QA4ECV

Quality Assurance for Essential Climate Variables

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Outline of a Framework for a QA Service in support of C3S

(Version 1.0)

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TERMS & ACRONYMS

ACSG	CEOS WGCV Atmospheric Composition Sub Group
AK	Averaging Kernel matrix
APM	Application Performance Metric
ATBD	Algorithm Theoretical Basis Document
BELSPO	Belgian Federal Science Policy Office
BIPM	Bureau International des Poids et Mesures
BIRA-IASB	Belgian Institute for Space Aeronomy
BRDF	Bi-directional Reflectance Distribution Function
C3S	Copernicus Climate Change Service
CAMS	Copernicus Atmosphere Monitoring Service
CCI	ESA's Climate Change Initiative
CDR	Climate Data Record
CDRH	Center for Devices and Radiological Health
CGMS	Coordination Group for Meteorological Satellites
CEOS	Committee on Earth Observation Satellites
CHARMe	Characterization of metadata to enable high-quality climate applications and services (EU FP7 project)
CLIPC	Climate Information Platform for Copernicus (EU FP7 project)
CO	Carbon Monoxide
CORE-CLIMAX	Coordinating earth observation data validation for re-analysis for climate services (EU FP7 Project)
DMITRI	Database for Imaging Multi-spectral Instruments and Tools for Radiometric Inter-comparison
ECV	Essential Climate Variable
EO	Earth Observation
ESA	European Space Agency
EU	European Union
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FAPAR	Fraction of Absorbed Photosynthetically Active Radiation
FAQ	Frequently Asked Questions
FP	Framework Program of the EU
GAIA-CLIM	Gap Analysis for Integrated Atmospheric ECV CLImate Monitoring
GCOS	Global Climate Observing System
GALILEO	Europe's initiative for a state-of-the-art global satellite navigation system
GECA	Generic Environment for Calibration and Validation

GEO	Group on Earth Observation
GEOmon	Global Earth Observation and monitoring (FP6 project)
GEOSS	Global Earth Observation System of Systems
GIFOV	Ground Instantaneous Field of View
GMES	Global Monitoring for Environment and Security (pre Copernicus)
GSE	GMES Service Element (ESA programme for pre-Copernicus services)
GSICS	Global Space-based Inter-Calibration System
HCHO	Formaldehyde
ICOS	Integrated Carbon Observing System
IEEE	Institute of Electrical and Electronics Engineers
INSPIRE	Infrastructure for Spatial Information in the European Community
ISO	International Organisation for Standardisation
JCGM	Joint Committee for Guides in Metrology
LAI	Leaf Area Index
LPV	CEOS WGCV Land Product Validation Sub-group
LUT	Look-up Table
MACC	Monitoring Atmospheric Composition and Climate
MTF	Modulation Transfer Function
NDACC	Network for the Detection of Atmospheric Composition Change
NMI	National Measurement Institute
NOAA	National Oceanic and Atmospheric Administration
NORS	Network of remote Sensing Ground-Based Observations in support of the GMES Atmospheric Service (EU FP7 Project building on GECA and GEOmon tools and methods and using NDACC network data)
NO_2	Nitrogen Dioxide
NPL	National Physical Laboratory (UK)
OLIVE	Online Validation Exercise
OSCAR	Observing Systems Capability Analysis and Review (WMO)
OSSSMOSE	Observing System of Systems Simulator for Multi-mission Synergies Exploration
ProDEx	Projet de Developpement d'Experience programme
QA	Quality Assurance
QA4ECV	Quality Assurance for Essential Climate Variables (EU FP7 Project)
QA4EO	GEO-CEOS Quality Assurance Framework for Earth Observation
QI	Quality Indicator
QMF	Quality Management Framework
QMS	Quality Management System
RADCALNET	Network of instrumented sites for radiometric calibration of EO optical sensors (formerly Landnet)
SADE	Structure d'Accueil de Données d'Etalonnage (Framework for Calibration Data)

SAF	EUMETSAT Satellite Application Facility
SBA	Societal Benefit Area
SI	Système International (international unit system)
SSD	Service Specification Document
TASTE / Multi-TASTE	Technical Assistance To ESA multi-mission validation using sondes, spectrometers and radiometers (series of ESA projects in support of the evolution of Envisat and Third Party Missions atmospheric composition data)
TUPT	Traceability and Uncertainty Propagation Tool
USGS	United States Geological Survey
VIM	Vocabulaire international de métrologie (JCGM 2008)
WGCV	CEOS Working Group on Calibration and Validation
WMO	World Meteorological Organization

EXECUTIVE SUMMARY

Climate change mitigation and adaptation has risen to the top of the agenda for many governments and international organisations. This has led to the establishment of projects and programmes dedicated to the development of long-term records of essential climate monitoring variables using space-borne assets. In support of the European Union's Earth Observation Programme's Copernicus Climate Change Service, the **Quality Assurance for Essential Climate Variables (QA4ECV)** project aims to fulfil a current gap in the delivery of climate quality satellite derived datasets by prototyping a robust, generic system for the implementation and evaluation of QA measures for satellite-derived ECV climate data record products. The purpose of developing and implementing a QA4ECV system is two-fold: 1) to provide ECV data product producers/science teams with the necessary resources (internationally endorsed tools, standards, methodologies) to develop products with embedded QA information that is presented in a clear and common format throughout the Earth Observation (EO) community and 2) to provide data users (scientists – policy-makers) with robust QA information as a means to quantitatively assess uncertainty and fitness-for-purpose of the data and derived products. Provision of such QA information will demonstrate traceability of products and simplify comparisons, including round-robin selection, between the same ECV produced by independent science teams. It will also provide data users with evidence-based confidence in the products and enable judgement on the fitness-for-purpose of various ECV CDRs for their specific applications.

This QA4ECV QA System Service Specification Document (SSD Version 1.0) scopes the concepts and requirements for the development and implementation of an operational QA system that will provide metrological traceability of ECV product algorithm and validation chains. The system will include access to: newly developed and existing multi-use and ECV-specific uncertainty analysis and validation tools; best practice guidance; community reference standards; full data provenance documentation; training materials and courses; as well as QA implementation and interpretation support. Components of the prototype QA system that will be developed during the QA4ECV project will be applied on six pilot ECV products (Albedo, LAI, FAPAR, NO_2, CO and HCHO) to demonstrate the functionality and provision of such QA information. A Quality Management System approach will be adapted to ensure QA tools and methods are implemented correctly and QA information is displayed appropriately. The intention of ECV developers gaining endorsement through an external evaluation as part of the QA4ECV system is to demonstrate to potential users that the QA information provided in the data product is readily available, relevant and in a clear and understandable format. Various levels of endorsement will correspond to the maturity of detail of QA compliance achieved.

The QA system will provide several functions, supporting those who ***create, validate*** and ***use*** ECV data records, as well as stipulating a mechanism for the impartial ***evaluation*** of quality metrics, uncertainty assessment and validation techniques for the continual improvement of climate data and services. The QA4ECV system will consider the following types of QA information associated with EO derived ECVs: Traceability; Uncertainty; Quality Indicators (QI); Validation, including independent reference data quality; Product and system maturity information; as well as Fitness-for-Purpose metrics. The QA4ECV framework set out within this SSD seeks to align with and build upon other relevant and successful EU projects that consider EO data quality and provenance issues, for example CHARMe and CORE-CLIMAX as well as international coordination bodies including the CEOS Working Group on Calibration and Validation, the joint CEOS CGMS Working Group on Climate as well as GCOS. Development of the QA system will benefit immensely from dedicated interaction with other ECV development teams such as the ESA CCI, EUMETSAT SAF network, as well as scientific data users in order to build capacity and ensure a robust and

valuable service is developed.

1. INTRODUCTION

1.1. BACKGROUND

Data from Earth Observation (EO) satellites are increasingly used to monitor the environment, understand variability and change, inform evaluations of climate model simulations and forecasts and manage natural resources. Policy makers are progressively relying on information derived from EO data to make decisions on mitigating and adapting to climate change. These decisions should be evidence based, which requires complete confidence in satellite-derived products. EO data and Essential Climate Variable (ECV) Climate Data Record (CDR) products will form a key information component of the European Union's Earth Observation Program's Copernicus Climate Change Service (previously GMES (Global Monitoring for Environment and Security)). Copernicus, together with the future positioning system 'GALILEO' and the European Directive on geospatial data infrastructures 'INSPIRE', form a major EU contribution to the Global Earth Observation System of Systems (GEOSS). The Copernicus Climate Change Service (C3S) will consist of a set of systems that collate data from multiple sources including EO satellites and in situ sensors such as ground stations, airborne and sea-borne buoys. The systems will process these data and provide policy-makers and users with reliable and current information related to environmental and security issues (http://www.copernicus.eu/).

The value of satellite-derived CDRs for decision making purposes is directly linked to the quality and fitness-for-purpose of the products. Although EO data and products are plentiful, it is still rare for them to have reliable and fully traceable information concerning their quality. The situation is further exacerbated because various versions of the same ECV parameter are offered by different data providers. These data products are created with independent or multiple sources of EO data using an array of retrieval algorithms including model-based reanalyses and assumptions. They are also provided at different spatial and temporal resolutions over varying time periods. Data users at all levels (scientists, public, commercial, government) need to be able to make informed judgement on the validity and fitness-for-purpose of the EO data products and derived CDRs that are available.

The Quality Assurance for Essential Climate Variables (QA4ECV) project aims to prototype a robust, generic system for the implementation and evaluation of QA measures for satellite-derived ECV climate data record products. With a view to enable data users to assess the extent to which scientific information is fit-for-purpose, GEO (Group on Earth Observations) mandated CEOS (Committee on Earth Observation Satellites) WGCV (Working Group on Calibration and Validation) to establish the general data quality strategy for the GEOSS, resulting in the creation of the Quality Assurance Framework for Earth Observation (QA4EO). The overarching principle of QA4EO is that data and derived products shall have associated with them a fully traceable indicator of their quality (QA4EO, 2010). The QA system of the QA4ECV project will sit within the broader GEOSS context and provide the framework, tools and data necessary for the adoption and implementation of QA4EO.

This Service Specification Document (SSD, Version 1.0) scopes the concepts for the development and implementation of an operational QA system that will provide metrological traceability of ECV product processing and validation chains and include access to both multi-use and ECV-specific uncertainty analysis and validation tools, best practice guidance, community reference standards and full data provenance documentation. The QA system will also provide a simple streamlined process for both internal (data producer/supplier) QA

compliance and external, independent evaluation (by end data users) of the fitness-for-purpose of any satellite-derived ECV product. Providing a means for data producers to offer evidence to justify their products use by service developers/providers such as the C3S will ensure end user confidence in the data sets and information provided. Figure 1 outlines the international context in which the QA4ECV system will be positioned. To ensure this is a comprehensive QA system for the wider EO community, it is anticipated that the QA4ECV framework will integrate results and findings from both existing and new QA systems developed within specific application areas (for example, ESA Multi-TASTE, ESA CCI, CHARMe, GECA/NORS, CLIP-C, CORE-CLIMAX, GAIA-CLIM, FIDUCEO).

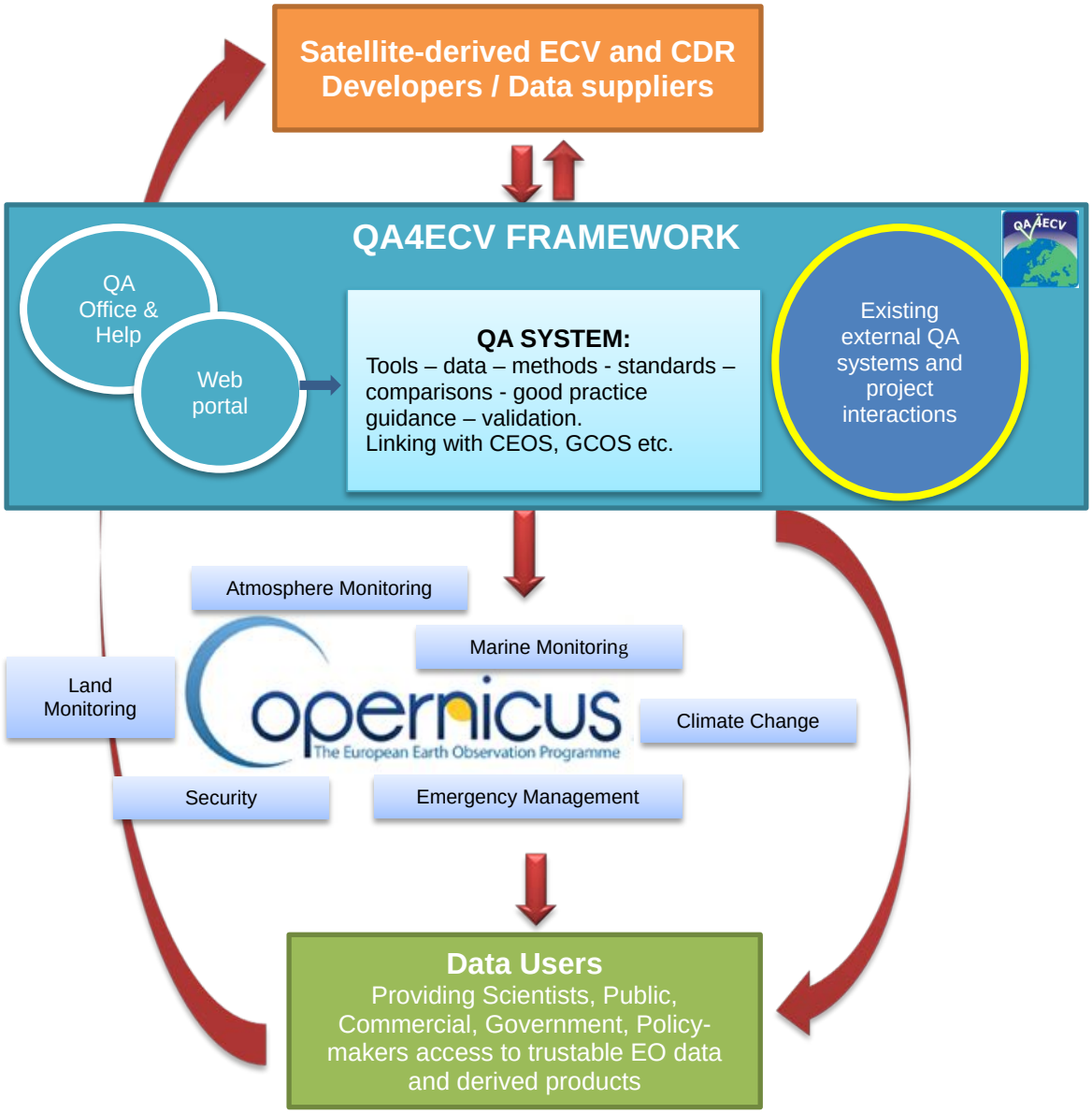


Figure 1: The utility of the QA4ECV service to data developers, suppliers, and international climate services (i.e. C3S) as well as end data users. Data producers may use the QA system to provide QA evidence and gain endorsements. End users may use the QA4ECV system to verify the quality and maturity of any EO derived ECV for their own specific applications, alternatively they may utilise derived information provided through C3S. The QA4ECV framework will integrate data, knowledge and lessons-learned from complimentary QA projects and programmes (outlined above).

1.2. PURPOSE OF THIS DOCUMENT

The European Union Framework 7 call under which the QA4ECV project is supported has the fundamental goal in support of the Copernicus Climate Change Service, “to develop rigorous quality assurance methodologies for satellite-derived ECV products.” It emphasises that this requires developing “traceable approaches that allow evaluation of the quality of satellite-derived and in situ measured ECV products and algorithms via an unbroken chain of comparisons to certified reference standards” i.e. as “used in metrology” and “wherever possible be traced to reference standards of SI derived units”. The GEO Quality Assurance Framework for Earth Observation was established to represent these principles and tailor them for the specific needs of the EO community (QA4EO, 2010 and http://QA4EO.org/). The intent of the QA4ECV system is to extend this concept and evolve it into a practical implementation to support the assignment of QA to ECV climate data records derived from satellites, specifically those ECVs that will be generated in the QA4ECV project: Albedo, Leaf Area Index (LAI), Fraction of Absorbed Photosynthetically Active Radiation (FAPAR), Nitrogen Dioxide (NO_2), Formaldehyde (HCHO) and Carbon Monoxide (CO).

This service specification document outlines the proposed framework as a basis for discussion and evaluation, for the QA4ECV system and will include the overall QA4ECV System and Process (Section 2), Specification of the QA4ECV System Components (Section 3) as well as QA4ECV Governance (Section 4) and Compliance Procedures (Section 5).

2. OVERVIEW OF THE QA4ECV SYSTEM FRAMEWORK

2.1. AIM OF THE QA SYSTEM

The purpose of developing and implementing a QA4ECV system is two-fold: 1) to provide ECV data product producers/science teams with the necessary resources (internationally endorsed tools, standards, methodologies) to develop products with embedded QA information that is presented in a clear and common format throughout the EO community and 2) to provide data users with robust QA information as a means to quantitatively assess uncertainty and fitness-for-purpose of data and derived products. Provision of such QA information will demonstrate traceability of products and simplify comparisons between the same ECV produced by independent science teams with different satellite data and algorithms. It will also provide data users with evidence-based confidence in the products and enable judgement on the fitness-for-purpose of various ECV CDRs for their specific applications. The aim of gaining endorsement through formal external evaluation as part of the QA4ECV system is to demonstrate to potential users that the QA information provided in the data product is readily available, relevant and in a clear and understandable format. Various levels of endorsement will correspond to the maturity of detail of QA compliance achieved.

The overall outcome of this QA system will be the prospect of a maturity-based QA endorsement on all ECV and CDR records leading to user confidence in those products and derived services in a manner consistent with other services of a non-EO based nature e.g. manufacturing and healthcare.

The system will provide several functions: supporting those who ***create*** ECV data records; supporting those who ***validate*** ECV data records; supporting those who ***use*** ECV data records; as well as stipulating a mechanism for the impartial ***evaluation*** of quality metrics, uncertainty assessment and validation techniques for the continual improvement of climate data and services. Access to a dedicated QA helpdesk facility to assist with the implementation and interpretation of QA will be vital across all components of the system.

The system will support science teams ***creating*** ECV records by:

- Ensuring access to community best practice for common processing steps
- Facilitating access to SI-traceability or other internationally agreed standards (where applicable)
- Providing tools to support practical Quality Assurance implementation
- Providing training in Quality Assurance and uncertainty assessment
- Establishing mechanisms to enable input data to be appropriately quality assured prior to it being ingested into ECV production processes
- Facilitating the demonstration of QA metrics in ECV product development in a transparent, consistent, and cost-effective manner

The system will support science teams ***validating*** ECV records by:

- Providing good practice guidance, tools, methods and reference standards to support practical validation
- Providing access to quality assured in situ and reference data sets
- Providing advice on best practice for sub-setting tools
- Providing visualisation tools to understand the validation results
- Providing training in QA, validation, uncertainty and fitness-for-purpose assessments

The system will support those who ***use*** ECV records by:

- Providing a means for independent evaluation of the QA metrics within the CDRs
- Providing documentation for and transparency in the ECV processing chain
- Simplifying and standardising the presentation of Quality Assurance information
- Providing a means of sub-setting CDRs to extract time-series of single point or user specified regions of interest
- Providing visualisation tools to understand the data and its associated uncertainties
- Ensuring the ability to maintain long-term data provenance records in a consistent and transparent way is established from the outset
- Providing a means to assess suitability of a product/service for an application

The system will provide a mechanism for the impartial ***evaluation*** of QA procedures by:

- A dedicated QA4ECV evaluation office with staff dedicated to support the QA process implemented by ECV CDR developers and facilitate QA knowledge adoption by data users
- Maintenance and continual update of the QA framework and system, reference standards and tools with scientific advancement

- Constructive advice and recommendations for improving ECV QA, uncertainty assessment and validation

2.2. BASIS OF THE QA SYSTEM

The QA4ECV system described within this document is based on existing Quality Management System (QMS) frameworks and principles similar to those defined in ISO 9001:2008. Such QMS frameworks and principles have been proven in use for many years and their adoption for QA4ECV would allow simplified integration of QA into many organisations' ECV processing systems. It is noted however, that respondents to the recent survey of user and supplier requirements for QA in satellite-derived ECV data products (Marks *et al*. 2014) considered the requirements of pre-existing ISO quality standards too stringent and formal for practical application in this context. Therefore, although fundamentally based on the frameworks and principles of such systems, the QA4ECV system will be developed to ensure it is a functional and flexible system tailored specifically to current EO and climate community needs. For example, concepts and governing principles outlined in QA/ Quality Control frameworks applied within the IPCC, GCOS and World Meteorological Organisation will be evaluated for their applicability and application within QA4ECV. It is envisioned that as the system prototyped in the QA4ECV project evolves over the long-term (i.e. 5 to 10 years), the requirements may form the basis of a more formal ISO standard.

2.3. OVERVIEW OF THE QA4ECV SYSTEM PROCESS

In order for the QA4ECV system to be successful it must be simple and intuitive, offer a wide range of tools and resources relevant to multiple EO disciplines and ensure the evaluation process is streamlined and follows a 'checklist' type strategy. Figure 2 outlines a quick start guide to the QA4ECV system, the specific detail of each component will be discussed in further sections.

The QA4ECV system should be accessible through an online portal (see Section 2.4). A dedicated QA4ECV Office (blue shaded region) will provide the backbone for the operation of the QA system. The office will be responsible for preparing evaluation criteria, ensuring the tools, data and training modules provided within the QA system are current and state of the art, offering guidance and support for use of the system tools, as well as conducting the evaluation and awarding endorsement for QA compliance. It will also ensure clear linkage with international cal/val activities and be instrumental in organising, coordinating and leading workshops, data comparisons and analyses. It should also provide directories of, and ideally direct access to, internationally accepted reference standards where available, for all stages of the products development and validation.

The QA System itself (orange shaded region) can be accessed and utilised in multiple ways by ECV product developers, data and product users as well as validation and QA evaluation teams. The system consists of a series of QA compliance procedures as well as user-friendly tools, methods, standards guidelines and training modules. The unique 'Traceability and Uncertainty propagation tool' (TUPT) being developed within the project, will support ECV CDR-developers to express the QA components and uncertainty assessment for their product processing chains. In addition, it will enable users and validation teams to

investigate the QA metrics, uncertainty and traceability of any ECV product associated with the system. Existing tools, methods and standards will either simply be implemented within (i.e. ECV product algorithm uncertainty propagation methods) or linked from external sources to the QA system (i.e validation good practice guidelines defined by the CEOS WGCV Land Product Validation and Atmospheric Composition sub-groups). Tools, methods and standards that require updating or further development for them to be integrated into the QA4ECV system will be assessed and implemented in relation to the priority requirements specified by the system users. For example, validation of atmosphere ECV CDRs will benefit from the experience gained with: 1) the operational validation of Envisat and Third Party Missions (through the Multi-TASTE validation system), 2) the metrology concepts and tools developed within GEOmon (FP6 project), 3) associated BELSPO/ProDEX projects (e.g. OSSSMOSE metrology simulator for atmospheric composition remote sensing), and 4) the architecture and tools pioneered in ESA's GECA project and implemented in the NORS server (FP7 project for prototyping an operational validation server for the MACC system outputs using ground-based NDACC data). New tools, methods and standards that are deemed necessary to improve the QA of the ECV CDRs being developed within QA4ECV will be scoped and if time/resources permit, developed through the life of the QA4ECV project (see Section 3 for more detail concerning tools, methods and standards). Noting that this type of QA system and evaluation activity is 'new territory' for the EO community, the framework set out within this document has been designed to allow 'levels of QA compliance' (see Section 5), which will be key in encouraging ECV developers to continually improve their product QA, whilst not limiting their entry into the system process.

2.4. QA4ECV WEB PORTAL

A web portal dedicated to the QA4ECV system will provide a central location for all QA4ECV information including, for example, links to access QA4EO documentation, descriptions of formal international and community reference standards, validation data sets, CEOS best practice protocols, comparison results, instrumentation manuals and ECV product QA evaluation reports. This type of information will be of interest to both data producers and users. The portal will also provide the entry point into the QA4ECV system traceability and uncertainty propagation tools. The QA4ECV system will house the tools (both generic multi-ECV and ECV-specific) to enable data producers to implement standardised QA procedures and where possible improve upon existing QA techniques (see Section 3). The system will also allow for internal and external ECV product QA compliance evaluation in a simple step-by-step approach and QA endorsement information. This process will be discussed further within Sections 4 and 5. Access to the QA system will be open following a nominal registration process with some password protected areas/tools to enable the QA Office and helpdesk to monitor usage and provide dedicated support where needed. As part of the QA system development process, user / customer feedback will be encouraged to drive improvements to both the QA system as a whole as well as its operation.

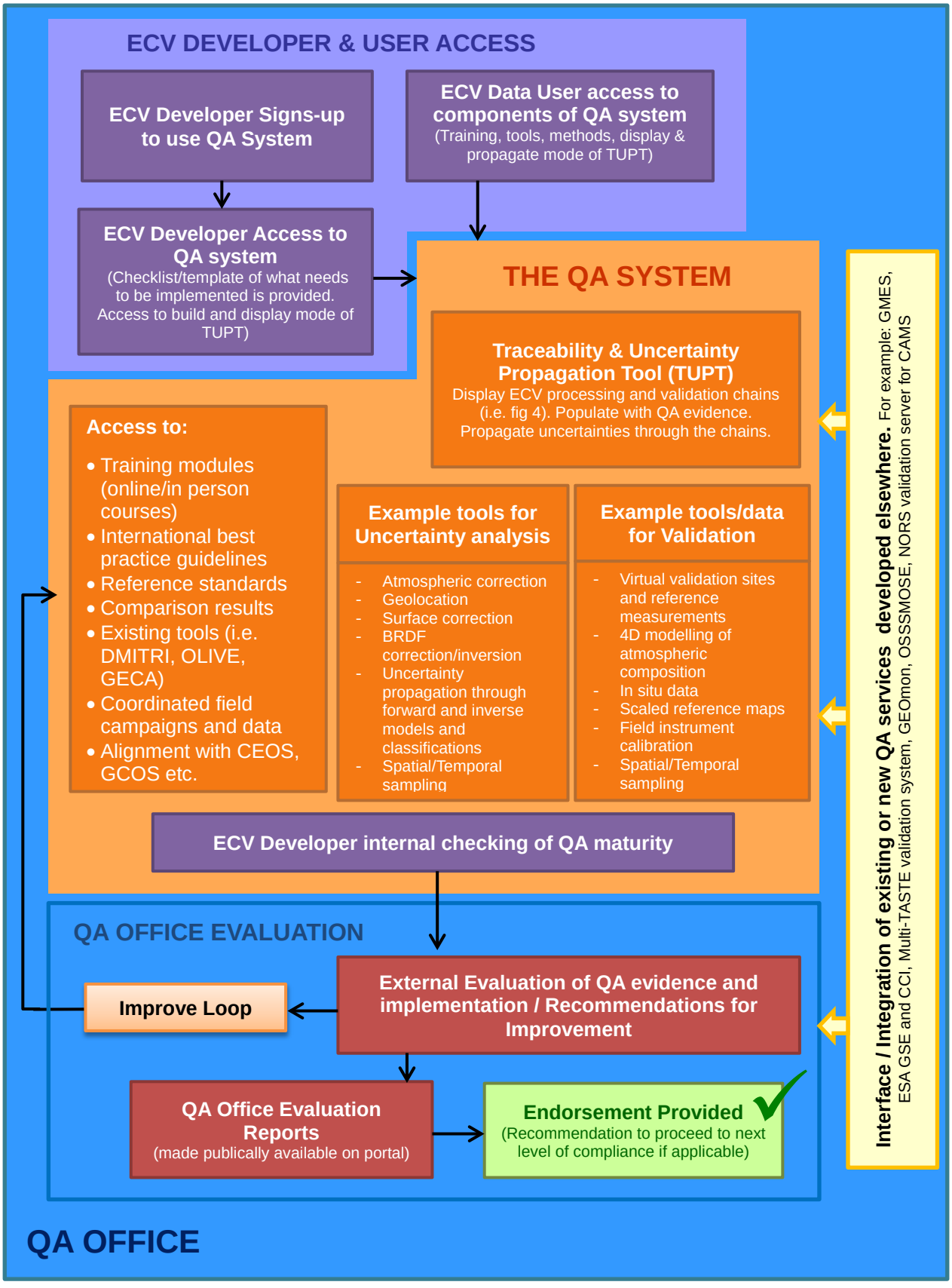


Figure 2: Overview of Framework for the implementation of the QA4ECV system including the

QA Office and QA System Components. The QA Office (blue) is the overarching body responsible for the QA system (orange) maintenance (ensuring up to date tools, data, training, QA and maturity evaluation templates and international coordination).

Summary of QA4ECV System Framework Requirements

- QA Office: staffed help-desk network for QA system maintenance, support and international coordination
- Website and portal with database of QA documents relevant to the system and from aligned entities i.e. CEOS WGCV (LPV, ACSG, IVOS and Climate), GCOS, ICOS, WMO
- Access to methods, tools and data from aligned bodies i.e. tools such as DIMITRI and OLIVE
- Access to training and advice
- First order product traceability diagrams
- First order validation traceability diagrams
- Evaluation records for ECV CDR products

3. THE QA4ECV SYSTEM COMPONENTS

3.1. QA INFORMATION CONSIDERED

The QA4ECV framework set out within this SSD seeks to align with and build upon other relevant and successful EU projects that consider EO data quality and provenance issues, for example CHARMe (http://charme.org.uk/) and CORE-CLIMAX (http://www.coreclimax.eu/) as well as international coordination bodies including CEOS (Committee on Earth Observation Satellites) Working Groups (including Cal/Val and Climate) and GCOS (Global Climate Observing System), among others.

The QA4ECV system will consider the following types of QA information associated with EO derived ECVs:

- Traceability
- Uncertainty
- Quality Indicators (QI)
- Validation, including independent reference data quality
- System maturity
- Fitness-for-purpose

Traceability will be divided into three categories with increasing levels of detail, as summarised in Figure 3. The first level infers a basic understanding of the processes involved in the data derivation and summary of supporting documentation (i.e. ATBD and

other product manuals) as well as data provenance (i.e. who, what, where, when, how?) following the cataloguing and versioning processes developed under CHARMe. The second level involves provision of information related to data processing, i.e. algorithms (and where possible access to code and look-up tables) used to develop the product as well as uncertainty assessments. The third level provides traceability in a metrological sense. That is as is understood and implemented by national metrology institutes (NMIs) and defined within the JCGM 200 (2012) International vocabulary of metrology as being the *"property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty"*. It is the philosophical level explicitly requested in the original FP 7 space call documents.

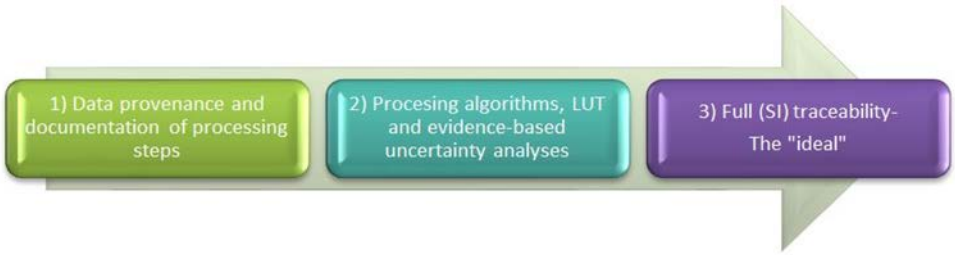


Figure 3: Stages of traceability.

Uncertainty is defined by the Joint Committee for Guides in Metrology as:
The 'parameter, associated with the result of a measurement that characterises the dispersion of the values that could reasonably be attributed to the measurand' (JCGM 100, 2008). Uncertainty metrics will be considered using both quality assured algorithms and product validation at a per pixel level. Variance and covariance matrices should be supplied.

Quality Indicators are defined as:
'A means of providing a user of data or derived products with sufficient information to assess its suitability for a particular application based on a quantitative assessment of its traceability to an agreed reference or measurement standard (ideally SI), but can be presented as numeric or a text descriptor, providing the quantitative linkage is defined' (QA4EO, 2013).

Validation is defined as:
*'The process of assessing, by **independent means**, the quality of the data products derived from the system outputs'* (Justice *et al*. 2000). Table 1 provides an example of a hierarchical approach to classify validation stages for satellite-derived land products that may also be adopted within the QA4ECV framework. This approach was endorsed by CEOS WGCV through consensus of the LPV (Land Product Validation) community in 2003 and revised in 2009 (Nightingale *et al.* 2010). For atmospheric data products, traceability chains of the validation process have been developed. These traceability chains depend on the atmospheric species, its environment (e.g. polar vs. tropical, urban vs. pristine, tropospheric vs. stratospheric), the degree of maturity of the retrieval and the intended use of the data. A major task within the QA4ECV project framework will be to formulate from published and community endorsed material, a generic QA/validation chain practically applicable to all atmospheric ECVs.

Table 1: CEOS WGCV Validation Hierarchy for Land Products.

Stage 1	Product accuracy is assessed from a small (typically < 30) set of locations and time periods by comparison with in situ or other suitable reference data.
Stage 2	Product accuracy is estimated over a **significant set of locations and time periods** by comparison with reference in situ or other suitable reference data. **Spatial and temporal consistency** of the product with similar products has been evaluated over globally representative locations and time periods.
Stage 3	**Uncertainties** in the product and its associated structure are well quantified from comparison with in situ or other suitable reference data. **Spatial and temporal consistency** of the product with similar products has been evaluated over globally representative locations and time periods. **Uncertainties are characterised in a statistically robust way over multiple locations and time periods** representing global conditions.
Stage 4	Validation results for stage 3 are **systematically updated** when new product versions are released and as the time-series expands.

System maturity - The maturity model for assessing the completeness of climate data records developed within the CORE-CLIMAX project will be applied (EUMETSAT (2014), Table 2). The CORE-CLIMAX maturity model is an adaptation of Bates et al. (2012), which was revised to be more generic so that it can be applied not only for satellite data sets, but for all climate data records (in situ, combined satellite and in situ, and reanalyses). The adapted approach has been discussed and agreed with many leading initiatives in Europe such as the EUMETSAT network of Satellite Application Facilities (SAF) and the ESA Climate Change Initiative. Internationally, the approach is supported by the WMO, CEOS-CGMS WG Climate, NOAA and USGS. It is currently applied by the CEOS-CGMS WG Climate to assess the status of the global collection of climate data records contained in the CEOS, CGMS and WMO ECV inventory (www.ecv-inventory.com).

Maturity is considered in three broad categories that give information on the grade of stability of the CDR generation process. The nomenclature for these broad categories has been imported from NOAA and follows (Bates et al. 2012):

- Maturity scores 1 and 2 establish Research Capability (RC): All aspects of the CDR are still under development;
- Maturity scores 3 and 4 establish an Initial Operations Capability (IOC): At this stage the CDR and associated material are available to the user community. The CDR has reached a status where its usefulness is completely demonstrated and decisions need to be made to sustain its maintenance and further development. At this stage so called transitions of CDR generation capabilities from research units to more operational oriented units are happening.
- Maturity scores 5 and 6: Full Operations Capability (FOC): At this stage the production of the CDR has been transitioned into operational environments, e.g., the whole processing process is under configuration management, fully automated and performance is monitored. The production chain meets the goal of acquiring capabilities to provide uninterrupted and indefinite data provision for climate

monitoring. The data provider, e.g., a space agency takes complete responsibility for the maintenance and also further development of the CDR. The specific development activities still are performed by scientists within or external to the responsible agency or both.

The maturity matrix is defined by thematic areas: software readiness (stability of code); metadata (amount and compliance with international standards); user relevant documentation (description of the processing steps and algorithms for scientific and general communities, user guides, etc.); uncertainty characterisation (quality and amount in time and space); public access, feedback and update (availability of data, structured feedback mechanism on improvements, regular update); and usage (uses by broader community) (EUMETSAT 2014). The underpinning technical detail that guides and supports the assessment process will be determined by the tools and processes developed or specified within the QA4ECV project.

Fitness-for-purpose relates to how well-suited the data set or CDR is for its designated roles or purposes. It encompasses the combination of all QA aspects as related to specific user requirements. CDR fitness-for-purpose will be assessed against other international criteria including for example: the LPV validation hierarchy and community endorsed atmospheric validation chains; the WMO (World Meteorological Organisation) Quality Management Framework (QMF) and requirements for observation of physical variables in support of WMO Programmes and Co-sponsored Programmes; OSCAR (Observing Systems Capability Analysis and Review, http://www.wmo-sat.info/oscar/requirements); as well as the formal evaluation of the compliance of the CDRs with GCOS (Global Climate Observing System) requirements outlined in the GCOS Implementation Plan (GCOS-154, 2011, to be updated in 2015). Further, development of an Application Performance Metric (APM) that attempts to evaluate the performance of an ECV CDR with respect to a specific application is currently being developed as part of the CORE-CLIMAX project. The APM will be realised in the form of an interactive tool via which a user can search for applicable datasets based on their project requirements. Thus, collaborative user engagement in the development of the QA framework is critical and will help steer the presentation of QA information and product fitness-for-purpose scenarios.

The QA components outlined above were considered essential in a recent survey of satellite data product users (Marks *et al*. 2014). However, survey respondents indicated that QA information in the majority of satellite products is currently insufficient, with uncertainty and traceability information being the least accessible components of products and their QA. Close alignment with the international satellite data product user community during the development of the prototype QA system will ensure that all tools, methods and datasets produced within the QA4ECV project are relevant, user-friendly and meaningful. The framework will include requirements for each of these areas and eventual ECV product evaluation and QA endorsements will be based on the degree of compliance with each requirement. Additional QA information may be included within the QA4ECV system and these will be incorporated into the QA system as it evolves.

Table 2: Top level CORE-CLIMAX Maturity Matrix showing the key areas to be assessed on a scale between 1-6.

Maturity	SOFTWARE READINESS	METADATA	USER DOCUMENTATION	UNCERTAINTY CHARACTERISATION	PUBLIC ACCESS, FEEDBACK, UPDATE	USAGE
1	Conceptual development	None	Limited scientific description of the methodology available from PI	None	Restricted availability from PI	None
2	Research grade code	Research grade	Comprehensive scientific description of the methodology, report on limited validation, and limited product user guide available from PI; paper on methodology is sumitted for peer-review	Standard uncertainty nomenclature is idenitified or defined; limited validation done; limited information on uncertainty available	Data avaliable from PI, feedback through scientific exchange, irregular updates by PI	Research: Benefits for applications identified DSS: Potential benefits identified
3	Research code with partially applied standards; code contains header and comments, and a README file; PI affirms portability, numerical reproducibility and no security problems	Standards defined or identified; sufficient to use and understand the data and extract discovery metadata	**Score 2** + paper on methodology published; comprehensive validation report available from PI and a paper on validation is submitted; comprehensive user guide is available from PI; Limited description of operations concept available from PI	**Score 2** + standard nomenclature applied; validation extended to full product data coverage, comprehensive information on uncertainty available; methods for automated monitoring defined	Data and documentation publically available from PI, feedback through scientifc exchange, irregular updates by PI	Research: Benefits for applications demonstrated. DSS: Use occuring and benefits emerging
4	**Score 3** + draft software installation/user manual available; 3rd party affirms portability and numerical reproducibility; passes data providers security review	**Score 3** + standards systematically applied; meets international standards for the data set; enhanced discovery metadata; limited location level metadata	**Score 3** + comprehensive scientific description available from data provider; report on inter comparison available from PI; paper on validation published; user guide available from data provider; comprehensive description of operations concept available from PI	**Score 3** + procedures to establish SI traceability are defined; (inter)comparison against corresponding CDRs (other methods, models, etc); quantitative estimates of uncertainty provided within the product characterising more or less uncertain data points; automated monitoring partially implemented	Data record and documentation available from data provider and under data provider's version control; Data provider establishes feedback mechanism; regular updates by PI	**Score 3** + Research: Citations on product usage in occurring DSS: societal and economical benefits discussed
5	**Score 4** + operational code following standards, actions to achieve full compliance are defined; software installation/user manual complete; 3rd party installs the code operationally	**Score 4+** fully compliant with standards; complete discovery metadata; complete location level metadata	**Score 4** + comprehensive scientific description maintained by data provider; report on data assessment results exists; user guide is regularly updated with updates on product and validation; description on practical implementation is available from data provider	**Score 4** + SI traceability partly established; data provider participated in one inter-national data assessment; comprehensive validation of the quantitative uncertainty estimates; automated quality monitoring fully implemented (all production levels)	**Score 4** + source code archived by Data Provider; feedback mechanism and international data quality assessment are considered in periodic data record updates by Data Provider	**Score 4+** Research: product becomes reference for certain applications DSS: Societal and economic benefits are demonstrated
6	**Score 5** + fully compliant with standards; Turnkey System	**Score 5** + regularly updated	**Score 5** + journal papers on product updates are and more comprehensive validation and validation of quantitative uncertainty estimates are published; operations concept regularly updated	**Score 5** + SI traceability established; data provider participated in multiple inter-national data assessment and incorporating feedbacks into the product development cycle; temporal and spatial error covariance quantified; Automated monitoring in place with results fed back to other accessible information, e.g. meta data or documentation	**Score 5** + source code available to the public and capability for continuous data provisions established (ICDR)	**Score 5** + Research: Product and its applications becomes references in multiple research field DSS: Influence on decision and policy making demonstrated

3.2. QA TOOLS

The QA4ECV system will house the tools (both generic multi-ECV and ECV-specific) to enable: a) data producers to implement standardised QA procedures and where possible improve upon existing QA techniques; and b) data users to investigate the product quality, uncertainty and suitability for their specific application. The current version of the Service Specification document does not claim to be exhaustive in the identification of generic or ECV-specific QA tools, methods or standards. As the QA4ECV project develops over the next 3-years (2015-2017), detailed specifications and development will occur based on priority needs of data producers and users. The update to this SSD at the end of the project will outline recommendations for further research that will be required to ensure the QA4ECV QA system and its components are both robust and beneficial to data developers and users. The following section outlines an initial overarching tool that will be prototyped to provide a visual interface to summarise and document, in a step wise manner, the end-to-end QA and degree of traceability of a CDR product. Additional tools, methodologies and standards that need to be developed to enhance QA of ECV data records are listed and discussed in the following sections.

3.2.1. TRACEABILITY AND UNCERTAINTY PROPAGATION TOOL

Key to understanding and expressing QA of any ECV data product is the ability to clearly display the processing steps taken to produce the dataset as well as those taken to validate the dataset. At a minimum, it is necessary to know the provenance of the input data, the algorithms and assumptions used. This information may be provided within algorithm theoretical basis documentation (ATBD) and other product user manuals, but is often buried in complex descriptions and it is difficult to grasp quickly. Therefore, this documentation is not consulted or applied effectively. Within the QA4ECV project, a functional prototype of a Traceability and Uncertainty Propagation Tool (TUPT) will be developed. The basic concept of the TUPT is a user-friendly graphical interface that can display (in an electronic interactive format) a visual diagrammatic version of an algorithm processing step traceability chain of an ECV product (and in principle any other EO product or validation process). Diagrams of algorithm traceability will be of the form shown in Figure 4. Note that at the entry level this would be displayed in terms of the central boxes representing the processing steps from product inputs to the ECV output. An indication of the linkages between steps (for uncertainty propagation) as well as the level of maturity (in terms of QA) of the step will also be provided. By clicking on each step this can then be expanded to another layer to give the detailed information about that step in terms of basic documentation, provenance, assumptions employed and uncertainty analysis. In parallel and where applicable, product validation chains will be developed in a similar fashion to show the validation process from source / in situ measurements, data processing steps to validation approach applied. An example validation chain for nadir Ozone profile retrievals is shown in Figure 5. This will promote and facilitate full end-to-end traceability. Information concerning data versioning, system and product maturity, algorithms and temporal components (i.e. multiple sensors through time) for CDRs must also be expressed. The operational version of the tool will incorporate simple script for each processing step that will facilitate propagation of real/test data through the chain to evaluate uncertainty and simulate the effects of alternative methods. Detailed specifications for the TUPT can be found in associated documentation.

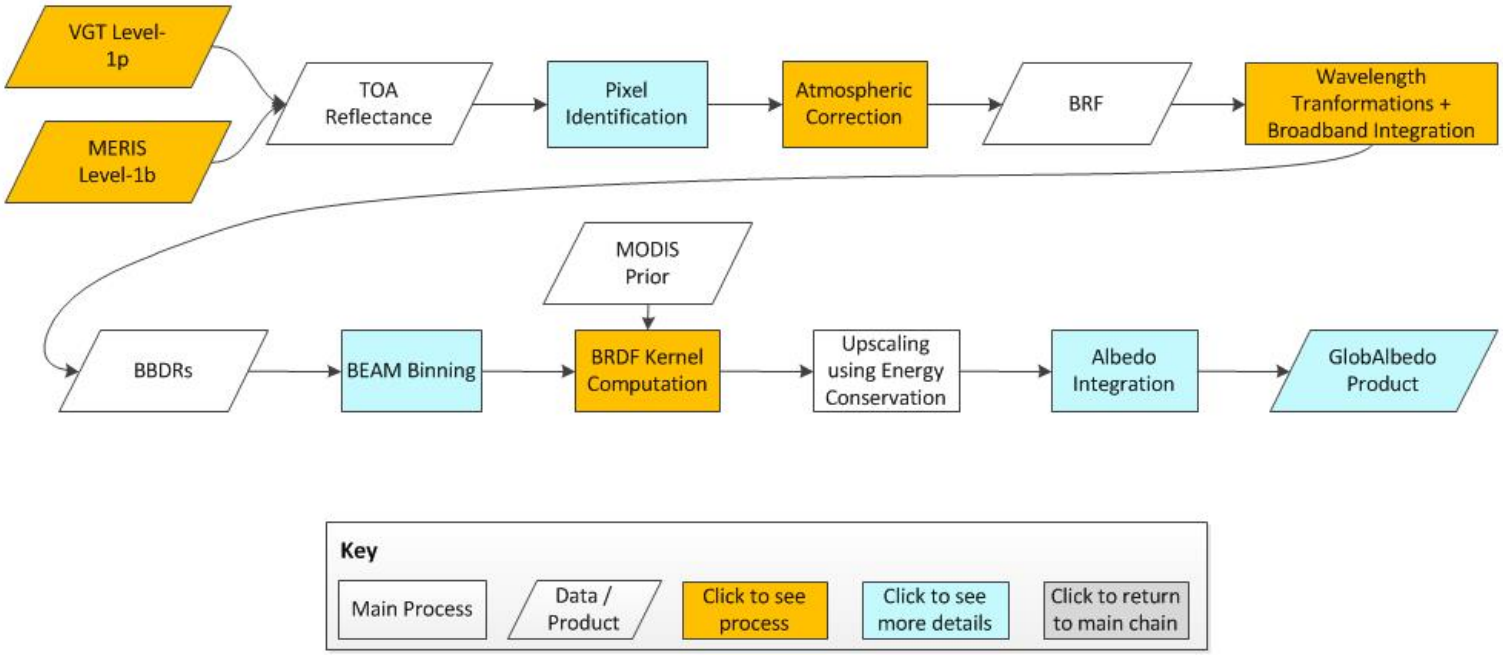
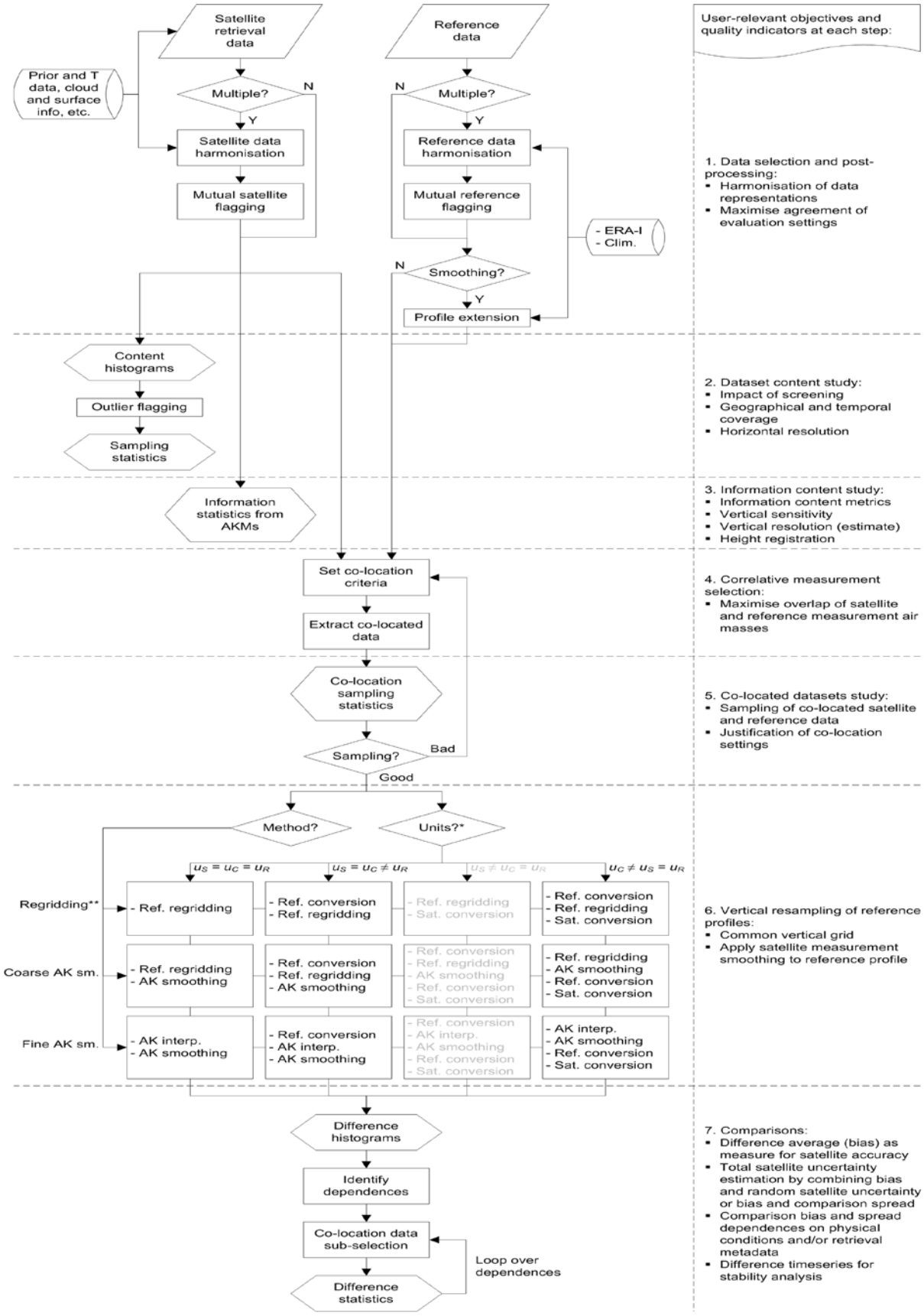


Figure 4: Example traceability diagram for the GlobAlbedo ECV product generation.



* u_S, u_C, and u_R for satellite, comparison, and reference units, respectively.
** Regridding only, or regridding including function smoothing (Gaussian, triangular, others). Regridding possibly by summation for sub-columns.

Figure 5: Example traceability diagram for the characterisation and geophysical validation of nadir Ozone profile retrievals (from Keppens et al. 2014).

3.2.2. ADDITIONAL QA4ECV SYSTEM TOOLS

In addition to the TUPT, it is essential to provide access to many other types of tools and reference standards applicable to EO data sets. A vital part of the QA4ECV project will involve understanding the commonalities across all ECV product processing chains in order to develop generic QA tools as well as identifying the "known unknown" areas where quality and uncertainty assessments are currently lacking. An initial evaluation of ECVs being developed through the QA4ECV project and as part of the ESA CCI (Climate Change Initiative) have highlighted a number of research areas, tools and standards that need to be addressed for QA evaluation purposes. These are outlined within Table 3 and will help shape the development of the QA system over the coming years.

Further, training materials (both online and in person), organised comparisons (field test site and lab based) as well as dedicated cal/val workshops are also a fundamental component to the QA system. Ensuring that data producers and users are familiar with the terminology and comfortable with mathematical procedures will improve the functionality and overall value of the QA system. It is noted that not all of the tools, methodologies and training materials required for comprehensive product QA can be explored and developed fully in the timeframe of the QA4ECV project.

Table 3: Example generic multi-application and ECV-specific tools, methods, standards to be considered, developed or adapted in the implementation of the QA4ECV service.

Tool/Data/Method/Standards/Training	Type	Land	Atmosphere	Ocean
Pre/Post-Launch – Level 1 data and products				
MTF spectral / spatial changes pre-post launch	Tool/Data	x	x	x
Access to L0 calibration information	Data	x	x	x
L1 data harmonisation, same satellite, multi-temporal/spatial	Tool/Data	x	x	x
L1 data harmonisation, multi-satellite, multi-temporal/spatial	Tool/Data	x	x	x
Spectral band-width correction	Tool/Data	x		x
Calibration test site characterisation information	Data/Standards	x		x
Access to reference standards (i.e. reflectance panels and their calibration, thermometers, gas standards etc.)	Data/Standards	x	x	x
Access to reference standards and comparisons over dedicated cal/val sites (i.e. RADCALNET of CEOS WGCV)	Data/Standards	x		x
Reflectance comparison analysis tool: Provides sensor-to-sensor comparisons over targets of interest across the globe. Enables re-analysis of existing sensor-to-sensor comparisons to take into account corrections for BRDF, atmospheric and spectral band effects and to enable comparison to any sensor of choice, or a '*virtual reference sensor*'. It also enables comparisons-of-comparisons and the combination of data from different reference sites. Extension to DIMITRI and SADE tools and databases	Tool	x		x

Data Correction Analysis Tool: A tool to actively normalise one raw EO data set / data record to match the spectral and radiometric properties of another data set or the virtual sensor	Tool	x	x	x
Atmospheric correction	Tool/Data/ Method/Standards	x		x
Surface correction	Tool/Data/ Method/Standards		x	
Spectral and radiometric calibration of radiance and irradiance data	Tool/Data/ Method/Standards	x	x	x
Quality Indicator standardisation within and across ECV	Standards	x	x	x
Uncertainty propagation through complex models	Tool/Method	x	x	x
Uncertainty assessment through a classification procedure	Tool/Method	x	x	x
Uncertainty propagation through forward and inverse models	Tool/Method	x	x	x
Geolocation / pixel aggregation /resampling / Orthorectification	Tool/Methods	x	x	x
BRDF correction / inversion	Tool/Method	x	x	x
Cloud detection / masking	Tool/Method	x	x	x
Full documentation of retrieval chain and settings	Data	x	x	x
Product Validation				
Virtual validation site modelling for retrieval algorithm assessment	Tool/Method	x		
Standards for in situ data collection of various ECV measurements	Method/Standard	x	x	x
Methods for reduction of smoothing and sampling differences (vertical, horizontal and temporal)	Method/Standard		x	
Cloud parameters retrieval : cloud fraction, top height/pressure, albedo, optical depth	Tool/Method		x	
Standards for field instrument calibration and implementation	Method/Standard	x	x	x
Methods for scaling (data point sampling to larger satellite pixel GIFOV)	Method/Standard	x		x
Methods for time-series, trend analysis and normalisation across long time scales	Method/Standard	x	x	x
Product comparison tool: This tool will allow users to compare between different EO products that represent the same measured parameter, but are created from different input data, using different algorithms or processing steps. E.g. OLIVE for biophysical parameters and Multi-TASTE for atmospheric composition parameters	Tool	x	x	x
Error budget of product comparison: This set of guidelines will allow validators to quantify apparent discrepancies due to the comparison method and related data manipulations, which add to the uncertainties associated with the measurements themselves. E.g. OSSSMOSE tool	Method		x	
Full documentation of validation chain and settings	Data	x	x	x
Training				
Radiometric uncertainty	Training	x	x	x
Uncertainty propagation through a processing chain	Training	x	x	x
Uncertainty propagation through complex models and classification procedures	Training	x	x	x
Data and product comparisons	Training	x	x	x
Use of field equipment	Training	x	x	x
QA Compliance Evaluation				
Templates to support QA implementation requirements	Templates	x	x	x
Templates to support documentation of QA processes	Templates	x	x	x

and evidence				
Templates to support QA evaluation	Templates	x	x	x
Comparison analysis tools / round robin and community reference value determination	Web based	x	x	x
FAQ and discussion forum capabilities	Web based	x	x	x

Summary of QA4ECV System Requirements

- User-friendly web-based access to current data, tools, standards and methods for QA of all ECV parameters (satellite, in-situ and modelled, from level-1 radiometric and level-2 data up to higher level data products and services) including any internationally agreed 'bias harmonisation' coefficients to facilitate interoperability
- Traceability / Uncertainty propagation tool:
    1. Draw, display and document QA evidence
    2. Pre-operational incorporation of simple script for each processing steps that will facilitate propagation of real/test data through the chain to evaluation uncertainty and simulate the effects of alternative methods/data
- Access to additional tools and data sets for uncertainty assessment and product validation
- Access to training materials (online and dedicated workshops), best practice guidance and international standards
- Management of and access to reference standards e.g. reflectance panels, thermometers, lamps, gas standards, international test sites for calibration and validation teams
- Discussion forum and planning of coordinated product and field comparison activities

4. QA4ECV SYSTEM GOVERNANCE

To effectively develop, implement and operate any QMS, the organisational structure and the skill sets of specific persons involved must be defined for a suite of tasks. This section scopes the initial requirements for the QA Evaluation/Endorsement organisation that should be formulated to implement the QA4ECV framework, as well as the responsibilities of the ECV CDR developing organisation. The applicability and extent of the QA System Governance roles will be explored and evaluated during the QA4ECV project. Recommendations on how this structure may evolve will be provided at the end of the project.

The following sections scope the detail of the QA evaluation process as this is a key feature in the operation of any QA framework. The rest of the QA service outlined in earlier sections of this specification document are the means to derive and present the information needed to form the content that is being evaluated. It should be noted that many of the system functions rely on access to metrological advice and access to traceable reference standards. It is thus highly valuable that metrological institutes, with appropriate expertise, play a role in

the operation and top-level local governance of the system. The overall governance of the QA framework would need to be defined and most likely would include representation from the EU, space and climate data agencies e.g. ESA, EUMETSAT, National/International metrological institutes (NPL, BIPM), specialist calibration laboratories e.g. BIRA-IASB and/or other organisations such as GCOS and WMO. The consortium may receive support from a formal European accreditation body or even ISO.

4.1. QA4ECV EVALUATION ORGANISATION

4.1.1. ORGANISATION, ROLES AND RESPONSIBILITIES

The QA Evaluation/Endorsement organisation should be specifically set up to manage the evolution of the QA4ECV framework and to assess the ECV CDR Developers' QA approach, providing endorsements as required. The exact form, including potential managing institution, staff requirements and resource allocation will be explored during the QA4ECV project. The organisation is likely to take the form of a distributed network of persons (in particular experts in each ECV), who will be responsible for the assessment of specific ECVs, as well as a central team of persons responsible for providing advice on the QA4ECV framework, the coordination of evaluations and the sign-off of endorsements.

It should be noted that the full rigour and independence implied by this process may not be applicable to all organisations, particularly during the early development phases and will depend on the level of QA compliance sought. For example, it may be perfectly reasonable and adequate for some service providers, particularly those whom already implement well developed internal QA procedures, to rely solely on a process of 'self-declaration'. In these cases it will be expected that documentary evidence will be provided to support the claims which will be assessed by the QA4ECV office and made available for consultation via its portal. The anticipated roles and responsibilities of each of the persons are listed in Table 4.

Table 4: QA4ECV Evaluation Organisation Roles and Responsibilities

Role	Responsibilities
QA4ECV System Expert & Overall Evaluator	• Collate information from the system and ECV experts to determine whether or not an ECV developer has met the requirements for accreditation. • Feedback decisions (including identified improvements) to the ECV developer • Audit the system in terms of ensuring all relevant information is provided • Audit the flags and validation QA information
ECV Expert	• Audit the processing details for each ECV Note: for the six ECVs considered in the QA4ECV project, at least one expert will be required for each domain (i.e. land and atmosphere products)
Helpdesk	• Provide support to ECV developers on using the QA system

4.2. ECV CDR DELIVERY TEAM

4.2.1. ORGANISATION, ROLES AND RESPONSIBILITIES

The ECV CDR developing organisation will require internal representatives responsible for the delivery and maintenance of their QA process through the QA4ECV system. In practice, more than one role may be fulfilled by one person. The roles and responsibilities of each role are listed within Table 5.

Table 5: ECV QA Delivery Team Roles and Responsibilities.

Role	Responsibilities
Responsible Organisational Manager	• Agree to the requirements of QA4ECV. Agreement by senior level /organisational management ensures that appropriate resources can be committed to the development of the system for the ECV CDR being developed.
QA4ECV Coordinator / Internal Checker	• Communicate with all relevant persons (i.e. ECV developer) to ensure that they are aware of their role and all relevant QA information is provided into the system • Advise the responsible manager on successes and issues associated with implementing the QA system • Submit required QA information • Liaise with the evaluation organisation • Undertake checking of the system to ensure all relevant information is included and is accurate • Upload details and results of all checking campaigns to the QA4ECV web portal
Satellite Products ECV Developer(s)	• Work through the QA system at the relevant level of compliance • Provide relevant QA information to the coordinator or directly into the web portal • Answer internal checker and evaluation organisations queries relating to QA information

Summary of QA4ECV System Governance Requirements

- Establishment of a Governance body under whose auspices the process operates
- Top level QA office technically managed with active links to a metrological institute
- QA system experts and help-desk in house to facilitate guidance through QA system and conduct ECV compliance evaluations
- Access to ECV specific experts trained in the QA system and evaluation process

5. QA COMPLIANCE VERIFICATION PROCESS

This section describes a formalised process which may be undertaken by the ECV developers to ensure effective and traceable implementation of the QA4ECV framework. This includes consideration of the level of compliance to be achieved, the process for undertaking each stage of compliance demonstration and how the framework is driven by continual improvement. An overview of the process is given in Figure 6.

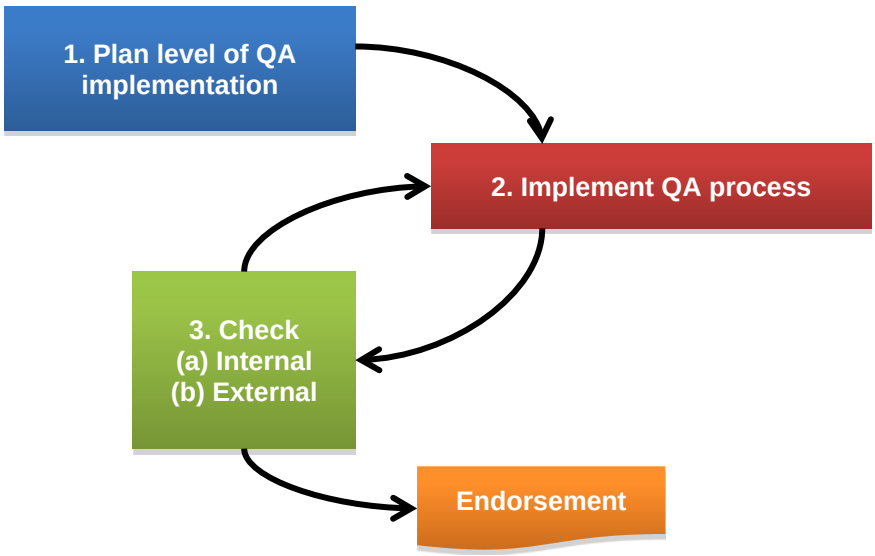


Figure 6: Proposed QA4ECV Process Overview for Compliance Verification.

5.1. PLAN

The planning stage (Step 1) is the starting point for a product developer wishing to utilise the QA4ECV framework. This stage includes:

1. Agreeing to implement a QA4ECV system
2. Choosing an appropriate level of compliance
3. Becoming familiar with the requirements of QA4ECV compliance

Agreement to implement a QA4ECV system will be undertaken by the ECV developer through the dedicated web portal. This stage must be agreed to by the person(s) responsible for ECV development within an organisation to ensure that appropriate resources can be dedicated to the implementation of the system. A pdf version of the agreement will be automatically generated and supplied to the ECV developer. Each ECV developer will sign up to a level of **compliance** associated with the QA4ECV framework. The levels of compliance will be provided in the form of the QA check-list aligned with the system maturity matrix (Table 2) and will be similar to those stated in Table 6.

The **requirements** associated with each level of compliance shall be provided to the user as part of the agreement documentation. These are the requirements against which an ECV developer's compliance shall be evaluated. It is the responsibility of the ECV developer to become well acquainted with these requirements to allow demonstration of compliance with the QA4ECV system.

Table 6: Example QA4ECV system levels of compliance to be aligned with the System Maturity Matrix (Table 2).

Level	Objective	Note
Level 1	Basic QA system implemented	This level consists of demonstrating that a QA system has been implemented and providing basic processing chains associated with the ECV products
Level 2	Detailed QA information provided	In addition to Level 1, this level consists of providing further details of quality indicators, providing background information on processing algorithms, developing traceability chains and undertaking uncertainty analysis
Level 3 – (*n-1)*	Further detailed QA and validation information	The specific number of levels and compliance procedures will be determined during the QA4ECV project
Level *n*	Fully traceable to SI	In addition to the previous defined levels, this level requires that details of data validation are provided, specific details of each processing algorithm are provided and all processing chains and uncertainty information is directly traceable to SI in a demonstrable manner

5.2. IMPLEMENT

The implementation stage (Step 2) is when all of relevant QA information for each ECV will be developed and uploaded to the online portal. This process will vary depending on the level of compliance which the ECV developer is implementing. In all cases, the process is likely to be an iterative one with internal assessments and (potentially) external assessments identifying additional information required or further details necessary.

This stage includes:

1. Statements detailing the QA system in place at the ECV developer organisations
2. Developing traceability chains and undertaking uncertainty analyses
3. Details of the quality indicators used within ECV products
4. Details of the validation undertaken on the ECV products and reference data

Further consideration of issues to do with software assurance, versioning (i.e. ECV CDR updates to algorithms, input datasets, ancillary information, validation), required updates if changes are made after accreditation and capturing official internal and external auditor communications will be made during the development of the QA system.

5.3. CHECK

The checking stage (Step 3) is one of the most important steps in the QA4ECV system as it allows for endorsements to be awarded and drives the continual improvement of the QA information. Checking is an iterative process and consists of two stages:

1. Internal checking of the system prior to external evaluation
2. External evaluation by the QA4ECV office

Internal checking of the system is required to ensure the QA information to be provided as evidence of compliance with the requirements is appropriate, relevant and correct. In addition, the checking allows demonstration that the ECV developer is taking responsibility for the QA of their product.
An external evaluation is defined in this context as the independent review of an organisation's QA4ECV QA system by someone external to the organisation who has not been involved in the development of the product. Formal auditing templates for each compliance level will be developed by the QA Office and tested as part of the QA4ECV system development. The external evaluation is likely to cover the following:

- Consideration of all documentation associated with the system
- Processing chains analysis
- Uncertainty propagation
- Compliance with international best practices

The external evaluation should be conducted by a staff member of the QA4ECV Office. If expertise for a particular ECV is not available within the QA4ECV office, a peer-review audit may be conducted. A scientific community member with the required skill set will, in these circumstances, be brought in to help with the external evaluation process. As per EU peer-review procedures, the candidate will be contracted to conduct the review in a fair and impartial manner. Once an ECV has been formally evaluated and endorsed at a particular QA compliance level, this information will be made publically available on the QA4ECV portal along with documentary evidence. The ECV developer/organisation will have full discretion as to the level of detail concerning the ECV processing chain, algorithms as well as QA evidence to be made publically available.

5.4. USER / CUSTOMER FEEDBACK

In addition to the formal QA processes outlined above, it is important to capture and take account of feedback from the QA system users. This will include all types of metrics related to ease of access and use of system components (i.e. tools and databases), timeliness on queries and simplicity of following the QA evidence templates, and endorsement process. This type of feedback will be essential, particularly in the early stages of the QA system development. Feedback will be carefully reviewed and changes made to reflect concerns in a timely manner. Web-based feedback forms and dedicated workshops will ensure that the QA framework and system meets all stakeholder needs and that the process of endorsement is consistent and reflects the needs of the customers.

Summary of QA4ECV Compliance Verification Process

- Establishment of a mechanism for formal ECV developer agreement to conduct product QA using the QA4ECV system
- Development of check-list templates for various levels of QA compliance
- Guidance through QA compliance level check-lists during QA evaluation process
- Development of compliance statements and visibility through web-portal
- Assistance with iteratively improving product QA compliance
- Mechanism to take account of user/customer feedback

6. QA4ECV FRAMEWORK SUMMARY

The QA4ECV project involves 17 consortium partners across Europe all with research interest in generating and/or evaluating the quality of land and atmosphere multi-decadal satellite-derived global ECV climate data records. The goal is that all of these emerging ECV time-series products be based on inter-satellite calibrated data, using state of the art retrievals and provided with fully traceable uncertainty metrics. A functional prototype of the QA4ECV framework and QA System tools, infrastructure and processes will be developed during the QA4ECV project lifetime (2014-2017).

This QA4ECV QA System Service Specification Document (SSD Version 1.0) scopes the concepts and requirements for the development and implementation of this operational QA system. The system will include access to: newly developed and existing multi-use and ECV-specific uncertainty analysis and validation tools; best practice guidance; community reference standards; full data provenance documentation; training materials and courses; as well as QA implementation and interpretation support. A Quality Management System approach will be adapted to ensure QA tools and methods are implemented correctly and QA information is displayed appropriately. The QA system will provide several functions, supporting those who ***create, validate*** and ***use*** ECV data records, as well as stipulating a mechanism for the impartial ***evaluation*** of quality metrics, uncertainty assessment and validation techniques for the continual improvement of climate data and services. The QA4ECV system will consider the following types of QA information associated with EO derived ECVs: Traceability; Uncertainty; Quality Indicators (QI); Validation, including independent reference data quality; Product and system maturity information; as well as fitness-for-purpose metrics. Further, the QA4ECV framework set out within this SSD seeks to align with and build upon other relevant and successful EU projects and international groups that consider EO data quality and provenance issues and will benefit immensely from dedicated interaction with other ECV development teams. Close alignment with data users will also ensure the QA system is capable of providing access to relevant and useful information. The prototype and iterative development of the QA system will ensure user confidence in the framework and its overall utility and practicality.

This type of framework and system for EO data and derived products is a new and challenging undertaking. It is anticipated that development of a fully operational QA system will be an iterative process over a number of years and involve a multitude of dedicated EO community members. The Service Specification Document will be revised as the QA system development progresses and updated at the end of the QA4ECV project. The revised version will include specification of an operational system and requirements for components that need to be developed further.

7. REFERENCES

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