D1_3 Interim report on User Requirements

Chris Merchant, Rhona Phipps
University of Reading

5/23/2018

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<td>Task 1</td>
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<td>Task 2</td>
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<tr>
<td>Task 3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3 Exercise 3: Thinking through the error effects in radiances (Mittaz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective</td>
</tr>
<tr>
<td>Information Preparatory to the Exercise 28</td>
</tr>
<tr>
<td>Toy Example Definition 28</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3.3 Exercises</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task 1</td>
</tr>
<tr>
<td>Task 2</td>
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<tr>
<td>Task 3</td>
</tr>
<tr>
<td>Task 4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4 What should define a Fundamental Climate Data Record?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Context</td>
</tr>
<tr>
<td>Task</td>
</tr>
<tr>
<td>Draft FCDR Definition &amp; Guidance – For Discussion and Feedback</td>
</tr>
</tbody>
</table>


2 Introduction

This document is to fulfill the FIDUCEO deliverable D1_3 Interim report on User Requirements as a result of user feedback garnered at the first FIDUCEO workshop: “Earth Observation Radiances to climate data records; metrological principles and their application”, held on 17th to 19th April 2018 at IPMA premises in Lisbon, with reference to [1].

Section 3 lists the workshop aims and who was the target audience.

Sections 4, 5 and 6 collate the feedback from plenary, breakout groups and the post workshop survey.

In the workshop, feedback was solicited on the following concepts of FIDUCEO: metrological principles, definition of Fundamental Climate Data Record (FCDR), evaluation of the FIDUCEO “easy FCDR” concept [2] and evaluation of the FIDUCEO Harmonisation concept [3].

2.1 Scope
To report on the feedback on the interpretation and implementation of FIDUCEO user requirements from the workshop attendees, including the users of beta-version easy FCDRs.

2.2 Version Control

<table>
<thead>
<tr>
<th>Version</th>
<th>Reason</th>
<th>Reviewer</th>
<th>Date of Issue</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>Initial version</td>
<td>RPhipps</td>
<td>23/5/18</td>
</tr>
</tbody>
</table>

2.3 Applicable and Reference Documents


http://www.fiduceo.eu/content/uncertainty-and-error-correlation-quantification-fiduceo-%E2%80%9Ceasy-fcdr%E2%80%9D-products-mathematical


http://www.fiduceo.eu/content/green-paper-needs-and-opportunities-beyond-h2020-project-fiduceo
2.4 Glossary

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>FCDR</td>
<td>Fundamental climate Data Record</td>
</tr>
<tr>
<td>EO</td>
<td>Earth Observation</td>
</tr>
<tr>
<td>SAF</td>
<td>Satellite Applications Facility</td>
</tr>
<tr>
<td>CCI</td>
<td>Climate Change Initiative</td>
</tr>
</tbody>
</table>
3 The workshop aims and the agenda

The workshop presented the metrological techniques developed in the FIDUCEO project, explained the vocabulary used and provided exemplars on how these techniques have been applied to specific sensor series.

The technical aims of the workshop were:

- Review the application of metrology to EO climate/environmental data
- Understand errors in EO radiances and FIDUCEO techniques to provide radiance covariances
- Understand uncertainty propagation from radiances to climate/environmental data
- Examine harmonisation across multiple EO sensors to obtain stable long-term records
- Introduce FIDUCEO exemplar level-1 products with feedback from trail-blazer users
- Discuss wider application of new methods to climate/environmental data record creation

The agenda for the workshop is listed in appendix A.1.

3.1 Workshop participants

The attendees were invited from the SAF network, CCI network, the attendees of an earlier ESA workshop on remote sensing uncertainties, and through the FIDUCEO advisors’ and FIDUCEO project team’s global contacts.

There were 43 participants – 27 external to project and 16 project partners.

The attendee organisations are listed in the appendix A.2.
## 4 Plenary/general comments on metrological principles

Comments with potential implications for FCDD requirements collected from participants during the plenary (information sharing) sessions on metrological principles are listed below (left column). The response column list project actions to be implemented in response, or identifies the existing requirement(s) that already address the comments [1].

<table>
<thead>
<tr>
<th>Comments</th>
<th>Response</th>
</tr>
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<tbody>
<tr>
<td>Presenting the propagation of uncertainty can give the impression that uncertainty accumulates in size through satellite processing levels, but some transformations also reduce uncertainty.</td>
<td>FIDUCEO-3, -5</td>
</tr>
<tr>
<td>Uncertainty analysis and data improvements of historic data may undermine investments in new/better instruments.</td>
<td>Nonetheless, the scientific and societal needs for the best information from historic sensors on the evolution of the Earth system means that such work must be pursued.</td>
</tr>
<tr>
<td>We need the methods of uncertainty analysis here applied to historic sensors to feed into better pre-launch characterisation and instrument design. Uncertainty tree diagrams should be a useful tool at Phase B-D in satellite missions, and in calibration/validation.</td>
<td>Transfer of FIDUCEO methodologies to future missions, such as the Copernicus extension missions, could indeed be invaluable in improving the FCDD data to be derived from those missions. It is beyond the immediate project scope, but has been recommended in the green paper [4] requested by the Commission at the 2017 General Assembly.</td>
</tr>
<tr>
<td>Flags are still needed in products even when uncertainty is provided.</td>
<td>FIDUCEO-16</td>
</tr>
<tr>
<td>Harmonisation needs to be implemented in a way that the revised calibrations are applicable across the full range of geophysical radiance.</td>
<td>FIDUCEO-34</td>
</tr>
<tr>
<td>Tools to visualise uncertainties (such as cross-channel error covariance, per pixel error correlation lengths, etc) could be provided.</td>
<td>Tools are planned and the proposed tools will be considered along with existing ideas.</td>
</tr>
</tbody>
</table>
5 Discussion groups feedback

The workshop attendees considered 4 topics in detail in break out discussions chaired by FIDUCEO team members. The break out chair is identified for each comment in parentheses.

5.1 Definition of FCDR

The teams were asked to comment on section 4.3 of the exercise book – Draft FCDR definition and guidance (see appendix).

The main points that will lead to a revision of the draft definition were as follows:

1. make purpose of FCDRs clearer (scientifically and societally)
2. records should not be required to be continuous
3. instead, a climate data record has to be "long term" enough to be useful for climate
4. the data must be calibrated, but not necessarily expressed in the physical (not geophysical) units -- i.e., counts with conversion factors could also be used
5. a short record with similar properties could be a Fundamental Data Record
6. the idea of a stringent definition is liked, but the idea that reprocessing that doesn't meet all aspects may still be extremely valuable was not clear enough
7. inclusion of uncertainty was held to be essential
8. not clear the harmonisation is relevant in every case

These comments will be taken forward within the context of the joint CEOS-CGMS Working Group for Climate.

Below, further points linked to FIDUCEO requirements are identified.

<table>
<thead>
<tr>
<th>Comments from non-FIDUCEO attendees</th>
<th>Response [or existing FIDUCEO requirement confirmed]</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Trigo) The GCOS definition of FCDR does not refer to FCDR uncertainty characterisation which is a major omission.</td>
<td>FIDUCEO-1, -4, -7</td>
</tr>
<tr>
<td>(Trigo) Any update of the FCDR definition needs to accommodate the possibility that the FCDR could comprise counts with the means to convert these to radiances, which is a more flexible approach.</td>
<td>Accommodated by FIDUCEO-1</td>
</tr>
<tr>
<td>(Woolliams) The content of ancillary data within scope for an FCDR needs clarification, and (Mittaz) should include level 0 calibration data.</td>
<td>FIDUCEO-37 should be expanded to provide the required clarifications.</td>
</tr>
<tr>
<td>(Woolliams) FCDR requirements are strict because many CDRs are made from them which have different needs.</td>
<td>FIDUCEO-1, -8</td>
</tr>
</tbody>
</table>
Table: Comments from non-FIDUCEO attendees and Response

<table>
<thead>
<tr>
<th>Comments from non-FIDUCEO attendees</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easy FCDR is a good solution to providing uncertainty information at a useful level of detail without greatly increasing data volume.</td>
<td>FIDUCEO-38</td>
</tr>
<tr>
<td>Users will need guidance and examples on how to use the easy FCDR uncertainty information well.</td>
<td>FIDUCEO-2, -5</td>
</tr>
<tr>
<td>Easy FCDR could be formulated in terms of counts with counts-to-radiance calibration.</td>
<td>Agreed, although in FIDUCEO the Full FCDR will fulfil this role.</td>
</tr>
<tr>
<td>A guidebook or summary of the useful clarified terminology associated with the easy FCDR could be produced.</td>
<td>User guides and the online FIDUCEO vocabulary will fill this role under FIDUCEO-6.</td>
</tr>
<tr>
<td>Correlation length scale is proposed only to be defined in terms of exponential de-correlation, but a data vector of correlation dependence could be a more flexible approach.</td>
<td>Agreed, and we will modify the easy FCDR definition to do this.</td>
</tr>
<tr>
<td>Dialogue with users is recommended to keep improving the easy FCDR and CDR concepts.</td>
<td>Agreed, and is pursued via the website and through the future FIDUCEO workshop, as well as much opportunistic activity with agencies and in conferences.</td>
</tr>
<tr>
<td>It is much more probable that CDR generators will use the easy FCDR than engage with the full FCDR that lies behind it.</td>
<td>Agreed that this is likely, although only the full FCDR gives the comprehensive legacy of information that gives the justification and traceability of the easy FCDR.</td>
</tr>
<tr>
<td>Training around the easy FCDR should include a beginners guide, a guide to FIDUCEO in general, and step-by-step explanations of harmonisation etc.</td>
<td>FIDUCEO 2, 5</td>
</tr>
</tbody>
</table>
### 5.3 Evaluation of harmonisation concept (breakouts and feedback)

<table>
<thead>
<tr>
<th>Comments from non-FIDUCEO attendees</th>
<th>Response [or existing FIDUCEO requirement confirmed]</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Mittaz) Other initiatives have tended to adopt bias correction approaches that amount to homogenisation, and thus there will be strong communication need.</td>
<td>FIDUCEO-34</td>
</tr>
<tr>
<td>(Mittaz) The propagation of harmonisation uncertainties will need worked examples for FCDR users.</td>
<td>Strengthen FIDUCEO-2 to include this explicitly.</td>
</tr>
<tr>
<td>(Mittaz) The justification for selected reference sensors will need to be clear. Vocabulary around harmonisation coefficients and error-in-variables solutions will need to be explained.</td>
<td>Strengthen FIDUCEO-34 to include this explicitly.</td>
</tr>
<tr>
<td>(Trigo) Harmonisation is better practice than homogenisation (unanimous view in this group), since the latter is more likely to introduce artefacts in principle. However, homogenised data are easier to use. (Hall) Homogenisation is adequate for some applications, but not likely CDRs.</td>
<td>We agree that better CDR quality should be obtainable if working from a harmonised FCDR than homogenised.</td>
</tr>
<tr>
<td>(Trigo) The sampling issues in harmonisation will be critical to success across the full range of radiance.</td>
<td>Agreed. This is an active area of investigation.</td>
</tr>
<tr>
<td>(Hall/Woolliams) Convincing evidence of harmonisation will take the form of more consistent CDRs obtained from harmonised FCDRs.</td>
<td>Agreed, part of CDR work in FIDUCEO.</td>
</tr>
<tr>
<td>(Woolliams) Time series of Simulated-Observed radiances using ERA-5 may help establish success of harmonisation.</td>
<td>Agreed, will consider feasibility of this approach within the project.</td>
</tr>
</tbody>
</table>

### 5.4 Legacy and Links (Plenary Discussion)

<table>
<thead>
<tr>
<th>Comments from non-FIDUCEO attendees</th>
<th>Response [or existing FIDUCEO requirement confirmed]</th>
</tr>
</thead>
<tbody>
<tr>
<td>It is not fully clear how the uncertainties might be exploited in re-analysis, which would be significant legacy if solved.</td>
<td>Will seek ongoing interactions with data assimilation centres to explore this question.</td>
</tr>
<tr>
<td>We want to R&amp;D in this area to continue, but not clear how to be funded. Will there be a FIDUCEO-2?</td>
<td>Research ideas and priorities have been mapped out jointly with external partners in RD[4]. Targeting missions in development is a very high priority, and would be extremely timely in the context of Copernicus extension.</td>
</tr>
</tbody>
</table>
6  Post workshop feedback from users (online questionnaire)

(43 participants – 27 external to project, 16 project partners)

(14 questionnaire responses as at time of writing)

<table>
<thead>
<tr>
<th>Questions</th>
<th>Options</th>
<th>14 responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall feedback on the workshop</td>
<td>Excellent, good, OK Poor</td>
<td>Excellent - 11 Good - 3</td>
</tr>
<tr>
<td>Do you understand the benefits in providing and using data uncertainties</td>
<td>Really clear, clear, ok, not so clear, unclear</td>
<td>Really clear -8 Clear - 6</td>
</tr>
<tr>
<td>Are you more likely to include/ request better/ use uncertainties from your data provider</td>
<td>Yes/ No</td>
<td>Yes - 14</td>
</tr>
<tr>
<td>How clear were the talks on the uncertainty concepts</td>
<td>Really clear, clear, ok, not so clear, unclear</td>
<td>Really clear -5 Clear - 8 OK - 1</td>
</tr>
<tr>
<td>How would you rate the exercises and demonstrations on the ability to help you in your understanding of the concepts</td>
<td>Excellent, good, OK Poor</td>
<td>Excellent - 4 Good - 10</td>
</tr>
</tbody>
</table>

Comments on the metrology theory:

<table>
<thead>
<tr>
<th></th>
<th>Project response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very mathematically oriented on the first 2 days and a bit daunting for a subset of the participants</td>
<td>Online training materials are in preparation that give the opportunity to study at a user’s own pace.</td>
</tr>
<tr>
<td>Maybe give more practical examples could make the understanding easier</td>
<td>Case study examples will be put in the product guidance.</td>
</tr>
<tr>
<td>Metrology theory is a very solid basis for calibration and especially for laboratory measurements, where one tries to reduce the error sources as much as possible. In remote sensing the measured signal is a mixture of desired response and undesired ancillary effects. The error sources of the measurement configuration that can be analysed may not always be the largest uncertainty for the final product. For example, a reflectance taken to represent the surface may be completely erroneous in a case of large flock of birds flying in the area covered by the pixel. Hence one can’t concentrate only in the uncertainty of the measurement principle. The “+0” term we use in the measurement equation explicitly is to account for any aspects that cannot be analysed directly in the measurement calculation.</td>
<td></td>
</tr>
<tr>
<td>I found particularly useful the examples on harmonisation vs homogenisation. Before the meeting and based on a quick reading of the blog I was really confused on the difference. I would expect</td>
<td>Noted, and indeed there will be online training.</td>
</tr>
<tr>
<td>Comments on FIDUCEO FCDR approach</td>
<td>Project response</td>
</tr>
<tr>
<td>-----------------------------------</td>
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</tr>
<tr>
<td>Well thought out and well structured.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Other comments</th>
<th>Project response</th>
</tr>
</thead>
<tbody>
<tr>
<td>A good networking opportunity as well so all good from my side</td>
<td></td>
</tr>
<tr>
<td>Excellent workshop, thanks a lot to all organisers. The exercises were a very good idea, although more time would have been required (difficult given the limited amount of time). Maybe the material of the exercises could have been sent in advance to the meeting. It would be nice to have the exercise AND the answers on the webpage, as they constitute nice learning examples. Why not organising a dedicated training workshop in the future together with Agencies, like ESA does for SNAP or for Copernicus Data training workshop? A higher level training would be nice too with real EO and uncertainty data, to handle the complexity in a real case.</td>
<td>The various useful suggestions are well noted.</td>
</tr>
<tr>
<td>I think it would be useful to compare the MW FCDR beta-version (AMSU-B/MHS) with the L1c V05 data of AMSU-B/MHS from the NASA PPS (TRMM/GPM era, 1997-present) (L1c are intercalibrated brightness temperatures, where the GPM-CO is used as reference). As member of the NASA PMM Science Team, and user of L1c data (and I hope of the MW FCDR) I would be very interested in being engaged in such activity.</td>
<td></td>
</tr>
<tr>
<td>The microwave sensor team will consider these suggestions.</td>
<td></td>
</tr>
<tr>
<td>I liked the software tutorial!</td>
<td></td>
</tr>
<tr>
<td>Selected presentations will be made available on the website.</td>
<td></td>
</tr>
<tr>
<td>Very good meeting. Thanks. Being a compete newbie, at the beginning I was lost. Probably I was expecting a more gradual progression and I found a bit difficult to immediately start discussion in the breakout sessions. I should have started preparing on the advance reading well before... Spending some more time on the exercises providing solutions with the supporting slides would be really helpful. The python module should be extended to some other examples (considering the time for the installation I was expecting a larger use of it). Will the presentations be made available? Hope so.</td>
<td></td>
</tr>
<tr>
<td>The project team clearly put significant thought and preparation into the workshop format and content. The result was a very intensive but informative workshop. I'm glad to see it was well attended and my impression is that all participants appreciated, and benefited, from the workshop.</td>
<td></td>
</tr>
</tbody>
</table>
7 Outcomes

7.1 Requirements updates

<table>
<thead>
<tr>
<th>D1.1 version of requirement</th>
<th>Update</th>
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<tbody>
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<td>FIDUCEO-37 should be expanded to provide the required clarifications.</td>
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<td>(Woolliams) The FCDR could correct for the effects on radiance of the drift in the orbit (local observation time) of sensors.</td>
<td>Instrument drift (FIDUCEO-28) must be addressed by harmonisation, but correcting observations for orbit drift is a CDR task (a view also articulated by other workshop participants).</td>
</tr>
<tr>
<td>FIDUCEO-2: FCDR producers should provide documented advice on how their FCDRs enable generation of uncertainty and traceability information in CDRs derived from them.</td>
<td>FIDUCEO-2: FCDR producers should provide documented advice and worked examples on how their FCDRs enable generation of uncertainty and traceability information in CDRs derived from them.</td>
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<tr>
<td>FIDUCEO-34: FCDR producers need to clearly explain what form of harmonisation has been applied, and give uncertainty estimates for harmonisation.</td>
<td>FIDUCEO-34: FCDR producers need to clearly explain what form of harmonisation has been applied, justify the selected reference, and give uncertainty estimates for harmonisation.</td>
</tr>
</tbody>
</table>

7.2 Points to be noted by the project

The points below will be tracked by the project coordinator and results/progress/feedback reported on in the Final FCDR User Requirements Report due at the end of the project.

<table>
<thead>
<tr>
<th>Section</th>
<th>Point to note</th>
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</tr>
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<tr>
<td><strong>Metrology theory comments</strong></td>
<td>Metrology theory is a very solid basis for calibration and especially for laboratory measurements, where one tries to reduce the error sources as much as possible. In remote sensing the measured signal is a mixture of desired response and undesired ancillary effects. The error sources of the measurement configuration that can be analysed may not always be the largest uncertainty for the final product. For example, a reflectance taken to represent the surface may be completely erroneous in a case of large flock of birds flying in the area covered by the pixel. Hence one can’t concentrate only in the uncertainty of the measurement principle.</td>
<td>The “+0” term we use in the measurement equation explicitly is to account for any aspects that cannot be analysed directly in the measurement calculation.</td>
</tr>
<tr>
<td><strong>Metrology theory comments</strong></td>
<td>I found particularly useful the examples on harmonisation vs homogenisation. Before the meeting and based on a quick reading of the blog I was really confused on the difference. I would expect to see it implemented as a tutorial.</td>
<td>Noted, and indeed there will be online training.</td>
</tr>
<tr>
<td><strong>Other comments</strong></td>
<td>Excellent workshop, thanks a lot to all organisers. The exercises were a very good idea, although more time would have been required (difficult given the limited amount of time). Maybe the material of the exercises could have been sent in advance to the meeting. It</td>
<td>The various useful suggestions are well noted.</td>
</tr>
</tbody>
</table>
would be nice to have the exercise AND the answers on the webpage, as they constitute nice learning examples. Why not organising a dedicated training workshop in the future together with Agencies, like ESA does for SNAP or for Copernicus Data training workshop? A higher level training would be nice too with real EO and uncertainty data, to handle the complexity in a real case.

Other comments
I think it would be useful to compare the MW FCDR beta-version (AMSU-B/MHS) with the L1c V05 data of AMSU-B/ MHS from the NASA PPS (TRMM/GPM era, 1997- present) (L1c are inter calibrated brightness temperatures, where the GPM-CO is used as reference). As member of the NASA PMM Science Team, and user of L1c data (and I hope of the MW FCDR) I would be very interested in being engaged in such activity.

Other comments
Very good meeting. Thanks. Being a compete newbie, at the beginning I was lost. Probably I was expecting a more gradual progression and I found a bit difficult to immediately start discussion in the breakout sessions. I should have started preparing on the advance reading well before...
Spending some more time on the exercises providing solutions with the supporting slides would be really helpful. The python module should be extended to some other examples (considering the time for the installation I was expecting a larger use of it). Will the presentations be made available? Hope so.

The microwave sensor team will consider these suggestions.

Selected presentations will be made available on the website.
# Agenda

## Agenda Day 1 - Tuesday 17\textsuperscript{th} April 2018

<table>
<thead>
<tr>
<th>Time</th>
<th>Title &amp; content</th>
<th>Lead</th>
</tr>
</thead>
<tbody>
<tr>
<td>1300</td>
<td>Welcome to IPMA &amp; local logistics, and welcome from the FIDUCEO team</td>
<td>Isabel Trigo/ Chris Merchant</td>
</tr>
<tr>
<td>1315</td>
<td>Overview objectives &amp; brief personal introductions</td>
<td>Chris Merchant/ all participants</td>
</tr>
<tr>
<td>1330</td>
<td>Requirements for climate data records</td>
<td>Chris Merchant</td>
</tr>
<tr>
<td>1400</td>
<td>Introduction to metrology</td>
<td>Emma Woolliams</td>
</tr>
<tr>
<td>1420</td>
<td><strong>Exercise 1:</strong> Thinking about GCOS-style requirements (in-room discussion)</td>
<td>Chris Merchant</td>
</tr>
<tr>
<td>1450</td>
<td>Uncertainty concepts – 1 – basic principles and vocabulary</td>
<td>Emma Woolliams</td>
</tr>
<tr>
<td>1515</td>
<td><strong>Break</strong></td>
<td></td>
</tr>
<tr>
<td>1545</td>
<td>Uncertainty concepts – 2 – uncertainty propagation</td>
<td>Sam Hunt</td>
</tr>
<tr>
<td>1610</td>
<td>Metrological uncertainty concepts – 3 – measurement function uncertainty analysis, introducing “tree diagrams”</td>
<td>Jon Mittaz</td>
</tr>
<tr>
<td>1635</td>
<td><strong>Exercise 2:</strong> “Toy” uncertainty analysis (in-room breakouts)</td>
<td>Jon Mittaz</td>
</tr>
<tr>
<td>1715</td>
<td>Poster set-up</td>
<td>Jon Mittaz</td>
</tr>
<tr>
<td>1730</td>
<td>Posters and drinks reception – foyer area</td>
<td>All</td>
</tr>
</tbody>
</table>
## Agenda Day 2 - Wednesday 18\textsuperscript{th} April 2018

<table>
<thead>
<tr>
<th>Time</th>
<th>Title &amp; content</th>
<th>Lead</th>
</tr>
</thead>
<tbody>
<tr>
<td>0915</td>
<td>Uncertainty concepts – 4 – structured errors and uncertainty propagation: The beauty of error covariance matrices in simplifying your life!</td>
<td>Emma Woolliams</td>
</tr>
<tr>
<td>0945</td>
<td><strong>Exercise 3:</strong> Thinking through the error effects in radiances (signals)</td>
<td>Jon Mittaz</td>
</tr>
</tbody>
</table>
| 1030   | FIDUCEO FCDRs (and CDRs) – Overview of features and objectives
- Microwave FCDR
- AVHRR FCDR                                                                                           | Martin Burgdorf Michael Taylor           |
| 11:05  | **Break**                                                                                                                                                                                                          |                                           |
| 1125   | FIDUCEO FCDRs (and CDRs) – Overview of features and objectives
- HIRS FCDR
- MVIRI FCDR                                                                                             | Gerrit Holl Frank Ruethrich              |
| 1200   | Easy-FCDR: purpose, format, content, potential uses
- Uncertainty, harmonisation, flags and improvements                                                      | Chris Merchant                            |
| 1245   | **Lunch Break** *(help with installation of ipython, if needed)*                                                                                                                                                |                                           |
| 1345   | Harmonisation requirements for CDR stability                                                                                                           | Emma Woolliams                            |
| 1400   | Radiance harmonisation for stability: concepts and state of the art, demonstration using iPython                                                        | Sam Hunt, Ralf Quast                      |
| 1500   | **Break**                                                                                                                                                                                                          |                                           |
| 1520   | Feedback from beta users - Experiences with pre-beta release easy-FCDRs data
- HIRS FCDR – Steffen Kothe (DWD)
- AVHRR FCDR – Abhay Devasthale (SMHI)
- MW FCDR – Bill Bell (ECMWF - C3S)
- MVIRI FCDR – Anke Tetzlaff (MeteoSwiss)                                                                 | Steffen Kothe Abhay Devasthale Bill Bell Anke Tetzlaff |
| 1640   | Radiance uncertainty propagation: principles, tool & Exercise/Demo (in room)                                                                            | Tom Block/ Jon Mittaz                    |
| 1730   | Close day 2, logistics for Day 3                                                                                                                       | Chris Merchant/ Isabel Trigo             |

*Hosted Dinner – see welcome pack for location and directions.*
## Agenda Day 3 - Thursday 19th April 2018

<table>
<thead>
<tr>
<th>Time</th>
<th>Title &amp; content</th>
<th>Lead</th>
</tr>
</thead>
<tbody>
<tr>
<td>0915</td>
<td>#GO TO 8th FLOOR # What is an FCDR – feedback on definition and guidance</td>
<td>Rob Roebeling</td>
</tr>
<tr>
<td>10:00</td>
<td>Break out discussion, feedback and synthesis</td>
<td>Jon Mittaz</td>
</tr>
<tr>
<td></td>
<td>Evaluation of the easy-FCDR concept (breakouts and feedback)*</td>
<td>Rapporteurs: CM, EW, JM, SH</td>
</tr>
<tr>
<td>1050</td>
<td>Break</td>
<td></td>
</tr>
<tr>
<td>1120</td>
<td>Break out discussion, feedback and synthesis</td>
<td>Emma Woolliams</td>
</tr>
<tr>
<td></td>
<td>Discussion: evaluation of harmonisation concept (breakouts and feedback)*</td>
<td>Rapporteurs: CM, EW, JM, SH</td>
</tr>
<tr>
<td>1210</td>
<td>FIDUCEO lessons learned summary. Objectives/plans for the remainder of FIDUCEO project</td>
<td>Rob Roebeling</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rhona Phipps</td>
</tr>
<tr>
<td>1240</td>
<td>Plenary discussion: legacy and future impact</td>
<td>Chris Merchant/ Rhona Phipps</td>
</tr>
<tr>
<td>1310</td>
<td>Closing remarks</td>
<td>Isabel Trigo</td>
</tr>
<tr>
<td>1320</td>
<td>Close</td>
<td></td>
</tr>
</tbody>
</table>

*Separate break-out rooms
A2. List of attendee organisations

Deutscher Wetterdienst
DLR
E.C. Joint Research Centre
ECMWF
ESA/ESRIN
Finnish Meteorological Institute
German Aerospace Center (DLR)
Institute of Atmospheric Sciences and Climate (ISAC) - National Research Council (CNR)
IPMA
LATMOS IPSL
LATMOS IPSL, Sorbonne Université
Met Office
Met Office Hadley Centre
Meteo-France
NPL, UK
Serco Spa
Solvo
Swedish Meteorological and Hydrological Institute (SMHI)
Telespazio Vega UK Ltd
University of Leicester
University of Zurich
B1. FIDUCEO Workshop - Group Exercises.

FCDR Users’ Workshop: Materials for Break-outs and Exercises

CJ Merchant, JMittaz, EWoolliams

University of Reading & National Physical Laboratory

3/7/18

FIDUCEO has received funding from the European Union’s Horizon 2020 Programme for Research and Innovation, under Grant Agreement no. 638822
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      1.3.3 Implications for radiances [10 mins] ....................................................................................... 22
      1.3.4 Feedback [10 mins across all groups] ..................................................................................... 22
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1 Exercise 1: Thinking about GCOS-style Requirements (Merchant)

1.1 Context
The Global Climate Observing System (GCOS) of WMO coordinates an implementation plan (https://library.wmo.int/opac/doc_num.php?explnum_id=3417) that informs the strategy of many Earth Observation programmes in the context of climate.

This includes observation system requirements.

The purpose of this exercise is to think carefully about what such statements of requirement mean for FCDR users generating climate data records, particularly with reference to uncertainty and stability.

1.2 Extracts
Some extracts from the product requirements tables are shown below for information, from the ocean, terrestrial and atmospheric tables respectively.
1.3 Questions for discussion and feedback

Each sub-group, please nominate 1 person to collect points relevant to each of the below on a flip-chart/notes page and report back to plenary at the end of the exercise.

1.3.1 Requirement measurement uncertainty [10 mins]

The notes to the tables state the following: “The required measurement uncertainties are presented as 95% confidence intervals (approx. 2 standard deviations).”

Task: Devise a consensus definition of “Measurement Uncertainty” for satellite-based products that you think could/should apply in the context of these product requirement tables.

Your definition will constitute the feedback from this task at the end of the session.

Use whatever background knowledge you have. You may want to consider:

- Is there any connection between the meaning of “measurement uncertainty” and the spatio-temporal resolution requirements?
- Does/should the uncertainty describe errors from noise, calibration, sampling, quantity definition differences, retrieval, some of these, or all of these?

1.3.2 Stability [10 mins]

Stability is not defined other than stating that the stability is quoted as per decade unless otherwise indicated.

Possible interpretations of the stability numbers are:

- Maximum magnitude of trend of the calibration of a measurement system over time. (Equivalent to maximum rate of change of measurement bias.)
- Maximum temporal deviation of the calibration (bias) of a measurement system during a decade. (This could include stability with respect to diurnal and/or seasonal variability.)
- As above, but with a standard deviation or confidence interval specified instead of “maximum”.
- As above, but focussed on stability of the data in products rather than the measurement system. (This distinction could matter if the sampling regime (and therefore the sampling errors) were subject to change over time.)

Task: Agree what would constitute evidence that product stability requirements had been met for a satellite-based climate data record.

1.3.3 Implications for radiances [10 mins]

Logically, these product requirements imply certain levels of radiance uncertainty and stability.

Task: Discuss what the product requirements imply for level 1 satellite data (FCDRs)? Is that connection to lower level data effectively made in contexts you are familiar with?

1.3.4 Feedback [10 mins across all groups]

Be succinct!

[Blank page for notes]
Exercise 2: “Toy” Uncertainty Analysis

2.1 Objective
For very simple hypothetical case (a “toy example”) work through part of an uncertainty analysis of a “measurement function”, using the FIDUCEO framework.

The FIDUCEO framework for such uncertainty analysis is, essentially:

- Clearly identify the measurement function
- Summarize the sources of uncertainty (“effects”) in an uncertainty tree diagram, in which the effects are related to specific terms in the measurement function
- For each effect, record the uncertainty characteristics in an effects table

and this exercise will introduce you to this process.

2.2 Information Preparatory to the Exercise

2.2.1 Toy Example Definition
The quantity to be determined

- the measurand is the volume of an imaginary room

Consider that the measurement is to be made using an ultrasonic device that measures the time between emitting a pulse of sound and receiving the echo from an opposite wall.

The measurement function (or, measurement function) for the measurand is therefore (in a standard form, \( y = f(x, a) + 0 \)):

\[
y = \frac{1}{8} x_1 x_2 x_3 a^3 + 0
\]

where:

- \( x_j \) for \( j=1 \) to 3 is the measured time for each dimension respectively
- \( a \) is the speed of sound, which acts somewhat like a calibration parameter here to convert time into distance
- \( 1/8 \) is an error-free factor assuming the room is really a cuboid
- \( +0 \) reminds us that reality may not correspond to our cuboid model exactly

2.2.2 Uncertainty tree diagram
The uncertainty tree diagram is a quick visual reference for the effects that have been analysed, structured around the measurement function. The example below just treats the terms \( x_1, a \) and \( +0 \) (\( x_2 \) and \( x_3 \) would obviously have branches similar to \( x_1 \)). From each term, a branch connects a term to the uncertainty in the term, via the sensitivity of the measurand to the term. This represents that the sensitivity of the result to an error in a term is independent of the effect causing the error. The uncertainty in \( x_1 \) in this imaginary example arises from two effects: (1) noise in the measured time, and (2) the fact that the finite size of the device (the exact location of the emitter/receiver) is not accounted for and is unknown.
Meanwhile, the effect identified relative to the parameter $\alpha$ is that the speed of sound used applies to a particular air temperature – but the actual temperature in the room is unknown.

### 2.2.3 Effects table

Analysing an effect means establishing a reasoned estimate for each of the following:

- the error distribution (probability density function) from the effect in the units of the term affected by the effect
- the degree of correlation in the error from the effect between one measurement and another
- the sensitivity of the measurand to the error from the effect

The estimate can be based on experiment, simulation, engineering data sheets, expert judgement ... whatever is the best available and feasible approach for the evaluation.

The results need to be documented, and for this purpose we developed a standard effects table to summarize the results for the case of satellite radiances, shown overleaf. This comes from a FIDUCEO report (D2.2) and the references in the table refer to sections in that report, which is available for further reading from www.fiduceo.eu.
<table>
<thead>
<tr>
<th>Table descriptor</th>
<th>How this is codified</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Name of effect</strong></td>
<td>A unique name for each source of uncertainty in a term of the measurement function</td>
<td>If a similar effect is present for several terms, the names should be unique, e.g. earth count noise, ICT count noise</td>
</tr>
<tr>
<td><strong>Affected term in measurement function</strong></td>
<td>Name and standard symbol of affected term</td>
<td>Usually an effect will only affect a single term, though there may be exceptions.</td>
</tr>
<tr>
<td><strong>Instruments in the series affected</strong></td>
<td>Identifier of the specific instrument / satellite platform where this effect matters</td>
<td>Some effects may only apply to certain instruments in an FCDR series, or may take a different correlation form for different instruments</td>
</tr>
<tr>
<td><strong>Correlation type and form</strong></td>
<td>element-to-element [elements]</td>
<td>A defined type</td>
</tr>
<tr>
<td></td>
<td>from line to line [lines]</td>
<td>Images is for GEO satellites, Orbits for LEO satellites.</td>
</tr>
<tr>
<td></td>
<td>between images [images]</td>
<td>Time is a more general quantity and needs an associated attribute describing the unit (e.g. day, week, month, year, epoch)</td>
</tr>
<tr>
<td></td>
<td>Between orbits [orbit]</td>
<td>The parameters defined for the particular type and form provided.</td>
</tr>
<tr>
<td></td>
<td>Over time [time]</td>
<td></td>
</tr>
<tr>
<td><strong>Correlation scale</strong></td>
<td>element-to-element [elements]</td>
<td>In units of elements, lines, time or images/orbits – what is the scale of the correlation shape?</td>
</tr>
<tr>
<td></td>
<td>from line to line [lines]</td>
<td>The parameters defined for the particular type and form provided.</td>
</tr>
<tr>
<td></td>
<td>between images [images]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Between orbits [orbit]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Over time [time]</td>
<td></td>
</tr>
<tr>
<td><strong>Channels/bands</strong></td>
<td>List of channels / bands affected</td>
<td>Channel names in standard form</td>
</tr>
<tr>
<td></td>
<td>Error correlation coefficient matrix</td>
<td>Some effects may only affect certain channels</td>
</tr>
<tr>
<td></td>
<td>A matrix</td>
<td></td>
</tr>
<tr>
<td><strong>Uncertainty</strong></td>
<td>PDF shape</td>
<td>Functional form of estimated error distribution for the term</td>
</tr>
<tr>
<td></td>
<td>units</td>
<td>Units in which PDF shape is expressed (units of term, or can be as percentage etc)</td>
</tr>
<tr>
<td></td>
<td>magnitude</td>
<td>Value(s) or parameterisation estimating width of PDF</td>
</tr>
<tr>
<td><strong>Sensitivity coefficient</strong></td>
<td>Value, equation or parameterisation of sensitivity of measurand to term</td>
<td></td>
</tr>
</tbody>
</table>
2.3 Tasks

2.3.1 Task 1
For the toy example, the effects related to term \(x_1\) are analysed in a simplified/adapted effects table below. Task: complete the table similarly for Effect 3. (There isn’t a unique correct answer, except for the sensitivity.)

<table>
<thead>
<tr>
<th>Table descriptor</th>
<th>Effect 1</th>
<th>Effect 2</th>
<th>Effect 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name of effect</td>
<td>Noise in measured time</td>
<td>Unknown offset (finite size of device)</td>
<td>Variations in speed of sound with room temperature</td>
</tr>
<tr>
<td>Affected term</td>
<td>(x_1)</td>
<td>(x_1)</td>
<td>(a)</td>
</tr>
<tr>
<td>Correlation</td>
<td>None: (r = 0). Noise means error is independent every time device is used</td>
<td>Full: (r = 1). The same unknown offset is present every time device is used</td>
<td></td>
</tr>
<tr>
<td>between</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>measurement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>in different</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>rooms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncertainty (u(x_1))</td>
<td>Could be evaluated by doing repeat measurements of the dimension of a room. The result would probably be a normal (Gaussian) error distribution. Uncertainty will have units of (s), and be the standard deviation of that Gaussian.</td>
<td>Must be a number between zero and the exterior dimension of the device. In absence of other information, the PDF for this error could be assumed to be uniform over this range, (\Delta x). A best guess correction of (\Delta x/2) could be inferred, and the standard uncertainty in that correction would be (\Delta x/\sqrt{12}) (standard result for top-hat distribution).</td>
<td></td>
</tr>
<tr>
<td>Sensitivity</td>
<td>(\frac{\partial y}{\partial x_1} = \frac{1}{8} x_2 x_3 a^3)</td>
<td>(\frac{\partial y}{\partial x_1} = \frac{1}{8} x_2 x_3 a^3)</td>
<td></td>
</tr>
</tbody>
</table>

2.3.2 Task 2
For Effects 1 & 2, what are the error correlations between the terms \(x_j\)?

2.3.3 Task 3
Come up with an examples Effect 4 that could cause error in the “+0” term.
3 Exercise 3: Thinking through the error effects in radiances (Mittaz)

3.1 Objective
For a very simple hypothetical case (a satellite-based “toy example”) work through some of the error-causing effects and associated correlation found in the radiances using the FIDUCEO framework.

The FIDUCEO framework for such analysis is, essentially:

- For each effect in the uncertainty tree diagram think about the type of effect present and how the data used have been gathered e.g.
  - Has a process such as averaging been used?
  - Is the effect recorded on a different timescale than the Earth observation data?
  - Is the effect constant over the complete mission
  - Etc.
- For correlated effects work out length/timescales on which the correlation exists
- For correlated effects assign a correlation type and form to be added to the effects table

and this exercise will provide extra practice with this approach.

3.2 Information Preparatory to the Exercise

3.2.1 Toy Example Definition
The quantity to be determined is

- Radiance (the channel-integrated spectral radiance in W m$^{-2}$ sr$^{-1}$, for example)

from an across-track scanning instrument. This instrument is: noisy, close to linear instrument, and has onboard calibration measurements taken every scan.
The instrument has a close-to-linear response to input radiance providing counts (C) as a measure of the detector response. For a single scan line the instrument looks at space (S, a cold target, effective radiance of zero at these wavelengths), an internal calibration target (ICT, assume a blackbody with an emissivity of one, a warm target) and a set of observations (pixels) of the Earth (E). The measurement function for the Earth radiance is therefore:

\[ L_{\text{Earth}} = a_0 + \frac{(C_E - C_S)}{(C_{\text{ICT}} - C_S)} L_{\text{ICT}}(T_{\text{ICT}}) + 0 \]

where

| \( a_0 \) | Radiance offset term derived from either pre-launch data or in-orbit harmonisation |
| \( L_{\text{Earth}} \) | Radiance of the Earth at a given pixel |
| \( L_{\text{ICT}} \) | Radiance of the internal calibration target/blackbody (ICT) given the estimated temperature of the ICT and the channel spectral response function (assumed to be known precisely) |
| \( T_{\text{ICT}} \) | Temperature of the internal calibration target/blackbody |
| \( C_S \) | Counts observed when looking at space |
| \( C_{\text{ICT}} \) | Counts observed when looking at the internal calibration target/blackbody |
| \( C_E \) | Counts observed when looking at the Earth at a given pixel |
| \( \frac{(C_E - C_S)}{(C_{\text{ICT}} - C_S)} \) | Instantaneous linear gain: Scales the ICT radiance according to the Earth counts, using the assumption that the instrument is linear (which it nearly is) |

Because of detector noise and/or other issues related to the calibration measurements it is common to do some form of averaging on the calibration data so the measurement function then becomes

\[ L_{\text{Earth}} = a_0 + \frac{L_{\text{ICT}}(T_{\text{ICT}})}{(C_{\text{ICT}} - C_S)} (C_E - C_S) + 0 \]

where the line over the variable denotes that the value is an average of a number of calibration observations rather than one instantaneous value.

Assuming that the detector noise effect is the same for the three views (Earth, Space and ICT) we can start filling out a set of effects tables as follows.
<table>
<thead>
<tr>
<th>Table descriptor</th>
<th>Effect 1</th>
<th>Effect 2</th>
<th>Effect 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Name of effect</strong></td>
<td>Detector Noise</td>
<td>Error in ICT temperature</td>
<td>Radiance bias term</td>
</tr>
<tr>
<td><strong>Affected term</strong></td>
<td>$C_E, C_S, C_{ICT}$</td>
<td>$T_{ICT}$</td>
<td>$a_0$</td>
</tr>
<tr>
<td><strong>Uncertainty u</strong></td>
<td>Can be derived from space view measurements based on the statistics of the data</td>
<td>ICT temperature measured using platinum resistance thermistors which themselves will have an associated uncertainty.</td>
<td>Offset in radiance which is often caused by stray light differences between different views, in this case between the Earth views and the space views. To keep this simple we will assume this is constant over the sensors lifetime. The uncertainty is derived from either pre-launch analysis or from an in-orbit Harmonisation process.</td>
</tr>
</tbody>
</table>

**Sensitivity**

\[
\frac{\partial L_{Earth}}{\partial C_E} = \quad \frac{\partial L_{Earth}}{\partial C_S} = \quad \frac{\partial L_{Earth}}{\partial C_{ICT}} = \\
\frac{\partial L_{Earth}}{\partial T_{ICT}} = \quad \frac{\partial L_{Earth}}{\partial a_0} =
\]

using $L_{ICT}(T_{ICT})$, which is available as a pre-calculated look-up table that converts the ICT temperature to a radiance.

Note that the sensitivity for the uncertainty on the ICT temperature, $\frac{\partial L_{Earth}}{\partial T_{ICT}}$, involves the derivative of the function $L_{ICT}(T_{ICT})$ that converts ICT temperature to radiance. Assume this has been pre-calculated by integrating the Planck function with the spectral response function.

We can now move onto thinking about the error correlations that are present due to uncertainties and the way the instrument is calibrated.
3.3 Exercises

3.3.1 Task 1
Consider how the sensitivities for the radiance measurement function would be calculated. (Some are easy to derive analytically.)

3.3.2 Task 2
Consider the averaging that is applied with the calibration data: in the measurement function the arithmetic mean over a centred window of $N$ scans is used for $\bar{C}_S$ and $\bar{C}_{ICT}$. The errors in these two averages causes an error in each Earth radiance. Think about how these errors are related for different Earth pixels. Qualitatively, what correlation of error will exist:

1) Between pixels in a single scan line?
2) Between pixels in different scan lines?
3) Between orbits?

Describe how the error correlation changes with the separation between pixels in each case (across and along track).

3.3.3 Task 3
In the case of Effect 2 (uncertainty on the ICT temperature), describe any error correlation structures that will arise from this effect. Consider different sources of uncertainty (effects) in the ICT temperature measurement.

Consider also if this were an instrument with multiple spectral channels what the error correlation between channels due to this effect may be.

3.3.4 Task 4
If this were a real instrument, list other uncertainty sources that could arise, including in the +0 term.
[If you have any extra time, you could consider sketching an uncertainty tree diagram for a sensor you know about and/or take some time to look at the FIDUCEO tree diagrams].
4 What should define a Fundamental Climate Data Record?

4.1 Context
The concept of FCDRs is that these are both precursors to the Climate Data Record of significant interest, and important datasets in their own right that need resources for their creation, maintenance and curation. A couple of definitions of FCDR have been proposed:

GCOS-154 (library.wmo.int/opac/doc_num.php?explnum_id=3710):

The term “Fundamental Climate Data Record” (FCDR) denotes a well-characterized, long-term data record, usually involving a series of instruments, with potentially changing measurement approaches, but with overlaps and calibrations sufficient to allow the generation of products that are accurate and stable in both space and time to support climate applications. FCDRs are typically physical measurements such as calibrated radiances, backscatter of active instruments, or radio occultation bending angles. FCDRs also include the ancillary data used to calibrate them.

NRC-2004 (www.nap.edu/read/10944):

Fundamental CDRs (FCDRs) are sensor data (e.g., calibrated radiances, brightness temperatures, radar backscatter) that have been improved and quality controlled over time, together with the ancillary data used to calibrate them.

The joint CGMS-CEOS Working Group on Climate is considering whether to propose a definition of FCDR for space agencies to consider adopting, which could influence their approach to their responsibilities in this area. The purpose of this exercise is to reflect and comment on a draft text that will be taken in revised form to the Working Group on Climate in due course, taking into account inputs given at this workshop.

4.2 Task
Discuss the draft definition and guidance to interpretation in the next section in groups. Take note of key points. One person from each group will have max 5 min to report back in plenary after the discussions.
Preamble: To support the generation of long-term Climate Data Records (CDRs), space agencies reprocess multi-mission archives to improve the consistency of the level 1 data from which CDRs are generated. The target outcome of such reprocessing and improvement activities is creation of a Fundamental Climate Data Record (FCDR).

Definition: An FCDR consists of a continuous, harmonised record of calibrated, geolocated, uncertainty-quantified sensor observations in geophysical units (such as radiance), together with all ancillary and underlying data used to calibrate the observations and estimate uncertainty.

Explanation and further guidance:

1. This FCDR definition is a target. In the context of CDR derivation from the FCDR, this definition may exceed the minimum requirement (threshold) to derive societal and scientific benefits for some applications. In the following points, “should” is used to indicate conditions necessary to meet this target FCDR definition.

2. The FCDR should be continuous. During periods of overlaps of sensors in series, all overlapping data should be included in the FCDR, since overlaps can also be exploited when deriving CDRs to maximise stability.

3. The FCDR should be harmonised. Harmonisation is the recalibration of the sensor observations in geophysical units, using a stated reference and/or overlaps with other sensors in the series. The purpose of the recalibration is to bring consistency between sensors given the known (best estimate) differences in instrument characteristics (e.g., spectral response functions) between sensors. A harmonised FCDR should support more stable CDRs to be derived.

4. The FCDR comprises calibrated quantities in geophysical units together with the underlying data from which the calibrated quantities are derived (such as Earth view counts and calibration target counts). “Together with” does not necessarily mean “in the same file”, but it needs to be possible unambiguously to trace the underlying data from the calibrated data. This requirement enables both use of calibrated quantities to generate CDRs, and potential re-estimation of calibrated quantities should further research improve understanding of the instrument calibration.

5. The data in the FCDR should be located using a clearly defined co-ordinate system for geolocation and time, exploiting the best available estimates of orbital elements.

6. Quantitative uncertainty information should be provided with the FCDR observations. The form of uncertainty information should reflect the nature of the sensor and its error characteristics, as well as the requirements for quantifying uncertainty in derived CDRs. Examples of uncertainty information include: standard uncertainty, fractional uncertainty, and error covariance matrices. Uncertainty may be provided as data arrays or (where valid, in order to minimise data volumes) as parametric expressions to calculate uncertainty from other data in the FCDR. Uncertainty information should be provided per orbit/file, per scan or per datum as necessary to represent any significant variability of uncertainty, while taking account of data volume.

7. Similarly to comment 4 above, data underlying or ancillary to the uncertainty estimates should also be provided together with the uncertainty information in the FCDR.

8. Flags relating to assessment of data quality and instrument status should be made available in the FCDR together with the observations and their uncertainty. To increase usability, summary flags may be provided that give simple guidance to users about the quality status of pixels based on expert understanding of which of the flags and instrument conditions indicate questionable or invalid data.

9. The FCDR format should be consistent across the various sensors of the series. Versioning and informative metadata should be implemented, including links from calibrated observations to ancillary data (if not in the same files).