

Calibration, Validation and Data Assimilation

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Some Definitions

- Calibration:
 - The process of quantitatively defining the system (including the instrument) response to known, controlled signal inputs.
- Validation:
 - The process of assessing by independent means the quality of the data products derived from the system output.

The process of **quantitatively** ...



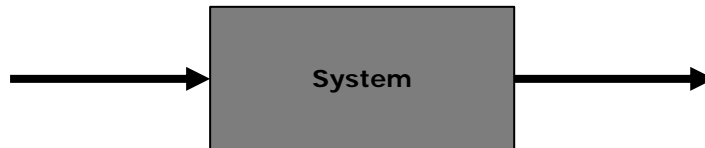
Quantitatively means that there is a quantity which is measured.

In order to be meaningful, this measure shall be given in an International System of reference.

Each measure shall be associated with proper Quality Indicator.

- Two aspects are included here:
 - There is a reference to the International System of Measure
 - It is required to associate to the measure Quality Indicators
- Every measure shall be traceable to the SI system (at least in the domains related to space and climate)
 - That implies that the instrument that is used to make the measure shall also be calibrated against international references
- A measure without Quality Indicators is not a measure.
 - Standard Deviations are Quality Indicators, but also all the information characterising the measure (e.g. temperature, pressure, vacuum, ...etc...)

The process of quantitatively defining the **system (including the instrument)** ...

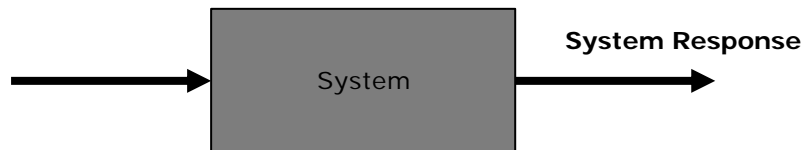


One should be careful in defining which **System** is being calibrated.

Often it only part of the instrument (e.g. without the antennae), or more than the instrument (e.g. including some external elements -wave guides, or some atmosphere if not in perfect vacuum)

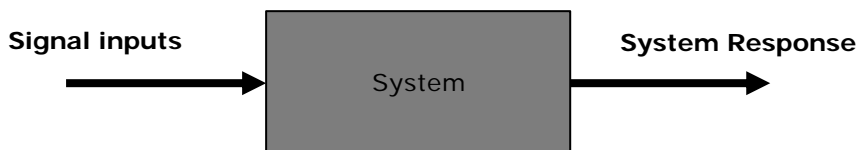
- The “System” shall be as simple as possible.
 - The more complex it is, more parameters shall be included to describe the overall system
 - All these parameters shall be properly characterised themselves
 - If assumptions are made, these assumptions shall be clearly stated and the impact on the calibration evaluated.
 - A system can be composed of many sub-systems each of them properly calibrated, the results of these calibration exercises at sub-system level being used for the calibration of the higher level system.
 - Thus the necessity for a proper traceability for all the elements of each sub-systems.

The process of quantitatively defining the **system** (including the instrument) **response** ...



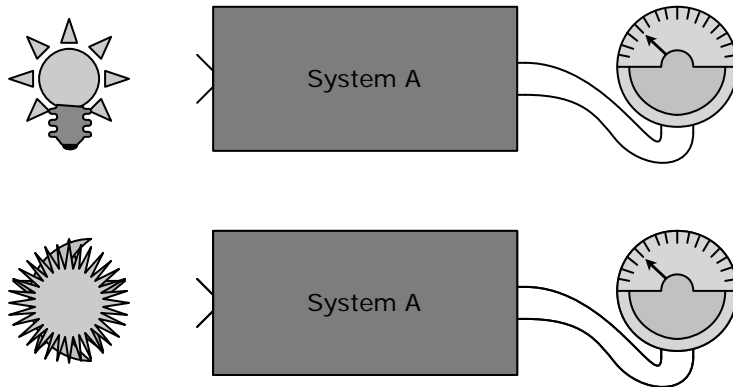
Following what is said in the previous viewgraph, the System Response is the response of the system which includes **not less** and **not more** than what was defined as the system at the beginning

The process of quantitatively defining the system (including the instrument) response to **known, controlled signal inputs**



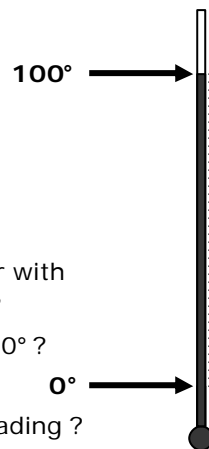
That indicates that the input signals are themselves traceable to SI (including QI, ...etc...).

- ...known, controlled signal inputs...

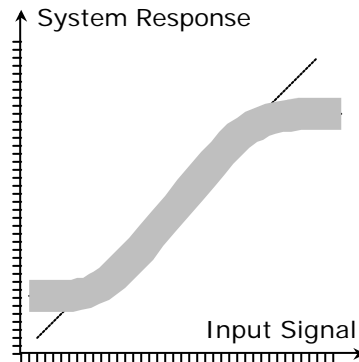


Some example of Calibration

- The thermometer
 - Easy ...
 - A bar at 0°
 - A bar at 100°
 - 100 divisions for each degree
- Some Questions ?
 - Is the expansion of the fluid linear with the temperature (which domain) ?
 - How precise are the 0° and the 100° ?
 - How precise is the interpolation ?
 - When in use how precise is the reading ?



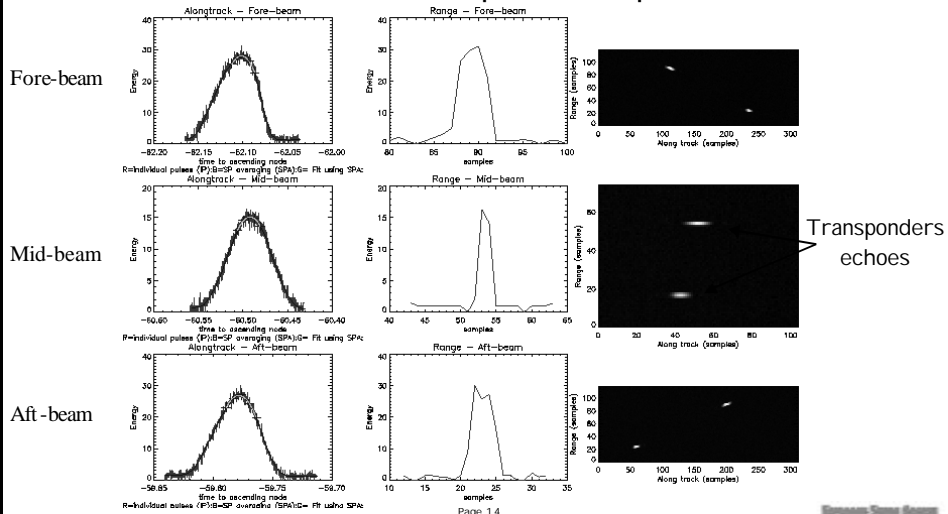
- A typical Calibration Curve has a limited validity range and includes:
 - Noise level
 - Saturation level
 - Biases
 - Standard Deviations
- All these elements shall be indicated if you want to have a full knowledge of the System and interpret correctly the System Responses.



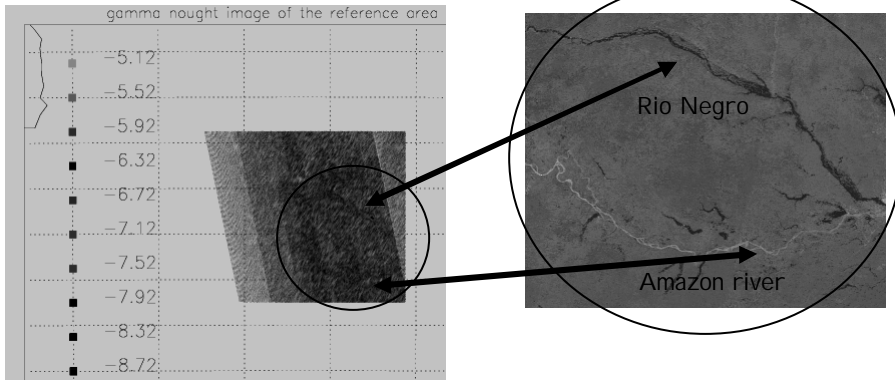
- ERS Scatterometer
 - Internal Calibration
 - A small part of the transmitted signal is time-delayed and fed in the Receiver
 - This allow the calibration of the Transmitter and the Receiver but:
 - doesn't include the scatterometer antennae
 - Add the Calibration sub-system in the "system" which needs its own characterisation
 - External Calibration
 - Transponders have been developed as external target for absolute calibration.
 - Extended Uniform known target are identified and used for relative calibration

- Absolute calibration: transponders in Spain
 - The Satellite sends RF pulses to the transponder
 - Pulses are amplified and recorded
 - Frequency shift of 540 kHz: to filter clutter
 - Pulses re-transmitted to satellite
- Relative calibration: Amazon rain forest
 - Use of a constant γ model
 - Assumed to be an isotropic target

Absolute calibration - Impulse Response Function

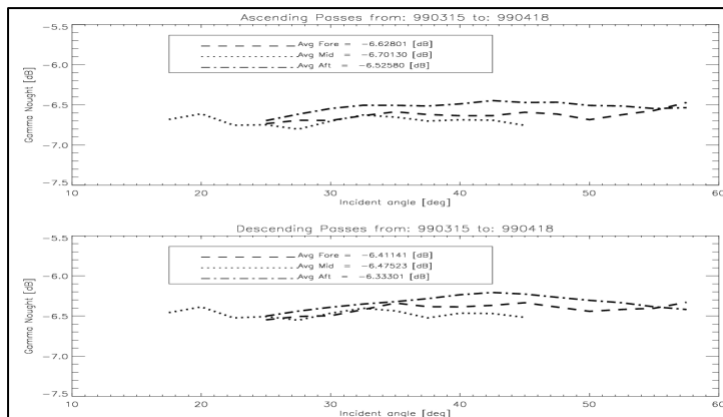


Relative calibration - Gamma-nought reference area



- Red: Trees
- Yellow: high backscatter (towns,...)
- Green: low backscatter (rivers,...)

These rivers should be removed from the gamma calibration area



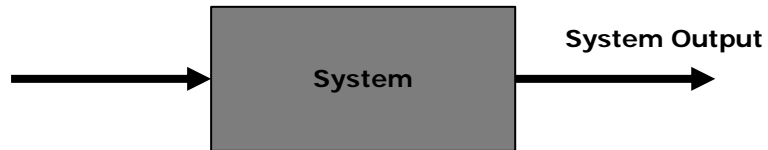
Break Point

Some Questions, Reactions, Comments ?

Validation

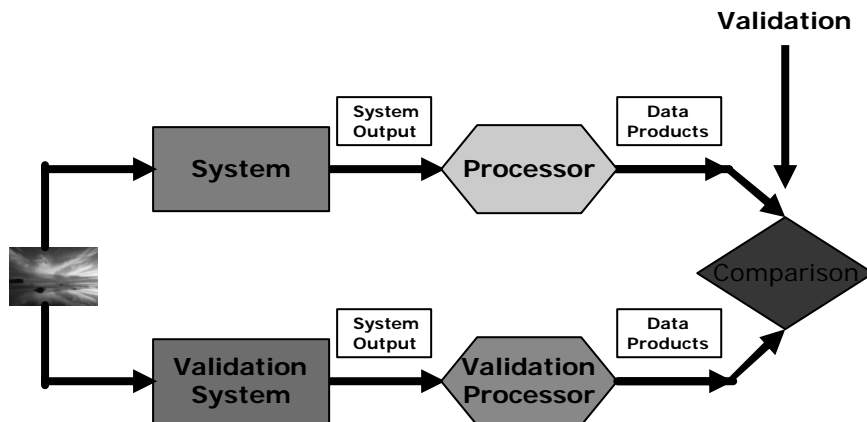
- The process of assessing by independent means the quality of the data products derived from the system output.

The process of assessing by **independent means** the quality of the **data products** derived from the system output

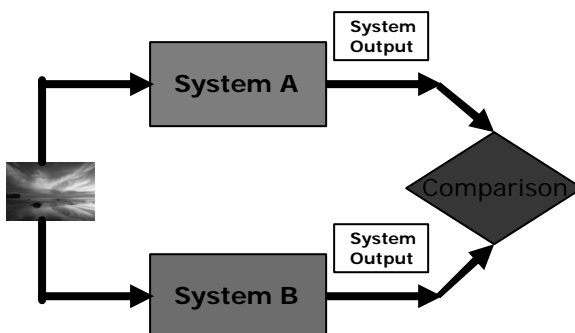


In the context of Validation, we are adding the concept of **independent mean** and the concept of **data product**.

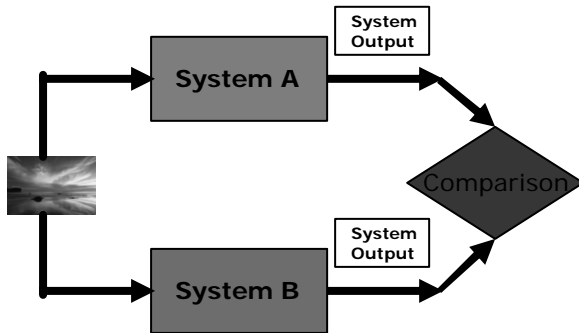
Note that system response is substituted by system output ...



- There are no reason why Validation should use the same Physical processes
 - Scatterometer is a Radar which measure the sea surface roughness ... a Scatterometer doesn't measure the wind.
 - An Anemometer measures the wind speed (and the direction) but doesn't measure the backscattering coefficient which is linked to the sea surface roughness...
 - The same with Sea Surface Temperature and the Infrared radiometry, multi-spectral radiometry and LAI (Leaf Area Index) or other biomass measurements.



Vicarious Calibration



- Vicarious Calibration consists in comparing the same physical entity (e.g. radiances) measured following the same physical process.

Vicarious Calibration and Inter-comparison



Objective:

Establish degree of equivalence between participants

Ensure robust traceability to SI (via NIST and NPL)

Establish protocols to facilitate future comparisons

15 radiometers

5 black bodies

9 participants plus NPL and NIST for traceability

Break Point

Some Questions, Reactions, Comments ?

New Space Missions For Understanding Climate Change

After this "short" introduction...

Why is Calibration and Validation fundamental
for understanding Climate Change ?

And for Data Assimilation ?

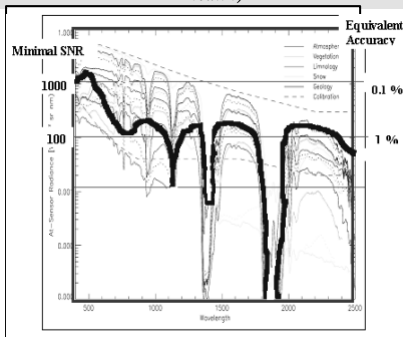
- Resolution adopted by CEOS Plenary 14 (Nov 2000)
- 1/ All EO measurement systems should be verified traceable to SI units for all appropriate measurands.
 - 2/ Pre-launch calibration should be performed using equipment and techniques that can be demonstrably traceable to and consistent with the SI system of units, and traceability should be maintained throughout the lifetime of the mission.

Traceability – Property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually through an unbroken chain of comparisons all having stated uncertainties

“Vocabulary for International Metrology (VIM) ISO”

Incoming Solar Radiation

Drives all the processes of the Earth System and potentially damaging (UV) to Biosphere (Human health)



Thermal Emitted Radiation

Atmosphere – Atmospheric chemistry

Water – Temperature

Land – Fires, Volcanoes, Pollution,

Solar Reflected Radiation

- | | |
|-------------|--|
| Atmosphere | - Aerosol (size & distribution)
- clouds
- pollution (impact on health) |
| Water | - pollution (originator)
- algae plumes |
| Land | - usage / condition
- type/quantity of vegetation
- minerals
- Carbon & hydrological cycles |
| Governments | - treaties, tax, planning |

Spatial variability requires good stability and SNR (signal to noise ratio) from a single sensor - but long term studies “climate change” need accuracy and consistency

Engineering specification of SNR should equate to accuracy

Need for improved Quality Assurance

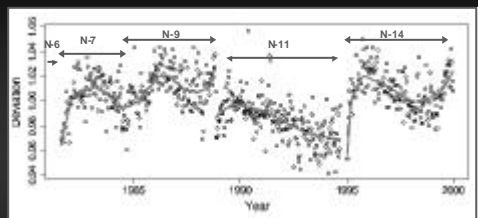


- Requirement**
- baseline for climate studies
 - global warming
 - detection of change
 - improve models
 - prediction of weather
 - monitoring the treaties
 - auditing carbon sinks
 - efficiency of carbon sinks
 - identify crops from space
 - automated innovation in measurement
- QA of operational services (GMES)**
- instrument synergy
 - compatible data sets

Global Monitoring Environment and Security (GMES)

- bias between sensors
- Modis & MISR differ by 10% on launch
- (Science requires 3%)

Anomalies in NOAA/AVHRR data



Normalised Difference Vegetation Index (NDVI) over "stable" desert as measured by AVHRR

- Demonstrates both in-flight "ageing" and initial calibration biases

To provide the evidence & establish confidence

Difficult to identify let alone "identical" instrumentation

Reference test-sites: e.g. GIANTS

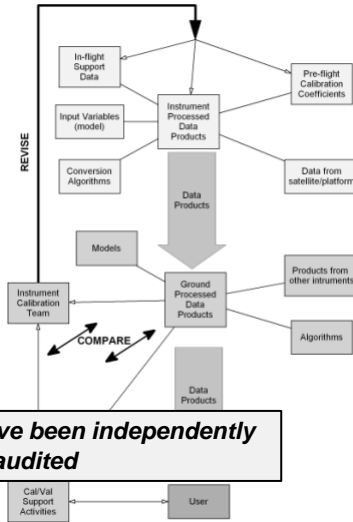


- GIANTS - Global Integrated Automated Network of Test Sites (P. Teillet of CCRS)
- Identify a few (5?) Spatially Uniform, temporally stable (radiometrically) "large" sites at various latitudes
 - e.g. Railroad valley, Libyan desert, La Crau, Dome C ...
 - Longer-term add vegetated sites
- Characterise site using common protocols and "traceable calibrated instruments" (in-situ team, aircraft, satellite?) multi-angle & time
 - Ideally instrument with automated monitoring equipment
- Archive and provide web access to test-site radiometric data and its associated uncertainties (ideally with high spectral and spatial resolution to allow easier reformatting to spectral bands and pixels of other sensors) in environmental conditions.
 - CEOS WGCV / WGISS test facility / ESA NILU Data centre
- Encourage all EO satellitesensors to view and compare its readings with those of ground site and publish results
 - Understand biases,
 - Allow lower cost sensors,
 - Improve user confidence,
 - Concentrate efforts on improving accuracy of test site data and atmospheric transmission

Validation

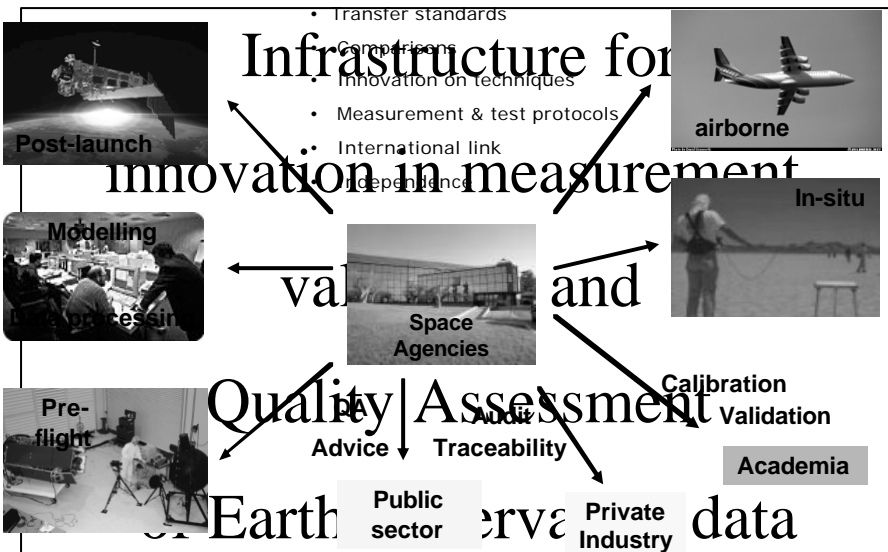


- Pre-flight
 - User specification
 - Instrument build compliance
 - Calibration?
- Post-launch
 - In-flight checks
 - Ground "Truth" comparison
 - Inter-sensor cross calibration
- Processed data released
 - "validated"
 - Uncertainty statement?



Rare for all these activities to have been independently reviewed and/or audited

Infrastructure for EO data



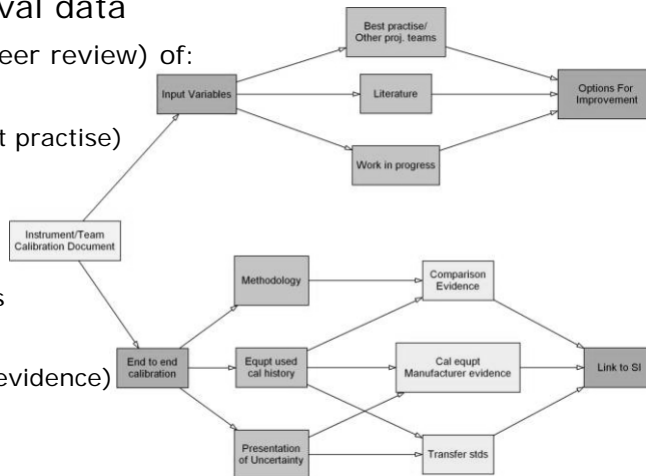
Project Review - Example



QA of cal/val data

- Independent (peer review) of:

- Methods (best practise)
- Models
- Completeness
- Traceability (evidence)



Page 33

European Space Agency

Readiness of the Community



*GEO will establish, within 10 years, its system of systems to provide timely data and products for local, national, regional, and international policy makers. In the implementation of GEOSS, harmonization of observations, real- or near real-time monitoring, **integration of information from in situ, airborne and space-based observations through data assimilation and models**, and early detection of significant and extreme events will be advocated. Integration of in situ, airborne and space-based observations within the various societal benefit areas will be encouraged, as will the establishment of global, efficient, and representative networks of in situ observation to support process studies, satellite data validation, and algorithm and model development, as well as the detection, documentation and attribution of change.*

The success of GEOSS will depend on data and information providers accepting and implementing a set of interoperability arrangements, including technical specifications for collecting, processing, storing, and disseminating shared data, metadata, and products. GEOSS interoperability will be based on non-proprietary standards, with preference to formal international standards. Interoperability will be focused on interfaces, defining only how system components interface with each other and thereby minimizing any impact on affected systems other than where such affected systems have interfaces to the shared architecture

Page 34

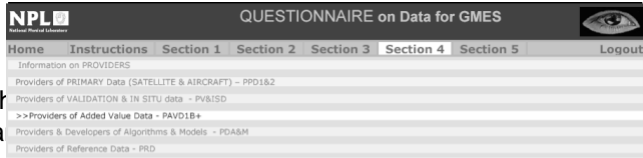
European Space Agency

Readiness of the Community



Survey

In 2002 NPL establish review by discipline a of implementation of f



4.3.1 PAVD1B+ About the PRIMARY DATA you use to generate Added Value Data Products (AVDP)

- Web site / cues

We understand that you may have many AVDP; in that case we would be grateful if you could send us (CONTACT) a complete listing in a form convenient to yourselves (URL, word document, pdf etc). However, in order to get the information we need to build statistics for our report, we would be clear why we need this as you progress (monthly identified, for example, Aerosol Optical-toider listing above, so you can click on it to

4.3.3 PAVD1B+ Instrument Calibration, Primary Data Validation & Uncertainty

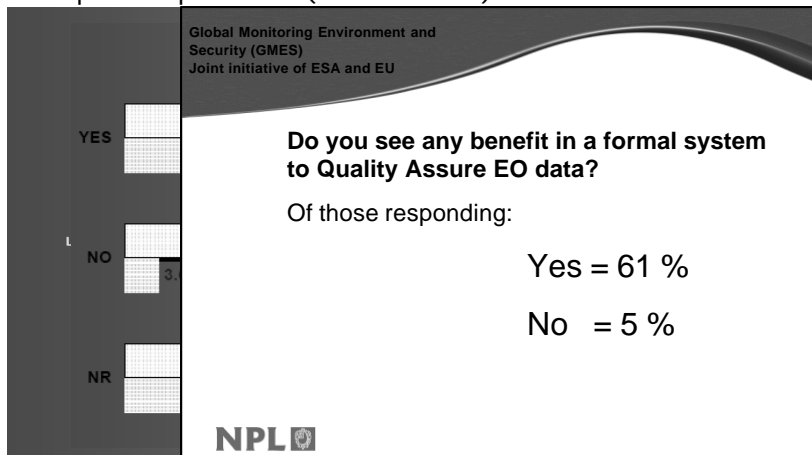
You are answering questions on: AVDP1

Identifier for PRIMARY EO DATA used to generate your AVDP <input type="text"/>	Do you request ACCURACY/QUALITY ASSURANCE statements for this PRIMARY data from the primary provider? YES <input type="checkbox"/> NO <input type="checkbox"/> If YES, do you... Rely on Primary Provider Statements <input type="checkbox"/> OTHER (describe) <input type="text"/>	Do you know how this PRIMARY data is VALIDATED Please select all that apply. Regular field campaigns? <input type="checkbox"/> Comparison with other instruments? <input type="checkbox"/> OTHER (describe - can include 'DON'T KNOW') <input type="text"/>	Do PRIMARY PROVIDERS supply you with UNCERTAINTY information on this PRIMARY data product? YES <input type="checkbox"/> NO <input type="checkbox"/> If YES, please describe, including traceability route <input type="text"/>	How did you OBTAIN this PRIMARY DATA? Commissioned by you <input type="checkbox"/> Purchased existing <input type="checkbox"/> Other <input type="checkbox"/> Commissioned by you <input type="checkbox"/> Purchased existing <input type="checkbox"/> Other <input type="checkbox"/> If ...
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Survey Results



- 6000 hits, (44 countries)
- 139 completed questions (25 countries)



Summary

- Primary scales, transfer standards and techniques now allow high accuracy to be achieved for both pre-flight and vicarious calibration (particularly for radiance)
- All aspects/steps of producing EO data products needs validation and traceability (instrument calibration and algorithms/models)
- Consistent presentation and breakdown of uncertainty budgets
- Flexibility to allow innovation
- Regular comparisons to evaluate biases
- Establish well characterised ground targets as “reference standards”
- For operational services QA is a “horizontal activity” – commonality, independence, transparency, efficiency
- Develop improved “in-flight” calibration methods e.g TRUTHS (Fox et al: Proc. SPIE 4881, p395 2003 & Adv. Space Res 32, p2253 2003)

For Earth Observation to provide the evidence to support policy and truly “operational” requires the industry and its data to be as robust as traditional industries

Break Point

Some Questions, Reactions, Comments ?



A QUALITY ASSURANCE
FRAMEWORK FOR
EARTH OBSERVATION

The result of two converging line



The first line is ESA internal

GMES - Observing our planet for a safer world

Managing natural resources and biodiversity, adapting to sea level rise, monitoring the chemical composition of our atmosphere: all depend on accurate information delivered in time to make a difference.

The European Earth Observation Programme (GMES) provides data useful in a range of issues including climate change and citizen's security. Land, sea and atmosphere – each Earth component is observed through GMES, helping to make our lives safer.

The ESA perspective



- From the ESA perspective it requires to provide data from a large variety of source and therefore lead to the definition of standards:
 - Interfaces – Heterogeneous Missions Accessibility (HMA)
 - The main objective of the project is to involve the stakeholders, namely national space agencies, satellite or mission owners and operators, in a harmonization and standardization process of their ground segment services and related interfaces.
 - Products Quality, Quality Control and Cal/Val
 - Requirement survey / definition for products to support QC and Cal/Val.
 - Definition of Quality Products.
 - Requirement definition for multi-mission Routine QC system
 - Inter-comparison protocols and guide lines definition for Calibration and Validation
 - An international workshop to discuss these issues

- Project Description
 - Establish a baseline specification of QA /QC tools and procedures needed to ensure implementation of “best practice” for operations of future sensors/missions in the “multi- mission” environment
 - Identification of a set of (if possible) generic “quality reporting indicators” and/or a means of “certification” of data products and their production, appropriate to the needs of their application and those of all stakeholders in the EO sector – data producer and user

- In parallel,
 - CEOS we underlining the importance of **Consistent Calibration and Validation** in its CEOS response to the GCOS Implementation Plan
 - GEO was including in its first Work Plan a task: **DA-06-02: GEOSS Quality Assurance Strategy**
Develop a GEO data quality assurance strategy, beginning with space -based observations and evaluating expansion to in-situ observations, taking account of existing work in this arena.

Convergence Workshop on Quality Assurance



- Linked to these activities it was decided to organise an international workshop to discuss the following aspects:
 - What constitutes a Cal/Val site ?
 - How should Auxiliary Data be efficiently handled ?
 - How can satellite and *in situ* data be accessed ?
 - What methodologies should be used for Calibration and Validation ?
 - How can Quality Control Processes be harmonised across missions ?
 - Is there a need for CEOS certification for QC and Cal/Val processes ?
 - Do users / operators demand for a CEOS certification for QC and Cal/Val processes ?
 - How should Validation Data be efficiently handled ?
 - How can *a posteriori* information on data quality be communicated to users?

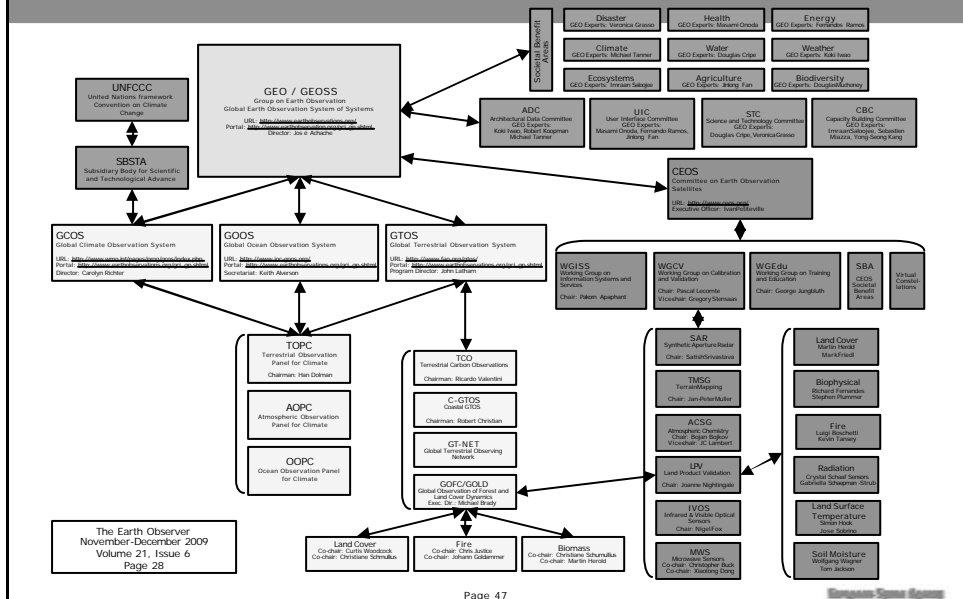
Three CEOS-GEO Workshops



- **Quality Assurance of Calibration & Validation Processes: Guiding Principles**
 - October 2nd- 4th, 2007
 - Hosted by: GEO Secretariat - Geneva, Switzerland
- **Quality Assurance of Calibration & Validation Processes: Establishing an Operational Framework**
 - May 6th to 8th, 2008
 - Hosted in Gaithersburg, USA by:
 - National Institute for Standards and Technology (NIST),
 - National Oceanic & Atmospheric Administration (NOAA)
 - National Aeronautics and Space Administration (NASA)
- **QA4EO Workshop on Facilitating Implementation**
 - September 29th to October 1st, 2009
 - Chaired by GEO - Hosted by TÜBİTAK UZAY - Antalya, Turkey

GEOSS Schematic

Linkages between International Programs



A Quality Assurance Framework for Earth Observation



- In view of the general concern for climate and therefore for the requirement to multi-sensor applications, there is a general need for the definition of a Quality Assurance Framework.
- QA4EO is an answer to that necessity and is the result of a wide international cooperation.
- QA4EO has been endorsed by CEOS and delivered to GEO.
- It is recognised by WMO and a necessity.
- It has been presented as one of the major contribution to climate research at COP 15.

1. GEO / CEOS Workshop on Quality Assurance of Calibration and Validation Processes: **Guiding Principles**

2-4 Oct 2007, Geneva, Switzerland

2. GEO / CEOS Workshop on Calibration and Validation Processes: **Establishing an Operational Framework**

6-8 May 2008, Gaithersburg, USA

3. QA4EO Workshop on **Facilitating Implementation**

29 Sept – 01 Oct 2009, Antalya, Turkey

1. Guiding Principle

- WGCV should establish Cal/Val best practices that are necessary to allow data to have an ascribed 'quality' associated with it. These best practices should include all aspects of the data processing chain from acquisition to delivery and archiving.
- These established Cal/Val best practices should become published guidelines, endorsed by CEOS and used by GEO.



Quality Control / Assurance and Best practice Guidelines on Calibration & Validation Processes: A Documentary Framework

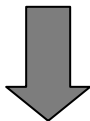
&

10 key guidelines

2. Establishing an Operational Framework



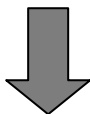
- Working to version 0.9 of the framework and guidelines, agreed the necessary changes and identified the need to include worked examples to improve clarity.



Version 1.0 completed and put forward for endorsement by CEOS. Endorsement was granted. Work began to optimise an implementation strategy for integration and use throughout the GEO community.



- Further review of documentation by GSICS (Global Space-based Intercalibration System) – an international collaboration to examine and harmonise data from operational weather satellites to improve climate modelling and weather forecasting)
- Restructuring of QA4EO framework into “The QA4EO Principles”
- Refining of the key guidelines documents into 7 key data quality guidelines
- Redrafting of all documentation to be more inclusive and applicable to the wider GEOSS community, with the inclusion of examples on how QA4EO could be implemented

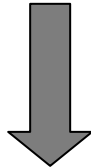


Version 3.0 of QA4EO Principles and key guidelines

3. Facilitating Implementation



- Workshop chaired by GEO, organised by CEOS and WMO
- Attendance included many representatives from the SBA communities
- Expanded the scope for QA4EO



Version 4.0 of QA4EO Principles and key guidelines to be produced by the end of March 2010

The Way Forward



- Establish a new QA4EO task team to include representation from the broader EO community, in particular ensuring representation from the GEO Societal Benefit Areas (SBAs)
- Draft a strategic plan to take QA4EO forwards and ensure its wider applicability within GEOSS
- Establish a QA4EO questionnaire to determine compliance. This questionnaire to be completed when each dataset is submitted into the GEO data depository or elsewhere to test compliance.
- Select a highly visible set of projects that span across the SBAs to exemplify QA4EO
- Present QA4EO at GEO-VII (ministerial)
- The QA4EO secretariat has been contacted by ISO to use QA4EO as a starting to define an ISO standard



QA4EO

A Quality Assurance Framework for Earth Observation



QA4EO Background

- The Global Earth Observation System of Systems (GEOSS) must deliver “timely, quality, long-term, global information ” to meet the needs of its nine “societal benefit areas”.
- This will be achieved through the synergistic use of data derived from a variety of sources (satellite, airborne and surface-based) and the coordination of resources and efforts of the members.
- Accomplishing this vision, starting from a system of disparate systems that were built for a multitude of applications, requires the establishment of an internationally coordinated framework to facilitate interoperability and harmonisation.
- The success of this framework is dependent upon the successful implementation of a single key principle:
 - ◆ all EO data and derived products shall have associated with it a documented and fully traceable quality indicator (QI).
- Success also necessitates the means to efficiently communicate this attributes to all stakeholders.

QA4EO

- The Quality Assurance framework for Earth Observation (QA4EO) was established and endorsed by the Committee on Earth Observation Satellites (CEOS) as a direct response to a Group on Earth Observations (GEO) Task DA-06-02 (now Task DA-09-01a).
- It has been endorsed by CEOS as a contribution to facilitate the GEO vision for GEOSS. The aim of GEOSS is to realize a future wherein decisions and actions are informed by coordinated, comprehensive and sustained Earth observations and information.
 - ◆ See GEOSS 10-Year Implementation Plan and in particular sections
 - 5.3 Architecture and Interoperability,
 - 5.5 Research Facilitation,
 - 6.1 (Governance) Functions



A QUALITY ASSURANCE
FRAMEWORK FOR
EARTH OBSERVATION



57

QA4EO Essential Principle

- In order to achieve the vision of GEOSS, Quality Indicators (QIs) should be ascribed to data and products, at each stage of the data processing chain - from collection and processing to delivery.
 - ◆ A QI should provide sufficient information to allow all users to readily evaluate a product's suitability for their particular application, i.e. its "fitness for purpose".
 - ◆ To ensure that this process is internationally harmonised and consistent, the QI needs to be based on a documented and quantifiable assessment of evidence demonstrating the level of traceability to internationally agreed (where possible SI) reference standards.

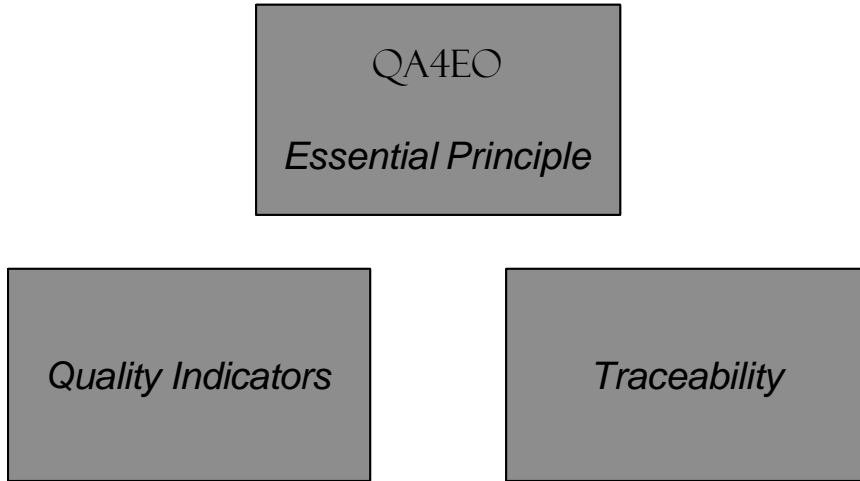


A QUALITY ASSURANCE
FRAMEWORK FOR
EARTH OBSERVATION



58

QA4EO Essential Principle



QA4EO Definitions

• Quality Indicator

- ◆ A mean of providing “a user” of data or derived product, (i.e. which is the results of a process) sufficient information to assess its suitability for a particular application.
- ◆ This “information” should be based on a quantitative assessment of its *traceability* to an agreed *reference* measurement standard (ideally SI) but can be presented as numeric or text descriptor providing the quantitative linkage is defined

• Traceability

- ◆ 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*.

Further Definitions

- **Reference (measurement) Standard:**

- ◆ Realization of the definition of a given quantity, ideally with stated quantity value and associated measurement uncertainty, used as a reference.
- ◆ Can be individual or community defined.

- **Uncertainty:**

- ◆ Non-negative parameter characterising the dispersion of the quantity values that are being attributed to a measurand (quantity), based on the information used.
- ◆ Where possible, this should be derived from an experimental evaluation but can also be an estimate based on other information, e.g. experience.



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61

QA4EO Executive Summary

- It is critical that data and derived products are easily accessible in an open manner and have associated with them an indicator of their quality traceable to reference standards (preferably SI) to enable users to assess its suitability for their application i.e. its “fitness for purpose”.
- This Quality Indicator needs to be unequivocal in its interpretation and derivation, yet sufficiently flexible, to be implemented across the full range of EO activities which are coordinated through GEO.
- This is the purpose of the Quality Assurance framework for Earth Observation (QA4EO) established to achieve this task.



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62

QA4EO Executive Summary

- QA4EO implementation is supported by a framework document and a set of key guidelines to assist in its interpretation and implementation .
- Organizations that fund and oversee the development and execution of Earth Observation programs are responsible for implementing the QA4EO key guidelines to their delivered data products
- A GEO Oversight Panel, composed of diverse members throughout the EO community, are responsible for managing QA4EO documents, clearly communicating QA4EO concepts to data providers and users alike, and mediating QA4EO disputes between data providers and users

Final Break Point

Some Questions, Reactions, Comments ?

- SI Système International
- QI Quality Indicators
- CEOS Committee of Earth Observation Satellites
- GEO Group for Earth Observation
- ISO International Standard Organisation
- GEOSS Global Earth Observation System of Systems
- QA4EO Quality Assurance Framework for Earth Observation
- WGCV CEOS Working Group on Calibration and Validation
- WMO World Meteorological Organisation
- SBA Societal Benefit Area
- COP Conference of Parties (COP 15 in Copenhagen)