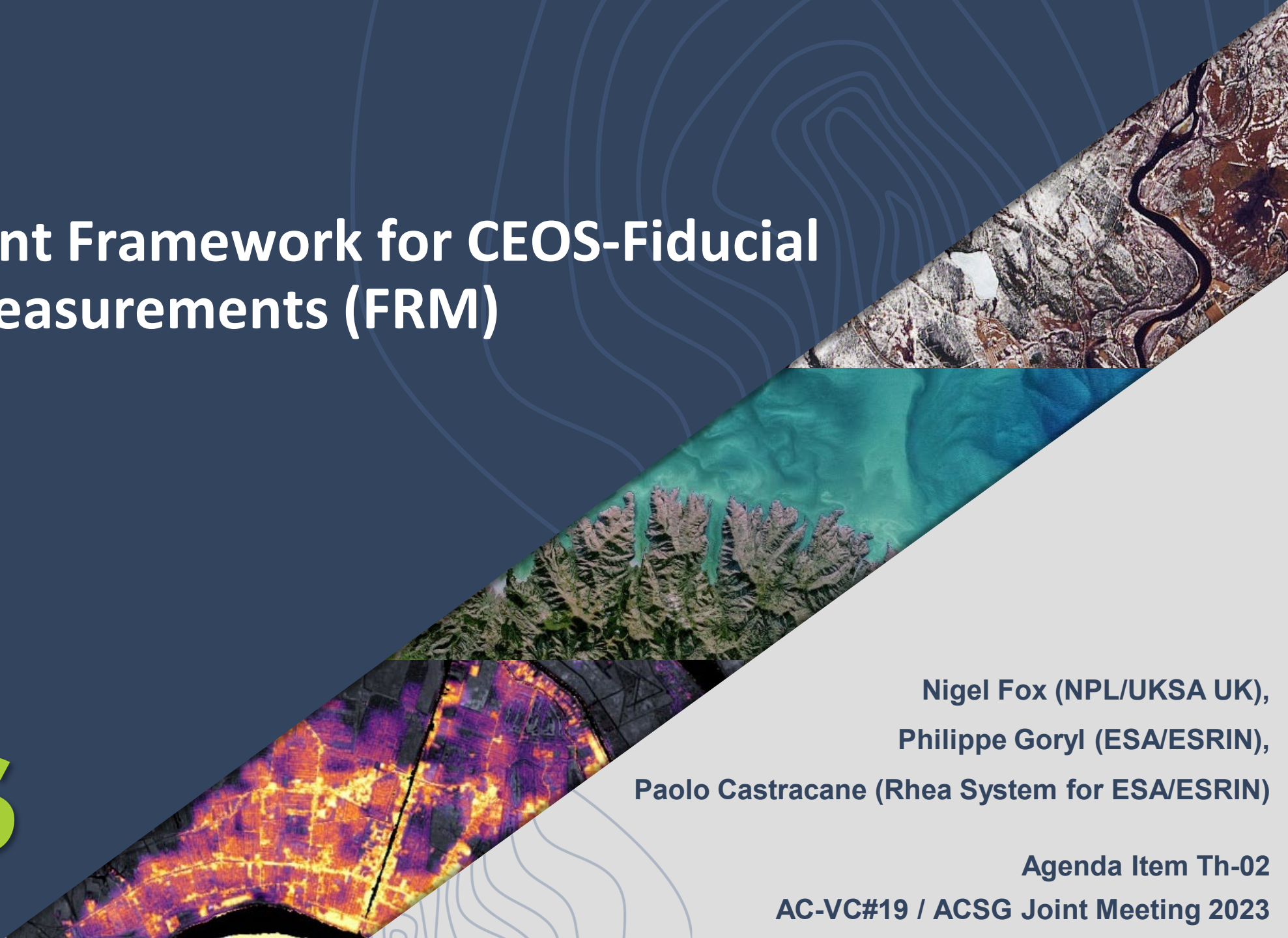
An Assessment Framework for CEOS-Fiducial Reference Measurements (FRM)



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Committee on
Earth Observation Satellites

Background and Objectives

Calibration and validation (Cal/Val) activities are a ***key component of an EO mission***, as it is the foundation for ***Trustworthiness*** for the mission data. Cal/Val activities require continuous efforts: before, during and after the mission lifetime.

Cal/Val activities have two main objectives:

1. to provide data products with documented and associated ***traceable uncertainty estimates***;
2. to gain knowledge in the sensor performance and the algorithms characteristics in order to improve their quality and reliability.

The understanding of the uncertainties has a long-term impact for most EO products and in particular for downstream and ***climate*** applications.

Background and Objectives

Cal/Val activities – Generic Approach

A post launch Calibration and Validation programme is composed of different complementary activities that can be combined together to produce fully documented and consolidated performances.

In general terms the different Cal/Val components are as follows:

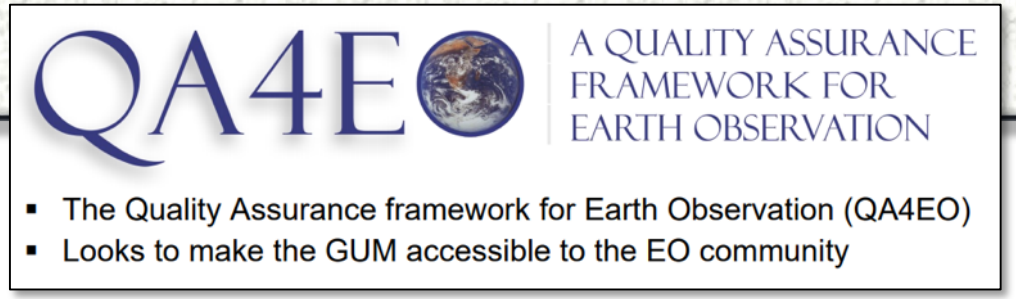
- Comparison against tailored and accurate ***Fiducial Reference Measurements (FRMs)***:
  few points but low uncertainty/high confidence; concept and label increasingly used but not always consistently!
- Comparisons against 'general ***in-situ data'***: more points less accurate individually;
- Comparisons against other sources: ***inter-satellite comparisons, satellite L3, climatologies, etc.***;
- Comparisons against ***models***: reanalysis, data assimilation, forward modelling, etc.;
- Comparisons between operational satellites (e.g., using GSICS best practises).

All the above components are important and to varying degrees necessary; the ***first component (FRM)*** is of particular importance because it gives a **reference,** properly characterised and traceable to standards and/or community best practises on which the Cal/Val results can be anchored and an uncertainty assessed.

CEOS-FRM Definition

Fiducial Reference Measurements (FRMs) are independent, fully characterised, and traceable (to a community agreed reference ideally SI) measurements tailored specifically to address the calibration/validation needs of satellite borne instruments making measurements of a particular measurand, that follow the guidelines outlined by the GEO/CEOS Quality Assurance framework for Earth Observation (QA4EO).

Nb: can be: site-based, network, from a 'platform' etc



https://doi.org/10.3390/rs15205017

CEOS-FRM Principles

1. **Traceability-** FRMs should have documented evidence of their traceability (bias and associated uncertainty) to a community agreed reference, ideally tied to the International System of units, SI, e.g. (via a comparison 'round robin' or other) with peers and/or a metrology institute together with regular pre-and post-deployment calibration of instruments. This should be carried out using SI-traceable 'metrology' standards and/or community recognised best practices, for both instrumentation and observations;

2. **Independence of satellite-under-test-** FRMs are independent from the satellite (under- comparison) geophysical retrieval process;

3. **Uncertainty budget-** A comprehensive uncertainty budget for all instruments used in deriving FRM of a particular measurand, including any transformation of the measurand to match that of the satellite product, is available and maintained;

4. **Documented protocols-** FRM protocols, procedures and community-wide quality management practices (measurement, processing, archive, documents, etc.) are defined, published and adhered to by FRM instrument deployments and usage;

5. **Accessibility-** FRM data, including metadata and documentation of processing, are accessible to other researchers allowing independent verification of processing systems. All data and information should be made available in a timely manner and in a form that is readily utilisable by a satellite operator;

6. **Representativeness-** FRM data allow the determination of the on-orbit uncertainty characteristics of satellite geophysical measurements via independent validation activities. It thus requires that the degree of representativeness of the FRM to that of the satellite observation and/or associated retrieval as well as the satellite to FRM comparison process needs to be documented and the uncertainty assessed. Note for any individual satellite instrument the exact sampling and elements of the comparison process may differ, even within a generic instrument/satellite class, but the documentation and evidence to support the uncertainty analysis must be presented in a manner that can be readily interpreted by a user.

7. **Adequacy of uncertainty-** The uncertainty of the FRM measurements, including the comparison process, must be commensurate with the requirements of the class of satellite/instrument/measurand they are specified to support.

8. **Utility (Return on Investment)-** FRM data are designed to apply to a class of satellite missions (several). They should not be mission-specific.

It should be noted that in using any CEOS-FRM data it is expected that the user provides a clear acknowledgement of the contribution of the FRM owner/provider in any reporting of results, verbal and written as well as to CEOS for the FRM QA framework. Each FRM provider may have their own required wording for acknowledgement and should be consulted individually if this is not on their documentation.

CEOS-FRM Endorsement process

The proposed framework takes a pragmatic approach relying on ***self-assessment*** and transparency/accessibility of evidence against a set of criteria which are subject to peer ***review through a board of experts led by CEOS WGCV***

In order to be flexible, maximise inclusivity and encourage the development and evolution of FRM from new or existing teams compliance with criteria will be based on a ***gradation scaling rather than a simple pass/fail***

The degree of compliance and associated gradation can then be presented in a ***Maturity Matrix model*** - EDAP like to allow intended users of the FRM to assess suitability for their application and indeed funders to decide on where and what aspects to focus any investment. The matrix model provides a visual 'simple' assessment of the state of any FRM for all given criteria making visible where it is mature and where evolution and effort needs to be expended.

In addition to this broad-based summary an overall ***classification of the degree of compliance*** will be provided based on meeting specific gradations for particular criteria (see slide)

An on-line catalogue will be provided by CEOS to host the listing of endorsed FRM capabilities

CEOS-FRM Maturity Matrix

Self-Assessment					Independent Assessor
Nature of FRM	**FRM Instrumentation**	**Operations/Sampling**	**Data**	**Metrology**	**Verification**
Descriptor	Instrument documentation	Automation level	Data completeness	Uncertainty characterisation	Guidelines adherence
Location/availability of FRM	Evidence of traceable calibration	Measurand sampling/representativeness	Availability and usability	Traceability Documentation	Utilization/feedback
Range of instruments	Maintenance plan	ATBDs on processing: algorithms/software	Data Format	Comparison/calibration of FRM	Metrology verification
Complementary observations	Operator expertise	Guidelines on transformation to satellite pixel	Ancillary Data 🔒	Adequacy for intended class of instrument/measurand	Independent verification
		FRM CLASSIFICATION			A B C D (to be selected)

Grade
Not Assessed
Not Assessable
Basic
Good
Excellent
Ideal

Draft Framework document

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Catalogue descriptor & basis for FRM assessment

Initial description of FRM as a pre-cursor to MM and to facilitate on-line search

1. **FRM measurand (FRM4?):** what is the FRM measurand? e.g. surface reflectance, Total Column CO2, Land surface Temp etc.
2. **For what 'class' or classes of instruments:** V-high resolution imager, Medium resolution imager, Lidar, Atmospheric spectrometer etc. **& observation characteristics** e.g. Nadir, limb-sounding etc
3. **Nature of FRM (temporal & spatial):**
   a. Near continuous sampling from a fixed location, A network of near continuous sampling 'sites', Instrument/method 'campaign' based
   b. from surface based sensor, Airborne, space, autonomous, operator
   c. Localised 'point' sample-based, integrated/averaged e.g. 'line-of-sight' volume for some atmospheric composition …

Catalogue descriptor & basis for FRM assessment

4. **Best Achievable Uncertainties:** What uncertainty can be achieved for the measurand for the defined class of instrument (including representativeness:-spatial, temporal, vertical/column for the class of instrument/satellite but not satellite-specific uncertainties).
5. **FRM Owner/operator Contact details:** Means to communicate with those responsible for all the information relating to the FRM.
6. **Access to FRM data**: URL (or other) means to obtain FRM data and documentary evidence of FRM characteristics, ideally following FAIR principles.
7. **Approximate start of FRM 'like' operations:** When did measurements of this type begin, how long has site existed and/or team being doing measurements etc even if not fully FRM compliant.

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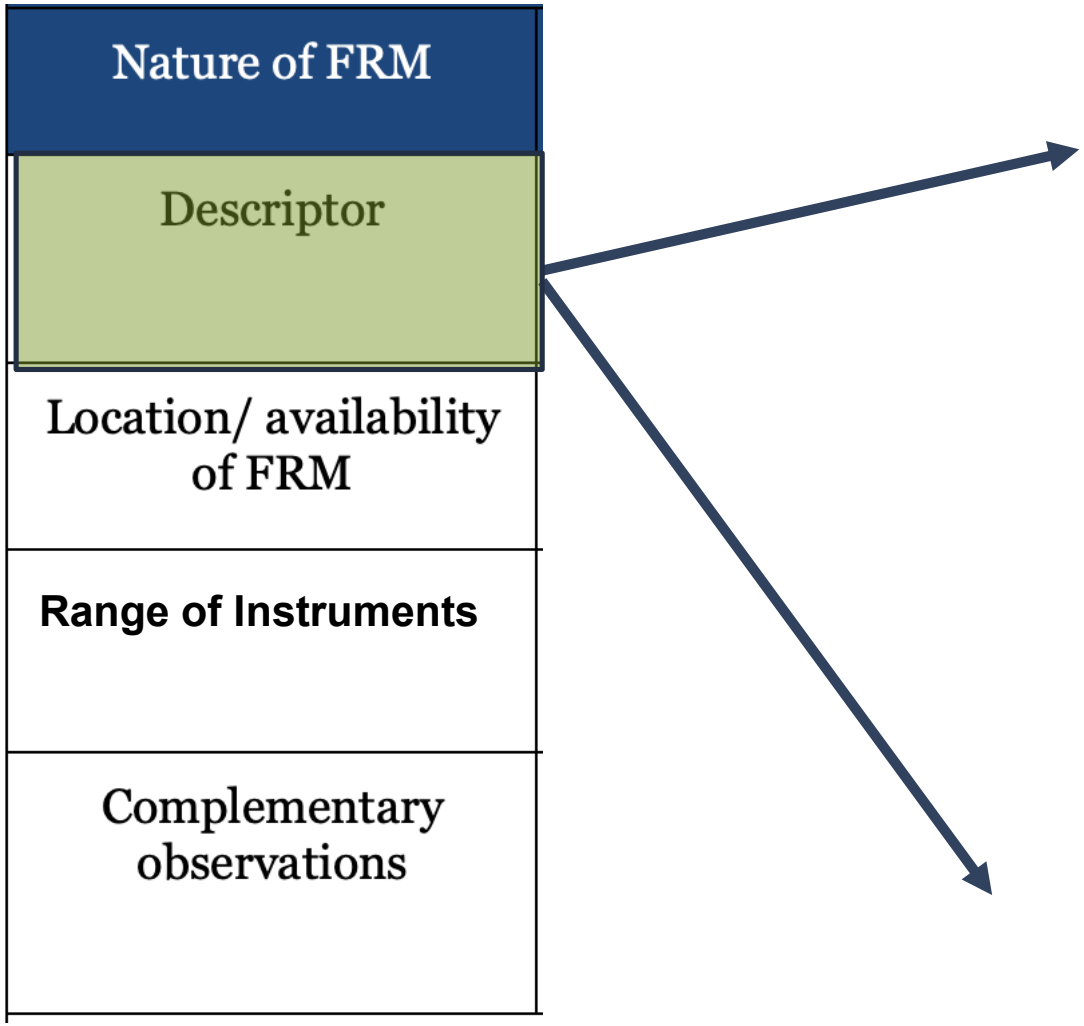
self-assessment FRM MM
Nature of FRM

Nature of FRM
Descriptor
Location/ availability of FRM
Range of Instruments
Complementary observations

Completeness of the general information relating to the nature of the FRM and its basic suitability for the class of sensors it is intended to be supporting.

- Information of the person PoC (Point of Contact) who is responsible for the FRM
- Adequacy of location and availability
- How broad is the range/number of sensors that can be served and presence of complimentary observations made at the same time/location

Example criteria



Grade	Criteria
Not Assessed	Assessment outside of the scope of study.
Not Assessable	Relevant information not made available.
Basic	All critical information available but incomplete or inaccessible evidence.
Good	information provided but some evidence would need to be requested.
Excellent	As Ideal but without a comprehensive dedicated website.
Ideal	A complete comprehensive template and an FRM website where all information is clearly and readily available.

self-assessment FRM MM
FRM Instrumentation

FRM Instrumentation
Instrument Documentation
Evidence of traceable calibration
Maintenance plan
Operator expertise

Information related to the FRM instrumentation:

- Documentation, Technical Manuals: Hardware and software
- Documentation demonstrating traceable calibration of all appropriate instrumentation used to establish FRM, indicating achieved performances and detailed uncertainty budgets
- QA and Maintenance processes and plans and Operator expertise (months/years of experience, trained and number of personnel etc)

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Traceable calibration

FRM Instrumentation
Instrument Documentation
Evidence of traceable calibration
Maintenance plan
Operator expertise

Grade	Criteria
Not Assessed	Assessment outside of the scope of study.
Not Assessable	Relevant information not made available.
Basic	Evidence of traceability and performance limited potentially to a pre-deployment calibration or manufacturers specification.
Good	Evidence of traceability available together with uncertainty budget but not necessarily independently reviewed or compared
Excellent	Adequate documentation to make clear the degree of traceability and associated uncertainty although comparison of peers not necessarily undertaken.
Ideal	Fully documented evidence of route of traceability and associated uncertainties (full breakdown including correlations) from the use of the instrument to make a measurement in support of FRM at location of its operational use, back to its link to an SI or community agreed reference. This should be presented following practises indicated by FIDUCEO, and available from the QA4EO website or similar. This should be evidenced by an independent comparison of performance against as a minimum, peers, under full range of operational conditions of the instrument. Ideally this would all be carried out following equivalent to ISO 17025

self-assessment FRM MM
Operations/sampling

Operations/ sampling
Automation level
Measurand sampling **/ representativeness**
ATBDs on **Processing: algorithms /software**
Guidelines on transformation to satellite Pixel

Information concerning activities in terms of level of automatization and documentation available for functional operation/sampling and processing to be representative of a satellite observation

CEOS-FRM Maturity Matrix

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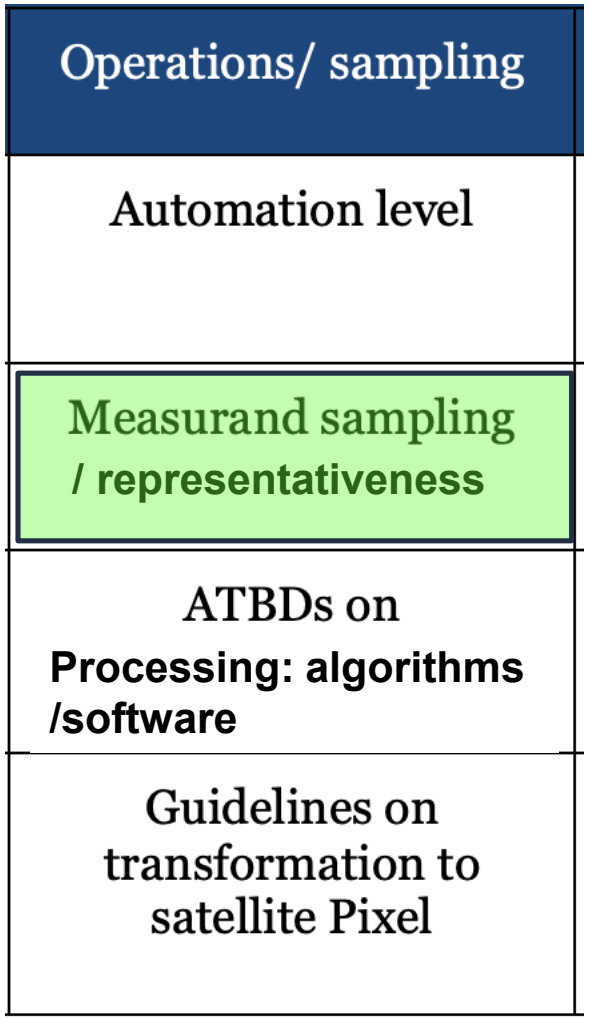
Measurand Sampling /Representativeness



Grade	Criteria
Not Assessed	Assessment outside of the scope of study.
Not Assessable	Relevant information not made available.
Basic	Typically a single point sample (not at satellite pixels scale) but with an estimate of the impact on the comparison to the satellite measurand due to inadequate representativeness.
Good	A set of samples that seek to scope the observation characteristics of the satellite instruments observation of the measurand for a given pixel but still relatively sparse resulting in an uncertainty that typically needs multiple observations to be adequately minimised.
Excellent	A broadly sampled target with observational based analysis of the effect of non-representativeness and a resultant uncertainty not dominating that of other contributions to the use of the FRM.
Ideal	The sampling characteristics of the FRM allow full representation of the satellite instruments observation for all observation conditions of the sensor (both the instantaneous observation and/or global) such that the resultant uncertainty contribution is small compared to the process as a whole. Note: to achieve full representativeness this is likely to require some form of network or 'set' of FRM observations and potentially very dense sampling if localised 'point like' observations are being made by the FRM

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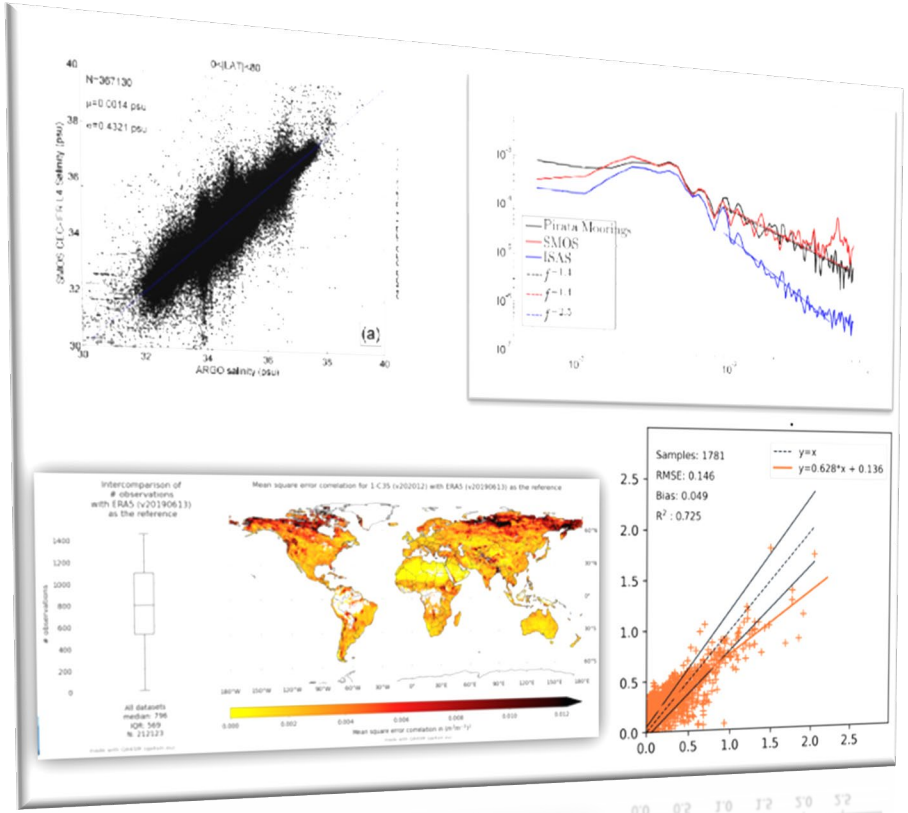
self-assessment FRM MM
Data

Data
Data completeness
Availability and Usability
Data Format
Ancillary Data

Descriptive information concerning the data (result of instrument measurement) provided in relation to the specifics of the data details itself, availability and usability (FAIR principles), format and ancillary products (when part of operation or processing)



CEOS-FRM Maturity Matrix

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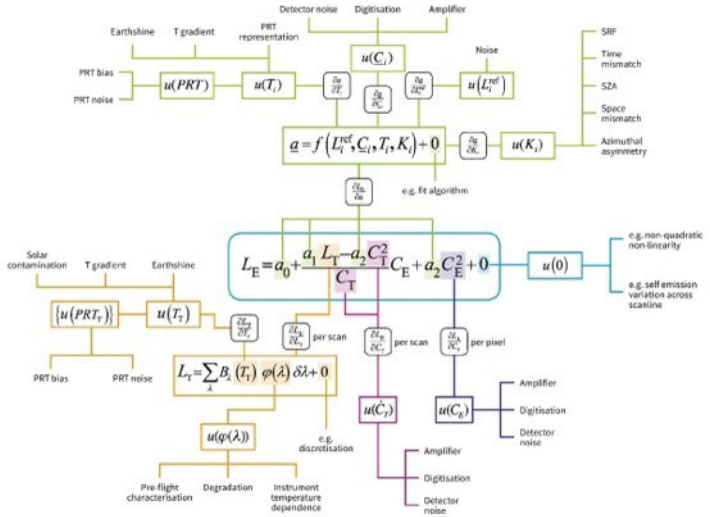
self-assessment FRM MM Metrology

Metrology
Uncertainty Characterisation
Traceability Documentation
Comparison/calibration of FRM
Adequacy for intended **Class of instrument/measurand**

Related to measurement quality of overall FRM, including calibration, traceability and uncertainty and degree of independent assessment.

Has a metric related to Uc level achieved by FRM i.e. its ‘fitness for purpose’ for self-declared applications



Mittaz et al. 2019

Independent assessor FRM MM Verification

Verification
Guidelines adherence
Utilisation/Feedback
Metrology verification
Independent Verificaton

The overall goal is to verify that the FRM is consistent with self-assessed criteria and that the evidence provided fully supports the assessment. This column is again subdivided into categories to provide some granularity to the verification process.

Note this requires CEOS community effort to review the self-assessed matrix

The degree of utilisation/impact in terms of citations, website visit, feedback provided etc is an important aspect

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Critical verification categories

GUIDELINES Adherence

Grade	Criteria
Not Assessed	Assessment outside of the scope of study.
Not Assessable	Relevant information not made available.
Basic	80% should be at least 'basic' and if not there should be a clear strategy to progress within a short (<3 month) timescale. Those categories in basic should have a strategy to progress towards greater compliance.
Good	More than 80% must meet the 'good' category and those in 'basic' should indicate a strategy to progress. >30 % should be in the green classification. There should be no 'basic' classifications in the metrology or Instrument columns and any in these columns only indicating 'good' should indicate a strategy to progress
Excellent	All categories are good or above with > than 80% in the green classification and those in the Metrology or instrument columns must meet excellent or above.
Ideal	All categories in the matrix fully meet the green classification i.e. Excellent or Ideal with at least half reaching the ideal category and of these, half must be contained within the metrology and FRM instrument column.

Independent Verification

Grade	Criteria
Not Assessed	Assessment outside of the scope of study.
Not Assessable	Relevant information not made available.
Basic	Some comparison evidence but limited ability to confirm or otherwise the declared FRM uncertainty
Good	Full compliance of declared FRM uncertainties through comparison to a reference of good but higher uncertainty than the FRM or near but not full compliance against a reference of comparable or lower uncertainty.
Excellent	Full compliance of declared FRM uncertainties through comparison to a reference with comparable uncertainties.
Ideal	Full compliance of declared FRM uncertainties through independent comparison to a reference of lower overall uncertainty

Class A & B must achieve some form of Green for all verification categories, with Class A needing 'Ideal' in the guidelines adherence

CEOS-FRM Overall Classification

To provide overall summary guidance to a user we have created the following four classes.

Class A – Where the FRM fully meets all the criteria necessary to be considered an FRM for a particular class of instrument and measurand. It should achieve a class of Ideal in the 'guidance adherence' criteria in the verification section of the MM and green (at least excellent) for all other verification categories where these have been carried out.

Class B – Where the FRM meets many of the key criteria and has a path towards meeting the Class A status in the near term. It should achieve at least Excellent in the 'guidance adherence' criteria in the verification section of the MM and green (at least excellent) for all other verification categories where these have been carried out. Ideally it should indicate a path towards achieving the high class.

Class C – Meets or has some clear path towards achieving the criteria needed to reach a higher class and provides some clear value to the validation of a class of satellite instruments/measurands. It should achieve at least Good in the guidance criteria in the verification section of the MM and at least good for all other verification categories where these have been carried out. Ideally, it should indicate a path towards achieving the high class.

Class D - Is a relatively basic adherence to the FRM criteria but where this is a strategy and aspiration to progress towards a higher class. This can be considered an entry level class for those starting out on developing an FRM. It should achieve at least Basic in the guidance criteria in the verification section of the MM and at least Good for all other verification categories where these have been carried out. FRM owners/developers must indicate a path towards achieving the high class.

Conclusion

- **CEOS WGCV have created a definition of FRM and a framework to facilitate demonstration of compliance**
  - **Suitable for single localised measurements and networks**
  - **A common framework for all satellite applications and technologies**
  - **Compliance demonstrated as a graded status to differentiate and encourage engagement and progression**
  - **Aim to aid FRM developers to differentiate themselves, funders to optimise resources and satellite operators to choose!**

- **FRM definition not changed but enhanced and clarified in some places**

- **Assessment Framework now under final testing with case studies from different communities**
  - **subject to revision**
  - **community input welcomed** DRAFT CEOS-FRM_Assessment_Framework_V_0.2.docx - Google Docs

- **Will look to create and populate a searchable catalogue of CEOS-FRM in near future.**