Measurement of Atmosphere climate variables

Measurement of Land climate variables
Inspired by CCI logo's
Involved partners

Quality Assurance for Essential Climate Variables

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FP7-SPACE-2013-1
Project No. 607405
Involved partners

QA4ECV is a partnership of:
• European scientists
• data providers
• developers of future climate services
• national standards institute
• international organisations

17 partners
6 European countries
UK: 3
Netherlands: 3
Belgium: 3
Germany: 4
Spain: 1
Greece: 1
International: 2
For Land: data providers often use different instruments and different algorithms to produce the same parameter. Case: **Albedo for a single location**

N.B. All EO albedos agree with each other BUT disagree with tower measurements. This is unusual but not uncommon.
For Atmosphere
Data providers use same instrument but different algorithms
Case: NO₂
User perspective

I need good new data ... and quickly. A new data product could be very good, but if it is not being conveniently served and described, it is not good for me...
So I am going to use whatever I have and know already.

This is where QA4ECV comes in

10/21/2011
Leptoukh QA4EO'11
Why QA4ECV is necessary

Users need clear info on validity of EO/climate data sets

Unique records available, but need info on strength/weakness

Need objective system

Need guidance

Quality Assurance System

- Provides traceable quality info on EO/climate data
- Tied to international standards
- QA tools to support user community in tracing quality
- Multi-decadal records for atmosphere/terrestrial ECVs

There is a need for quality-assured long-term climate data records

<table>
<thead>
<tr>
<th>Maturity</th>
<th>Software readiness</th>
<th>Validation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Under development</td>
<td>...</td>
</tr>
<tr>
<td>2</td>
<td>Minor changes</td>
<td>...</td>
</tr>
<tr>
<td>3</td>
<td>...</td>
<td>Continuous cross-checking</td>
</tr>
</tbody>
</table>
QA4ECV project objectives

• QA4ECV will show how trustable assessments of satellite data quality can facilitate users in judging fitness-for-purpose of the ECV Climate Data Record.

• QA4ECV will provide quality assured long-term Climate Data Records of several ECVs relevant for policy and climate change assessments.

ESA Climate Change Initiative

Wed, 2010-09-01 11:03
Climate change is arguably the greatest challenge facing mankind in the twenty-first century. Its importance has been recognised in reports from the IPCC and from UNFCCC, and the overwhelming economic consequences are set out in the Stern Report.

GCOS Essential Climate Variables

The 50 GCOS Essential Climate Variables (ECVs) (2010) are required to support the work of the UNFCCC and the IPCC. All ECVs are technically and economically feasible for systematic observation. It is these variables for which international exchange is required for both current and historical observations. Additional variables required for research purposes are not included in this table. It is emphasized that the ordering within the table is simply for convenience and is not an indicator of relative priority.

<table>
<thead>
<tr>
<th>Domain</th>
<th>GCOS Essential Climate Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmospheric (over land, sea, and ice)</td>
<td>Air temperature, Wind speed and direction, Water vapour, Pressure, Precipitation, Surface radiation budget.</td>
</tr>
<tr>
<td>Upper-air</td>
<td>Temperature, Wind speed and direction, Water vapour, Cloud properties, Earth radiation budget (including solar Irradiance).</td>
</tr>
</tbody>
</table>
3 Land ECVs and 3 Atmosphere precursors

Land ECVs
- Spectral albedo, LAI & FAPAR
- Surface and vegetation state
- Indicators for land use change, biosphere activity
- Measured since 1980s
- Evaluate carbon cycle & water cycle in climate models

Atmosphere ECVs
- NO$_2$, HCHO & CO
- Air pollutants
- Drive ozone and aerosol formation
- Measured since 1995/2000
- Evaluate atm. chemistry modules in climate models
- Provide info on effectiveness of policies, trends in fires etc.

ECV sets do exist to some extent, but they are not necessarily coherent and not quality assured.
Work flow of QA4ECV

Objective 1

WP2: Design and development of QA system for ECV validation

Objective 2

WP4: Harmonised ECV retrieval schemes and multi-decadal data records

Objective 3

WP5: QA of ECV products using traceable reference standards

Objective 4

WP6: Fitness for purpose of pilot ECV products for climate service users
QA framework and tools: based on best practices to facilitate harmonization, evaluation and demonstration of ‘traceability’

• Visualisation of status of end to end traceability of process chain enabling robust consistent propagation of uncertainties
  – Detailed examples for 6 ECV case studies + top-level for other CCI ECV’s

• Harmonisation (bias removal) of sensor-sensor TOA Level 1 data

• Prototype a top-level (Copernicus) QA framework to facilitate user confidence in data and information (‘metrological traceability’)
  – Means for data providers, including in-situ validation, to evidence QA of data & algorithms reducing duplication of effort of ECV service providers
    • Evaluate potential of ‘certification’ process (not ISO but community specific)
  – Support for ‘Self’ and ‘external’ audit of traceability and QA
  – Identification and means to deliver common ‘international reference standards’
  – Guidance, templates, case studies, on uncertainty evaluation, comparisons...

• Generalise key principles (e.g. QA4EO) but recognise and demonstrate different implementation methods for different ECV services
  – Means for customers to assess ‘fitness for purpose’ (input to maturity matrix)
  – Web based interfaces to provide full accessibility of QA information
Outline of prototype QA Service to support Copernicus / ESA CCI

- Variety of service specific QA implementation routes
- Embedded National Metrology Institute to ensure SI traceability of input data, validation data and delivered information
- Forum to share best practice and provide guidance on uncertainties and documenting evidence
- ‘One-stop-shop’ for ECV QA information/standards
Top-level tool: visualization of traceability

e.g. for SST

- Tools / support to create web based diagrams showing end to end traceability
  - Layers of detail (top level through to detail in a single process)
  - Status of metrological traceability: strong, medium, weak
  - Type of reference standards
    - Embedded links of documentary evidence
  - Underpinning equations to propagate uncertainty
End-to-end validation of the retrieval chain

During the first phase of CDOP, an end-to-end validation approach has been designed and demonstrated for GOME-2 NO₂ total and tropospheric column measurements. In compliance with international QC/QC standards, the idea is to evaluate independently all critical individual components of the level-1-to-2 retrieval chain. Evaluations are carried out by means of a suite of correlative observations performed by complementary ground-based and satellite instruments supported by radiative transfer and chemical-transport modelling tools.

To ensure that the final product of such a complex production chain is validated meaningfully, validations cannot be limited to comparisons with correlative measurements of the final total column data. An end-to-end validation of critical individual components of the level-1-to-2 retrieval chain has been set up, e.g. to detect uncertainties affecting intermediate parameters but possibly cancelling each other in the final data product.
Use of Quality Assurance system

General usage
• How to document ECV to demonstrate QA in consistent manner will all be useable by any ECV
• Methods and processes to bias correct/harmonise L1 sat data will be useable by all
• The framework and methods can be used with minor adaptation of details
• Reference standards that can be used to support all ECVs and how they can be made 'traceable'.

Prospective
• a Copernicus service (prototype at end of project) is to provide support and review to data providers (to help them deliver QA)
• Also service to enable users to independently 'audit' data providers.
It is our ambition to:

- Produce ECVs based on the community’s best practices
- ‘State-of-science’
- Step-by-step analysis of all components
- Per-pixel uncertainty estimate

Example for Atmosphere case

\[
\hat{X}_{tr} = \frac{N_s(y) - N_{s,sl}}{M_{tr}(x_{a,tr}, \hat{b})}
\]

\(N_s, N_{s,sl}, M_{tr}\) are all error sources
Multi-decadal Atmosphere precursors
NO$_2$ and HCHO from UV/Vis sensors

A. Richter, IUP Bremen
Policy control with OMI NO$_2$ retrievals over Europe

Continuous reduction (2004-2010): -2% to -5%

Recession Change (2008-2009): -15% to -30%

Formaldehyde and CO from space

Formaldehyde signature from vegetation

CO from fires

De Smedt, BIRA
Atmosphere precursors

CO & VOC emissions (HCHO precursor)

CO & VOC emissions (HCHO precursor)

Nitrate aerosol

Health, visibility, climate

OH (sink for pollutants & greenhouse gases)

Smog

Human, ecosystem, crop health

Greenhouse gas

NOx

Cleansing agent

OH

Spectral + broadband albedo (1982 - )
LAI, FAPAR derived from there

What we need is the fusion of different sensor radiances to provide a consistent albedo output.
Example of harmonisation: GlobAlbedo (broadband) Fusion of multiple EO sensors using an optimal estimation framework

- Per pixel uncertainty
- BBDR consistency between different sensors
- Fapar/LAI derived from albedos

QA4ECV will fuse more sensors including GEO to obtain more BRF samples.
Atmosphere benefits from Land efforts

Surface albedo is a key input parameter in NO$_2$ and HCHO AMFs

- Improved spectral (BRDF) albedo leads to better knowledge of the a priori state vector in Atmosphere ECV retrievals

1º x 1º GOME-LER at 758nm cf 0.25º x 0.25º MERIS AlbedoMap (Muller et al., IGARSS07) for July 2006 showing SCIAMACHY pixels superimposed
QA4ECV user requirements survey: preliminary results

• User requirements of quality assurance for atmosphere and land satellite data products
• Link sent to >10,000 people- ~2% response rate

www.qa4ecv.eu/survey
QA4ECV user requirements survey: preliminary results

• Focused on four aspects of quality assurance:
Quality flags

- Do the products you use contain quality flags?
Traceability

• 90% of users say that it is important/very important to known the processing chain

• Is the processing chain information easily accessible?

• 95% of users would use the data if it were accessible

http://www.qa4ecv.eu/survey
Validation

- Are the products you use validated?

[Bar charts showing validation percentages for Albedo, fAPAR, LAI, Amounts of nitrogen dioxide (NO2), Amounts of carbon monoxide (CO), and Amounts of formaldehyde (HCHO).]
Uncertainty

- Do the products you use include uncertainty values/statement of confidence?
Preliminary conclusions from user survey

• If quality assurance information is readily available it would be useful.
• Uncertainty and traceability information are the least readily accessible quality assurance components.
• Although quality flags are contained in many products these are often insufficient for the application.
• Quality assurance in atmospheric products appears better than for land products
Possible conclusion from supplier survey

IF I HAD ASKED MY CUSTOMERS WHAT THEY WANTED, THEY WOULD HAVE SAID A FASTER HORSE.

- Henry Ford
Detailed objectives of QA4ECV

1. Rigorous QA methodologies for satellite ECV products
   • QA framework applicable to many ECVs
   • SW tools for ‘do-it-yourself’ QA
   • SI standards as in QA4EO (through NPL)

2. Multi-decadal satellite-derived global ECV records
   • 3 Terrestrial and 3 Atmospheric ECVs w/ global coverage
   • Not yet covered by ESA or EUMETSAT activities; 20-30 yr

3. Traceable QA applied to ECV retrievals and products
   • QA4ECV approach applied to independent reference data, ECV retrievals, and final products

4. Information on quality and fit-for-purpose nature of datasets
   • QA Office to audit ECV records against GCOS, WMO crit.
   • Assess impact of ECV records for applications
### Validation and User Requirements

<table>
<thead>
<tr>
<th>HARMOZ L2</th>
<th>Total uncertainty</th>
<th>Stability</th>
<th>Consistency representation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>UTLS</td>
<td>LS</td>
<td>MA</td>
</tr>
<tr>
<td>TROP</td>
<td>Mid</td>
<td>POL</td>
<td>TROP</td>
</tr>
<tr>
<td>GOMOS</td>
<td>&lt; 30 hPa</td>
<td>&lt; 50 hPa</td>
<td>high S</td>
</tr>
<tr>
<td>MIPAS</td>
<td>&lt; 50 hPa</td>
<td>&lt; 80 hPa</td>
<td>high S</td>
</tr>
<tr>
<td>SCIA</td>
<td>&lt; 50 hPa</td>
<td>&lt; 70 hPa</td>
<td>high S</td>
</tr>
<tr>
<td>OSIRIS</td>
<td>&lt; 50 hPa</td>
<td>&lt; 70 hPa</td>
<td>high S</td>
</tr>
<tr>
<td>SMR</td>
<td>no data</td>
<td>single profile noise &gt; 20%</td>
<td>no data</td>
</tr>
<tr>
<td>ACE-FTS</td>
<td>–</td>
<td>&lt; 80 hPa</td>
<td>high S</td>
</tr>
</tbody>
</table>

**User req.** – 8–15% – 1–3%/decade –

**Compliant with user requirements?**
- YES
- PARTIAL
- NO

**Courtesy D. Hubert, ESA Ozone_cci Final Review**
## Validation and User Requirements

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Filtering</strong></td>
<td></td>
<td>~ 3 %</td>
<td>~ 10 %</td>
<td></td>
</tr>
<tr>
<td><strong>Geographical sampling</strong></td>
<td>SAA and mid-Asia missing</td>
<td></td>
<td>SAA missing</td>
<td></td>
</tr>
<tr>
<td><strong>DFS</strong></td>
<td>5 to 5.5</td>
<td>5 to 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Vertical resolution (resolving length estimate)</strong></td>
<td>TS 6 km to TS-col.</td>
<td>&gt; 50 km</td>
<td>&gt; 50 km</td>
<td></td>
</tr>
<tr>
<td></td>
<td>UT/LS 3 to 6 km</td>
<td>10 to 20 km</td>
<td>10 to 20 km</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MA 3 to 10 km</td>
<td>&gt; 50 km</td>
<td>&gt; 50 km</td>
<td></td>
</tr>
<tr>
<td><strong>Height registration offset</strong></td>
<td>TS 5 to 20 km (SZA dep.)</td>
<td>5 to 20 km (SZA dep.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>UT/LS negligible</td>
<td>negligible</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MA -10 to -30 km</td>
<td>-10 to -30 km</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Accuracy (bias)</strong></td>
<td>TS -10 to -30 % (-5 DU)</td>
<td>7 to 8 % (1 DU)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>UT/LS -5 to 15 % (-2 to 5 DU)</td>
<td>1 to 4 % (1 DU)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MA -15 to 0 % (-3 to 0 DU)</td>
<td>-15 to 0 % (-3 to 0 DU)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Temporal dependence</strong></td>
<td>/</td>
<td>Hardly any</td>
<td>Increased bias around and below TP for northern hemisphere winter</td>
<td></td>
</tr>
<tr>
<td><strong>Meridian dependence</strong></td>
<td>60-90 Negative bias around and below TP, small positive around ozone maximum</td>
<td>Negative bias around and below TP, positive around ozone maximum</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>30-60 Negative bias below TP</td>
<td>Negative bias below TP</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0-30 Increased bias below TP</td>
<td>Increased bias below TP, related to bias for small SCD values</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SCD dependence</strong></td>
<td>Relation with meridian dependence less clear</td>
<td>Clearly related to meridian dependence</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>CF dependence</strong></td>
<td>Slightly decreasing (more negative) bias with CF</td>
<td>Slightly decreasing (more negative) bias with CF</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Comparison spread</strong></td>
<td>TS 10 to 15 % (2 to 5 DU)</td>
<td>30 to 35 % (4 to 5 DU)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>UT/LS 5 % (3 DU)</td>
<td>5 % (3 DU)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MA 5 to 10 % (0 to 3 DU)</td>
<td>5 to 10 % (0 to 3 DU)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Satellite random uncertainty</strong></td>
<td>TS 10 to 40 %</td>
<td>10 to 30 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>UT/LS ~5%</td>
<td>~5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MA 3 to 5 %</td>
<td>3 to 5 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total uncertainty</strong></td>
<td>TS 10%</td>
<td>14 to 50 %</td>
<td>12 to 36 %</td>
<td></td>
</tr>
<tr>
<td></td>
<td>UT/LS 8%</td>
<td>7 to 16 %</td>
<td>5 to 7 %</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MA 8%</td>
<td>3 to 18 %</td>
<td>3 to 18 %</td>
<td></td>
</tr>
</tbody>
</table>

Courtesy A. Keppens, ESA Ozone_cci Final Review
How will QA4ECV reach its objectives?

Step 1: Develop a Quality Assurance System

- *Use of QA tools and methods for any ECV?*
- *QA tools and methods useful for Copernicus Climate Service?*

Demo of best practices in QA4ECV useful to Copernicus Services

The top-level tools developed: traceability assessment & visualisation (uncertainty propagation), templates for evaluating and presenting uncertainty, best practise on QA of validation data (comparisons how to run/analyse etc). How to document ECV to demonstrate QA in consistent manner will all be useable by any ECV, they will all need their own specific inputs and potentially support to implement but this is all intended to be available.
How will QA4ECV reach its objectives?

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# Maturity Matrix

**Example of a maturity matrix - Bates and Barkstrom v4.0**

<table>
<thead>
<tr>
<th>Maturity</th>
<th>Software Readiness</th>
<th>Metadata</th>
<th>Documentation</th>
<th>Product Validation</th>
<th>Public Access</th>
<th>Utility</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Conceptual development</td>
<td>Little or none</td>
<td>Draft Climate Algorithm Theoretical Basis Document (C-ATBD); paper on algorithm submitted</td>
<td>Little or None</td>
<td>Restricted to a select few</td>
<td>Little or none</td>
</tr>
<tr>
<td>2</td>
<td>Significant code changes expected</td>
<td>Research grade</td>
<td>C-ATBD Version 1+ ; paper on algorithm reviewed</td>
<td>Minimal</td>
<td>Limited data availability to develop familiarity</td>
<td>Limited or ongoing</td>
</tr>
<tr>
<td>3</td>
<td>Moderate code changes expected</td>
<td>Research grade; Meets int'l standards: ISO or FGDC for collection; netCDF for file</td>
<td>Public C-ATBD; Peer-reviewed publication on algorithm</td>
<td>Uncertainty estimated for select locations/times</td>
<td>Data and source code archived and available; caveats required for use.</td>
<td>Assessments have demonstrated positive value.</td>
</tr>
<tr>
<td>4</td>
<td>Some code changes expected</td>
<td>Exists at file and collection level; Stable. Allows provenance tracking and reproducibility of dataset. Meets international standards for dataset</td>
<td>Public C-ATBD; Draft Operational Algorithm Description (OAD); Peer-reviewed publication on algorithm; paper on product submitted</td>
<td>Uncertainty estimated over widely distributed times/location by multiple investigators; Differences understood.</td>
<td>Data and source code archived and publicly available; uncertainty estimates provided; Known issues public</td>
<td>May be used in applications; assessments demonstrating positive value.</td>
</tr>
<tr>
<td>5</td>
<td>Minimal code changes expected</td>
<td>Complete at file and collection level; Stable. Allows provenance tracking and reproducibility of dataset. Meets international standards for dataset</td>
<td>Public C-ATBD, Review version of OAD, Peer-reviewed publications on algorithm and product</td>
<td>Consistent uncertainties estimated over most environmental conditions by multiple investigators</td>
<td>Record is archived and publicly available with associated uncertainty estimate; Known issues public. Periodically updated</td>
<td>May be used in applications by other investigators; assessments demonstrating positive value</td>
</tr>
<tr>
<td>6</td>
<td>No code changes expected</td>
<td>Updated and complete at file and collection level; Stable. Allows provenance tracking and reproducibility of dataset. Meets current international standards for dataset</td>
<td>Public C-ATBD and OAD; Multiple peer-reviewed publications on algorithm and product</td>
<td>Observation strategy designed to reveal systematic errors through independent cross-checks, open inspection, and continuous interrogation; quantified errors</td>
<td>Record is publicly available from Long-Term archive; Regularly updated</td>
<td>Used in published applications; may be used by industry; assessments demonstrating positive value</td>
</tr>
</tbody>
</table>