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ESA CLIMATE CHANGE INITIATIVE

CCI PROJECT GUIDELINES

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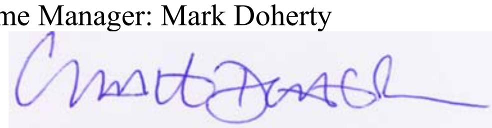

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1 Scope

This document is summarize the outcome of the first collocation meeting of the ESA Climate Change Initiative, held at ESA ESRIN, Frascati, Italy 12th-15th September 2010.

The collocation meeting brought together representatives of all eleven CCI project teams, to discuss issue of common interest to all. The collocation had three major objectives

- To orient all project teams to common objectives
- To activate interactions between the project teams
- To prepare joint communication with the international science community

The output of the collocation is here recorded as a series of recommendations, as formulated by the collocation participants, drawing upon the collective expertise of all CCI projects teams.

These guidelines are intended to assist the CCI teams to implement their projects and generate ECV data products in a consistent manner, as explicitly required by GCOS.

2 Introduction

The CCI programme objectives and scope are described in the document "ESA Climate Change Initiative: Description [EOP-SEP/TN/0030-09/SP] "[1]

The work to be carried out on each ECV is specified in the Statement of Work for the CCI "ESA Climate Change Initiative Phase 1: Scientific User Consultation and Detailed Specification [EOP-SEP/SOW/0031-09/SP]"[2]

The first tender of the CCI programme resulted in the projects for the following ten ECVs:

GCOS ECV	CCI Project	Science Leader
A.4	Cloud_cci	Deutscher Wetterdienst (*R.Hollmann*)
A.7	Ozone_cci	BIRA-IASB (*M. Van Roozendael*)
A.8	Aerosol_cci	DLR / FMI (*T Holzer-Popp / G.De Leeuw*)
A.9	GHG_cci	U.Bremen IUP (*M.Buchwitz*)
O.2	Sea_Level_cci	LEGOS-CNES (*A Cazenave*)
O.3	SST_cci	U. Edinburgh (*C Merchant*)
O.4	Ocean_Colour_cci	Plymouth Marine Laboratory (*S. Sathyendranath*)
T.2.1	Glaciers_cci	U. Zurich (*F.Paul*)
T.5.1	Landcover_cci	Université Catholique de Louvain (*P.Defourney*)
T.9	Fire_cci	U. Alcala (*E.Chuvieco*)

[1] http://earth.eo.esa.int/workshops/esa_cci/ESA_CCI_Description.pdf
[2] http://earth.eo.esa.int/workshops/esa_cci/ao6207SoW.pdf

No proposal has yet been selected for sea-ice.

The project scope and team composition for each of these projects is described in the document "ESA CCI Projects Description".

Each CCI project team typically includes experts from ten or more research organizations. Each team has a sub-group with specialist scientific expertise in EO, a sub-group specialised in climate research and modelling, and a sub-group of system engineering experts.

Each team has a science leader, who will ensure the overall scientific integrity of the project throughout the next three years. The science leader will also ensure that each CCI project maintains effective working links to the appropriate international climate science programmes, initiatives and projects, and to other CCI project teams. Each science leader is directly supported by a project manager who will ensure communication within the project team, maintenance of schedule, tracking of actions, deliverables and reporting to ESA.

All ten projects will work in parallel on the following tasks during the next three years

- Requirements Analysis and Product Specification
- Algorithm Development, inter-comparison and Selection
- System Prototyping and ECV production
- Final Product Validation and User Assessment
- System Specifications
- Project Management

Each team will develop and inter-compare algorithms, and produce, validate and characterize, global satellite-based data sets responding to the GCOS requirements for a given ECV.

Each team will deliver a standard set of documents which, after internal review by the project team and acceptance by the ESA, will be made publicly available, as a way of stimulating feedback and facilitating cooperation with other scientific teams.

Each team will set-up a project web site with all information needed to ensure coordination and consistency with related projects. Each web site will provide open access to data products and project documents.

The CCI project deliverables (data, quality, cal/val, documentation, review, open access) have been specified in accordance with the "Guideline for the Generation of Satellite-based Datasets and Products meeting GCOS Requirements" (GCOS-129, March 2009).

3 User requirements and feedback to GCOS

3.1 Introduction

The development of the Climate Change Initiative (CCI) products is to be driven by Global Climate Observing System (GCOS) needs and climate user requirements[3].

The process of assessing user requirements, providing recommendations and setting priorities that feed into the product specifications should follow the guidance presented below, common to all CCI team efforts to collate, harmonize, publish, update and manage the user interaction process and to feed back into the GCOS process.

User requirements commonly evolve and cooperation with users is a continuous process that requires regular updates and should accommodate different scenarios of user requirements for different applications, user groups, and at different points in time.

Recommendation: UR-1

It is important to provide both the technical specification and the rationale of how and why these requirements have been defined.

3.2 Process of assessing the user requirements for the CCI datasets

The Committee on Earth Observing Satellites (CEOS) GCOS user requirements[1] database and GCOS implementation plan reports are used as a reference. The GCOS requirements have threshold, breakthrough and goal values specified and pertain to a restricted set of applications. They serve as reference to define the anticipated contribution of each CCI project in terms of its dataset characteristics. The requirements for model validation, development and long term monitoring can be different and should be specified differently for some ECVs.

The Climate Modelling Users Group (CMUG) is refining GCOS requirements by consulting the climate modelling community through various means (e.g. questionnaire, workshop, interviewing experts) for each ECV. They then specify a set of requirements for the various climate modelling

3 'Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC', up-dated August 2010; “Guideline for the Generation of Datasets and Products Meeting GCOS Requirements”, in May 2010; “Guideline for the Generation of Satellite-based Datasets and Products meeting GCOS Requirements”. All reports are available under http://www.wmo.int/pages/prog/gcos/index.php. There will be an up-date of the ”Systematic Observation Requirements for Satellite-based Products for Climate Supplemental details to the satellite-based component of the Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC” in January 2011.

applications which include model development, model validation, model initialisation, definition of boundary conditions and data assimilation. The CMUG are doing an analysis of their requirements by comparing with the original baseline from GCOS and highlighting where there are differences. The results are published in their URD report which is updated periodically and made available on the CMUG website.

The CCI projects themselves will undertake their own more detailed user surveys to gather requirements for each ECV from a broader set of climate users, not only the climate modellers. The CMUG will undertake a review of all the CCI URDs by comparing them with their own URD and the GCOS requirements. The CMUG will then advise ESA of their overall analysis of the user requirements which will take into account the GCOS reference, their own and the CCI proposals. Any significant discrepancies between the CMUG and CCI requirements will then need to be addressed by ESA and through CMUG-CCI meetings.

3.3 Assessing the strength of user needs

Understanding why potential users will have specific needs in three to five years' time and the consequences of not meeting a particular need will help in gauging the strength of each requirement.

Recommendation UR-2

Discussion with users to allow an assessment of the importance of a specific requirement by a particular application is recommended.

It can be a difficult task for users to assess some of their future requirements. Review of the User Requirements Document (URD) by those canvassed will prompt critical appraisal of their statements in light of those of their peers. Review by panels relating to each user application, but independent from the potential users surveyed will also ensure robustness of conclusions. Open review provides opportunities for further improvements.

Recommendation UR-3

Ensure review of User Requirements Document by potential users, related bodies and interested parties to refine assessment of the strength of the requirements.

Decisions will need to be made at later stages in translating the URD to a product specification document. Retention of full transcripts of user questionnaire responses/potential user interactions with names (where permitted) and types of application associated will ensure traceability of requirements to particular applications and facilitate good decision making.

Recommendation UR-4

Retain full records of all user interactions to ensure traceability of requirements.

3.4 GCOS Principles

The Implementation Plan and its Satellite Supplement are part of a continuous review and assessment cycle, which leads into a report on progress of the required actions. The GCOS science panels for the atmosphere, land and ocean review the principles of climate observations.

In a letter[4], GCOS and WCRP are asking the worldwide organizations to support the international expert groups involved in scientific analysis, intercomparison and peer-review options of climate data records. Such effort is essential for world-class climate science and sound decision-making. The letter calls, inter alia, for adherence by groups and institutions involved in climate data record generation to the new Guideline for the Generation of Datasets and Products Meeting GCOS Requirements5, to support transparency, traceability and scientific review.

Recommedation UR-5

Provide input to and participate in GCOS reviews, e.g. by providing detailed feedback on applicability and achievability of GCOS user requirements in co-location and CMUG meetings.

3.5 Robustness of requirements

The combination of requirements gathered by GCOS, the CMUG and CCI ECV projects, lead to the following recommendations and considerations on their expected robustness:
It is expected that in Phase 1 of the CCI projects the robustness of the recommendations will be thoroughly tested (as discussed above) and would result in useful feedback to the GCOS process.

It is acknowledged that in some cases the product specifications resulting from the CCI projects will not reach the stringent GCOS requirements, although it is in general believed that the improved products are nonetheless of value to the climate modelling community as in many cases the CCI products will provide for the first time uncertainty estimates with their products. There are

[4] Available under: http://www.wmo.int/pages/prog/gcos/index.php
[5] Available under: http://www.wmo.int/pages/prog/gcos/index.php

also specific cases where the definition of the ECV itself by GCOS may influence the capability of the CCI project to meet the GCOS requirements.

Additionally it is recognized that the GCOS requirements are not solely based on requirements from the climate modelling community but also from climate scientists looking at trends in observational data, climate impacts etc.

Recommendation UR-6

A standard template should defined, providing specific sets of requirements for specific applications along with their rationale and provided to the CCI teams by early October.

As we foresee that recommendations themselves may evolve,

Recommendation UR-7

Requirements coming from CMUG and individual CCI projects should be combined into overall requirements that will improve consistency across ECVs.

3.6 Translating from URD to Product Specification

Clearly, not every requirement can be met and pragmatic choices have to be made in translating from the URD to the Product Specification Document (PSD). The CCI products could also be very useful for those in communities outside of climate research, but the role of the CCI is to develop ECV products that meet the needs of GCOS. It is important to be very clear about the rationale behind the choices made.

Recommendation UR-8

A section should be included in the Product Specifications Document to clearly document the decisions for the choices made in translating user requirements into product specification.

4 Round-Robin algorithm inter-comparison and selection

4.1 How to select the 'best' algorithm?

What is 'best'?

Recommendation RR-1

The meaning of the 'best' algorithm and of how to select it (evaluation protocol) has to be defined before the start of the Round Robin exercise. The definition of 'best' and the scope of the Round Robin exercise have to be specified in the Product Validation Plan (PVP).

The definition of what is best may differ for different products and should be given in the context of the CCI objectives. Examples of criteria that could be applied to determine what is best are:

- Validation, criteria which are specified in the PVP: best in a statistical meaning from comparison with independent determinations of the same variable
- Error characterization: smallest error
- Processing time: fast enough to produce reasonable results in a reasonable time
- Climate relevance
- Maturity of the algorithm: published and peer-reviewed
- Best for the application: algorithms may be more suitable in different conditions or environments: land / ocean or other surface conditions; day / night; etc.

Algorithm selection:

Recommendation RR-2

The Round Robin should be made at the beginning of the project based on objective criteria. There should be one or more iterations to show algorithm improvement throughout the project. The most objective algorithm selection would be based on blind testing to avoid any bias.

Which algorithms are included?

Recommendation ?
Not all algorithms are included. Some CCI's have proposed options to include other algorithms. It is understood that the Round Robin will be open (see further below):

- Results are public
- Data are public

- Criteria must be documented and transparent

4.2 Is the Round Robin real?

Recommendation RR-3

Every CCI project has to perform a Round Robin exercise. In the exceptional case that a final algorithm has been pre-selected, separate modules need to be tested also for this pre-selected algorithm. Furthermore, the pre-selection criteria should be in line with the CCI objectives.

For some CCI products extensive inter-comparisons have recently been made (e.g. GEWEX for clouds) and there is no need to duplicate the effort to provide a baseline.

Only an honest round robin can identify strengths and weaknesses in the individual algorithms. The iterations show algorithm improvement in the course of the CCI.

4.3 How to create a common environment to enable consistent algorithm inter-comparison?

Recommendation RR-4

The same auxiliary and Level 1 data should be used in the processing, as well as the same reference data.

The latter could include (list not exclusive):

- Synthetic data
- High quality independent measurements, e.g., ground based
- Model results

The reference data need to be representative for the cci products and must cover a wide range of conditions of climatological relevance: long-term, geophysical parameters, seasonality, etc. The same formats must be used for the presentation of the round robin output to facilitate easy comparison of the results and avoid unnecessary software development.

4.4 Is the Round Robin really open and are external participants involved?

Recommendation RR-5

The round robin results need to be open and the algorithm must be well-documented and public, but the actual code does not need to be public.

External participants are encouraged to participate in the Round Robin exercise on the condition that they comply to the rules that:

- the algorithm must be well-documented and public
- they provide results in the agreed data format
- input is timely delivered
- no financial support will be given from the cci project
- there is no extra effort from the cci partners other than inclusion of the results in the round robin data base

Recommendation RR-6

The algorithm selection should be made by an independent team that is not directly involved in the algorithm development, although of course the members of that team should be experts. The selection shall be made based on a Round Robin evaluation protocol developed beforehand and providing objective criteria.

4.5 Which tools do already exist – do we need new ones?

Recommendation RR-7

The development of new tools should only be considered when really needed and no good tools for the purpose are available.

Tools will be used for data ingestion, processing and graphical display and other tool swill be used for data intercomparion (with a possible link t validation activities). However, all teams and partners and ESA have tools but it takes manpower to sue and maintain them. Therefore the development of new tools should only be considered when really needed and no good tools for the purpose are available.

Summary:

- Define the criteria for what means ‘best’ before the start of the Round Robin.
- Baseline round robin and one or more iterations to show improvement.
- Algorithm selection should be based on blind testing by independent team not involved in algorithm development.
- Round Robin criteria must be documented and transparent.
- Round Robin exercises should be made in all cci, also for pre-selected (according to cci objectives) algorithms for which modules need to be tested to show strengths, weaknesses and improvement.
- Use of the same auxiliary and reference data in the Round Robin exercise.
- Ensure that the same Level 1 data are used when comparing algorithms applied to the same instrument.
- Provide results in a common output format.
- Round Robin results will be open and participating algorithms must be well-documented and public
- The Round Robin is open to external participants provided that there is no extra effort for the cci partners
- A Round Robin algorithm evaluation protocol needs to be developed
- New tools for data ingestion or data comparison should only be developed when there is a real need.

5 Validation

5.1 Introduction

A critical step in the acceptance of the CCI products by the GCOS and CMC communities is providing confidence in the quality of each CCI product and its uncertainties through validation against independent data such as ground based reference measurements or alternate estimates from other projects and sensors.

Owing to time constraints consideration was only given to validation of Level 2 products. Further discussions are needed regarding validation of Level 1 and Level3 & higher products.

5.2 Definition

What is validation?
It was clear that a common definition of validation was needed to facilitate consistency across each CCI project. There are several definitions of validation available from various agencies, and it was agreed that the Committee on Earth Observing Satellites Working Group on Calibration and Validation (CEOS-WGCV) definition would be adopted within the CCI programme, which defines validation as:

> ***"The process of assessing, by independent means, the quality of the data products derived from the system outputs".***

It is assumed that the term *data product* in the above definition refers to both the geophysical parameter and its uncertainties, so it is vital that all available information on data uncertainty is used and validated.

Recommendation V-1

All CCI projects should use the definition of validation approved by the CEOS-WGCV.

5.3 Independence

How do we ensure that the validation of ECV data products is truly independent?

The CCI project will produce a set of output products that require validation, including in particular, any associated quality indicators and uncertainties. Ideally the validation process should follow clearly defined protocols and should be independent from the production process. The independence of the validation process should follow three requirements:

1. CCI project teams shall use, for validation, in situ or other suitable reference datasets that have not been used during the production of their CCI products.

2. CCI project teams shall consider the independence of the geophysical process and ensure that if a particular auxiliary dataset is used in the production of their CCI products then the same dataset is not used in the validation and, if required, alternative auxiliary data are used.

3. CCI project teams shall ensure that the validation is carried out (or at least verified) by staff not involved in the final algorithm selection; ideally the validation of the CCI products should be carried out by external parties, i.e. by staff / institutions not involved in the production of the ECVs products.

Recommendation V-2

All CCI project Product Validation Plans (PVP) shall adhere to the above three requirements regarding independence.

5.4 Protocols

Do we need new protocols for the validation of ECV data products?

There is a large spread of topics and retrieved climate variables within the CCI project. Consequently, the user communities have diverse requirements and different indicators/measurements are needed to express the quality and usefulness of a derived product. Therefore the validation protocol will differ from ECV to ECV and individual CCI project teams have already developed adequate validation procedures for their particular ECV. A point, which is as important as the specific protocol, is traceability. Only a transparent traceable validation procedure will be accepted by the user community and is mandatory for the CCI project. This is especially important for validation procedures which rely on statistical quantities going beyond relative simple statistical measures such as bias and standard deviation. Long term stability requirements, representation errors, spatio/temporal error correlations, or regional relative biases are examples in this context. For land products for example, the CCI project could follow terminology approved by the CEOS Land Product Validation Subgroup (LPVS: http://lpvs.gsfc.nasa.gov/).

Recommendation V-3

The CCI consortia shall use established, community accepted, traceable validation protocols where they exist. If such protocols do not exist then CCI projects may adapt existing protocols if appropriate and in any event shall offer their final protocol for future community acceptance.

5.5 Datasets

How do you select datasets for validation?

Every CCI output product requires some form of validation. However, it is clear that unique independent reference data may not always be available. Data for validation should be selected to ensure complete coverage of the various spatial and temporal scales in each CCI product. Therefore, the selection of validation data sets should follow different levels of rigour depending on the level of independence of each data set, thus making sure that some level of confidence can be given to every output product. Each CCI product should contain an indication of the level (or confidence) in the data quality resulting from the validation process.
Possible levels may include validation with:

1. Independent in situ data (the 'true' reference dataset)
2. Other in situ data
3. Large scale comparisons with other satellite datasets
4. Large scale comparisons with historic datasets, climatologies
5. Impact studies using other CCI products

This approach (levels of validation) is adopted by the CEOS-LPVS (see Section 3) who have a four level approach to validation that depends on the temporal and spatial coverage of available reference data, thus providing a confidence estimate in each product even where little if any in situ data exists.

Recommendation V-4

Each CCI project shall select appropriate validation data to ensure that an adequate level of validation (confidence) is applied to all output products. The level of validation (confidence) should be indicated in the output product.

5.6 Infrastructure

What current infrastructure do we have for validation today, can efforts/tools be shared across ECVs, and is new infrastructure (data, archives, etc.) needed to meet ECV requirements?

Currently, each CCI project has its own specificities in terms of ECVs and thus of validation datasets and protocols. In the first year, each team will re-use their existing validation infrastructure based on their expertise and needs. It is anticipated, as progress is made by each consortium (delivery of the PVP, definition of archived data to collect, etc.), that new validation requirements emerge and/or overlap across other ECVs. The need for a common centralized infrastructure (possibly hosted or elaborated by CMUG) to store validation (including common reference data available from other space agencies and previous ESA activities) and ancillary datasets should be carefully examined. Each CCI team is asked to keep in mind requirements of openness and possible sharing when further developing its validation infrastructure and to specifically examine common opportunities / synergies at the next co-location meeting.

Recommendation V-5

The CCI programme should hold a dedicated session (or workshop) on common validation infrastructure during (or prior to) the next co-location meeting.

5.7 Ultimate goal

When is an ECV data product considered "validated"?

To assure the quality of an ECV data product, and that the product specifications are reached, a validation process shall be performed. The validation is an ongoing process that shall take into account requirements and responses from users. The validation process is unique to each CCI project and must be fully documented in the PVP. The validation process should use approved community protocols where they exist and must be fully traceable and subject to scrutiny by peer-review.

Recommendation V-6

The PVP shall fully describe the validation process for each CCI project. An independent international review board of experts should be invited to review the PVP of each project team. Each CCI project should involve experts from the CMUG throughout their validation activities. A CCI product will be deemed to be validated once all steps of the validation process documented in the PVP have been completed and documented accordingly.

6 Uncertainty characterization

6.1 Common Definition of Terms

Recommendation UC-1

All CCI projects should use the same definition of terms in their work on Uncertainty Characterisation.

The following example text could be used as Section 2 of the 'Uncertainty Characterization Document'. If individual CCI project teams chose to provide their own Section 2 they should not modify the given definitions.

Describing error and uncertainty

A measurement is a set of operations having the object of determining the value of a quantity. Following BIPM (2008) it is helpful to define the term measurand as

- **Measurand:** particular quantity subject to measurement

so that the phrases 'true value of a quantity' and value of the measurand are synonymous.
Very few instruments directly measure the measurand. Generally an instrument reports the effect of a quantity from which the magnitude of the measurand is estimated. As an example, an instrument sensitive to infrared light might be used to measure the temperature of an object.
The process of measurement is inexact, so that difference between a measured value and the value of the measurand is called the error. Traditionally (e.g. Beers, 1975) the word 'error' has also meant a numerical value that estimates the variability of the error if a measurement is repeated (i.e. a width of the distribution of possible errors). This dual meaning of "error" can lead to confusion or ambiguity. To separate these meanings and avoid confusion the BIPM (2008) definitions are used, i.e.

- **Error (of measurement)**: result of a measurement minus a true value of the measurand

- **Uncertainty (of measurement)**: is a parameter, associated with the result of a measurement that characterizes the dispersion of the values that could reasonably be attributed to the measurand.

Except in a few cases the "true" value of the error is not known, and the magnitude of the error is hypothetical. An error is viewed as having a random component and a systematic component. Following BIPM (2008) the definitions of these terms are:

- **Random error:** result of a measurement minus the mean that would result from an infinite number of measurements of the same measurand carried out under repeatable conditions,

- **Systematic error:** mean that would result from an infinite number of measurements of the same measurand carried out under repeatable conditions minus the true value of the measurand.

In general terms the random error is variable from measurement to measurement, whereas the systematic error is the same for each measurement. Although it is not possible to compensate for the random error, its effect on uncertainty in our estimate of the measurand can usually be reduced by averaging over a number of independent repeat observations.

The statistical distribution of random error can be described by a probability density function (pdf) of which the **expected value** (i.e., the average over the pdf) is zero. As the random error often arises from the addition of many effects the central limit theorem suggests that a Gaussian distribution is a good representation of this pdf. Therefore the random uncertainty value commonly adopted for a single observation is equal to the one-sigma standard deviation that would be obtained from repeated measurements of the same quantity under the same conditions. If N repeated uncorrelated observations are available, the random uncertainty is the one-sigma standard deviation multiplied by a factor of $1/\sqrt{N}$ (under the Gaussian assumption). The smallest possible change in value that can be observed can be taken as ½ the uncertainty. This value can also be used as the detection limit of the instrument.

The total uncertainty attributed is the combination of this random uncertainty and systematic uncertainty. Often a correction can be applied to compensate for the systematic effects. It is assumed that correction is done such that, after correction, the expected value of the error arising from a systematic effect is zero. A systematic uncertainty remains, however, characterized by the uncertainty in the correction.

There are many reasons why a measurement[6] is uncertain. For example, error components in satellite remote sensing may include terms such as

- instrument noise,
- error arising from simplifications in radiative transfer,
- calibration error,
- geolocation/interpolation error,
- error arising from the uncertainty in parameters used to derive the measurement.

[6] Measurement here is used to include satellite retrievals (estimates by some process of inversion) of measurands, although by some strict usage of "measurement", it is typically radiance that a sensor on a satellite actually measures.

An **Uncertainty budget** is a list of random and systematic errors with estimates of the uncertainty they contribute to the measurement (preferably with information about how component uncertainties combine). Standard methods of error propagation (e.g. Hughes and Hase, 2010) are used to transform uncertainties into measurement units. The total uncertainty is the total combined accounting for any correlation between component errors.
In some cases the measurement process returns a vector of measurands. The error between the components of the measurand may not be independent so is represented by an uncertainty covariance matrix defined by:

$$\text{uncertainty covariance matrix} = \begin{bmatrix} \langle\epsilon_1\epsilon_1\rangle & \langle\epsilon_1\epsilon_2\rangle & \cdots & \langle\epsilon_1\epsilon_n\rangle \\ \langle\epsilon_2\epsilon_1\rangle & \langle\epsilon_2\epsilon_2\rangle & \cdots & \langle\epsilon_2\epsilon_n\rangle \\ \vdots & \vdots & & \vdots \\ \langle\epsilon_n\epsilon_1\rangle & \langle\epsilon_n\epsilon_2\rangle & \cdots & \langle\epsilon_n\epsilon_n\rangle \end{bmatrix}$$

where ε_i denotes the error on the i^{th} measurand and <ab> denotes the expectation value of ab. If the measurands are independent then the off-diagonal terms are zero and the uncertainty on each measurand is given by the square-root of the corresponding diagonal element. For vector measurements, the uncertainty budget is a list of random and systematic errors with estimates of their associated uncertainty covariance matrices.

Two qualitative terms not defined in BIPM (2008) but commonly used to describe a measurement (e.g. Beers, 1957, Hughes and Hase, 2010) are precision and accuracy defined here as:

- **precision**: a measurement which has a small random uncertainty is said to have high precision

- **accuracy**: a measurement which has a small systematic uncertainty is said to have high accuracy

Validation of Measurements

Validation is the assessment of a measurement and the uncertainty attributed to it. This is principally achieved by **external validation,** i.e. comparison of a measurement to an independent measurement and assessment of their consistency relative to their estimated uncertainties. This independent estimate of the measurand is termed the **validation value**. The discrepancy is then defined as

- **discrepancy:** the difference between the measurement and the validation value

A small average discrepancy with respect to the root-sum-square of the measurement and validation value uncertainties is indicative of an accurate measurement, but could also result from a fortuitous cancellation of error terms.

For a small number of measurements it is possible to report individual discrepancies. However, for the large number of measurements typical of satellite remote sensing validation involves statistically characterising the discrepancies. There are often regimes of instrument behaviour for which uncertainties can be expected to differ, so it is usual to characterize discrepancies for the minimum number of regimes of consistent instrument behaviour. The choice of regimes could come from a cluster analysis of discrepancy (if the difference in regimes causes differences in systematic error), but more commonly comes from knowledge of the measurement process.

The statistical characterization of the discrepancies within a regime is made through three **quality parameters.** Consider the set of *n* measurements $\{x_1 \pm \delta x_1, x_2 \pm \delta x_2, x_3 \pm \delta x_3, \dots x_n \pm \delta x_n\}$ of some quantity together with the set of validation values $\{v_1 \pm \delta v_1, v_2 \pm \delta v_2, v_3 \pm \delta v_3, \dots v_n \pm \delta v_n\}$ made of the same quantity. The quality parameters are then:

- **Bias:** the mean value of the discrepancy, i.e.:

$$\text{bias} = b = \frac{\sum_{i=1}^{n} (x_i - v_i)}{n}$$

- **Chi-squared:** the goodness of fit between the actual and estimated uncertainties of measurement and validation values, defined by:

$$\chi^2 = \frac{1}{n} \sum_{i=1}^{n} \frac{(x_i - v_i)^2}{\delta x_i^2 + \delta v_i^2}$$

- **Stability**: the change in bias with time defined as:

$$\text{stability} = \frac{b(t+\Delta t) - b(t)}{\Delta t}$$

The expectation value of the bias is the sum of the residual systematic errors in the measurement and the validation value. The bias can only be attributed to the measurement if the residual systematic error in the validation value is known a priori. In an ideal case the bias would be zero. The expected value for χ^2 is unity. A value lower than this indicates the uncertainties attributed to the measurements or the validation values or both are too high. A value greater than unity indicates the uncertainties attributed to the measurements or the validation values or both are too low.

In the ideal case the stability would be zero over any timescale. In remote sensing the stability can display periodicity related to factors such as instrument drift or solar illumination of the satellite -

both over an orbit and seasonally. It is suggested that the stability is estimated at the same temporal scale that any trends in the data are calculated.

It may be that the quality parameters are independent of the measurement magnitude and conditions of measurement and apply at all locations and times. In that case the three quality values adequately characterize the quality of measurement. More commonly, the quality values vary so a **validation table** is used to summarise the bias, χ^2 and stability for regimes of consistent instrument behaviour.

In some case **internal validation** can be used to check reported uncertainty. Consider the situation where an instrument measures the same quantity under conditions where the reported uncertainty does not vary. Then the variability of the measurements should agree with the reported random uncertainty.

Comparing Measurements with a Model

Further understanding can be achieved through comparison of measurements with model output. In this approach, a model is sampled to give model values at the same place and time as the measurement values. The same three quality parameters can be calculated. However these caveats apply

- the model error may not be reported and may have to be assumed,
- the bias cannot be attributed to the model or measurements without reference to additional information

An estimate of interpolation uncertainty must be included if the model reports results at different times and location from the measurements so that the model results are interpolated to the measurement location.

If the model is at a coarser resolution than the measurements an approach could be to compare the model value with a (weighted) average of the measurements. The fact that the systematic uncertainty is correlated needs to be accounted for if this approach is taken.

The statistical comparison of model and measurement data must account for bias due to sampling. For example a monthly time series comparison between model output and averaged measurements may show bias due to conditions, such as cloud coverage, under which measurements are not possible.

6.2 Common Table of Contents for Uncertainty Characterisation Document Deliverable

Recommendation UC-2

The "Uncertainty Characterisation" document from all CCI projects should follow a common table of contents (see below):

1. Introduction

2. Definition of terms

- *Error, Uncertainty, Uncertainty information, Uncertainty characterisation, Validation, Accuracy, Precision, Stability, Representativity, Error co-variance matrix, etc.*

3. Sources of errors

- *Description of the sources of error contributing to uncertainty in the data products: qualitative-quantitative uncertainties, symmetric vs. asymmetric uncertainties, global vs. regionally differing uncertainties, error correlations, data pre-screening and other factors affecting the representativity of the data product, ...*

4. Methodology to determine uncertainties

- *Steps in algorithms, error propagation, analytical and empirical approaches to determining product uncertainties,*

5. Documentation of uncertainties in the products

- *Error budget analysis and results.*
- *e.g. uncertainty per land cover class, overall statistics on uncertainties per product pixel*

6. Guidelines for using the products

- *how to use the data without introducing new uncertainties (e.g. level 2 to level 3 transition, data product representativity)*
- *how to use the uncertainty information*

7. Conclusion

8. Bibliography

- *e.g. peer reviewed publications on the methodology for characterising the uncertainties, cross reference to the validation reports, etc*

6.3 References

Beers, Y., Introduction to the theory of error, Addison-Wesley, Massachusetts, 1957.

BIPM, Guide to the Expression of Uncertainty in Measurement (GUM), Bureau International des Poids et Mesures, 2008. (http://www.bipm.org/en/publications/guides/gum.html.)

Hughes, I.G., and T.P.A. Hase, Measurements and their uncertainties, Oxford University Press, Oxford, 2010.

7 ECV interdependencies

7.1 Introduction

While each ECV plays a specific role in the understanding of the climate system, no scientific analysis indicates one ECV is more or less important than another. The need to adopt an integrated approach, encompassing all ECVs, is thus of paramount importance. The CCI programme represents more than a set of individual projects and it is both in the interest of, and an opportunity for, each of the projects to interact with the other teams.

The success of the CCI Programme and its long-term viability will depend on the contribution it makes to resolving some of the key scientific questions for which ECV products are required. Thus the project teams must be able to identify where the priority contribution to advancing understanding of the climate system lies, how the project will work towards product uptake in this priority area, what the product requirements in terms of quality and consistency are to achieve this, what the limitations are and the value of the product in the context of other ECVs. Five questions can thus be posed and are addressed in the following paragraphs.

7.2 How will CCI help advance understanding of major components of the climate system?

e.g. carbon-cycle, chemistry-climate interaction, and radiative forcing?

A fundamental requirement for each of the teams is to contribute to the CCI Programme objective of advancing understanding of the major components of the climate system. To do this each team must identify the priority it sees in terms of given key components of the climate system, establish strong connections to the external community addressing these components and ensure that the outputs generated for this task are taken-up by this community.

Since advances in understanding these components are unlikely to be purely a function of a single given ECV it is necessary to identify which of the ECVs are priorities for improvement in addition to the one they are working on and, for the ECVs being considered currently in the CCI Programme, it is necessary to establish working relationships between ECV projects to address the relevant component.

Each team should identify which of the key components of the climate system that it sees as a priority in addressing e.g. Carbon Cycle Budget Improvement, Sea Level Budget Closure, Radiative Forcing characterisation, and Chemistry-Climate Interaction).

Recommendation EI-1

Given the identified key component of the climate system considered to be the priority target, each team should identify which of the other ECVs it needs to interact with to help address that component.

7.3 How can we ensure the scientific inter-consistency of all ECVs produced within CCI, and how can we evaluate it?

A fundamental criterion to make an advance in understanding of the climate system through generation of ECV products is that the products generated are themselves an advance over the current status quo. A large number of pre-existing products are available but in general they are differ across time and space and differ among themselves for the same product, are not scale independent and are incompatible between common products (e.g. land cover v f_{APAR}). To make a major advance these issues need to be given close attention including use of terminology e.g. accuracy, precision, consistency, product name.

Consistency in many regards could be considered as even more important than accuracy. It should also be noted that there are cases where 'inconsistency' may bring increased understanding of process and appropriateness of product assumptions and this is part of the process of the development – being the same may lead to the wrong conclusions while being different allows further insight.

Each project team, CMUG and the CCI Programme as a whole should define clearly what for them the term consistency actually means and hence how to evaluate it. The observation and model communities both within the projects but also between them (including CMUG) should clearly describe what the terms for the product and the model, including their uncertainties, actually are.

7.4 How important is the consistency of the input data used for different ECVs?

As indicated above, all teams must pay close attention to the assumptions made in the generation of products if they are to be comparable or compatible across time and space. This applies to ensuring the source of the baseline data is consistent but also the use of ancillary data. Ancillary data are easily overlooked in product generation as they are often inbuilt in some processing schemes. Typical examples include digital elevation models (DEM) (used in e.g. atmospheric correction, geo-location, land-ocean identification, height/velocity/mass balance determination in glaciers, cloud-snow separation), meteorological fields e.g. from ECMWF (wind direction & speed, pressure, ozone, water vapour all from model runs and hence with risk of circularity) and vegetation/land type (biome determination, threshold change, seasonality switches). The degree to which these elements affect the product output and its comparability with other ECV outputs will vary with ECV and needs to be addressed at bilateral level as a continuous process. As well as the underlying input data there are often underlying assumptions in product generation (and model parameterisation) that require clear documentation.

All teams should provide clear documentation of all input data used and check bilaterally with other teams in how far consistent use of input data is assured or can be achieved.

New data could create problems so changes with respect to older data versions should be well understood and be characterised in terms of modifications of parameterisation in models, of retrieval assumptions, and of ancillary data. All teams shall assess the consequences of introducing new data on product generation steps and in model parameterisations.

7.5 How important are the ECVs not yet started in CCI - or not within its scope

The CCI Programme has been constrained to focus on those ECVs where the biggest impact on advancing understanding is expected, maximizing use of data from the ESA and other European archives and exploiting the expertise already present in Europe. As a result 10 ECV projects have been started so far with an 11th under re-submission (sea ice). Since there may be a significant impact on the ability to contribute to advancing understanding of the climate system if key datasets are missing there is a need to identify these missing products and to address the impact and likely paths to resolution. This information is vital for prioritizing subsequent investments by ESA. Key missing ECVs identified during the collocation meeting were:

- Sea ice information especially for SST and Sea Level ECV.
- Ice sheets for Sea Level and Glacier ECV - completeness and process understanding
- Biomass for use with fire disturbance products to determine combustion efficiency and emission amount (Fire ECV)
- Surface albedo (CMUG)

Recommendation EI-2

All CCI Project teams should assess what is missing for their science question (and ECV task), identify priorities for future ECV projects and feedback at the earliest opportunity to ESA.

7.6 Should CCI project teams take any actions to account for ECV interactions?

The full benefit that accrues from participation in a collective programme such as CCI is derived through the interaction between the participants at within- and between- project level. This requires establishment of 'practical' means of achieving such interaction.

Recommendation EI-3

All CCI Project teams should consider establishing bilateral agreements, and where necessary undertake joint progress meetings, invite other teams to specific workshops and undertake mutual document review.

Where appropriate, and not assured during the regular CMUG–ECV team meetings, specialist workshops of climate modellers across ECV teams should also be considered.

There is significant benefit to interaction between ECVs in particular when dealing with the International Research Programmes e.g. WCRP, IGBP. Table 1 indicates which programmes/projects have been linked to different ECV projects. The ECV teams should undertake bilateral activities to accrue maximum benefit to the CCI programme.

Table 1: Initial CCI project linkages to International Research Programmes

	Project	GHG	Ozone	Aerosol	Cloud	SST	Sea Level	Ocean Colour	Land Cover	Fire	Glacier	CMUG
IGBP	AIMES											
	SOLAS											
	IGAC		●	Aerocom								
	ILEAPS											
	IMBER							MAREMIP				
	GLP											
	LOICZ											
	PAGES											
WCRP/WMO	CLiC										●	
	CLIVAR						●					
	GEWEX			●	●							
	SPARC		CCMVal	CCMVal								
	WCRP-M			CMIP5								CMIP5
	WOAP						●					
	JCOMM						GLOSS					
	GAW	NDACC	NDACC, SHADOZ WMO-O3SAG	●								
	SCOPE-CM			● tbd	GSICS							
ESSP	GCP									● tbd		
	GWSP											
	GECAFS											
	GECHH											
EC	FP7 projects	MACC	MACC	MACC Passodoble		Myocean	Myocean	Myocean MEECE	GHG-Europe Geoland2			IS-ENES ERACLIM EURO4M
EUM	Eumetsat projects		O3SAF	●	CMSAF	OSISAF						
OTHER	UNEP		●									
	Aerocom			●								
	IO_3C		●									
	TCCON	●										
	OSTST						●					
	GCOS						OOPC				WG MS	
	GODAE					GHRSST	●					
	IOC						PSMSL					
	IOCCG							●				
	GEO							Chlorogin SAFARI				
	GTOS								GOFC-GOLD	GOFC GOLD		
	UNFCCC								REDD	REDD		
	FAO								●	●		

Acronyms for Table 1

IGBP	**International Geosphere Biosphere Programme**
AIMES	Analysis, Integration and Modelling of the Earth System
GLP	Global Land Project
IGAC	International Global Atmospheric Chemistry
ILEAPS	Integrated Land Ecosystem Atmosphere Study
IMBER	Integrated Marine Biochemistry and Ecosystem Research
LOICZ	Land Ocean Interactions in the Coastal Zone
PAGES	Past Global Changes
SOLAS	Surface Ocean Lower Atmosphere Study

WCRP	**World Climate Research Programme**
CLiC	Climate and Cryosphere Project
CLIVAR	Climate Variability and Predictability Project
GEWEX	Global Energy and Water Cycle Experiment
SPARC	Stratospheric Processes and their Role in Climate
WCRP-M	WCRP Modelling Theme includes Working Group on Coupled Modelling (WGCM), Working Group on Numerical Experimentation (WGNE), Working Group on Seasonal to interannual Prediction (WGSIP), Working Group on Ocean Models Development (WGOMD) and GEWEX Modelling and Prediction Panel (GMPP)
WOAP	WCRP Observations and Assimilation Panel a current activity of the WCRP Observations and Analysis Theme

WMO	**World Meteorological Organisation**
GCOS	Global Climate Observing System
GAW	Global Atmosphere Watch
JCOMM	Joint Technical Commission for Oceanography and Marine Meteorology (Joint with International Oceanographic Commission)
SCOPE-CM	Sustained, Co-Ordinated Processing of Environmental Satellite Data for Climate Monitoring (CMA, EUMETSAT (serving as Secretariat), JMA, NOAA, and USGS as technical agencies, CGMS, CEOS, GCOS, GSICS and WMO providing oversight and support through the Executive Panel)
WMO-O3-SAG	WMO Scientific Advisory Group for Ozone

ESSP	**Earth System Science Partnership**

composed of IGBP, WCRP, DIVERSITAS (Global Biodiversity Research Programme) and IHDP (International Human Dimensions Programme))

GCP	Global Carbon Project
GECAFS	Global Environmental Consequences for Agriculture and Food Security
GECHH	Global Environmental Consequences for Human Health
GWSP	Global Water Systems Project

EUM	**EUMETSAT European Organisation for the Exploitation of Meteorological Satellites**

CMSAF	Satellite Applications Facility on Climate Monitoring
OSISAF	Satellite Applications Facility on Ocean and Sea Ice
O3SAF	Satellite Applications Facility on Ozone and Atmospheric Chemistry Monitoring

EC	**European Commission (FP7:7th Framework Research Programme)**

ERACLIM	European Reanalysis Capability for Global Climate Monitoring
EURO4M	European Reanalysis and Observations for Monitoring
IS-ENES	Global Environmental Consequences for Human Health
MACC	Monitoring Atmospheric Composition and Climate
MEESE	Total Carbon Column Observing Network
MyOcean	Global Environmental Consequences for Agriculture and Food Security

Others	**Various Affiliations**

Aerocom	Aerosol Comparisons between Observations and Models
CCMVal	Chemistry-Climate Model Validation Activity for SPARC
ChloroGIN	Chlorophyll Global Integrated Network of GOOS/GEO (Task Number EC-06-07)
CMIP5	Coupled Model Intercomparison Project Phase 5 of the IPCC
IOC	Intergovernmental Oceanographic Commission
IOCCG	International Ocean Colour Coordinating Group
IO_3C	International Ozone Commission
FAO	United Nations Food and Agriculture Organisation
GEO	Group on Earth Observations
GHRSST	Group for High-Resolution Sea Surface Temperature of GODAE

GTOS	Global Terrestrial Observing System
GLOSS	Global Sea-Level Observing System conducted under the auspices of JCOMM and the Intergovernmental Oceanographic Commission (IOC)
GODAE	Global Ocean Data Assimilation Experiment
GOFC-GOLD	Global Observation of Forest and Land Cover Dynamics Panel of GTOS
GSICS	Global Space-based Inter-Calibration System of WMO and the Coordination Group for Meteorological Satellites (CGMS)
NDACC	Network for the Detection of Atmospheric Composition Change
OOPC	Ocean Observations Panel for Climate coordinated by GCOS, Global Ocean Observing System (GOOS) and WCRP
OSTST	Ocean Surface Topography Science Team
PSMSL	Permanent Service for Mean Sea Level run by UK National Oceanography Centre under funding from IOC and UK Natural Environment Research Council (NERC)
SAFARI	Societal Applications in Fisheries and Aquaculture using Remotely-sensed Imagery of GEO (Task Number AG-06-02)
SHADOZ	Southern Hemisphere Additional Ozonesondes Network
TCCON	Total Carbon Column Observing Network
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
WGMS	World Glacier Monitoring Service

8 EO data requirements and pre-processing

8.1 EO Data Requirements

- *Who is using what? (sensor, dates, product level, version, etc.)*
- *When do you need these or are they all needed in the first few months? Timelines?*

Large volumes of data are requested by the CCI projects to develop the climate relevant ECV output products. A clear and detailed list of data needs per CCI including the anticipated source and version is needed, in particular to estimate the number of data requests that may come and to decide on the most efficient way to coordinate and deliver requested data sets.

The EO Data Requirements Document that has been distributed by ESA in preparation of the collocation meeting is a good first attempt to provide a comprehensive overview of the data needs across the CCI projects. This Draft needs revision and update. In particular, timelines are urgently needed for reprocessed datasets so that we can identify discrepancies between CCI needs and Agency/data provider plans, including coordination with future reprocessing. The document shall also include a table of contacts for each dataset – one for the supplier, a person technically aware of sensor quality issues and a person from each CCI who will be responsible for datasets.

Recommendation DR-1

Each CCI project should provide revised, updated, and complete inputs so that the EO Data Requirements Document can be consolidated, including a detailed procurement time schedule that will enable timely data delivery from the data suppliers to the CCI projects.

8.2 Data consistency

- *How to ensure data version consistency between CCIs?*
- *Is this a real concern?*

If different CCIs (or even different parts of a CCI) use different versions of input data, the outputs will invariably be unpredictably different. Algorithms tuned for one processing version of input data may have unexpected issues if run without tuning against a different version. Institutes may already hold archives of data without sure provenance (e.g. some Ocean Colour data processors already hold multiple versions of the MERIS level 2 datasets acquired piecemeal from the rolling archive). This issue applies not only to core data like MERIS but also to auxiliary data.

Recommendation DR-2

Each CCI project team should appoint a data manager.

The data manager should contact upstream data providers to ensure the correct versions of all relevant data are being used, to verify the consistency of institute data archives and to acquire new versions from an appropriate and consistent master copy if required.

Ideally all CCIs would use the same versions of data, but practical issues may prevent this. Instead, CCIs should allow for traceability when data are shared or disseminated - the versions of core and auxiliary data used must be documented, ideally at a product file level but at least at a CCI dataset "release" level.

- *How to facilitate sharing of data between projects? Could be challenging, particularly for non-ESA data. (partially covered above by versioning issue)*

The EO data requirements document should include what datasets (and version) are or will be available at each institute. The document can indicate whether an institute is willing to share some or all of a dataset, so other institutes can then contact them to negotiate a transfer by whatever means is appropriate.

8.3 Data Access

- *Are there any restrictions and/or obstacles in accessing the required data?*
- *Are appropriate data use agreements in place (non-ESA data)?*
- *Are there workarounds and can they be shared?*

The biggest issue identified was redistribution of data – both within a CCI and between CCIs. Some datasets/data providers restrict redistribution (e.g. EUMETSAT and JAXA, but not NASA or ESA), mostly for purposes of accounting. This issue particularly pertains to the Round Robin data exchanges, which should be freely available.

Recommendation DR-3

Each CCI project team should review data policies for the datasets they require and identify any issues (restrictions or high costs for third party data).

Where possible, each CCI team should resolve these issues with the data providers themselves. If required, or if it significantly reduces duplication of requests, ESA may be involved. ESA may support the CCIs by checking existing agreements with other agencies.

8.4 Level 1b

- *How you are going to handle the current updates?*
- *Is the first L1b (as presented) sufficient to effectively develop the ECV prototypes?*
- *How are you going to report on problems? Feedback/information mechanisms? Interfaces to QWGs and international science teams?*
- *How to contribute Specs for improving L1b algorithms implemented in the Ground Segment?*

This question is addressing the interface from space agencies to the CCI teams on the data input side. In most cases L1b data constitute the input to the CCI processing chain, and consequently its quality or error, respectively, determines the quality of the ECV, and finally if the GCOS requirements are met or not. It is really a crucial question, and in brief, the SoW requirements of "best possible quality" can be directly translated into the requirement of getting the best possible quality of L1b data from the agencies. Any planned improvement has to be made aware to the CCI teams, and improved L1b have to be used.

The SoW includes investigation into radiometric calibration and geometric correction, which requires pre-L1b data (ideally L1a data and calibration software). This is the approach NASA takes with, for example, MODIS data. This is the ideal but not practical within the project timeframe.

Recommendation DR-4

> *As a practical solution, **CCIs should closely cooperate with ESA's Data Quality Working Groups (QWG), which monitor L1b product quality and recommend improvements to the agency.***

In an early phase of the CCI project, instrument QWG and CCI working on the same data should meet in order to transfer state of the art and existing know-how from QWG to CCI. This dialogue should be continued, e.g. by yearly meetings or alternatively by appointing a member of the CCI as QWG member. Any consolidated improvement found by the CCI should be reported to the QWG.

ESA, QWGs in particular, and CCI science leaders should discuss and agree if and how the work done on L1b improvements should be reported at CEOS WGCV level in order to link the work to the international community.

9 DATA STANDARDS

9.1 Which metadata standards shall CCI projects use?

Metadata is fundamental to CCI even at prototype phase. There is a clear need for all CCI teams to be fully aware of the different types of metadata required to effectively manage CCI data sets: **Archive** (file level), **Browse** (e.g. objective information about the data set, HMA, METAFOR), **Character** (e.g. information related to the data set e.g., quality information, paper references etc), **Discovery** (e.g. Inspire, GEOSS…). There may be some overlap between information in these categories, but generally information propagates up as it is aggregated from files and supplemented with discovery information. For Archive metadata, the climate and forecasting (CF) conventions are used extensively by the climate community and more widely (Marine communities, meteorological communities, satellite communities). Good governance, controlled vocabularies, and support are available and are not very restrictive. It is important to realise that the addition of extra fields to suit specific community requirements is permitted by CF. ECV-specific extensions can be added (e.g., version number, tracking_id) by CCI teams. CF can be used as a metadata convention, even if file format isn't netCDF.

CCI should include a unique tracking ID for each file. This allows files to be referenced, and linked up to processing description, input data, documentation etc. Download the software from http://www.ossp.org/pkg/lib/uuid/.

Discovery metadata is a "quick win" as it is relatively easy to develop for a dataset because it just relies on the dataset being well documented. How this is implemented depends on the CCI system.

Browse metadata should be consistent across ECVs links to the Heterogeneous Mission Accessibility (HMA) system should be explored. A cross CCI discussion is required to specify what and how this should be handled in CCI.

Character metadata should be consistent across CCI and options include Metafor/CMIP5 quality control tooling for quality metadata[7]

Some CCI teams require more guidelines on what CF entails. ESA should provide pointers to advice (e.g. web page). There are limitations to CF-conventions that are relevant to satellite data as they are in some cases, not well specified for certain swath data products (particularly conical scanning instruments). CCI teams need to volunteer to get more involved with process to develop CF-satellite, so that these can be handled properly
http://www.unidata.ucar.edu/support/mailinglist/mailing-list-form.html

Recommendation DS-1

Use CF conventions for Product File Level Metadata. CCI teams agreed to comply to this guideline in addition to existing obligations with other communities (e.g., GTOS, GLIMS WGMS).

- CCI should develop a CF baseline template example for all teams to use as a baseline. (e.g. by the proposed Data Standards WG – see later)
- Teams should add ECV specific CF extensions **as required**
- Appropriate information should be included at this level (e.g. version, URL to documentation, tracking_id, creator, owner, etc) for traceability.
- Ensure documentation and advice is available to data producers (need for a DS-WG)

Recommendation DS-2

Use (TBD existing standard) for Discovery Metadata for each Data Set (collection of products).

- CCI needs to define the way in which data will be managed. Only then can a suitable method for data discovery be established. This is an urgent priority as everyone needs to find what data is available.
- Ensure documentation and advice is available to data producers (need for a DS-WG)

Recommendation DS-3

CCI data products should include a unique tracking ID for each Data Product file in the file metadata.

- This allows files to be referenced, and linked up to processing description, input data, documentation (issues of traceability) etc. using the CMIP5 approach (id number generator code available from http://www.ossp.org/pkg/lib/uuid/
- CCI should take advice from CMIP5 on the use of tracking_id within the CCI data management system.
- A unique tracking_id on its own is still extremely beneficial
- Ensure documentation and advice is available to data producers (need for a DS-WG).
- Processes within the product pipeline which manipulate data products should keep a manifest (plain text in the first instance, with a format specification tbd) of input data tracking_id(s), a description of the process, and the output tracking_id(s).

9.2 Should we have a single format standard for CCI?

It is clear that different format proliferation is bad practice and precludes the use of standardised tools, approaches and use of open and available pre-existing tools. netCDF is well known and already quite widely used in the CCI teams. netCDF is the preferred format for CMUG, CMIP-5, and various other communities. However some data formats in use by CCI teams (Shapefiles and

GeoTiff) are currently not easily transformed to netCDF. CCI format guidelines refer to products supplied externally, e.g. to climate and other communities. Within own project teams or own science communities there is no need to change behaviour. The teams agreed to accept 3 standard formats, netCDF, shapefiles (for vectors) and GeoTiff. Some CCI teams require more guidelines or help with data formats and the need for advice and links to resources explaining formats was clearly expressed. A wiki page was requested to capture these details.

Currently, 2 versions of netCDF exist: netCDF4 and CDF3 netCDF4 allows native compression and shares common libraries with HDF-5 and includes many other features. Today, it is perhaps not supported by as many tools as version 3 raising issues of compatibility. However, it is expected that tools are likely to be compatible with netCDF4 in a relatively short period. netCDF4 is an end goal for CCI , but netCDF3 can be used for an interim period if necessary.

Recommendation DS-4

Use netCDF as a file format. Version 4 should be used but version 3 may be used until Jan 1st 2012 (allowing time for tools to mature).

- Ensure netCDF documents and examples are available to the CCI community (need for a DS-WG)
- Ensure netCDF code readers/writer tools are shared within CCI to reduce overhead (e.g., different languages supported) and improve consistency (need for a DS-WG)
- Ensure documentation and advice is available to data producers (need for a DS-WG)

Recommendation DS-5

In addition to use of CF & netCDF, for specific user communities (e.g. GLIMS for GLACIERS_cci), shapefiles and GeoTIFF files may be used.

- Ensure documentation and advice is available to data producers (need for a DS-WG)

9.3 What standards are required for CCI data content?

The need to standardise data content was agreed. It was noted that there was not yet sufficient knowledge of how data product and document content could be standardised and the group was unable to conclude on clear guidelines for content standards.

However, there is a clear need to ensure that relevant documents are linked to data files (e.g. use CF metadata URL pointers to the relevant ATBD). Documents should be maintained in a document library (may be virtual, distributed) but clear permanent links are required that can be referenced (DOI?). This is an implementation issue and needs to be clarified (need for a DS-WG).

Recommendation DS-6

Relevant documentation must be associated with data files using appropriate metadata (at least file level) e.g. URL pointer in GHG data file to ATBD specification used to produce the product.

9.4 What are the constraints on CCI data standards?

netCDF is the climate standard data format (CMIP5, marine ECVs, recommended by CMUG) . Many CCI teams already use netCDF (8/11 CCI teams use netCDF but Land, Glaciers, Fire are not using netCDF). Shapefiles and GeoTiff translations not yet readily handled in netCDF and these should be used as required.

No guideline is needed

9.5 How are we going to manage CCI data standards?

Managing data standards is required in CCI. This is to ensure that CCI data services are aligned and maintained for users. The guideline recommends that each CCI team nominate 1 person to a CCI Data Standards Working Group (DS-WG) that will manage CCI data standards. Experience suggests that this approach is required to achieve success. This approach also allows teams to feed back on proposed standards, iterate and move forward with consensus and enhances coordination and communication to avoid duplication of effort. A Wiki page is recommended to provide a focal point for discussion managed either by ESA or CMUG. CCI data standards need to be discussed with data management and a joint (or single) working group may be appropriate.

Recommendation DS-7

Convene a data-standards and data-management group with representatives from each CCI team and associated wiki discussion page.

- A CCI Data Standards Working Group provides framework for discussions and sharing knowledge
- Experience suggests that a CCI DS-WG should be supported by an appropriate information exchange resource/framework (e.g. wiki, regular meetings)

10 CCI Web sites and data access

10.1 Website Templates.

Recommendation WS-1

All CCI web sites should be based on a common template (to be provided by ESA by end October 2010).

A draft website tree structure has been be provided by ESA (see
Figure 1. Proposed web site structure) for guidance. The projects are encouraged to use the integration, installation and instructions package based on the DRUPAL CMS.

If a particular ECV project cannot use the provided CMS they should make best efforts to align with its look-and-feel and structure.

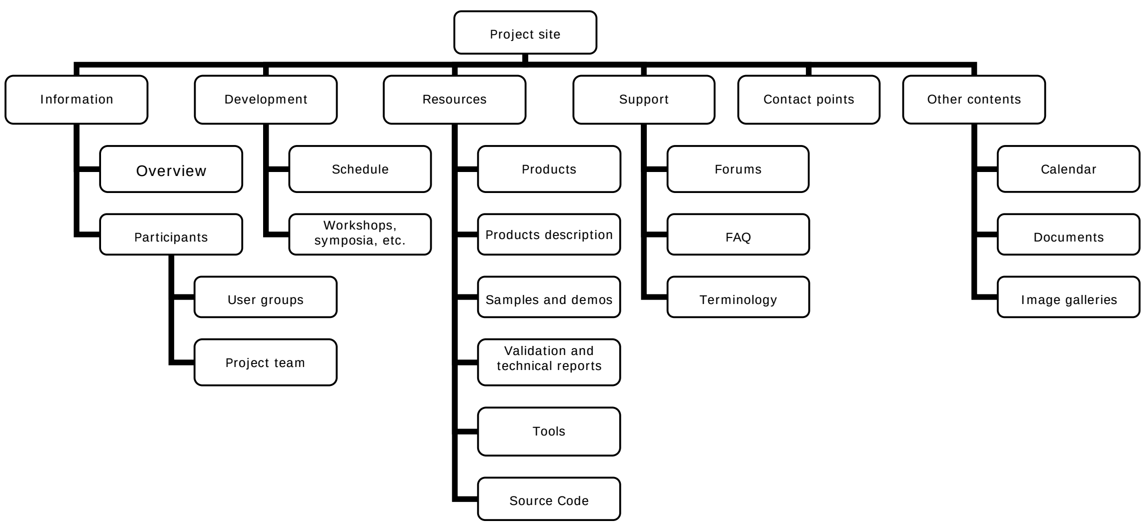

Figure 1. Proposed web site structure

Action #1 - ESA should deliver by end of the month the tailored Content Management System to be used by all ECV teams.

10.2 Website Update

Each ECV contractor is contracted to host, maintain and administer its own website.

Recommendatino WS-2

Standard procedures should be applied to update and review each CCI web site every month at least.

10.3 Domain Name

Recommendation WS-2

CCI Project teams should apply the following URL naming convention: ***www.esa-<ecv>-cci.org*** *(e.g: www.esa-landcover-cci.org)*

10.4 User Registration

It is the ECV team's responsibility to register this name and similar additional names with other extensions (e.g. .info, .net).

Recommendation WS-3

Access to the public part of each ECV website should be unrestricted. Registration for data download shall be minimal and optional (e.g. email address). Every project shall ensure that the usage of the data products should be correctly acknowledged.

Different access roles and associated rights shall be identified and implemented if needed for project management.

10.5 FAQS and Blogs

Recommendation WS-4

CCI Project teams should use communication tools such as Newsletters, Forums, FAQs and Blogs. A Newsletter could be published every 6 months.

Action #2 - ESA should deliver by end of October a common template to be used by all ECV teams for their newsletters.

10.6 Visualisation Tools

Recommendation WS-5

Each CCI team will provide an appropriate set of tools for visualisation: These tools should be accessible on-line or downloadable.

10.7 Data Mirroring

Recommendation WS-6

Access to the CCI output data products via mirror sites should be encouraged so as to maximise data access and secure archiving of the data products

For instance, DLR has offered to mirror the 4 atmospheric ECVs.

11 System Engineering

Recommendation SE-1

Set up a CCI System Engineering Working Group (SEWG), with at least a representative of all CCI teams.

The group's main objective is to simplify the engineering tasks benefiting from the synergies of all the CCI systems. This will be achieved by

- ensuring that system engineering is performed in a coordinated way,
- ensuring that system engineering is aware of relevant ongoing activities,
- harmonising system engineering documentation,
- Optimising operational performance (e.g. GRID, Cloud, data locality, …etc…)
- preparation a dictionary of common terminologies for documentation and communication.

Recommendation SE-2

Create a strategy for the development of a CCI system architecture.

The first action of the SEWG will be to collect "Preliminary System Analysis" tech notes to be written by each CCI team. Each tech note shall briefly describe each ECV prototype system in terms of input, output and the processing to be performed. The SEWG will review the preliminary designs in order to derive a starting point to discuss commonality across different systems.

Recommendation SE-3

Prototype code should be evaluated with respect to possible use in operational mode.

Well written prototype code may be migrated to an operational level. System engineers to review existing code and develop plan to make it high quality, robust, runtime performant, parallelizable, System requirements have to be carefully taken into account. Small improvements in performance may not really pay off and even be more expensive than providing more computation power.

Recommendation SE-4

Based on the Preliminary System Analysis, start an assessment process by extracting the similarity and constraints for all ECVs.

The preliminary analysis shall also provide a hint to define a common interface (e.g. parameters, data I/O, aux files, life cycle management, processor status, see JOB order of the MMFI). This interface will be designed in a way allowing for module exchange between ECVs and also for a later integration in different computing environment, e.g. Cloud infrastructures or systems run by Grid engines.

Recommendation SE-5

Based on the strategy for the development of a CCI system architecture, develop guidelines on how to implement that strategy.

For example (in case cloud computing is selected as part of the strategy), look for a-priory guidelines how to set up EO data processing in the cloud. How should code be developed to make it distributable in the cloud. Another example could be the harmonisation of data access.

Recommendation SE-6

There is a need to find out whether a standard set of quality control functions are part of the operational system. These need to be defined for each ECV.

Discussion: Provide guidelines for harmonizing IODD/DPM input.
This is a key for the early identification common processing functions / modules (e.g. pre-processing from L1b) and discuss with science teams if they are shareable and reusable. Might consider ECSS, but tailor it to very lightweight requirements.

Discussion: How is the Algorithm Validation organised (by whom in which environment)?

Discussion: How is the Processor Acceptance Testing organised (by whom in which environment)?

Discussion: How are different system levels defined? At which levels (onion ring) do we have common requirements, e.g.

- Host infrastructure, hardware, data centre, private clouds
- Data storage & access

- Processing System Software
- Processing Framework (API)
- Science modules (processors)

From: http://www.webwisdom.com/Support/resources/collaborativeComputing.html

> *Collaborative computing is a term describing a variety of activities where people interact with one another using desktops, laptops, palmtops, and sophisticated digital cellular phones. As computers are best at handling data and representing information, person-to-person communication is enriched by an ability to share, modify, or collaboratively create data and information.*

12 CCI Science Agenda

The ESA CCI is part of a wider coordinated response of all CEOS Space Agencies, to the needs of GCOS and UNFCCC. CEOS has established a new working group on Climate (WG-CLIM) which will coordinate actions of different Space Agencies, including ESA, EUMETSAT, DLR, CNES, CSA, NASA, NOAA, JAXA, INPE, ISRO, amongst others.

In Europe ESA, EUMETSAT and EC are cooperating closely, to foster scientific excellence, coherence and long-term sustenance for space-based monitoring of climate. The JRC report (2009) "European Capacity for Monitoring and Assimilating Space-based Climate Change Observations – Status and Prospects"[8] is a first result of this coordination.

Discussions at CCI collocation highlighted that:

- GCOS poses long-term scientific and technological challenges to the EO Community
- Multiple expert teams and various programmes worldwide will contribute to each ECV
- Scientific cooperation, independence, openness and traceability are all essential

The CCI programme is thus initiating and structuring activities within Europe that should in future be sustained on a long-term, continuous basis. An approach that is to scientific excellence, ensures operational robustness and delivers cost effectiveness is mandatory.

The CCI project teams and ESA are aware that potential scientific partners and funding bodies, are currently planning projects and programmes that will also respond to GCOS. In the interests of efficiency it is important that they should be kept well-informed on the scope and schedule of the CCI programme and its projects.

In particular they should be informed of what CCI *will not* do, as well as what it *will* do.

Recommendation SA-1

The CCI project teams and ESA should jointly issue a "CCI Science Agenda" document describing the overall scientific scope of CCI and its linkage to international programmes.

The aim being to facilitate scientific cooperation and effective planning of related programmes.

[8] http://publications.jrc.ec.europa.eu/repository/bitstream/111111111/13553/1/cc_and_space_final_report_100310_jrc_report.pdf

Appendix A: Recommendations Summary

User Requirements and feedback to GCOS	
UR-1	*It is important to provide both the technical specification and the rationale of how and why these requirements have been defined.*
UR-2	*Discussion with users to allow an assessment of the importance of a specific requirement by a particular application is recommended.*
UR-3	*Ensure review of User Requirements Document by potential users, related bodies and interested parties to refine assessment of the strength of the requirements.*
UR-4	*Retain full records of all user interactions to ensure traceability of requirements.*
UR-5	*Provide input to and participate in GCOS reviews, e.g. by providing detailed feedback on applicability and achievability of GCOS user requirements in co-location and CMUG meetings.*
UR-6	*A standard template should defined, providing specific sets of requirements for specific applications along with their rationale and provided to the CCI teams by early October.*
UR-7	*Requirements coming from CMUG and individual CCI projects should be combined into overall requirements that will improve consistency across ECVs.*
UR-8	*A section should be included in the Product Specifications Document to clearly document the decisions for the choices made in translating user requirements into product specification.*

Round-Robin algorithm inter-comparison and selection	
RR-1	*The meaning of the 'best' algorithm and of how to select it (evaluation protocol) has to be defined before the start of the Round Robin exercise. The definition of 'best' and the scope of the Round Robin exercise have to be specified in the Product Validation Plan (PVP).*
RR-2	*The Round Robin should be made at the beginning of the project based on objective criteria. There should be one or more iterations to show algorithm improvement throughout the project. The most objective algorithm selection would be based on blind testing to avoid any bias.*
RR-3	*Every CCI project has to perform a Round Robin exercise. In the exceptional case that a final algorithm has been pre-selected, component modules need to be tested also for this pre-selected algorithm. Furthermore, the pre-selection criteria should be in line with the CCI objectives.*
RR-4	*The same auxiliary and Level 1 data should be used in the processing, as well as the same reference data.*
RR-5	*The round robin results need to be open and the algorithm must be well-documented and public, but the actual code does not need to be public.*
RR-6	*The algorithm selection should be made by an independent team that is not directly involved in the algorithm development, although of course the members of that team should be experts. The selection shall be made based on a Round Robin evaluation protocol developed beforehand and providing objective criteria.*
RR-7	*The development of new tools should only be considered when really needed and no good tools for the purpose are available.*

Validation	
V-1	*All CCI projects should use the definition of validation approved by the CEOS-WGCV.*
V-2	*All CCI project Product Validation Plans (PVP) shall adhere to the above three requirements (see section 5.4) regarding independence.*
V-3	*The CCI teams shall use established, community accepted, traceable validation protocols where they exist. If such protocols do not exist then CCI projects may adapt existing protocols if appropriate and in any event shall offer their final protocol for future community acceptance.*
V-4	*Each CCI project shall select appropriate validation data to ensure that an adequate level of validation (confidence) is applied to all output products. The level of validation (confidence) should be indicated in the output product.*
V-5	*The CCI programme should hold a dedicated session (or workshop) on common validation infrastructure during (or prior to) the next co-location meeting.*
V-6	*The PVP shall fully describe the validation process for each CCI project. An independent international review board of experts should be invited to review the PVP of each project team. Each CCI project should involve experts from the CMUG throughout their validation activities. A CCI product will be deemed to be validated once all steps of the validation process documented in the PVP have been completed and documented accordingly.*
Uncertainty Characterization	
UC-1	*All CCI projects should use the same definition of terms in their work on Uncertainty Characterisation.*
UC-2	*The "Uncertainty Characterisation" document from all CCI projects should follow a common table of contents (see section 6.2)*

ECV Interdependencies	
EI-1	*Given the identified key component of the climate system considered to be the priority target, each team should identify which of the other ECVs it needs to interact with to help address that component.*
EI-2	*All CCI Project teams should assess what is missing for their science question (and ECV task), identify priorities for future ECV projects and feedback at the earliest opportunity to ESA.*
EI-3	*All CCI Project teams should consider establishing bilateral agreements, and where necessary undertake joint progress meetings, invite other teams to specific workshops and undertake mutual document review.*
Data Requirements and pre-processing	
DR-1	*Each CCI project should provide revised, updated, and complete inputs so that the EO Data Requirements Document can be consolidated, including a detailed procurement time schedule that will enable timely data delivery from the data suppliers to CCI projects.*
DR-2	*Each CCI project team should appoint a data manager.*
DR-3	*Each CCI project team should review data policies for the datasets they require and identify any issues (restrictions or high costs for third party data).*
DR-4	*CCI Project teams should closely cooperate with ESA's Data Quality Working Groups (QWG), which monitor L1b product quality and recommend improvements to the agency.*

Data Standards	
DS-1	*Use CF conventions for Product File Level Metadata. CCI teams agreed to comply to this guideline in addition to existing obligations with other communities (e.g., GTOS, GLIMS WGMS).*
DS-2	*Use (TBD existing standard) for Discovery Metadata for each Data Set (collection of products).*
DS-3	*CCI data products should include a unique tracking ID for each Data Product file in the file metadata.*
DS-4	*Use netCDF as a file format. Version 4 should be used but version 3 may be used until Jan 1st 2012 (allowing time for tools to mature).*
DS-5	*In addition to use of CF & netCDF, for specific user communities (e.g. GLIMS for GLACIERS_cci), shapefiles and GeoTIFF files may be used.*
DS-6	*Relevant documentation must be associated with data files using appropriate metadata (at least file level) e.g. URL pointer in GHG data file to ATBD specification used to produce the product.*
DS-7	*Convene a data-standards and data-management group with representatives from each CCI team and associated wiki discussion page.*

CCI Web Sites and Data Access	
WS-1	*All CCI web sites should be based on a common template (to be provided by ESA by end October 2010)*
WS-2	*Standard procedures should be applied to update and review each CCI web site every month at least.*
WS-3	*CCI Project teams should apply the following URL naming convention: www.esa-<ecv>-cci.org (e.g: www.esa-landcover-cci.org)*
WS-4	*Access to the public part of each ECV website should be unrestricted. Registration for data download shall be minimal and optional (e.g. email address). Every project shall ensure that the usage of the data products should be correctly acknowledged.*
WS-5	*CCI Project teams should use communication tools such as Newsletters, Forums, FAQs and Blogs. A Newsletter could be published every 6 months.*
WS-6	*Each CCI team will provide an appropriate set of tools for visualisation: These tools should be accessible on-line or downloadable.*
WS-7	*Access to the CCI output data products via mirror sites should be encouraged, so as to maximise data access and secure archiving of the data products*

System Engineering	
SE-1	*Set up a CCI System Engineering Working Group (SEWG), with at least a representative of all CCI teams.*
SE-2	*Create a strategy for the development of a CCI system architecture.*
SE_3	*Prototype code should be evaluated with respect to possible use in operational mode.*
SE-4	*Based on the Preliminary System Analysis, start an assessment process by extracting the similarity and constraints for all ECVs.*
SE-5	*Based on the strategy for the development of a CCI system architecture, develop guidelines on how to implement that strategy.*
SE-6	*There is a need to find out whether a standard set of quality control functions are part of the operational system. These need to be defined for each ECV.*
CCI Science Agenda	
SA-1	*The CCI project teams and ESA should jointly issue a "CCI Science Agenda" document describing the overall scientific scope of CCI and the linkage with international programmes.*

Appendix B: Participants

Participant	Affiliation	User Reqts & GCOS	Round Robin	Valdation	Modles confrontation	Uncertqainty Characterizt	ECV Interdependencies	Data Requirements	Data Standard	System Engineering	Web Comms Data access	CCI Science Plan
Nic Rayner	*Hadley Centre*	●										
M Herold	*U Wageningen*	●										
Roger Saunders	*Hadley Centre*	●										●
Irena Khlystova	*MPI*	●										
Carolin Richter	*GCOS*	●										
Mark Dowell	*JRC*	●										●
Olivier Arino	*ESA*	●										
Yannis Faugere	*CLS*		●									
Carsten Brockman	*Brockmann C*		●					●				
Richard Theis	*GAF AG*		●									
Michel Van Roozendael	*BIRA*		●									●
Gerrit DeLeeuw	*FMI*		●									
Rene Preusker	*FUB*		●									
Claus Zehner	*ESA*		●									
Sophe Bontemps	*UC Louvian*			●								
Emilio Chuvieco	*U Alcala*			●								●
Stefan Kinne	*MPI*			●								
Thierry Philpin	*Meteo France*			●								
Rainer Hollman	*DWD*			●								●
Max Reuter	*IUP U Bremen*			●								
Gary Corlet	*U Leicester*			●								
Frederic Achard	*JRC*			●								
Bojan Bojkov	*ESA*			●								
Stephano Ciavatta	*PML*				●							
Tony Paine	*U Bristol*				●							
Ulrika Wilken	*SMHI*				●							
Frederic Chevallier	*LSCE (MACC)*				●							
Paul Van Der Linden	*Hadley Centre*				●							
Serge Planton	*Meteo France*				●							
Peter Braesike	*U Cambridge*				●							
Eric Guillyardi	*IPSL*				●							
Pierre Philippe Mathieu	*ESA*				●							

Participant	Affiliation	User Reqts & GCOS	Round Robin	Valdation	Modles confrontation	Uncertqainty Characterizn	ECV Interdependencies	Data Requirements	Data Standard	System Engineering	Web Comms Data access	CCI Science Plan
C Merchant	*U Edinburgh*					●						●
Roland Doerffer	*GKSS*					●						
Pierre DeFourny	*UC Louvain*					●						●
Martin Schultz	*U Julich*					●						
Sylvie Kloster	*MPI*					●						
Don Grainger	*U Oxford*					●						
David Tan	*ECMWF*					●						
Simon Pinnock	*ESA*					●						
Shuba Sathyendranath	*PML*						●					●
Tony Payne	*U Bristol*						●					
Catherine Ottlé	*LSCE*						●					
Bernard Pinty	*JRC*						●					
Mark Weber	*IUP U Bremen*						●					
Thomas Holzer-Popp	*DLR*						●					●
Stephen Plummer	*ESA*						●					
Diego Loyola	*DLR*							●				
Andreas Wiesmann	*Gamma*							●				
Mike Grant	*PML*							●				
Rose Munro	*EUMETSAT*							●				
Philippe Goryl	*ESA*							●				
Pierre Femnias	*ESA*							●				
Thorsten Fehr	*ESA*							●				
Nigel Houghton	*ESA*							●				
Peter Regner	*ESA*							●				
Mickael Ablain	*CLS*								●			
Tobias Bolsch (tbc)	*U Zurich*								●		●	
Dymtro Martynenko	*DLR*								●			
Gunther Lichtenberg	*DLR*								●			
Bryan Lawrence	*BADC*								●			
Victoria Adams	*BADC*								●			
Craig Donlon	*ESA*								●			

Participant	Affiliation	User Reqts & GCOS	Round Robin	Valdation	Modles confrontation	Uncertqainty Characterizn	ECV Interdependencies	Data Requirements	Data Standard	System Engineering	Web Comms Data access	CCI Sciemce Plan
Meinhard Wolfmuller	*DLR*									●		
Petra Fuchs	*DWD*									●		
Norman Fomferra	*Brockman*									●		
Ivan Williams	*Logica*									●		
Oscar Perez Navarro	*GMV*									●		
Pascal Lecomte	*ESA*									●		
John Swinton	*Vega*										●	
Paul Spinks	*Sp. ConnecXions*										●	
Dimitri Letterer	*UC Louvian*										●	
M Snellings	*BIRA*										●	
Jose Ramos Perez	*DEIMOS*										●	
Giles Larnicol	*CLS*											●
Frank Paul	*U Zurich*								●			●
Hartmut Boesch	*U Leicester*											●
Paul Mason	*ESA CSAB*											●
Mark Doherty	*ESA*											●