrations of coloured dissolved organic matter.

The Ocean_Colour_cci team also enquired with users whether or not to use Coastal Zone Colour Scanner (CZCS) data in an ocean colour ECV product, in order to extend the record further back in time. The majority of responses considered CZCS as not being accurate enough.

Based on this requirements analysis, the Ocean_Colour_cci project decided on the way forward:

- To make highest resolution ocean colour radiance data available, along with subsampling, binning and mapping tools;
- To provide normalised water-leaving radiances at full spectral and temporal resolution, along with online tools for generating products using different algorithms;
- To associate each Ocean_Colour_cci product with error specification, along with details of how the errors are estimated for different regions and provinces;
- To ensure long-term, stable and sustained delivery of products ; and,
- To move towards algorithms that have the potential to merge Case 1 and Case 2 waters in a seamless manner.

In particular, the following products will be targeted in Ocean_Colour_cci (detailed specifications in Table 15): Chlorophyll-a concentration (Chl-a) [mg m^{-3}], water-leaving radiance [W m^{-2} sr^{-1}], normalised water leaving radiance $L_{wn}(\lambda)$ [W m^{-2} sr^{-1}] , spectral attenuation coefficient for downwelling irradiance $K_d(\lambda)$ [m^{-1}], total absorption a [m^{-1}], total backscattering b_b [m^{-1}], absorption by coloured dissolved organic matter a_{CDOM} [m^{-1}], backscattering by particulate matter b_{bp} [m^{-1}], and absorption by phytoplankton a_p [m^{-1}].

The specification of errors requires meticulous analyses of the various sources of error in ocean-colour products, namely instrument specifications, instrument calibration procedures, atmospheric corrections, and in-water algorithms. Approaches to error characterization include neural networks and fuzzy logic.

The project intends to process the complete time series of relevant available satellite data from MODIS, MERIS, SeaWiFS, and possibly CZCS.

Linkages

Ocean colour and aerosols are intimately linked in their combined effect on upwelling radiance measured at the sensor. Retrieval of one requires assumptions on the other quantity; therefore the Ocean_Colour_cci and Aerosol_cci teams have established a close dialogue. Both projects use data from the MERIS sensor. The Ocean_Colour_cci team exchanged experience gathered by the SST_cci project in gathering user requirements.

5.8 Glaciers_cci

Collection of Requirements

The requirements analysis performed by the Glaciers_cci team mainly describes the needs of the glacier research and mapping communities. Gathering of requirements for mapping glaciers and ice caps included GCOS-107 and previous GCOS documents, the IGOS Cryosphere theme report (WMO, 2007), feedback from the World Glacier Monitoring Service (WGMS) and the Global Land Ice Monitoring from Space (GLIMS) project, members of the project-internal climate research group, and results of electronic questionnaires (19 individuals responded). Findings from recent projects, such as GlobGlacier and ice2sea, were also considered. CCI CMUG requirements were discussed, but wider inclusion of requirements related to climate modelling is yet to occur, mainly owing to limited representation of glaciers in current climate models. A review of further scientific literature on glacier-climate coupling was carried out.

The Glaciers_cci project follows the terminology for glaciers and ice caps adopted in IPCC (2007), Annex I. Ice sheets (i.e. Greenland and the East and West Antarctic Ice Sheets) are excluded from this project; plans for a dedicated CCI project on ice sheets are underway.

Discussion, Conclusion, Traceability

The Glaciers_cci user requirements analysis identified, as a principal need, a detailed and globally complete glacier inventory (focussing on glacier area), and better data consistency through complete error characterization. Data gaps in certain areas should be filled to complete the inventory (see Figure 10 for an example of a complex system of glaciers and ice caps on Ellesmere Island in the Canadian Arctic). A more complete inventory would support a number of applications including a better assessment of glacier contributions to sea-level rise, boundary conditions and validation datasets for climate models, and support to hydrological applications (Raup *et al.*, 2007; Zemp *et al.*, 2009).

Users also identified glacier elevation changes and glacier velocity fields as useful products in addition to glacier areal extent, both to support the derivation of glacier mass balance. For elevation changes, a focus should be on mountain ranges with long-term *in situ* measurements of mass balance to assess how well these measurements represent the entire mountain range (e.g. Paul and Haeberli, 2008). Velocity fields would be most important, *inter alia*, to improve estimates of the ice loss from calving glaciers.

According to the analysis, users expect that scenarios of future climate conditions as provided by global and regional climate models (GCMs/RCMs) will become an important tool for assessing the future evolution of glaciers and ice caps (e.g. Radic and Hock, 2011). Glacier changes over time need to be assessed, and GCMs/RCMs could provide input data required for the glacier models in use. In turn, extents of glaciers and ice caps are not yet assimilated in global climate models, and regional modellers have only started using glacier coverage as a boundary condition (Kotlarski *et al.*, 2010). For consistent initial conditions, climate modellers expect a spatially complete glacier area dataset, and close coincidence of all data (i.e. areal extent mapped for all glaciers within a time period of a few years). As an intermediate goal, a more or less complete glacier inventory can help in validating climate model output (e.g. Ghan *et al.*, 2006).

In response to the user consultation, the Glaciers_cci project decided, as its principal objective, to contribute to the completion of the global glacier inventory, using Landsat TM/ETM+, SPOT, ASTER and PALSAR data. This will be done as a contribution to WGMS through GLIMS and follow guidelines established by GLIMS.

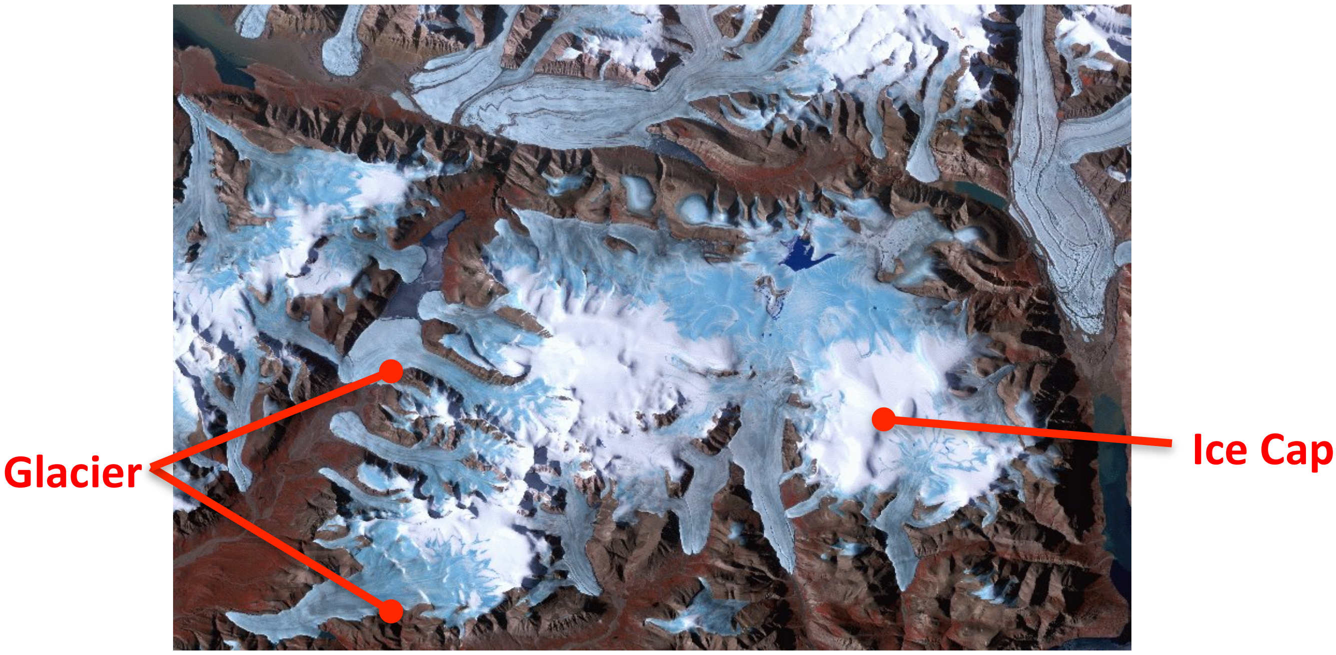

Figure 10: Example of glaciers and ice caps from space as investigated in the Glaciers_cci project (image from Ellesmere Island, Canada, taken by the ASTER instrument on 29 July 2000). An ice cap completely covers the underlying topography, is characterized by radial flow and can have distinct outlet glaciers.

The work will include determining glacier outlines (2D vectors) in as yet poorly covered regions: Canadian and Russian Arctic, Greenland (local glaciers and ice caps only), Alaska, Svalbard, Himalaya, Patagonia, Antarctic Peninsula. Different levels of completeness of existing inventories were determined for these regions to guide further action. Production will be oriented toward the period 1999-2003, but will also cover other time periods where appropriate (subject to data availability as determined by acquisition time, cloud cover etc). Close coordination with ongoing projects is envisaged to avoid duplication. A second goal is to supplement all data already in the GLIMS database with topographic inventory information.

In response to user requirements, the Glaciers_cci team also plans to perform glacier change assessments (length, area, elevation, volume) based on a complete inventory and information on glacier topography, and to determine glacier velocity fields where possible.

Elevation changes for individual glaciers and ice caps will be derived from repeat altimetry (ICESat and RA-2, with a focus on relatively flat Arctic regions) and Digital Elevation Model (DEM) differencing (in all other regions). National DEMs and data from the Shuttle Radar Topography Mission (SRTM), ASTER and the TanDEM-X radar satellite will be used. For producing glacier velocity fields, more targeted user consultation will be necessary to define the details of the products (regions, periods etc.). Data mainly from SAR and InSAR sensors (ASAR, PALSAR) will be used for this purpose.

A summary of all planned Glaciers_cci products and expected characteristics is given in Table 16. The GCOS requirements as given in GCOS-107 were considered achievable by the Glaciers_cci team.

Methodological improvements to glacier mapping and monitoring from space are sought in the following areas: definition of a glacier entity from space (e.g. location of drainage divides and connection of tributaries), separation of glaciers from seasonal and perennial snow cover (for both radar and optical), cloud and cloud shadow screening (for optical systems), precise mapping of debris-covered ice (for both radar and optical), and intercomparison between glaciological data as obtained from space and in the field. Reaching community consensus on these issues is planned in the "round robin" intercomparison phase of the project.

Linkages

It is planned to provide the high-resolution (30 m) glacier maps from all over the world as a validation dataset to the Land_Cover_cci project. Members of the Glaciers_cci team provided input to the 2011 update of GCOS (2006). Further linkages to other CCI teams will be explored.

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5.9 Land_Cover_cci

Collection of Requirements

Gathering user requirements was performed in a comprehensive manner, using internationally-agreed high-level requirements (GCOS-107, GCOS (2004, 2010), GTOS (2009); IGOS-Land (Townshend *et al.*, 2008), IGOS-Carbon (Ciais *et al.*, 2010)) and a user consultation mechanism, including a broad range of different user groups: (1) a group of key climate modellers, most of them also participating in the CCI Climate Modelling User Group, (2) associated climate users who are involved in the development of climate models and applications (15 responses received) and (3) the broad land cover data community, as reflected in the scientific literature and represented by users of the ESA GlobCover product coming from academia, the commercial sector, NGOs, and governments and international organizations (ordered by number of responses received, in total 372). Feedback from international initiatives such as the WCRP CORDEX and, partly, from the numerical weather prediction users have been taken into account. Finally, the user consultation also targeted the set of requirements for the next generation of models. This is driven by the notion that the CCI products will need to consider not only today's but also future user requirements.

Discussion, Conclusion, Traceability

The Land_Cover_cci requirements analysis placed emphasis on exploring the diversity of land cover applications from the perspective of: climate modellers on global and regional scales, Earth system modelling, carbon cycle studies, vegetation modelling, and integrated assessments.

The findings of the user requirement analysis highlight *inter alia* that:

- There is a need for both stable land cover data and a dynamic component in form of time-series and changes in land cover;
- Consistency among the different model parameters is often more important than accuracy of individual datasets;
- Land cover products should provide flexibility to serve different scales and purposes both in terms of spatial and temporal resolution;
- The relative importance of different class accuracies varies significantly depending on which surface parameter is estimated; the need for stability in accuracy should be reflected in implementing a multi-date accuracy assessment;
- More than 90% of users find the UN Land Cover Classification System a suitable approach for thematic land cover characterization; this is also considered compatible with the plant functional type concept used in many climate models; and,
- The quality of land cover products is to be made transparent, e.g. by including information on the probability for the land cover class and other quality indicators (see Figure 11 on the relative importance of classes to users).

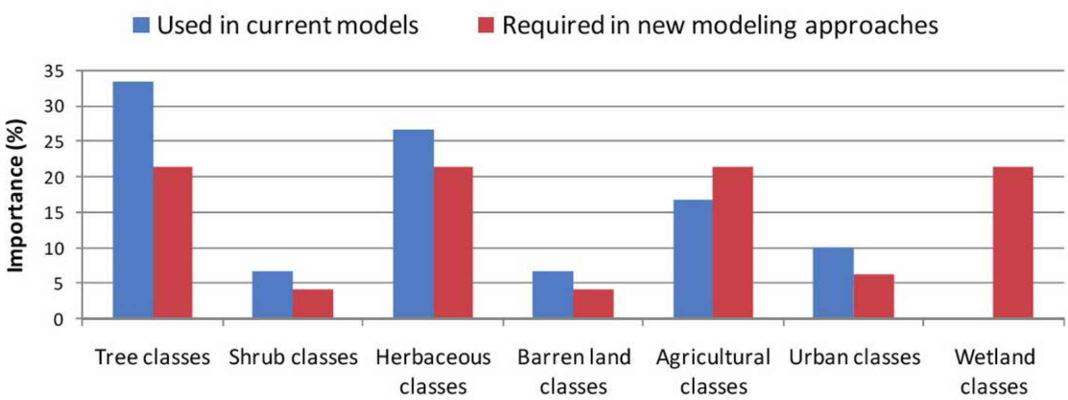

Figure 11: The importance of land cover classes for climate modellers, according to the Land_Cover_cci analysis of key user requirements.

The user consultation showed that, although the range of requirements coming from climate research is broad and growing, there is a good match between requirements coming from different user groups and the high-level requirements from GCOS, CMUG and relevant international bodies. A summary of user requirements for land cover products is given in **Table 6**.

Table 6: Summary of Land_Cover_cci user requirements analysis.

	Threshold requirement	Target requirement
	Coverage and sampling	
Geographic Coverage	*Global*	*Global with regional and local specific products*
Temporal sampling	*Best/stable map and regular updates*	*Monthly data on vegetation dynamics and change*
Temporal extent	*1-2 years, most recent*	*1990 (or earlier)-present*
	Resolution	
Horizontal Resolution	*1000 m*	*30 m*
Vertical Resolution	-	-
	Error/Uncertainty	
Precision	*Thematic land cover detail sufficient to meet current modeling user needs*	*Thematic land cover detail sufficient to meet future model needs*
Accuracy	*Higher accuracy than existing datasets*	*Errors of 5-10% either per class or as overall accuracy*
Stability	*Higher stability than existing datasets*	*Errors of 5-10% either per class or as overall accuracy*
Error Characteristics	*Independent one-time accuracy assessment*	*Operational and independent multi-date validation*

The project builds upon the ESA GlobCover project heritage in cooperation with the NASA MODIS team, aiming at consistent products. Based on the requirements analysis, the Land_Cover_cci project will generate:

1. Global surface reflectance time series for three different periods (centred on 2000, 2005 and 2010) based on MERIS (full and reduced resolution) and SPOT-VEGETATION data, and with associated metadata.

2. Global land cover products for three different periods based on the above time series and associated metadata, including an accuracy assessment for each product. These will be at 300 m and 5 km spatial resolution (Table 17 gives a summary).

Reference periods from 1998-2002, 2003-2007, and 2008-2012, respectively, will be the basis for the above products. ASAR radar imagery will be tested to improve mapping of wetlands and urban areas. Improved algorithms will be developed and validated for various uncertainty factors, such as geolocation, spectral and radiometric sensor calibration, atmospheric correction, land-water mask, and cloud /cloud shadow detection. Tests will be run using SAR imagery to improve mapping of specific classes. Full characterization of final product uncertainties is also planned.

Land_Cover_cci products should aim to be better than the ~70% overall accuracy of currently available land cover maps, but it is recognized that the GCOS and CMUG requirements (between 5 and 15% overall accuracy) are hard targets to achieve. However, given the emphasis in the CCI on climate modelling, the proposed products are expected to address most of the climate modelling user needs. Every effort will nevertheless be made to meet the GCOS requirements (GCOS-107) and to adhere to GCOS guidelines (GCOS, 2010a). The project will use the UN Land Cover Classification System (LCCS; Di Gregorio, 2005), the currently most comprehensive, internationally applied (supported by more than 90% of consulted users) and flexible framework for land cover characterization.

Systematic mapping of land cover change using high-resolution imagery (10-30m pixel size; T.5.2 in GCOS-107) has not been addressed in the Land_Cover_cci project.

The project also allows for an opportunity to revisit land cover conceptually. Rather than perceiving land cover as more or less stable classes with (bio)physical characteristics (e.g. GTOS, 2009), land cover classes can be organized as a function of temporal and spatial scale (of the observation). A distinction should be made between land cover state (as defined by a stable set of features) and land cover condition (with variability over time, e.g. the annual cycle of fire presence, vegetation phenology, snow occurrence). Related uncertainty information will be generated at the class level.

Linkages

Fields of collaboration with other CCI teams have been identified: spatio-temporal consistency should be verified with the Fire_cci team, and consultation has started with the Aerosol_cci team about the treatment of surface and cloud masking procedures. Synergy with the Cloud_cci (with respect to cloud screening) and Glaciers_cci (for consistency checks) will be explored.

GCOS-107 provides a generalised requirement while other assessments provide much more detail (e.g. DiGregorio, 2005; Townshend *et al.*, 2008). Therefore, in the process of updating GCOS-107 during 2011, the determination of detailed requirements must investigate these assessments, and include the generation of community consensus definitions of the required classes and their interpretation across a range of spatial resolutions.

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5.10 Fire_cci

Collection of Requirements

The Fire_cci project concentrates in its first phase on responding to the need for long-term maps of burned area. In order to gather information on observational requirements by the user community, the Fire_cci project carried out a user survey, which resulted in almost 50 responses by actual or potential users of burned area products. Responses came from the data assimilation, modelling, and Earth observation communities, with a bias toward the latter two. Details included product accuracy, stability, resolution, and intended field of application. Those included monitoring of fire-related trace gas emissions and aerosols, monitoring and modelling of carbon fluxes, land cover mapping, fire hazard assessment, and seasonal-to-interannual vegetation dynamics. The project team also analysed the requirements stated by GCOS and the CCI CMUG. Expressions of need from community workshops and initiatives such as Integrated Global Observations of the Land were also taken into account.

Discussion, Conclusion, Traceability

The Fire_cci team found in their analysis that better error characterization of existing products and generally more accurate, unbiased burned area products were overarching key user needs. The most useful product types identified are annual syntheses of burned pixels (at instrument resolution, CEOS 'level 2'), followed by annual maps of burned patches and thirdly by gridded products at various resolutions in time and space. For the gridded, multi-sensor product, weekly composites were preferred over monthly composites, and spatial resolution of 0.5°x0.5° or higher was rated as most useful (see Figure 12); this preference is determined *inter alia* by the modelling scale of interest (regional versus global modellers).

Accuracy of the burned area product depends on product spatial resolution due to commission and omission errors. According to the Fire_cci survey, users expect slightly higher accuracy for commission (error in match between burned area identified from space and reality) than for omission (error in match between area identified from space as non-burned and reality). The need for a balance between both types of accuracy was nevertheless emphasized. Spatial resolution and scale (global, regional, local)-dependent accuracy requirements were not explored in the analysis and are yet to be determined (see e.g. Roy *et al.*, 2006; Chuvieco, 2009).

Overall, respondents to the user survey identified 5%/15%/25% as target/breakthrough/threshold accuracy (understood as maximum tolerable error) of burned area maps. Spatial resolution was interpreted as geolocation accuracy of individual burns, resulting in a 1 km target. Temporal resolution requirements relate to determining the timing of fire events, and range from 1-2 days as target, with strong dependence on application area, to 6/9 days (breakthrough/threshold). As the stability of burned area products, users demand less than 15% year-to-year variability of product error characteristics.

In addition, the survey identified, as a priority, the inclusion of metadata information on date of burn detection (e.g. start and end date) and burn severity into the burned area product (pixels, patches). For gridded products, information on burn severity classes, dominant vegetation cover (at the time of burn) and estimates of errors in commission and omission should be included.

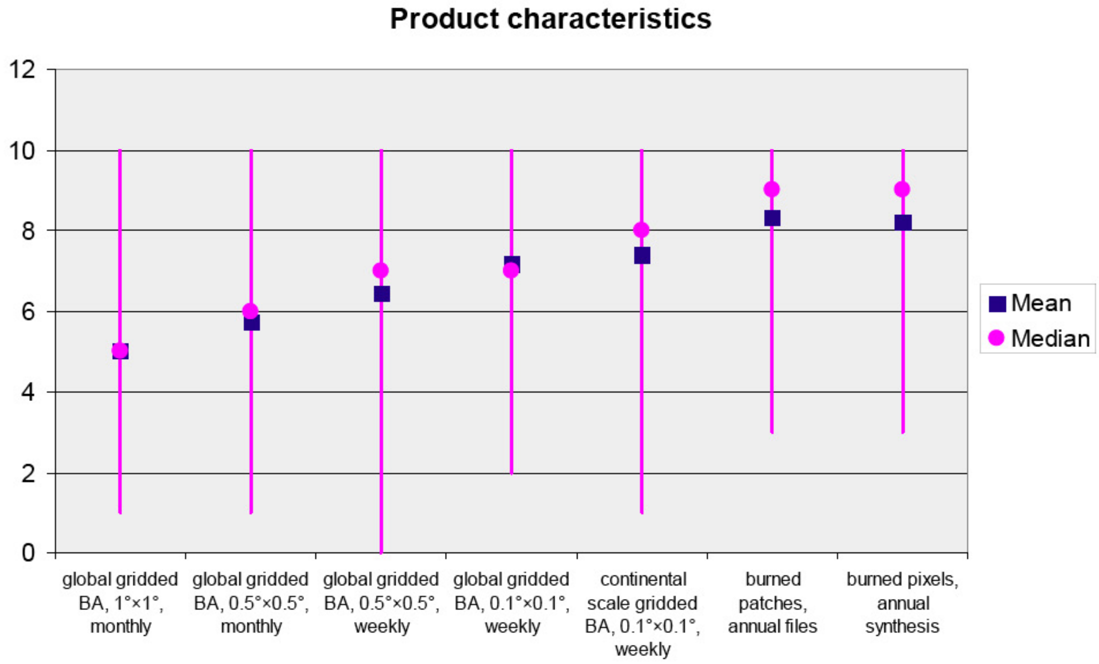

Figure 12: Result of Fire_cci user consultation: types of burned area (BA) products rated as useful on a scale from 0 (no use) to 10 (maximum use); vertical lines denote the range of answers provided. The results are based on responses from nearly 50 actual or potential users of burned area products.

The Fire_cci project will focus on the key variable identified in GCOS-107, burned area. It will incorporate active fire observations as a supplemental variable to improve detection of burned area across varying biomes. Generating a gridded product as well as a pixel-based synthesis product in the Fire_cci project is expected to satisfy a maximum range of potential users. In order of priority, the project will generate:

- Pixel-based monthly synthesis products, indicating the day of burn detection (based on daily single-sensor products); and,
- Global gridded burned area products (0.5° x 0.5° spatial resolution, based on pixel-based products).

The monthly pixel-based product will be based on a synthesis of daily burned area maps at instrument resolution, including the date of burn, and sensor and retrieval-specific levels of confidence. Since some areas might be burned twice in a calendar year (mainly in tropical regions with a dry season around January), monthly aggregates lend themselves better toward detailed analysis of seasonal trends compared to products aggregated over a year.

The gridded products will contain information on burned area integrated over a certain time period within geographic grid cells, along with data on the burning process (land cover, burning conditions, and burn efficiency) for each cell. Gridded products will be generated from the pixel-based products. Temporal compositing is planned on a bi-weekly basis for a sufficient number of cloud-free scenes, and weekly composites will be explored. Sensor-specific sensitivity studies suggest that maps generated from pixel-based products should only include burned patches exceeding a minimum size (5-10 times the instrument resolution). This threshold will be reviewed in the course of the project, given that small fires can have a significant impact on climate and ecosystems.

In specifying Fire_cci product characteristics, the team tried to strike a balance between target ('ideal') needs expressed by users (irrespective of technical possibilities) and 'realistic' needs which take into account physical limitations of sensors. Data from ATSR, AATSR, VEGETATION, and MERIS will be used in the Fire_cci project. Expected product specifications are summarized in Table 18.

Algorithm development and validation will focus on 10 test sites of 500 x 500 km^2, covering the maximum time range of each instrument, i.e. ATSR-2 (1995-2008), VEGETATION (1998-2009) and MERIS (2003-2009). These study sites will include at least one example from the major biomes affected by fires, namely tropical forests, tropical savannahs, boreal forests, and temperate-Mediterranean forests. They are selected by considering historical records of fire occurrence and the suggestions of end-users and the GOFC-GOLD regional networks.

In addition to these time series, five years worth of global coverage products will be generated (for 1999, 2000, 2002, 2003, and 2005) to demonstrate performance at the global scale. Comprehensive validation using existing high-resolution data (e.g. Landsat TM/ETM+) will be performed to check the accuracy and stability of the product.

The proposed methodology and algorithm intercomparison is expected to improve geometrical accuracy of products and remove atmospheric effects and other factors affecting product quality (such as clouds, water, snow, shadows). Other error sources have been identified as being instrument-specific (calibration, atmospheric correction, land/water mask), algorithm-specific (remaining burn, burn conditions), and inherent to the validation process (quality of reference data).

The team will endeavour to strengthen the collaboration between the observational and modelling communities, to enable a quantitative assessment of Dynamic Global Vegetation Models (DGVMs) and Earth System Models (ESMs). Model-to-model and model-to-observations intercomparisons are foreseen for studying the relationships between burned area, carbon cycle and vegetation at various temporal and spatial scales, including the impact of burned area on climate projections.

Linkages

Commonalities of the Fire_cci project with other ECVs were found, both in terms of necessary pre-processing and comparison of product output. As a result, interaction with the Cloud_cci team was established to define common requirements. The Fire_cci team also identified a number of issues potentially common to all CCI projects, such as geometric and atmospheric correction, cloud masks, land/water masks, geographic projections used for products, and common file standards.

Results of the user requirements analysis were provided as input to the 2011 update of GCOS-107, including more detail on sampling requirements (grid size resolution etc.). It was recommended that the GCOS requirements for fire disturbance include breakthrough and threshold values, both in terms of accuracy and precision, reflecting current technical limitations.

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5.11 Sea Ice_cci

The Arctic and Antarctic seas are dominated by sea ice which has a dominant seasonal cycle as well as interannual variability and long-term trends. The regions play a key role in the global climate system where the cryosphere is a sensitive indicator of climate change. Requirements for sea ice data are closely linked to requirements for ocean and atmospheric observations and modelling in the polar regions.

Collection of requirements

The Sea_Ice_cci team reviewed and analysed several user requirement documents prepared for ocean and sea ice observation from satellites, including the EUMETSAT Application Expert Group, the ESA GMES Service Element ICEMON project, the IGOS Cryosphere Theme Report, and the GCOS-154 (GCOS, 2011) Requirements for sea ice. It paid attention to the wide variety of applications areas of sea ice climate data, ranging from climate research activities to marine biology and ecosystems research, management of marine resources, sea transportation, offshore exploration, design and construction of vessels and platforms, impact on indigenous people, insurance, governance and policy making. Though the project focus is on climate research and modelling activities, it also considered requirements from other user groups. A user survey was also performed during the period 26 March-4 May 2012, to which took part 91 respondents from a broad range of countries and institutions.

Discussion, Conclusions, Traceability

The single most important parameter for most of the users is ice concentration followed by the derived ice area and extent. Ice thickness and ice drift is important or very important for more than 80 % of the users. For the other parameters only between 5 and 15 % answered that these parameters are not relevant. The conclusion for this survey is that the demand for sea ice data is much larger than the basic ECV parameters defined by GCOS (ice concentration and ice thickness). There is therefore a significant user potential for new satellite derived products for sea ice.

Error characterisation for the sea ice ECVs is an important part of the study, and users were therefore asked about their requirements for three different error parameters: BIAS: defined as the offset of the mean satellite observations from the “true” values; PRECISION: defined as scatter of multiple measurements of a constant target, and STABILITY: defined as drift in observed mean value of a constant target over a decade. However many respondents lacked a clear view on requirements on error characterization.

For ice concentration the majority of the respondents required daily sampling, 10-20 km spatial resolution and measurement precision better than 10 %. For ice thickness, the majority of the respondents required spatial resolution better than 50 km and measurement precision better than 20 cm. The temporal resolution of ice thickness data is envisaged to be about a month for satellite altimeter retrievals. The requirement for long-term stability is 2 % per decade for ice concentration and 5 cm per decade for ice thickness. Requirements for other sea ice parameters such as ice drift, ice volume, snow cover, melt pond fraction, albedo, surface temperature, sea ice salinity and others were investigated. The Sea_Ice_cci project will not provide data sets on these parameters, but recommendation is made to extend sea ice data sets with more parameters in future studies of sea ice data in climate research.

Unlike other projects the Sea_Ice_cci does not deal with a single variable but with a component of the Earth’s climate system which full characterization involves a suite of different, partly independent geophysical variables. The sea ice ECV, as defined by GCOS, is the sea ice concentration (SIC). However, GCOS-154 also states that: “Ice volume is an important component of high-latitude heat and is needed to characterize the seasonal to inter-annual variability in freshwater export (in the form of sea ice) from the polar oceans” and “Ice volume estimates require estimates of ice thickness in combination with ice concentrations.” Therefore, the sea ice thickness (SIT) is at least as important as SIC and therefore the second ECV targeted within the project.

As a result, and in agreement with the user consultation, the Sea_Ice_cci project plans to produce two major sea ice products:

- Long term essential climate variable (ECV) sea ice concentration product for both hemispheres; and,
- Long term ECV sea ice thickness product for the Arctic.

The SIC ECV will be available for both hemispheres at daily temporal resolution for the period 11/1978 to 12/2008. It will be derived from satellite passive microwave imager data. The SIT ECV will be available for the Arctic Ocean with monthly temporal resolution for the period 1993 to 2012. It will be derived from satellite radar altimetry data.

Linkages

The Sea_Ice_cci project has obvious commonalities with the Sea_Level cci, in terms of data sources as well as processing algorithms and error characterization. It also has linkages with several other ECVs, such as SST, clouds, ocean colour, glaciers and ice sheets (which are part of the current set of CCI ECVs), snow cover, albedo and sea surface salinity.

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5.12 Soil Moisture_cci

The objective of the Soil_Moisture_cci project is to produce the most complete and most consistent global soil moisture data record based on active and passive microwave sensors. This novel ECV soil moisture product should benefit a wide range of applications and users.

Collection of requirements

A thorough user requirement analysis was performed at the beginning of the project, including a literature review of the documented user requirements to date and the analysis of a user questionnaire that was made available online in October 2012. Requirements from the modelling community were also gathered a CMUG meeting in Toulouse (14-16 May 2012). The nine GEO Societal Benefit Areas (SBAs) were used as an appropriate way to classify user requirements, it being justified by the fact that soil moisture is one of the only three Earth observation parameters (out of the twenty five highest ranked) that are seen as a priority for all nine SBAs.

The User consultation was carried out with a comprehensive questionnaire. 65 users (over 80 % from research or higher education sectors) participated to the survey. All SBAs were represented, with the main interests relating to climate, water, agriculture, ecosystems and disasters. The merged active and passive product is the preferred product aggregation. But only one half of the users is interested in knowing the product accuracy or precision, and even less its stability. Only one third of the users are interested in a grid resolution better than 25 km. Daily values and monthly averages are the preferred time coverages, global and regional the preferred spatial coverages.

Discussion, Conclusions, Traceability

As a matter of fact, several decade-long soil moisture data records have been released within the last eight years, so the generic user requirements for ECV soil moisture data records are already reasonably well understood.

The merged product is the output of blending the active and passive soil moisture products, which are derived from SMMR, SSM/I, TMI and AMSR-E for the passive data sets, and AMI-WS, and ASCAT for the active data sets, produced following the method described by Liu, Parinussa *et al.* (2011), Liu, Dorigo *et al.* (2012) and Wagner (2012). The homogenized and merged product presents surface soil moisture with a global coverage and a spatial resolution of 0.25°, and the temporal resolution is 1 day with its reference time at 0:00 UTC. The soil moisture data are provided in volume metric units [m³m⁻³]. The ECV product version 0.1 is provided as global daily images.

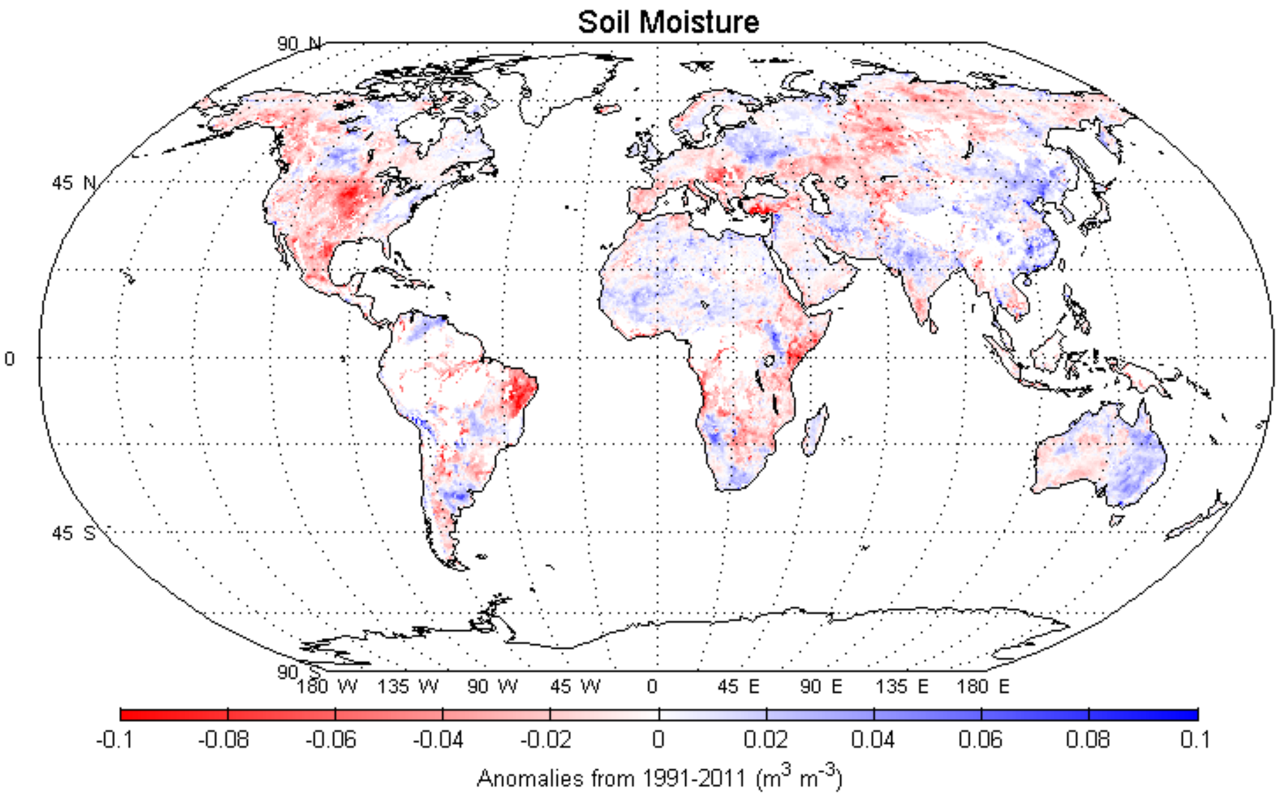

Figure 13: Soil moisture anomalies for the year 2012 from the ESA's CCI satellite-based soil moisture product (Parinussa et al. 2013).

Linkages

In the process of merging the passive and active soil moisture data sets the GLDAS Noah Land Surface Model and soil porosity data have been used. A close collaboration has been established with the CMUG, and a joint workshop has been held in Toulouse in May 2012.

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5.13 Ice Sheets_cci

The goal of the Ice_Sheets_cci project is to set up a long term and reliable production of a set of key parameters from ice sheets derived from available and future satellite observations. The selected key parameters are: the Surface Elevation Change (SEC); the Ice Velocity (IV); the Grounding Line Location (GLL); and, the Calving Front Location (CFL). The project focuses on the Greenland ice sheet including its outlet glaciers. Antarctica is not directly included at this stage, but similar methods will presumably be implemented to Antarctica later.

Collection of requirements

The user requirement analysis was carried out as the first task in the Ice_Sheets_cci project. There is a global interest in understanding the dynamics of ice sheets and their response to climate changes, based on the need to understand the consequences of present and future changes of ice sheet mass in order to predict their contribution to the global and regional sea level change. The whole issue of the basal conditions and the relation to fast flowing ice streams is a critical point in understanding the ice sheet response to global warming. While surface velocity and elevation changes observed from satellites can be interpreted to provide information of basal conditions, *in situ* data and airborne data are needed in addition to satellite data to address this problem.

The direct users of the Ice_Sheets_cci data products are a relatively broad group covering several scientific communities: ice sheet modellers, remote sensing scientists, surface mass balance modellers, ocean and climate modellers, as well as regional authorities and organizations interested in monitoring the ice sheets for practical or political reasons.

Several set of requirements have been produced by various expert organizations and user groups. The GCOS requirements for the Ice Sheets ECV are to produce "*Ice-sheet elevation changes, supplemented by fields of ice velocity and ice mass change*". In the framework of the Integrated Global Observing Strategy (IGOS), a set of recommendations for development of ice sheet observations has been formulated in 2007. In addition the Ice_Sheets_cci project has developed and distributed a questionnaire. 67 people representing a wide range of activities in relation to ice sheet research have responded to this survey, including members of the project Climate Research Group and of the CMUG.

Discussion, Conclusions, Traceability

It is clear from the responses that the main contributions from these data products are 1) to improve mass balance estimates of the Greenland ice sheet (in accordance with GCOS requirements), and 2) to provide validation data for ice sheet models, which is needed to understand ice sheet dynamics and predict future mass changes of ice sheets and related contribution to global sea level change.

From the responses to the survey, the Ice_Sheets_cci project has identified the locations of particular interest to users, and their preferences in terms of grid and data format, resolution and accuracy, priorities in terms of spatial and temporal coverage, file formats and access to data.

Some of the requirements for the Ice_Sheets_cci ECV parameters identified based on overall responses to the questionnaire are listed below.

User requirements for ECV parameters

	SEC	IV	GLL	CFL
MINIMUM spatial resolution	1-5km	100m-1km	100m-1km	100m-500m
OPTIMUM spatial resolution	<500m	50m	50m	50m
MINIMUM temporal resolution	annual	annual	annual	annual
OPTIMUM temporal resolution	monthly	monthly	monthly	monthly
MINIMUM accuracy	0.1-0.5m/yr	30	-	-
OPTIMUM accuracy	<0.1 m/yr	10	-	-
What times are observations needed	all year	all year	all year	all year

Linkages

The ECV parameters included in the Ice_Sheets_cci project only represent a selected set, based on a subset of the available space-based FCDRs, with special focus on utilizing ESA mission data to the fullest extent for climate modelling and ice sheet monitoring. Satellite measurements such as microwave backscatter, able to detect seasonal onset and stop of melting of the ice sheet, and direct measurements of mass changes by GRACE, are not included. The selected parameters do, however, provide a major value-added product for the general climate modelling and monitoring community.

The provision of basic ice velocity time series will provide important data on glacier dynamics changes, and – combined with ice thickness data and accumulation data in the interior – another source of overall mass balance of the ice sheets. The scientific usefulness of such data has also been demonstrated in the recent ESA/NASA IMBIE exercise [Shepherd *et al.*, 2012] for intercomparison of different EO data for estimating the overall mass balance of Greenland and Antarctica.

The Ice_Sheets_cci project has obvious commonalities with the Sea_Level cci, in terms of data sources as well as processing algorithms and error characterization. It also has linkages with several other ECVs, such as sea ice (which are part of the current set of CCI ECVs), snow cover and albedo.

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6 THE CCI CLIMATE MODELLING USER GROUP

In addition to the currently ten ECV_cci teams, a CCI Climate Modelling User Group (CMUG) consisting of major European climate modelling centres has been set up with a cross-cutting mandate (see Figure 13). Its inception recognizes the essential role of climate models in understanding climate change and variability, and in providing better predictions and projections. Climate models are a key user of satellite climate datasets and ECV products.

At all stages of the CCI programme, it is CMUG's task to provide a climate modelling perspective on the work performed by the ECV-specific projects in the CCI. This includes feedback to ECV_cci project output (such as the requirements analyses summarized in this report), and testing datasets generated in the CCI within their models. The CMUG emphasizes the important role of climate modelling as a primary user of CCI output.

As part of its tasks, the CCI CMUG:

1. Gathered the climate modelling community requirements for satellite climate datasets and products; and,
2. Analysed ECV_cci user requirements, and plans for ECV products from a climate modelling user perspective.

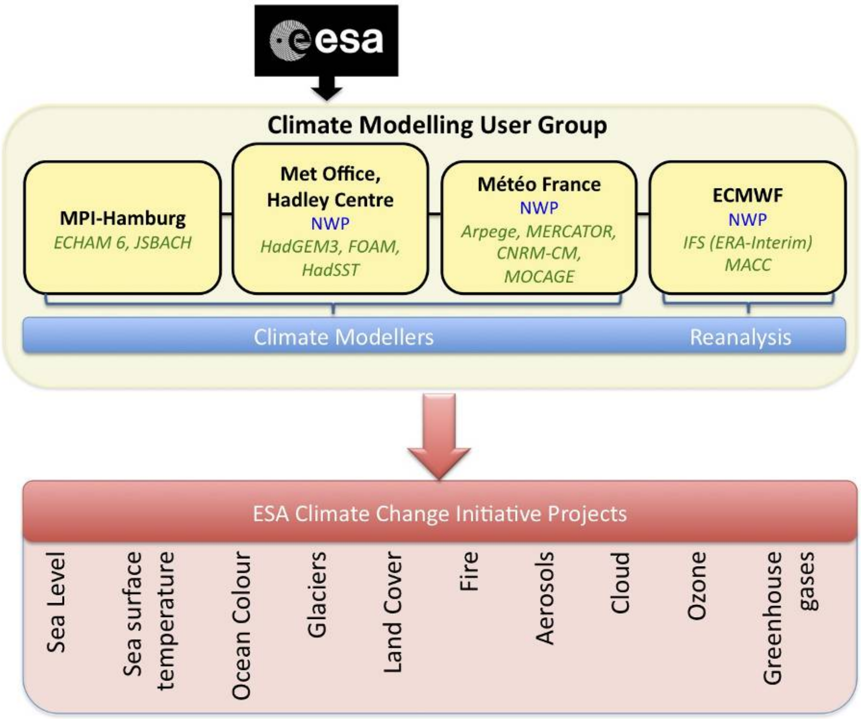

Figure 13: Situation of the Climate Modelling User Group (in yellow) within the ESA CCI.

6.1 Climate Modelling Requirements

The climate modelling user requirements for satellite datasets and ECV products were gathered by CMUG through a workshop, a survey, and interviews with 35 members of the community. The requirements gathered are representative of the full range of modellers and were separated into six broad application areas.

As generic requirements, the CMUG found that satellite data are used:

Climate monitoring and attribution:

- to provide long-term datasets to monitor particular parameters with or without *in situ* data to ascertain decadal and longer-term changes. Models can then be used to attribute the observed variations to natural and anthropogenic forcings and internal variability (Hegerl *et al.*, 2007; Stott *et al.*, 2000).

Model development and validation:

- to compare measured parameters, or combinations of observed and/or reanalysed parameters, with model equivalents on hourly up to decadal timescales, in order to assess the processes and biases in the models and to constrain the processes. Comparison of satellite data and climate model output is facilitated by including 'observation operators' which calculate from the model fields the variable as if measured by the satellite; this avoids the uncertainties in the retrieval of conventional variables from satellite data. Satellite data are also used to help evaluate the skill of seasonal to decadal forecasts (Smith *et al.*, 2007).

Model initialization and definition of boundary conditions:
- to initialise and constrain seasonal forecasting models with, for example, realistic estimates of soil moisture and sea surface temperature (Douville, 2004).

Data assimilation for seasonal and decadal forecasts:
- for data assimilation: the experience of satellite data assimilation at NWP centres, which now provides the major impact on forecast skill, can be applied to seasonal to decadal forecasting. Only satellite data can provide truly global coverage at horizontal scales now used in models (~50 km) although radiosondes will still have better vertical resolution. In order for models to be able to assimilate a particular ECV, it must be represented within the model as a prognostic variable.

Quality control of *in situ* observations:
- to help identify biases in the current and past *in situ* observing network. Comparisons of Microwave Sounding Unit (MSU) retrievals to "families" of radiosondes (Christy *et al.*, 2007) have identified shortcomings both in the raw radiosonde data and the satellite datasets.

Reanalyses:
- to provide homogeneous data, with good estimates of random errors and bias correction uncertainties, for reanalyses. Existing reanalyses are already very useful for model validation, especially in combination with independent satellite data; the next generation of reanalyses also needs to be sufficiently homogeneous to allow the estimation of long-term trends (Bengtsson *et al.*, 2007).

CMUG also highlighted cross-ECV issues, such as error characterization and terminology, model-specific data formats, data processing levels, naming conventions and data access.

The requirements gathering exercise led by CMUG provided modelling-specific requirements for detailed parameters, product resolutions, and errors/uncertainties along the above application areas for all ECVs addressed in the CCI. All ECV_cci projects used the CMUG results in their requirements analyses, and key outcomes have been referred to in the ECV-specific sections where appropriate.

6.2 CMUG Review of ECV_cci Requirements Analyses

In addition to stating its 'own' requirements, the CMUG also analysed the ECV_cci requirements and plans for ECV products from a, by reviewing all user requirements and product specification documents (URDs and PSDs). This is to ensure mutual coherence and consistency among ECV_cci projects, and to streamline the use of CCI products in the climate modelling domain. This CMUG task is somewhat similar to the exercise leading to the present report, but done from a climate modelling user perspective. CMUG also established useful synoptic views on the CCI, such as the currently planned ECV_cci product time series (Table 7) and linkages identified between ECVs needed for consistent product generation (Table 8). CMUG (2011a) and CMUG (2011b) contain details. On this basis, a continuing dialogue between the CMUG and ECV_cci projects has been established.

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7 CONCLUDING ANALYSIS

Collection of Requirements

The collection of user requirements for satellite climate datasets was done by ECV_cci projects through different approaches. Some consulted with a broad range of actual and potential users (e.g. through online surveys), some contacted a known user base (via meetings and personal contacts), some worked mostly from existing requirements (e.g. in the peer-reviewed literature). This diversity reflects different levels of international community coordination and varying degrees of linkage to the climate community, represented in part by GCOS and CMUG. Most ECV_cci projects produced requirements specific for different climate application areas, and many additional and useful requirements were identified that will to some extent be addressed by the projects. A wealth of material has been collected, and the present summary only partly does justice to the large body of work accomplished by the CCI. More information on details of the requirements gathering can be found in the documents listed in Appendix D.

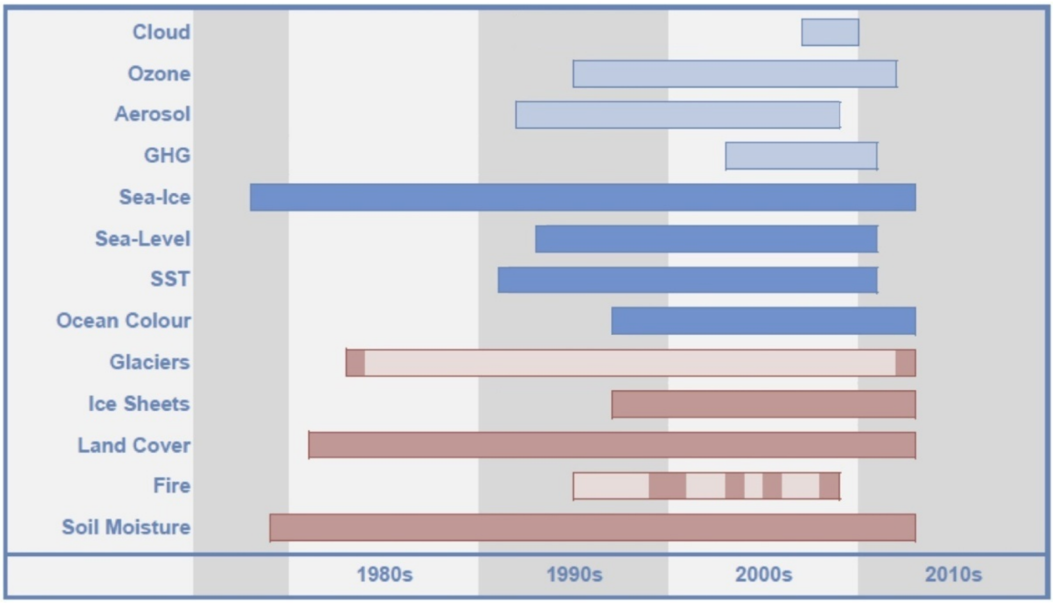

Table 7: ECV product time series in phase I of the CCI). Short time series are mainly used for intercomparing methods and retrieval algorithms.

Discussion, Conclusion, Traceability

The ECV products planned by the CCI are largely compliant with GCOS aims and objectives. All ECV_cci projects took note and discussed the requirements in GCOS-107, and many teams made suggestions for refining them. Transparency and traceability have been guiding principles in the CCI from the start, and all ECV_cci projects are striving to heed those principles. For some ECVs, generating long-term ECV products can be initiated soon, particularly in cases where methodologies and associated algorithms are mature. Many ECV_cci projects however identified a strong need for methodological intercomparison in retrieving ECVs before large-scale (re)processing of archives can start. The CCI will provide for this need in its first phase. The resulting variety of time series covered by the ECV_cci projects is reflected in Table 7.

Linkages

ECVs are a useful, but only one way of specifying observations of the complex and highly coupled climate system. Therefore, physical linkages between different ECVs need to translate into programme and project-level connectivity. All ECV_cci projects have identified areas for collaboration among each other, be they indispensable for ECV product generation, or more optional and for exploration. The CMUG and other CCI mechanisms facilitate the linkage among ECV_cci projects (see Table 8). Integration of ECV_cci output in the climate modelling context will further enhance integration between different ECVs.

	SST	Sea level	Clouds	Sea ice	Ocean Colour	Aerosol	GHG	Land cover	Fire	Ozone	Glaciers	Ice sheets	Soil moisture
SST		x	x	x	x	x				x			
Sea level	x			x								x	
Clouds	x			x	x	x	x	x	x	x			
Sea ice	x	x	x		x					x	x		

Ocean Colour	x		x	x		x							
Aerosol	x		x		x			x	x	x	x		
GHG			x			x			x	x			
Land cover			x			x			x		x		x
Fire			x			x	x	x		x			x
Ozone			x			x	x						
Glaciers				x		x		x				x	
Ice sheets		x									x		
Soil moisture								x	x				

Table 8: Linkages between ECVs identified by the CCI Climate Modelling User Group (after CMUG, 2011b).

8 CONCLUDING REMARKS

The CCI requirements analysis has generated a wealth of information related to the use of satellite data for a wide range of climate and climate-related applications. It provides a response by ESA to the needs expressed by GCOS, the UNFCCC and the international climate community at large, as represented by the WCRP, the IPCC and other international bodies, including in Europe. This analysis is a contribution to the work of international space agencies engaged in the CEOS Working Group Climate, to ESA's collaboration with EUMETSAT in the area of climate, and to the build-up of a European GMES Climate Service.

Many ECV products planned by the CCI are compliant with GCOS aims and objectives. There are good scientific and technical reasons where this is not or not yet the case, and this document gives insight into the details. All ECV_cci projects gathered user requirements widely, discussed and summarized them, and drew conclusions for their planned work ahead. Transparency, traceability and scientific excellence are guiding principles in this process, to which all ECV_cci projects are striving to adhere. To this end, each project will continue to closely collaborate with users and peers worldwide through key international science bodies (listed in Appendix C).

In turn, the CCI requirements analysis has provided deep insight into the needs, concerns and future expectations of worldwide users of satellite data for climate applications. The critical review of requirements as stated in the GCOS Satellite Supplement in support of the 2004 GCOS Implementation Plan (GCOS-107) resulted in a number of useful and well-founded suggestions for refining the requirements, as timely input to the 2011 update of GCOS-107. Once the CCI has generated ECV products, a systematic assessment of the CCI impact on the different climate application areas will be necessary.

APPENDIX A COMPARISON OF PLANNED CCI PRODUCTS WITH GCOS (2006) REQUIREMENTS

Table 9: Cloud ECV products planned by Cloud_cci project, their target characteristics, and comparison with GCOS (2006) target requirements.

Variable/ Parameter	**Horizontal Resolution**		**Vertical Resolution**		**Temporal Resolution**		**Accuracy (Total error)**		**Stability (per decade)**		**Instrument(s) used**	**FCDR**	**Time period covered**
	CCI	GCOS	CCI	GCOS	CCI	GCOS	CCI	GCOS	CCI	GCOS	CCI	CCI	CCI
Cloud cover	50km	100km	-	-	Monthly (based on 3h)	3h	0.08 or 10% (syst. err.), 20% (rand. err.)	10%	n/a	n/a	(A)ATSR-AVHRR-MODIS-MERIS	VIS/NIR imager radiances	2007-2009
Cloud top height	50km	100km	-	-	Monthly (based on 3h)	3h	0.3/0.3/0.8km (high/mid/low-level clouds)	0.5km	n/a	n/a			
Cloud top temperature	50km	100km	-	-	Monthly (based on 3h)	3h	2/3/5K (syst. err.), 5/7/9K (rand. err.) for high/mid/low-level clouds	0.3K	n/a	n/a			
Cloud liquid water path	50km	100km	-	-	Monthly (based on 3h)	3h	30%	10%	n/a	n/a			
Cloud ice water path	50km	100km	-	-	Monthly (based on 3h)	3h	40%	10%	n/a	ne/a			

Table 10: Ozone ECV products planned by Ozone_cci project, their target characteristics, and comparison with GCOS (2006) target requirements; (*) a range of values separated by "-" denotes a proposed target-threshold distinction (future goal *vs.* currently achievable in project).

Variable/ Parameter	Region	Horizontal Resolution		Vertical Resolution		Temporal Resolution		Accuracy (Total error)		Stability (per decade)		Instrument(s) used	FCDR	Time period covered
		CCI	GCOS	CCI	GCOS	CCI	GCOS	CCI	GCOS	CCI	GCOS	CCI	CCI	CCI
Total column ozone	Tropics	20-100km*	5-50km (troposphere), 50-100km (stratosphere)	-	-	3 days	3h	2% (7DU) (trends) 3% (10DU) (variability)	5% (troposphere), 10% (stratosphere)	1-3%	1% (tropos), 0.6% (stratos)	GOME, SCIAMACHY, GOME-2	UV spectral radiances	1995-2010 (GOME); 2 years tbd (others)
	Mid-lat	20-100km												
	Polar	20-100km												
Ozone profile (nadir viewing)	Trop	100-200km	5-50km (troposphere), 50-100km (stratosphere)	6km (Trop column)	0.5km (trop) 0.5-3km (strat)	3 days	3h	10% (trends), 20% (variability)	5% (troposphere), 10% (stratosphere)	1-3%	1% (tropos), 0.6% (stratos)	GOME, SCIAMACHY, GOME-2, OMI	UV spectral radiances	2008-2009 (most probably)
	UTLS			3-6km				8% (trends), 15% (variability)						
	Middle Atm (Strat)			3-10km				8% (trends), 15% (variability)						
Ozone profile (limb viewing, strat only)	Lower Strat	100-300km	50-100km (stratosphere)	1-3km	0.5-3km (strat)	3 days	3h	8% (trends), 15% (variability)	10% (stratosphere)	1-3%	0.6% (strat)	SCIAMACHY, GOMOS, MIPAS, ACE-FTS	UV spectral radiances	2008-2009 (most probably)
	Middle Atm			3-5km										

	(Strat)													

Table 11: Aerosol ECV products planned by Aerosol_cci project, their target characteristics, and comparison with GCOS (2006) target requirements; no vertical resolution requirements is stated since all parameters are column integrated values.

Variable/ Parameter	Horizontal Resolution		Temporal Resolution		Accuracy (Total error)		Stability (per decade)		Instrument(s) used	FCDR	Time period covered
	CCI	GCOS	CCI	GCOS	CCI	GCOS	CCI	GCOS	CCI	CCI	CCI
Aerosol optical depth (at 4 wave-lengths)	10km	1km	1 day	1 day	Not stated; subject to validation	0.01	Not stated; subject to validation	0.005	ATSR-2, AATSR, MERIS, SCIAMACHY, POLDER, GOME(-2), AVHRR	VIS/NIR/ SWIR spectral radiances	1997, 2008
Fine mode fraction (based on AOD at 4 wave-lengths)	10km	n/a	1 day	n/a	Not stated; subject to validation	n/a	Not stated; subject to validation	n/a	ATSR-2, AATSR, MERIS, POLDER, SCIAMACHY, GOME(-2), AVHRR	VIS/NIR/ SWIR spectral radiances	1997, 2008
Dust fraction	10km	n/a	1 day	n/a	Not stated; subject to validation	n/a	Not stated; subject to validation	n/a	ATSR-2, AATSR, MERIS, POLDER, SCIAMACHY, GOME(-2), AVHRR	VIS/NIR/ SWIR spectral radiances	1997, 2008
Absorption AOD (or SSA)	50km	n/a	1 day	n/a	Not stated; subject to validation	n/a	Not stated; subject to validation	n/a	OMI, SCIAMACHY, GOME	UV spectral radiances	1997, 2008

Table 12: GHG ECV products planned by GHG_cci project, their target characteristics (over land), and comparison with GCOS (2006) target requirements; no vertical resolution requirements is stated since all parameters are column integrated values; x/y/z denote target (goal)/breakthrough/threshold requirements.

Variable/ Parameter	**Horizontal Resolution**		**Temporal Resolution**		**Accuracy**		**Stability**		**Instrument(s) used**	**FCDR**	**Time period covered**
	CCI	GCOS	CCI	GCOS	CCI	GCOS	CCI	GCOS	CCI	CCI	CCI
CO_2 concentration (column-averaged dry air mole fraction)	10-60km	10-250km	3-6 days	3h	Systematic error: < 0.2 / 0.3 / 0.5 ppm Random error single obs.: < 1 / 3 / 8 ppm Random error 1000^2 km^2 monthly: < 0.3 / 1.0 / 1.3 ppm	3ppm (total)	< 0.2 / 0.3 / 0.5 ppm/year	3ppm/decade (trends), 1ppm/decade (sources, sinks)	SCIAMACHY, TANSO	NIR/ SWIR/IR spectral radiances	2003-2010
CH_4 concentration (column-averaged dry air mole fraction)	10-60km	10-250km	3-6 days	3h	Systematic error: <1 / 5 / 10 ppb Random error single obs.: < 9 / 17 / 34 ppb Random error 1000^2 km^2 monthly: < 3 /	20ppb (total)	< 1 / 5 / 10 ppb/year	n/a	SCIAMACHY, TANSO	NIR/ SWIR/IR spectral radiances	2003-2010

					5 / 11 ppb						

Table 13: Sea Level ECV products planned by Sea_Level_cci project, their target characteristics, and comparison with GCOS (2006) target requirements.

Variable/ Parameter	Horizontal Resolution		Temporal Resolution		Accuracy (Total error)		Stability (per decade)		Instrument(s) used	FCDR	Time period covered
	CCI	GCOS	CCI	GCOS	CCI	GCOS	CCI	GCOS	CCI	CCI	CCI
Global mean sea level	50km	25km	10 days	1 day	2-4 mm	1 cm	0.5mm/yr	0.5mm	Altimeters on Jason 1/2 Topex/Poseidon, Envisat, ERS-1/2, GFO	Radar altimetry	1993-2010
Regional sea level	25km	25km	Weekly	1 day	1 cm	1 cm	1mm/yr	0.5mm	Altimeters on Jason 1/2, Topex/Poseidon, Envisat, ERS-1/2, GFO	Radar altimetry	1993-2010

Table 14: Sea Surface Temperature (SST) ECV products planned by SST_cci project, their target characteristics, and comparison with GCOS (2006) target requirements.

Variable/ Parameter	Horizontal Resolution	Temporal Resolution	Accuracy (Total error)	Stability (per decade)	Instrument(s) used	FCDR	Time period covered

	CCI	GCOS	CCI	GCOS	CCI	GCOS	CCI	GCOS	CCI	CCI	CCI
SST (skin, sub-skin)	0.05°	1 km	1 day	3 h	0.1 K (over 1000km scales)	0.25 K (no spatial scale)	0.05 K	0.1 K	ATSR, AATSR, AVHRR	IR, passive MW imagery	1991-2010

Table 15: Ocean Colour ECV products planned by Ocean_Colour_cci project, their target characteristics, and comparison with GCOS (2006) target requirements.

Variable/ Parameter	**Horizontal Resolution**		**Temporal Resolution**		**Accuracy (Total error)**		**Stability (per decade)**		**Instrument(s) used**	**FCDR**	**Time period covered**
	CCI	GCOS	CCI	GCOS	CCI	GCOS	CCI	GCOS	CCI	CCI	CCI
Chlorophyll-a concentration	1 km	-	1 day	-	25-30%	-	1 %	-	MERIS, MODIS; SeaWiFS	VIS/NIR imagery	2002-2010; 1997-2010
Water-leaving radiance	1 km	1 km	1 day	1 day	<5%	5%	1%	1%	MERIS, MODIS; SeaWiFS	VIS/NIR imagery	2002-2010; 1997-2010
Spectral attn coefficient for downwelling irradiance	1 km	-	1 day	-	10-25%	-	1%	-	MERIS, MODIS; SeaWiFS	VIS/NIR imagery	2002-2010; 1997-2010
Total absorption and back-scattering coefficients	1 km	-	1 day	-	10-25%	-	1%	-	MERIS, MODIS; SeaWiFS	VIS/NIR imagery	2002-2010; 1997-2010
Coloured dissolved org matter abs'n	1 km	-	1 day	-	25-30%	-	1-5%	-	MERIS, MODIS; SeaWiFS	VIS/NIR imagery	2002-2010; 1997-2010

Suspended particulate matter back-scattering and phytoplankton absorption	1 km	-	1 day	-	25-30%	-	1-5%	-	MERIS, MODIS; SeaWiFS	VIS/NIR imagery	2002-2010; 1997-2010

Table 16: Glaciers and Ice Caps ECV products planned by Glaciers_cci project, their target characteristics, and comparison with GCOS (2006) target requirements. (*) Time period for glacier area is conditional to data availability in target regions, and other periods may be covered where appropriate.

Variable/ Parameter	**Horizontal Resolution**		**Temporal Resolution**		**Accuracy (Total error)**		**Stability (per decade)**		**Instrument(s) used**	**FCDR**	**Time period covered**
	CCI	GCOS	CCI	GCOS	CCI	GCOS	CCI	GCOS	CCI	CCI	CCI
Glacier area / 2D outlines	30m	30m	5 years	1 year	Not yet specified	5%	Not yet specified	5%	Landsat TM/ETM+, SPOT, ASTER	VIS/NIR	1999-2003*
Glacier elevation change	Not yet specified	-	Not yet specified	-	Not yet specified	-	Not yet specified	-	ASTER, ALOS PALSAR, ASAR, RADARSAT, SRTM, ICESat, RA-2	VIS/NIR, SAR, radar altimetry	Not yet specified
Surface velocity	15-30m	-	Not yet specified	-	5-10m/yr	-	Not yet specified	-	ALOS PALSAR, ASAR, RADARSAT	Imaging radar, SAR	Not yet specified

Table 17: Land Cover ECV products planned by Land_Cover_cci project, their target characteristics, and comparison with GCOS (2006) target requirements.

Variable/ Parameter	**Horizontal Resolution**	**Temporal Resolution**	**Accuracy (Total error)**	**Stability (per decade)**	**Instrument(s) used**	**FCDR**	**Time period covered**

	CCI	GCOS	CCI	GCOS	CCI	GCOS	CCI	GCOS	CCI	CCI	CCI
Land cover	300m, 5km	250m-1km	1 year, 5 years	1 year	20%	15%	15-20%	15%	VEGETATION, MERIS, ASAR	VIS/NIR imagery, SAR	2000, 2005, 2010

Table 18: Fire ECV products planned by Fire_cci project, their target characteristics, and comparison with GCOS (2006) target requirements; a distinction is made between pixel-based and gridded products.

Variable/ Parameter	**Horizontal Resolution**		**Temporal Resolution**		**Accuracy (Total error)**		**Stability (per decade)**		**Instrument(s) used**	**FCDR**	**Time period covered**
	CCI	CCI	CCI	GCOS	CCI	GCOS	CCI	GCOS	CCI	CCI	CCI
Burned area (pixel-based)	300m-1.2km (pixel size)	300m-1.2km (pixel size)	Monthly composites, 3.5 day accuracy of burn date	1 day	20%	5%	15%	5%	ATSR, AATSR, VEGETATION, MERIS	SWIR/TIR spectral radiances	1995-2009 (for test sites); 1999, 2000, 2002, 2003, 2005
Burned area (gridded)	0.5°	0.5°	1-2 weeks	1 day	20%	5%	15%	5%	ATSR, AATSR, VEGETATION, MERIS	SWIR/TIR spectral radiances	1995-2009 (for test sites); 1999, 2000, 2002, 2003, 2005

Table 19: Sea Ice ECV products planned by Sea_Ice_cci project, their target characteristics, and comparison with GCOS (2011) target requirements.

Variable/ Parameter	Horizontal Resolution		Temporal Resolution		Accuracy (Total error)		Stability (per decade)		Instrument(s) used	FCDR	Time period covered
	CCI	GCOS	CCI	GCOS	CCI	GCOS	CCI	GCOS	CCI	CCI	CCI
Concentration	10-20 km (min) <10 km (target)	250m	Daily	Weekly	<10%	5% ice area fraction	2%	5%	SSM/I, SMMR	Passive microwave imagery	Nov 1978-Dec 2008
Thickness	10-50 km (min) <10 km (target)			Monthly	<0.2m	0.1 m	5%	Unspecified	RA ERS-1 & 2, RA2 Envisat	Radar altimetry	1993-2012

Table 20: Ice Sheets ECV products planned by Ice_Sheets_cci project, their target characteristics, and comparison with GCOS (2011) target requirements.

Variable/ Parameter	Horizontal Resolution		Temporal Resolution		Accuracy (Total error)		Stability (per decade)		Instrument(s) used	FCDR	Region covered	Time period covered
	CCI	GCOS	CCI	GCOS	CCI	GCOS	CCI	GCOS	CCI	CCI	CCI	CCI
Surface elevation change	5 km <500 m (optimum)	100m	Quarterly Monthly (optimum)	30 days	0.1-0.5 m/yr (min) <0.1 m/yr (optimum)	0.1 m/yr	-	0.1 m/yr	ERS 1/2, Envisat (relative to a reference DEM)	RA	Greenland	1991-2011
Ice velocity	500 m 50 m (optimum)	1 km	Annual (min) Monthly (optimum)	30 days	30-m/yr (min) 10 m/yr (optimum)	10 m/yr	-	10 m/yr	ERS 1/2, Envisat	SAR offset tracking, DInSAR, AMI	Ice margin, northern drainage basin, Jakobshavn and Upernavik glaciers of Greenland	Various periods between 1991 and present
Calving front location	100-500 m (min) 50 m (optimum)	-	Annual Monthly (optimum)	-	-	-	-		ERS 1/2, Envisat, MERIS, MODIS	SAR, optical data (Manual delineation)	15 outlet glaciers (1/yr), 4 priority outlet glaciers (4/yr) of Greenland	1991 to present
Grounding line location	100 m-1 km (min) 50 m (optimum)	-	Annual (min) Monthly (optimum)	-	-	-	-		ERS 1/2 SAR, Envisat ASAR	InSAR	Big floating glaciers in the North of Greenland	1991 to present

Table 21: Soil Moisture ECV products planned by Soil_Moisture_cci project, their target characteristics, and comparison with GCOS (2011) target requirements.

Variable/ Parameter	Horizontal Resolution		Temporal Resolution		Accuracy (Total error)		Stability (per decade)		Instrument(s) used	FCDR	Time period covered
	CCI	GCOS	CCI	GCOS	CCI	GCOS	CCI	GCOS	CCI	CCI	CCI
Volumetric soil moisture	Merged product, 25 km/0.25°, global coverage	50 km	Daily	Daily	-	$0.04m^3/m^3$	-	0.01 $m^3/m^3/yr$	Passive microwave imagery, SAR, scatterometer	SMMR, SSM/I, TMI, AMSR-E AMI-WS, ASCAT	1979-present

APPENDIX B ESA CCI STRUCTURE (MAY 2011)

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SST_cci	Craig Donlon
Ocean_Colour_cci	Peter Regner
Glaciers_cci	Stephen Plummer
Land_Cover_cci	Olivier Arino
Fire_cci	Stephen Plummer
Sea ice	Pascal Lecomte
Soil Moisture	Pascal Lecomte
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CCI Project Teams:

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University of Valencia, Spain
Rutherford Appleton Laboratory (RAL), UK
University of Oxford, UK
Laboratoire de Météorologie Dynamique (LMD), France
Deutsches Zentrum für Luft- und Raumfahrt (DLR), Germany
University of Bremen, Germany
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Ozone_cci

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Karlsruhe Institute of Technology, Germany
Koninklijk Nederlands Meteorologisch Instituut (KNMI), The Netherlands
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MeteoSwiss, Switzerland
University of Athens, Greece
Rutherford Appleton Laboratory (RAL), UK
Royal Meteorological Institute of Belgium, Belgium
University of Cambridge, UK

Aerosol_cci

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University of Bremen, Germany
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CNRS ICARE Data Center, France
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Belgian Institute for Space Aeronomy, Belgium
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Norwegian Meteorological Institute, Norway
Max-Planck Institute for Meteorology (MPI-M), Germany
Norwegian Institute for Air Research (NILU), Norway
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GHG_cci

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Sea_Level_cci

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SST_cci

Science Lead: Chris Merchant (University of Edinburgh) Prime Contractor: University of Edinburgh, UK Subcontractors: UK Met Office University of Leicester, UK MétéoFrance Danish Meteorological Institute, Denmark Norwegian Meteorological Institute, Norway Brockmann Consult, Germany SpaceConneXions, UK

Ocean_Colour_cci

Science Lead: Shubha Sathyendranath (PML) Prime Contractor: Plymouth Marine Laboratory (PML), UK Subcontractors: NERSC, Norway HYGEOS, France Brockmann Consult, Germany Vega, UK Helmholtz-Zentrum Geesthacht, Germany European Commission Joint Research Centre (EC JRC), Ispra

Glaciers_cci

Science Lead: Frank Paul (University of Zurich) Prime Contractor: University of Zurich, Switzerland Subcontractors: ENVEO, Austria GAMMA AG, Switzerland University of Oslo, Norway University of Leeds, UK University of Bristol, UK

Land_Cover_cci

Science Lead: Pierre Defourny (Université catholique de Louvain)

Prime Contractor: Université catholique de Louvain, Belgium

Subcontractors:
Brockmann Consult, Germany
University of Jena, Germany
Wageningen University, The Netherlands
European Commission Joint Research Centre (EC JRC) Ispra
UK Met Office Hadley Centre
Laboratoire des Sciences du Climat et l'Environnement (LSCE), France
Max Planck Institute for Meteorology (MPI-M), Germany

Fire_cci

Science Lead: Emilio Chuvieco (University of Alcala de Henares)

Prime Contractor: University of Alcala de Henares, Spain

Subcontractors:
GAF AG, Germany
CNRS Institut de recherche pour le développement (IRD), France
FZ Jülich, Germany
Laboratoire des Sciences du Climat et de l'Environnement (LSCE), France
Deutsches Zentrum für Luft- und Raumfahrt (DLR), Germany
Instituto Superior de Agronomia (ISA), Portugal
University of Leicester, UK
GMV Aerospace, Spain

Sea_Ice_cci

Science Lead: Stein Sandven, NERSC, Norway

Prime Contractor: Nansen Environmental and Remote Sensing Centre (NERSC)

Subcontractors:
CGI, UK
Met.no, Norway
DMI, Denmark
FMI, Finland
UCL, UK
University of Cambridge, UK
University of Bremen, Germany
University of Hamburg, Germany
IFREMER, France
MPI-M, Germany

Ice_Sheets_cci

Science Lead: René Forsberg, DTU Space, Denmark Prime Contractor: Space Department, Danish Technical University, Denmark Subcontractors: S[&]T, Norway ENVEO, Germany University of Leeds, UK GEUS, Denmark Niels Bohr Institute, Denmark NERSC, Norway DMI, Denmark

Soil_Moisture_cci

Science Lead: Wolfgang Wagner, TU Wien, Austria Prime Contractor: Technical University, Wien, Austria Subcontractors: GeoVille Information Systems GmbH (GeoVille), Austria Angewandte Wissenschaft Software und Technologie GmbH (AWST), Austria Vrije Universiteit Amsterdam (VUA), The Netherlands Eidgenössische Technische Hochschule Zürich (ETH Zürich), Switzerland Finnish Meteorological Institute (FMI), Finland University College Cork (UCC), Ireland Norwegian Institute for Air Research (NILU), Norway

Climate Modelling User Group (CMUG)

Science Lead: Roger Saunders (UK Met Office Hadley Centre) Prime Contractor: UK Met Office Hadley Centre) Subcontractors: European Centre for Medium-Range Weather Forecasts (ECMWF) Max-Planck Institute for Meteorology (MPI-M), Germany Météo France

APPENDIX C CCI PROJECT INTERFACES TO INT'L PROGRAMMES, WORKING GROUPS AND ORGANIZATIONS

CCI Project	GHG_cci	Ozone_cci	Aerosol_cci	Cloud_cci	SST_cci	Sea_Level_cci	Ocean_Colour__cci	Land_Cover_cci	Fire_cci	Glaciers_cci	Sea_Ice_cci	Ice_Sheets_cci	Soil_Moisture_cci
	IGBP												
AIMES													
SOLAS													
IGAC		●	Aerocom										
ILEAPS	●												
IMBER													
GLP													
LOICZ													
PAGES													
	WCRP/WMO												
CLiC										●	●	●	
CLIVAR						●							
GEWEX			●	●									●
SPARC		CCMVal	CCMVal										
WCRP-M			CMIP5										
WOAP						●							
JCOMM						GLOSS							
GAW	NDACC	NDACC, SHADOZ, WMO-O3-SAG	●										
SCOPE-CM			● tbd	GSICS									
GCW										●	●	●	

CCI Project	GHG_cci	Ozone_cci	Aerosol_cci	Cloud_cci	SST_cci	Sea_Level_cci	Ocean_Colour_cci	Land_Cover_cci	Fire_cci	Glaciers_cci	Sea_Ice_cci	Ice_Sheets_cci	Soil_Moisture_cci
	ESSP												
GCP									● tbd				
GWSP													
GECAFS													
GECHH													
	Other												
UNEP		●											
Aerocom			●										
Int Ozone Comm		●											
TCCON	●												
OSTST						●							
GCOS						OOPC				WGMS			
GHRSST					●								
GODAE Ocean View						●							
Int Ocean Comm						PSMSL							
IOCCG							●						
EUMETSAT		O3SAF	●	CMSAF	OSISAF								
GEO							ChloroGIN SAFARI						
GTOS								GOFC-GOLD	GOFC-GOLD				●
UNFCCC								UN-REDD	UN-REDD				
FAO								●	●				

APPENDIX D ESA REFERENCES

ESA CCI documents used in this report:

ECV project	User Requirements Document (URD)	Product Specification Document (PSD)	Source
Cloud_cci	V1.0 (1 Dec 10)	V1.0 (25 Mar 11)	www.esa-cloud-cci.org: resources: documents (only URD available)
Ozone_cci	V1.1 (29 Apr 11)	V1.1 (29 Apr 11)	www.esa-ozone-cci.org: project content: documents
Aerosol_cci	V1.4 (1 Mar 11)	V1.0 (18 Feb 11)	www.esa-aerosol-cci.org: resources: documents
GHG_cci	V1.0 (3 Feb 11)	V1.3 (14 Feb 11)	www.esa-ghg-cci.org: documents
Sea_Level_cci	V1.1 (4 Mar 11)	V1.0 (4 Mar 11)	www.esa-sealevel.org: resources: documents (only URD available)
SST_cci	V2 (30 Nov 10)	VE (3 Feb 11)	www.esa-sst-org: resources: documents (only URD available)
Ocean_Colour_cci	V1.9 (26 Jan 11)	V1.4 (16 Feb 11)	www.esa-oceancolour-cci.org: resources: documents (only URD available)
Glaciers_cci	V0.8 (5 Mar 11)	n/a	Personal communication
Land_Cover_cci	V2.2 (22 Feb 11)	V0.1 (31 Jan 11)	www.esa-landcover-cci.org: resources: documents: Deliverables (only URD available)
Fire_cci	V2.0 (25 Feb 11)	V1.7 (10 May 11)	www.esa-fire-cci.org: resources: documents
Sea_Ice_cci	V1.0 (1 June 12)	V1.1 (20 Aug 12)	www.esa-sea-ice-cci.org: resources: documents
Ice_Sheets_cci	V1.5 (3 Aug 12)	V1.2 (18 Oct 12)	www.esa-ice-sheets-cci.org: resources: documents
Soil_Moisture_cci	V0.6 (30 Nov 12)	V1.0 (26 Nov 12)	www.esa-aerosol-cci.org: resources: documents
CMUG	V1.32 (22 Feb 11)	-	www.cci-cmug.org: ECV Project Resources

ESA (2009): *ESA CCI Statement of Work 1*, issue 1.4 revision 1 (9 Nov 2009), ESA Reference No. EOP-SEP/SOW/0031-09/SP, http://www.esa-cci.org

APPENDIX E GLOBAL REFERENCES

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CEOS (2006): *Satellite Observation of the Climate System* - The Committee on Earth Observation Satellites (CEOS) Response to the Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC, October 2006. http://www.ceos.org/pages/CEOSResponse_1010A.pdf

GCOS (2004): *Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC*. GCOS-92 (WMO/TD-No 1219). http://www.wmo.ch/pages/prog/gcos/Publications/gcos-92_GIP.pdf

GCOS (2006): *Systematic observation requirements for satellite-based products for climate*. GCOS-107 (WMO/TD No. 1338). http://www.wmo.int/pages/prog/gcos/Publications/gcos-107.pdf

GCOS (2009): *Progress Report on the Implementation of the Global Observing System for Climate in support of the UNFCCC 2004-2008*. GCOS-129 (GOOS-173, GTOS-70, WMO/TD-No. 1489). http://www.wmo.int/pages/prog/gcos/Publications/gcos-129.pdf

GCOS (2010a): *Guideline for the Generation of Datasets and Product Meeting GCOS Requirements*. GCOS-143 (WMO/TD-No. 1530). http://www.wmo.int/pages/prog/gcos/Publications/gcos-143.pdf

GCOS (2010b): *Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC (2010 Update)*. GCOS-138 (GOOS-184, GTOS-76, WMO/TD-No. 1523). http://www.wmo.int/pages/prog/gcos/Publications/gcos-138.pdf

GCOS (2011*): Systematic Observation Requirements for Satellite-Based Data Products for Climate (2011 Update) – Supplemental details to the satellite-based component of the "Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC (2010 Update)"*. GCOS-154 (WMO, December 2011).

Ohring G., Wielicki B., Spencer R., Emery B., and Datla R. (Eds) (2004): *Satellite Instrument Calibration for Measuring Global Climate Change*. National Institute of Standards and Technology, NISTIR-7047, March 2004. http://www.nist.gov/pml/div685/pub/upload/nistir7047.pdf

Ohring G., Wielicki B., Spencer R., Emery B., and Datla R. (2005): *Satellite Instrument Calibration for Measuring Global Climate Change – Report of a Workshop*. Bull. Amer. Met. Soc., September 2005, 1303-1313.

WMO (2011a): *Database of Observational Requirements* (Last update: 1 March 2011). http://www.wmo.int/pages/prog/sat/Databases.html

APPENDIX F CEOS DATA PROCESSING LEVEL DEFINITIONS

- Level 0 – Reconstructed unprocessed instrument data at full space time resolution with all available supplemental information to be used in subsequent processing (e.g. ephemeris, health and safety) appended.

- Level 1 – Unpacked, reformatted level 0 data, with all supplemental information to be used in subsequent processing appended. Optional radiometric and geometric correction applied to produce parameters in physical units. Data generally presented as full time/space resolution. A wide variety of sub level products are possible.

- Level 2 – Retrieved environmental variables (e.g. ocean wave height, soil moisture, ice concentration) at the same resolution and location as the level 1 source data.

- Level 3 – Data or retrieved environmental variables which have been spatially and/or temporally re-sampled (i.e. derived from level 1 or 2 products). Such re-sampling may include averaging and compositing.

- Level 4 – Model output or results from analyses of lower level data (i.e. variables that are not directly measured by the instruments, but are derived from these measurements).

Reference:

CEOS (2008): *Interoperability Handbook, Issue 1.1*, Working Group on Information Systems and Services, Committee on Earth Observation Satellites, February 2008
http://www.ceos.org/images/WGISS/Documents/Handbook.pdf

APPENDIX G GLOSSARY OF ACRONYMS

AATSR	Advanced Along Track Scanning Radiometer
ACE-FTS	Atmospheric Chemistry Experiment – Fourier Transform Spectrometer
ACOS	Atmospheric CO2 Observations from Space
AeroCOM	Aerosol Comparisons between Observations and Models
AERONET	Aerosol Robotic Network
AIMES	Analysis, Integration and Modelling of the Earth System
ALOS	Advanced Land Observation Satellite
AMSR	Advanced Microwave Scanning Radiometer
AOD	Aerosol Optical Depth
ARC	AATSR Reprocessing for Climate
ARPEGE	Action de Recherche Petite Echelle Grande Echelle
ASAR	Advanced Synthetic Aperture Radar
ASTER	Advanced Space-borne Thermal Emission and Reflection Radiometer
ATSR	Along-Track Scanning Radiometer
AVHRR	Advanced Very High Resolution Radiometer
BIRA-IASB	Belgian Institute for Space Aeronomy
CCI	Climate Change Initiative
CCM	Chemistry-Climate Model
CCMVal	Chemistry-Climate Model Validation Activity for SPARC
CEOS	Committee on Earth Observation Satellites
ChloroGIN	Chlorophyll Global Integrated Network
CLiC	Climate and Cryosphere Project
CLIVAR	Climate Variability and Predictability
CM SAF	Climate Monitoring Satellite Application Facility
CMIP5	Coupled Model Intercomparison Project Phase 5
CMSAF	EUMETSAT Satellite Applications Facility on Climate Monitoring
CMUG	Climate Modelling User Group
CORDEX	Coordinated Regional Climate Downscaling Experiment
CNRM-CM	Centre National de Recherches Météorologiques – Climate Model
CZCS	Coastal Zone Color Scanner
CryoSat	Cryosphere Satellite
DEM	Digital Elevation Model
DGVM	Dynamic Global Vegetation Models
DLR	Deutsches Zentrum für Luft- und Raumfahrt
DU	Dobson Unit
DWD	Deutscher Wetterdienst
EC	European Commission
ECHAM	European Centre Hamburg Model
EC JRC	European Commission Joint Research Centre
ECMWF	European Centre for Medium-Range Weather Forecasts
ECV	Essential Climate Variable
ENVISAT	Environmental Satellite
EO	Earth Observation
ERA	ECMWF Reanalysis
ERS	European Remote Sensing Satellite
ESM	Earth System Model
ESSP	Earth System Science Partnership
ETM	Enhanced Thematic Mapper (Landsat)
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FAO	Food and Agriculture Organization of the United Nations
FAPAR	Fraction of Absorbed Photosynthetically Active Radiation

FCDR	Fundamental Climate Data Record
FMI	Finnish Meteorological Institute
FOAM	Forecasting Ocean Assimilation Model
FTS	Fourier Transform Spectrometer
GAC	AVHRR Global Area Coverage
GAW	Global Atmosphere Watch
GCOS	Global Climate Observing System
GCM	Global Circulation Model
GCP	Global Carbon Project
GCW	Global Cryosphere Watch
GEMS	Global and regional Earth-system (Atmosphere) Monitoring using Satellite and in-situ data
GEO	Group on Earth Observations
GFO	GEOSAT Follow-on Altimeter
GECAFS	Global Environmental Consequences for Agriculture and Food Security
GECHH	Global Environmental Consequences for Human Health
GEWEX	Global Energy and Water Cycle Experiment
GHG	Greenhouse Gas
GHRSST	Group for High-Resolution SST
GMES	Global Monitoring for Environment and Security
GLIMS	Global Land Ice Monitoring from Space
GLOSS	Global Sea-Level Observing System
GLP	Global Land Project
GODAE	Global Ocean Data Assimilation Experiment
GOFC-GOLD	Global Observation of Forest and Land Cover Dynamics
GOME	Global Ozone Monitoring Experiment
GOMOS	Global Ozone Monitoring by Occultation of Stars
GOSAT	Greenhouse Gases Observing Satellites
GSICS	Global Space-based Inter-Calibration System
GTOS	Global Terrestrial Observing System
GWSP	Global Water Systems Project
HadGEM	Hadley Centre Global Environment Model
HadSST	Hadley Centre Sea Surface Temperature Dataset
IASI	Infrared Atmospheric Sounding Interferometer
ICESat	Ice, Cloud and Land Elevation Satellite
IGAC	International Global Atmospheric Chemistry
IGACO	Integrated Global Atmospheric Chemistry Observations
IGBP	International Geosphere-Biosphere Programme
IGOS	Integrated Global Observing Strategy
IFS	Integrated Forecast System
ILEAPS	Integrated Land Ecosystem Atmosphere Study
IMBER	Integrated Marine Biogeochemistry and Ecosystem Research
Int Ocean Comm	Intergovernmental Oceanographic Commission
Int Ozone Comm	International Ozone Commission
IOCCG	International Ocean Colour Coordinating Group
IPCC	Intergovernmental Panel on Climate Change
IR	Infrared
JAXA	Japan Aerospace Exploration Agency
JCOMM	Joint Technical Commission for Oceanography and Marine Meteorology
JSBACH	Jena Scheme for Biosphere-Atmosphere Coupling in Hamburg
LAI	Leaf Area Index
LEGOS-CNES	Laboratoire d'Etudes en Géophysique et Océanographie Spatiale – Centre National de la Recherche Scientifique (French National Centre for Scientific Research)
LCCS	UN Land Cover Classification System
LIDAR	Light Detection and Ranging

LOICZ	Land Ocean Interactions in the Coastal Zone
MACC	Monitoring Atmospheric Composition and Climate
MERIS	Medium Resolution Imaging Spectrometer
METOP	Meteorological Operational Polar Satellite
MIPAS	Michelson Interferometer for Passive Atmospheric Sounding
MOCAGE	Modèle de Chimie Atmosphérique de Grande Echelle
MODIS	Moderate Resolution Imaging Spectroradiometer
MPI	Max Planck Institute
MS	Member States (of ESA)
MSU	Microwave Sounding Unit
MW	Microwave
NASA	National Aeronautics and Space Administration
NDACC	Network for the Detection of Atmospheric Composition Change
NIES	Japan National Institute for Environmental Studies
NIR	Near Infrared
NOAA	National Oceanic and Atmospheric Administration
NWP	Numerical Weather Prediction
O3SAF	EUMETSAT Satellite Applications Facility on Ozone and Atmospheric Chemistry Monitoring
OOPC	Ocean Observations Panel for Climate
OSISAF	EUMETSAT Satellite Applications Facility on Ocean and Sea Ice
PAGES	Past Global Changes
PALSAR	Phased Array type L-band SAR
PARASOL	Polarization and Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar
POLDER	Polarization and Directionality of the Earth's Reflectances
PROMOTE	Protocol Monitoring for the GMES Service Element: Atmosphere
PSD	Product Specification Document
PSMSL	Permanent Service for Mean Sea Level
OMI	Ozone Monitoring Instrument
RA	Radar Altimeter
RCM	Regional Climate Model
RRR	Rolling Review of Requirements
SAR	Synthetic Aperture Radar
SAFARI	Societal Applications in Fisheries and Aquaculture using Remotely-sensed Imagery
SCIAMACHY	Scanning Imaging Absorption Spectrometer for Atmospheric Cartography
SCOPE-CM	Sustained, Co-Ordinated Processing of Environmental Satellite Data for Climate Monitoring
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SEVIRI	Spinning Enhanced Visible and Infrared Imager
SHADOZ	Southern Hemisphere Additional Ozonesondes Network
SOLAS	Surface Ocean Lower Atmosphere Study
SPARC	Stratospheric Processes And their Role in Climate Change
SPOT (VGT, HRV)	Satellite Pour l'Observation de la Terre (Végétation, Haute Résolution)
SRTM	Shuttle Radar Topography Mission
SSA	Single Scattering Albedo
SST	Sea Surface Temperature
SWIR	Shortwave Infrared
TANSO-FTS	Thermal And Near infrared Sensor for carbon Observation - Fourier Transform Spectrometer
TCCON	Total Carbon Column Observing Network
TIR	Thermal Infrared
TM	Thematic Mapper
TOMS	Total Ozone Mapping Spectrometer
Topex/Poseidon	Ocean Surface Topography Experiment

TMI	TRMM Microwave Imager
TRMM	Tropical Rainfall Measuring Mission
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UN-REDD	The United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries
URD	User Requirements Document
UTLS	Upper Troposphere Lower Stratosphere Region
UV	Ultraviolet
VIS	Visible
WCRP	World Climate Research Programme
WCRP-M	WCRP Modelling Theme
WGCM	WCRP/CLIVAR Working Group on Coupled Modelling
WGMS	World Glacier Monitoring Service
WMO	World Meteorological Organization
WMO-O3-SAG	WMO Scientific Advisory Group for Ozone
WOAP	WCRP Observations and Assimilation Panel