Quality Assurance framework for EO-based fire products

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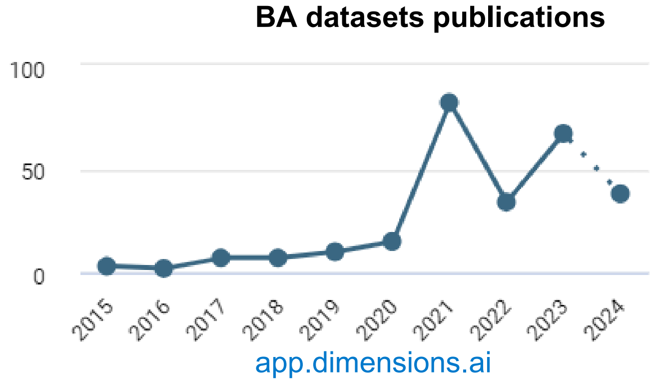
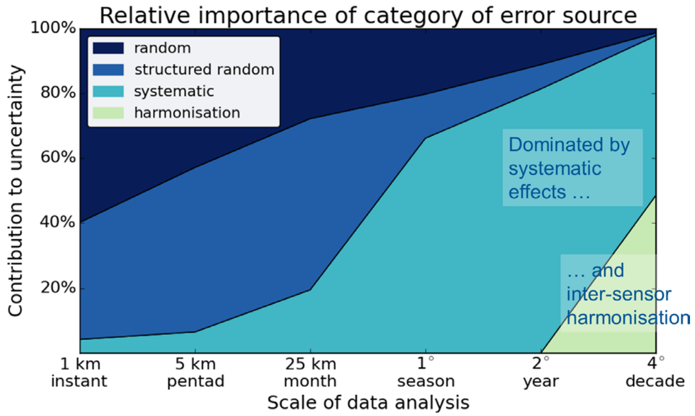
WHY THE NEED FOR QUALITY?

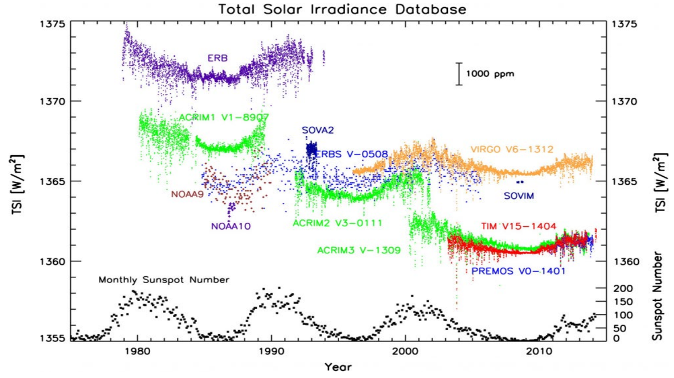
Quality of products is **important** because of:

- **Application** - the use of data products of which the quality of data production process is unknown or weak (cloud processing and user-friendly ML/AI apps)
- **Impact** - the existence of defective data contributing to unsatisfactory and unusable results (trends sourced in the measurement/processing process)
- **Dissemination** - data used, and product produced are in accordance to the needs of a single organization (lack a coherent and integrated vision which is necessary to ensure interoperability and co-operation)
- **Comparability** - data which are not immediately re-usable due to lack of consistency between products and other existing co-related data;

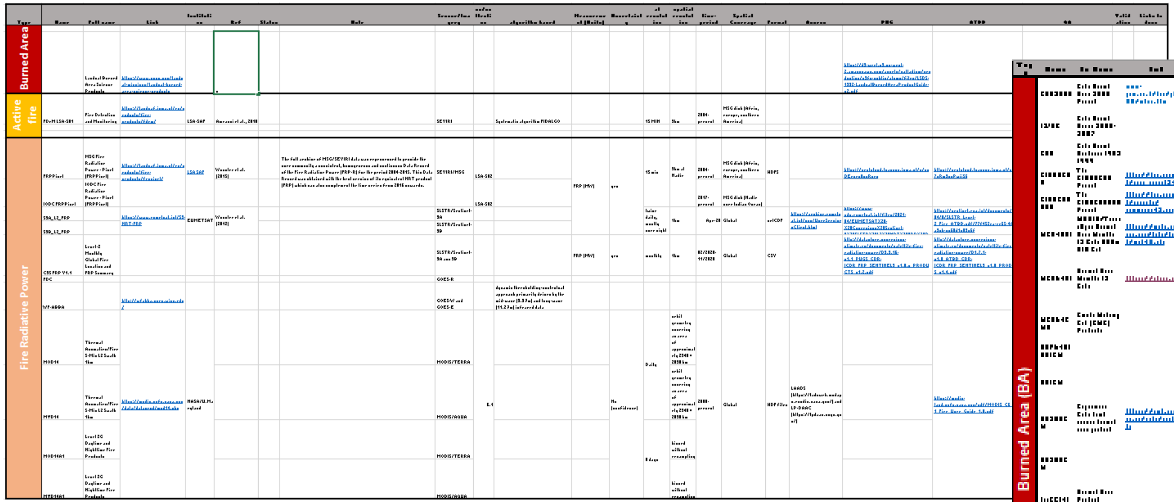
Reliable access to good quality, <u>trustworthy</u> and <u>reproducible</u> data and information is needed in all areas of fire research/applications







L2



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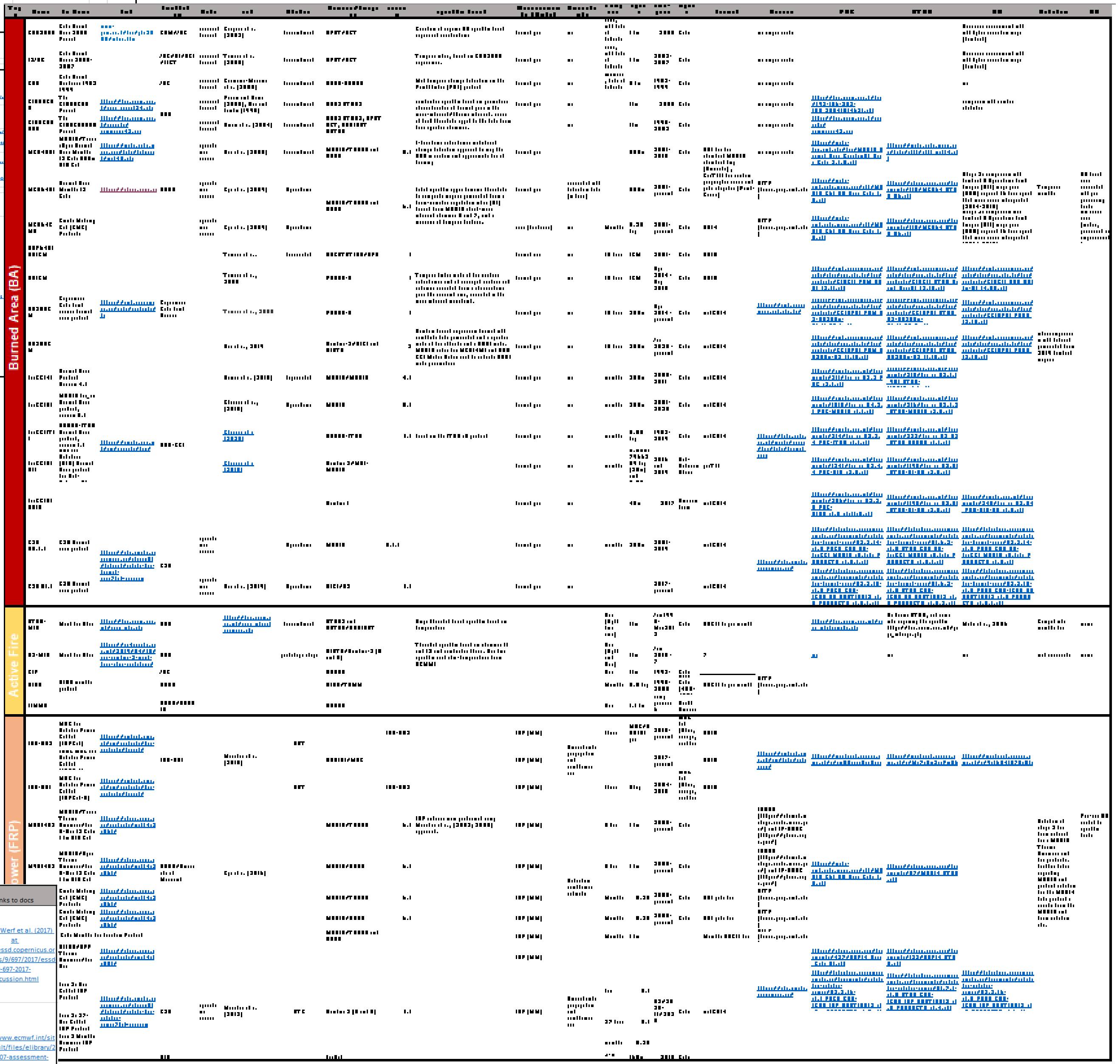


Identified 52 fire products (BA, AF, FRP), global or hemispherical cover), at various processing stages and latencies (NRT, NCT).

- Documentation (PUM, ATBD, QA)
- Service Architecture
- Format, resolutions and metadata
- Uncertainty
- Validation

L4

Type	Name	Link	Institution	Note	ref	Status	imagery	version	algorithm based	Temporal resolution	spatial resolution	time-period	Spatial Coverage	Validation	QA	Links to docs
Burned Area	**Global Fire Emissions Database (GFED)**	https://www.globalfiredata.org/	VUA	aimed for biomass burning emissions accounting, developed using the standard NASA MODIS BA product compled with a model to account for small undetected fires	Giglio et al. (2013), Randerson et al. (2012), van der Werf et al. (2017)	Research focused, in operation	MODIS (TERRA & AQUA)	4s	MCD64 C6 BA product	monthly	0.25deg	1995-present	global	Inter-comparison of global inventories, small fires model evaluation using country level statistics		van der Werf et al. (2017) at https://essd.copernicus.org/articles/9/697/2017/essd-9-697-2017-discussion.html
Fire Radiative Power	**Global Assimilation System (GFAS)**	https://www.ecmwf.int/en/forecasts/dataset/global-fire-assimilation-system	ECMWF	aimed for biomass burning emissions monitoring, based on the standard MODIS FRP product coupled with a daily fire cycle model to account for non monitored FRP	Giglio et al. (2018), Kaiser et al. (2012), Andela et al (2015)	operational service	MODIS (TERRA & AQUA)	1	MCD14 C6.1 FRP product	daily	0.1deg	2000-present	global	Inter-comparison of global inventories, daily fire cycle model evaluation using SEVIRI/MSG data characterization	https://www.ecmwf.int/sites/default/files/elibrary/2013/7707-assessment-global-fire-assimilation-system-gfasv1.pdf	https://www.ecmwf.int/sites/default/files/elibrary/2013/7707-assessment-global-fire-assimilation-system-gfasv1.pdf

QUALITY GAPS OF EO PRODUCTS?

NPL

The key findings of a survey focused on ECV (Nightingale et al., 2019) and CCVS project

- Need for **consolidated, short, simple** guidance documents, frequently **updated** using consistent and **metrologically sound vocabulary**
- **Traceability chains** to enable an understanding of the product (implementation of E2E)
- **Validation** of the product by **independent means** and Inter-comparison exercises to understand to identify advantages and disadvantages, that is **consistent in time and spatially represented**
- **Quality flag** information at **pixel level** consistent between products
- Registry of **known issues** or problems (assessment of the quality of all ancillary data used, implications for use of diering cloud masks, classification routines and gridding schemes).
- Understanding **uncertainties and error correlation** (consider propagation from L1)
- Consistency of the product over time and space

QA4EO

Principle

"It is critical that data and derived products are easily accessible in an open manner and have associated with them an indicator of their quality traceable to reference standards (preferably SI) to enable users to assess its suitability for their application, i.e. its **fitness for purpose**."

WHAT IS QUALITY MEASUREMENT SYSTEM?

Quality Assurance is essentially the "quality metadata" for each dataset and service according to define requirements, standards and best practice guides

Quality Assessments provides science-based information about the performance according to quality indicators and attributes in the context of a realistic use cases.

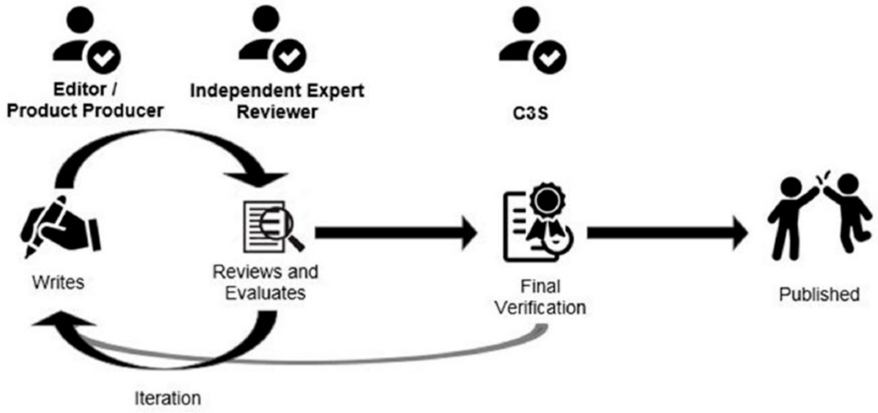
QUALITY ASSURANCE
framework

QUALITY ASSESSMENTS
evaluation

?

Quality indicators for EO fire data

FITNESS FOR PURPOSE
uptake



HOW TO DEFINE DATA QUALITY: THE ATTRIBUTES

Within the fire community, quality assessment is normally perceived as being associated with **validation process** (but it is much more than that)

Quality assurance of data needs to be defined by International quality standards, considering the product's characteristics and life cycle (*) focussing on:

- **the service/system,**
- **available information,**
- **the usability**
- **the data**

* Attributes as defined and adapted from the ISO/IEC 25024, Systems and software engineering: Systems and software Quality Requirements and Evaluation (SQuaRE) — Measurement of data quality

HOW TO DEFINE DATA QUALITY? THE INDICATORS

- QIs include information about the product data, generation, flags, uncertainty characterisation, validation and the system.

Quality Evaluation Matrix

Input data	Pre-processing	Measurement	Uncertainty	Validation	Efficiency	System
Auxliary data	Spatial consistency	Algorithm	Characterization type	Ref data QA	Format	QA/QC plan?
Imagery source	calibration/corrections	Verification	Sources tracked	Approach/Results	Understandability	Access
QA tracked	Flagging	Upscalling	Temporal stability	Spatila/Temporal Consistency	Mapping unit	Latency
	Normalization/compositing	gap filling	Geolocation Uncertainty	Representativeness	Complience	Baseline updates
	Harmonization/Mosaiking			Inter-comparrisons	Revisions/Updates	Version Control
					Tools	Requirements
					Completeness	

HOW TO EVALUATE THE MATURY OF A PRODUCT

- Evaluation is made by assessing the type and fraction of information provided and available to the reviewer.
- Four levels of achievement ranging from Poor, Basic, Good and Excellent can be defined.
- To achieve a rating of Excellent, almost all QI details per individual section must be provided with substantial credible detail, while a score of Basic would indicate that minimal explanation of a QI was provided and that good practices (if currently available) were not necessarily followed.
- Poorly classified means that this information was not accessed or was not addressed by the product developers

Not accessed
Poor
Basic
Good
Excellent

UNCERTAINTY AND VALIDATION INDICATORS

Uncertainty	Not applicable	Not accessed	Poor	Basic	Good	Excellent
Characterization type		No information available	none	empirical model (confidence)	general uncertainty model	E2E uncertainty propagation model (per-pixel)
Sources tracked				some sources (importance unidentified)	major sources affecting product algorithm	All sources (L1, aux.info, pre-processing, major sources)
Stability				limited period one site	limited period and over several sites	covering the full product period and scale
Geolocation Uncertainty				comparison external data site	Based sollely on source imagery	Full traceability through pre-processing steps

Validation	Not applicable	Not accessed	Poor	Basic	Good	Excellent
Ref data QA		No information available	none	single measurement unit	addiotional layers (flags)	... and Uncertainties
Approach/Results				comparison ref data (field, HR image) limited sites	Comparison with ind. data considering uncetainties	..., comparison data classed as CEOS FRM
Temporal consistency				only one season	more than one season	covering all seasons
Inter-comparrisons				with another product, same imagey	multiple products	...,X-ECV consistency
Representativeness				opportunistic site(s)	LC based	Following startefied ramdom sampling scheme

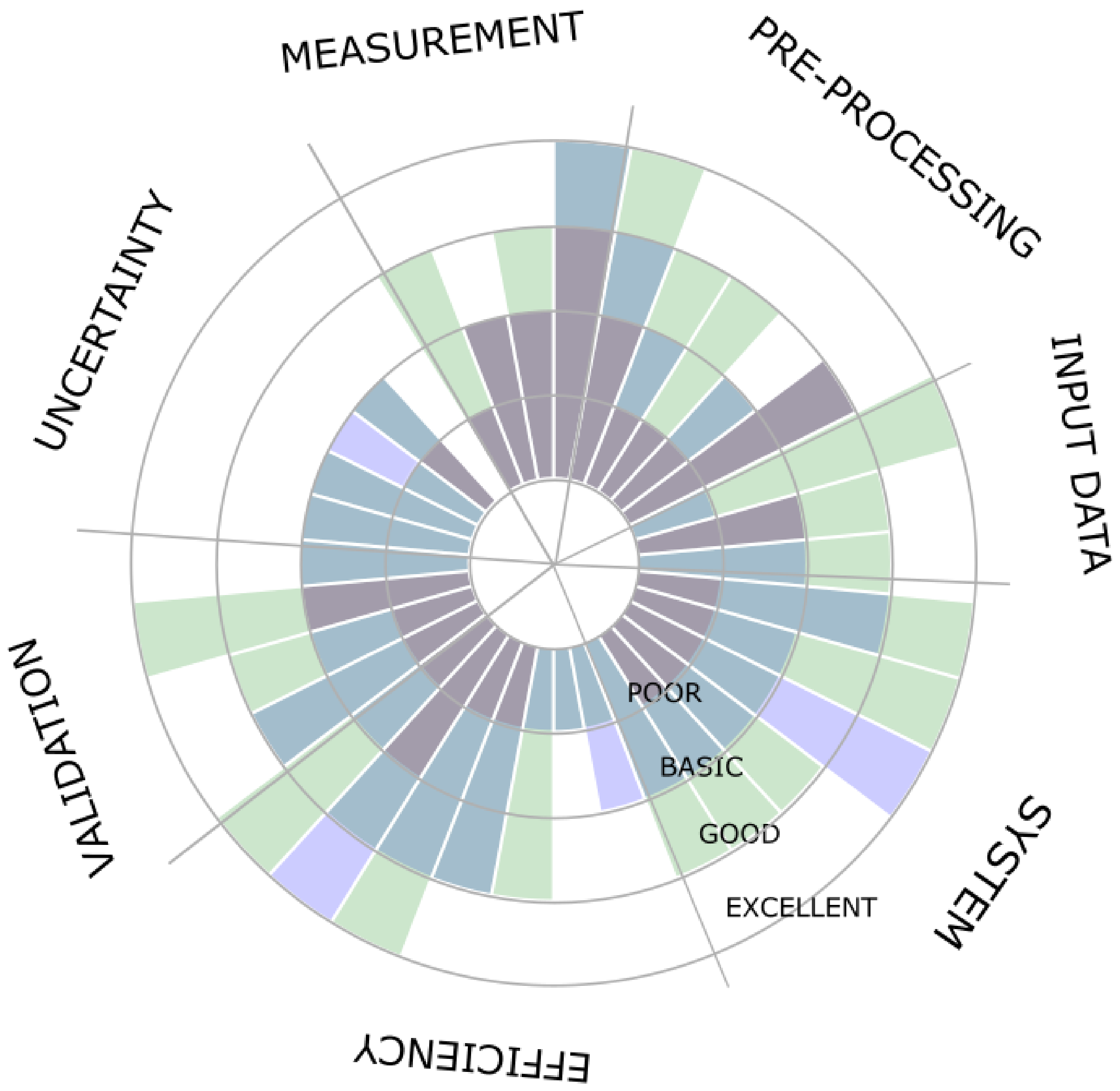
FIT FOR PURPOSE ASSESSMENT

- Grading system allows for a quick comparison of the products QI by user to assess what product is best for each application

Product A – average research exercise, focused on algorithm exploration, limited validation, no details or service

Product B – version 1 of an NRT product, more details, minimal concern with quality (validation) with some support

Product C – Established product with various iterations and at higher validation stage, and overall concern with quality and support

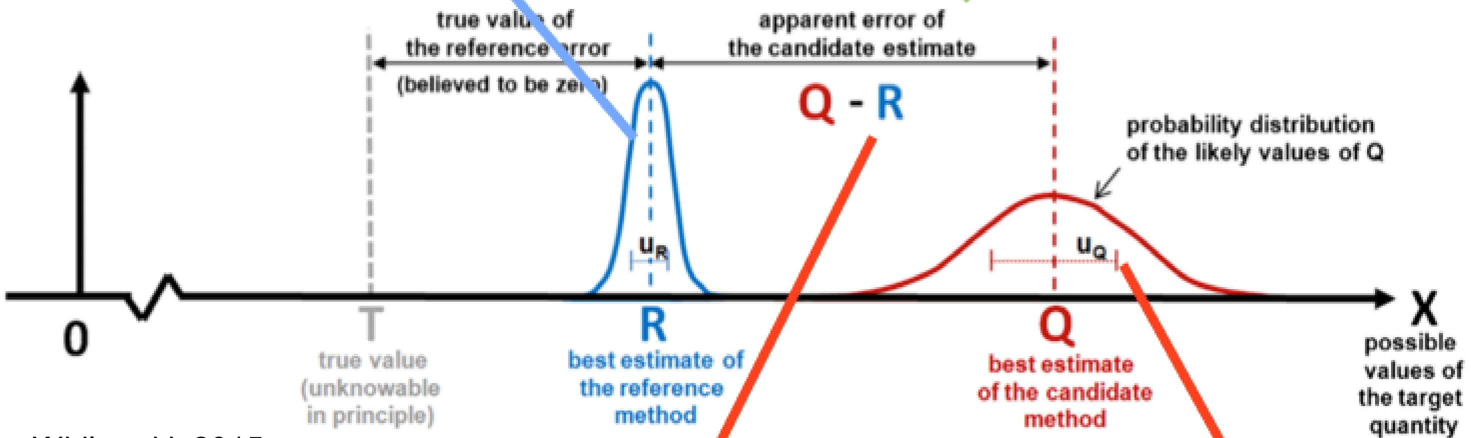


NOTE: THE ROLE OF UNCERTAINTY IN VALIDATION

Field measurement uncertainty

The apparent error between satellite-based and in-situ measurements are also a result of the uncertainty of both: but how can we quantify the contributions separately?

$$E_N = \frac{|\rho_1 - \rho_2|}{k\sqrt{u_1^2 + u_2^2 + u_{\mathrm{comp}}^2}}$$



Widlowski, 2015

equivalence ratio E_N

< 1 suggests that the two measurements agree within their uncertainties,

> 1 suggests that measurements don't agree or that at least one of the uncertainties is underestimated.

Validate satellite-based products, space ECVs vs ground-based values

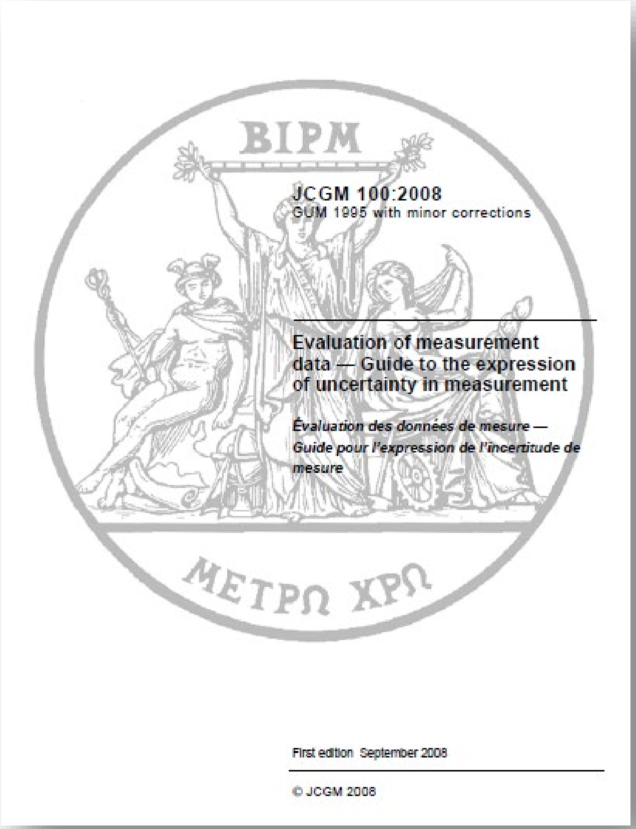
Test conformity with GCOS requirements

	Validation Stage - Definition and Current State	Variable
0	No validation. Product accuracy has not been assessed. Product considered beta.	
1	Product accuracy is assessed from a small (typically < 30) set of locations and time periods by comparison with in-situ or other suitable reference data.	**Snow** **Fire Radiative Power**
2	Product accuracy is estimated over a significant set of locations and time periods by comparison with reference in situ or other suitable reference data. Spatial and temporal consistency of the product and consistency with similar products has been evaluated over globally representative locations and time periods. Results are published in the peer-reviewed literature.	**fAPAR** **Phenology** **Burned Area** **Land Cover** **LAI**
3	Uncertainties in the product and its associated structure are well quantified from comparison with reference in situ or other suitable reference data. Uncertainties are characterized in a statistically rigorous way over multiple locations and time periods representing global conditions. Spatial and temporal consistency of the product and with similar products has been evaluated over globally representative locations and periods. Results are published in the peer-reviewed literature.	**Vegetation Indicies** **Albedo** **Soil Moisture** **LST & EmissiSvity**
4	Validation results for stage 3 are systematically updated when new product versions are released and as the time-series expands.	**Active Fire**

CHALLENGES: UNCERTAINTY CHARACTERIZATION IN BA MAPS

What makes uncertainty propagation through classification challenging?

- output – a categorical property


BIPM

JCGM 100:2008
GUM 1995 with minor corrections

Evaluation of measurement data — Guide to the expression of uncertainty in measurement

Évaluation des données de mesure — Guide pour l'expression de l'incertitude de mesure

First edition September 2008

© JCGM 2008

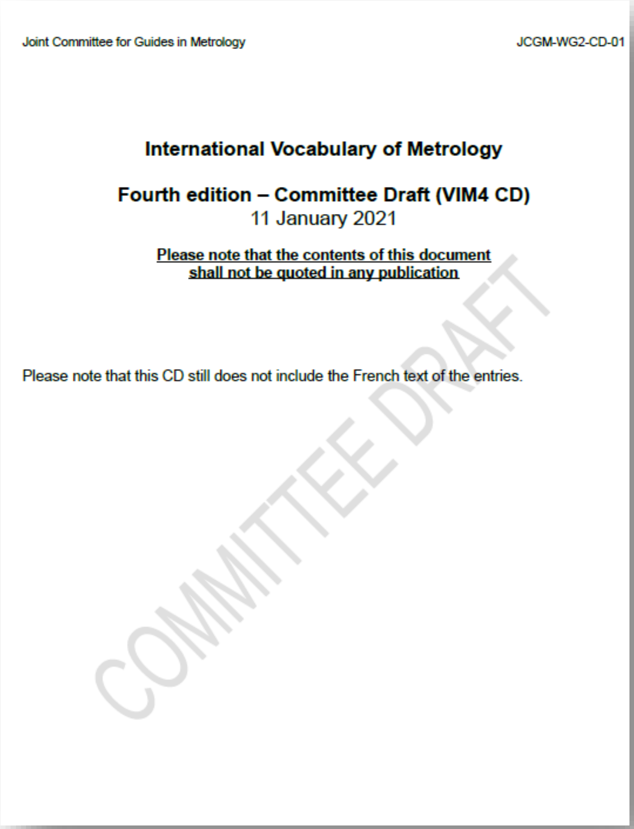
https://doi.org/10.59161/JCGM100-2008E

The GUM does not cover measurands, which are categorical (i.e., non-quantitative)

!!! However, interest to categorical properties in metrology community has been growing !!!

An entire chapter on categorical properties (particularly, nominal properties) was added to the latest draft of the VIM4

!!! VIM4 only provides definitions, GUM-like instructions are needed !!!


Joint Committee for Guides in Metrology JCGM-WG2-CD-01

International Vocabulary of Metrology

Fourth edition – Committee Draft (VIM4 CD)
11 January 2021

Please note that the contents of this document shall not be quoted in any publication

Please note that this CD still does not include the French text of the entries.

COMMITTEE DRAFT

https://www.bipm.org/documents/20126/54295284/VIM4_CD_210111c.pdf

UNCERTAINTY CHARACTERIZATION IN ML APPROACHES

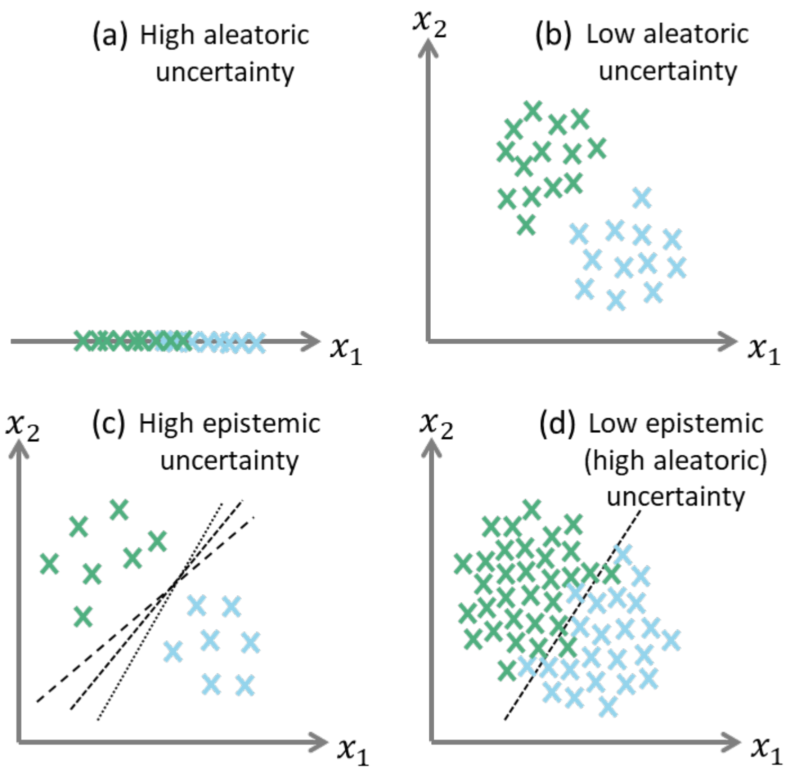
What makes uncertainty propagation through ML methods challenging?

- No physically-based model, the model is learned from the data (a specific challenge is its training)

!!! However, evaluation of uncertainty of a ML model output has been an active area of research in the data science community !!!

They distinguish two uncertainty components: epistemic and aleatoric, and propose methods to estimate them. EO is starting to adopt

!!! How these methods fit into metrological framework is an open question !!!



https://doi.org/10.1007/s10994-021-05946-3

STANDARD FOR METROLOGICAL UNCERTAINTY ANALYSIS IN EO DATA

There have been multiple projects focused on producing guidance on how to adapt the metrological approach to uncertainty analysis for EO data, e.g.

According to these guidance, uncertainty analysis is a stepwise process:

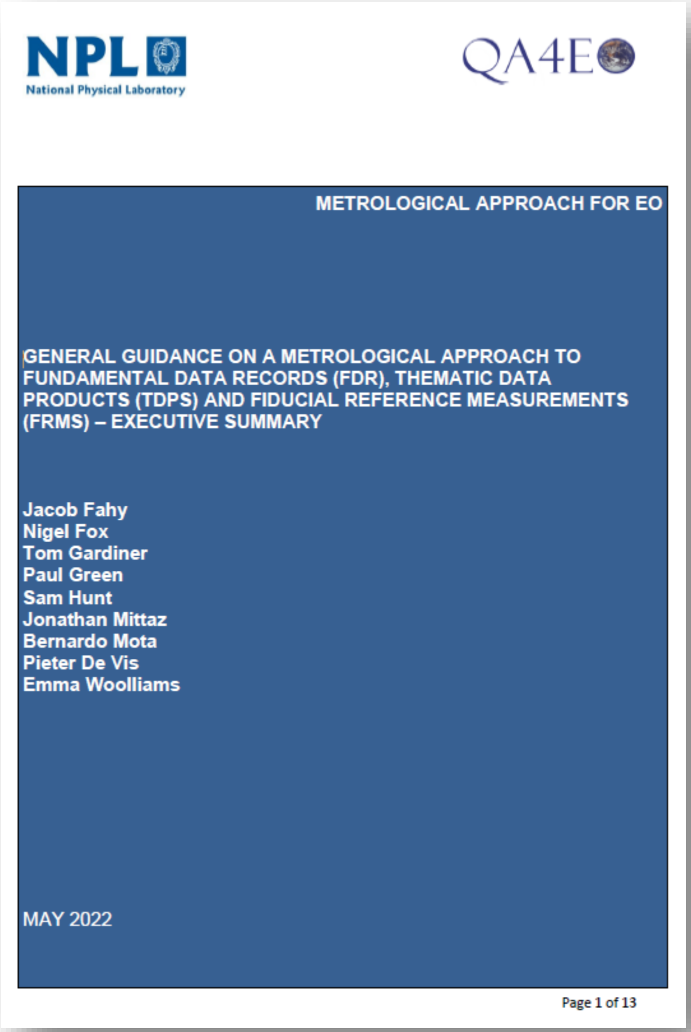
Step 1. Define the measurand and the measurement model

Step 2. Establish the traceability with a diagram

Step 3. Evaluate each source of uncertainty and fill out an effects table

Step 4. Calculate the data product and uncertainties

Step 5. Document uncertainties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METROLOGICAL APPROACH FOR EO

GENERAL GUIDANCE ON A METROLOGICAL APPROACH TO FUNDAMENTAL DATA RECORDS (FDR), THEMATIC DATA PRODUCTS (TDPS) AND FIDUCIAL REFERENCE MEASUREMENTS (FRMS) – EXECUTIVE SUMMARY

Jacob Fahy
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Paul Green
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Jonathan Mittaz
Bernardo Mota
Pieter De Vis
Emma Woolliams

MAY 2022

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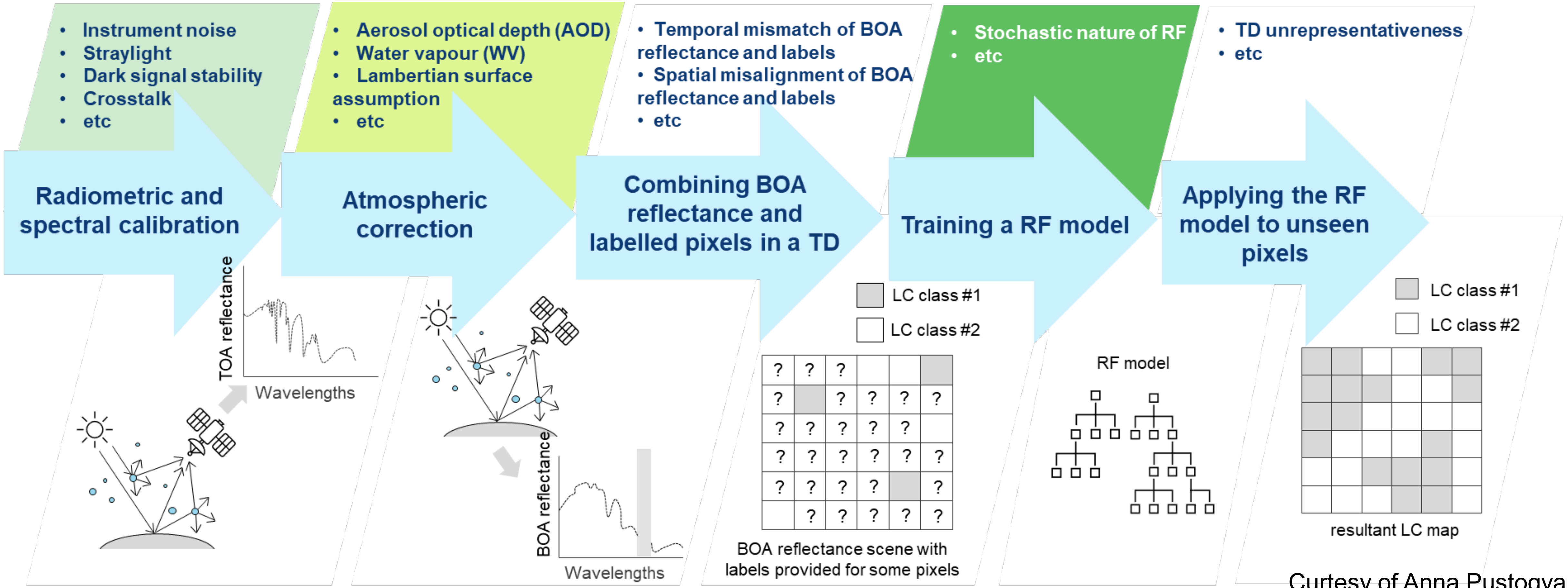
https://qa4eo.org/docs/1_Executive_Summary.pdf

UNCERTAINTY TRACEABILITY OF EO-BASED CLASSIFICAYION MAPS

(Step 2)

- The processing chain starts from satellite measurements and leads to a LC map
- It includes several steps, each step has multiple uncertainty sources



Curtesy of Anna Pustogvar

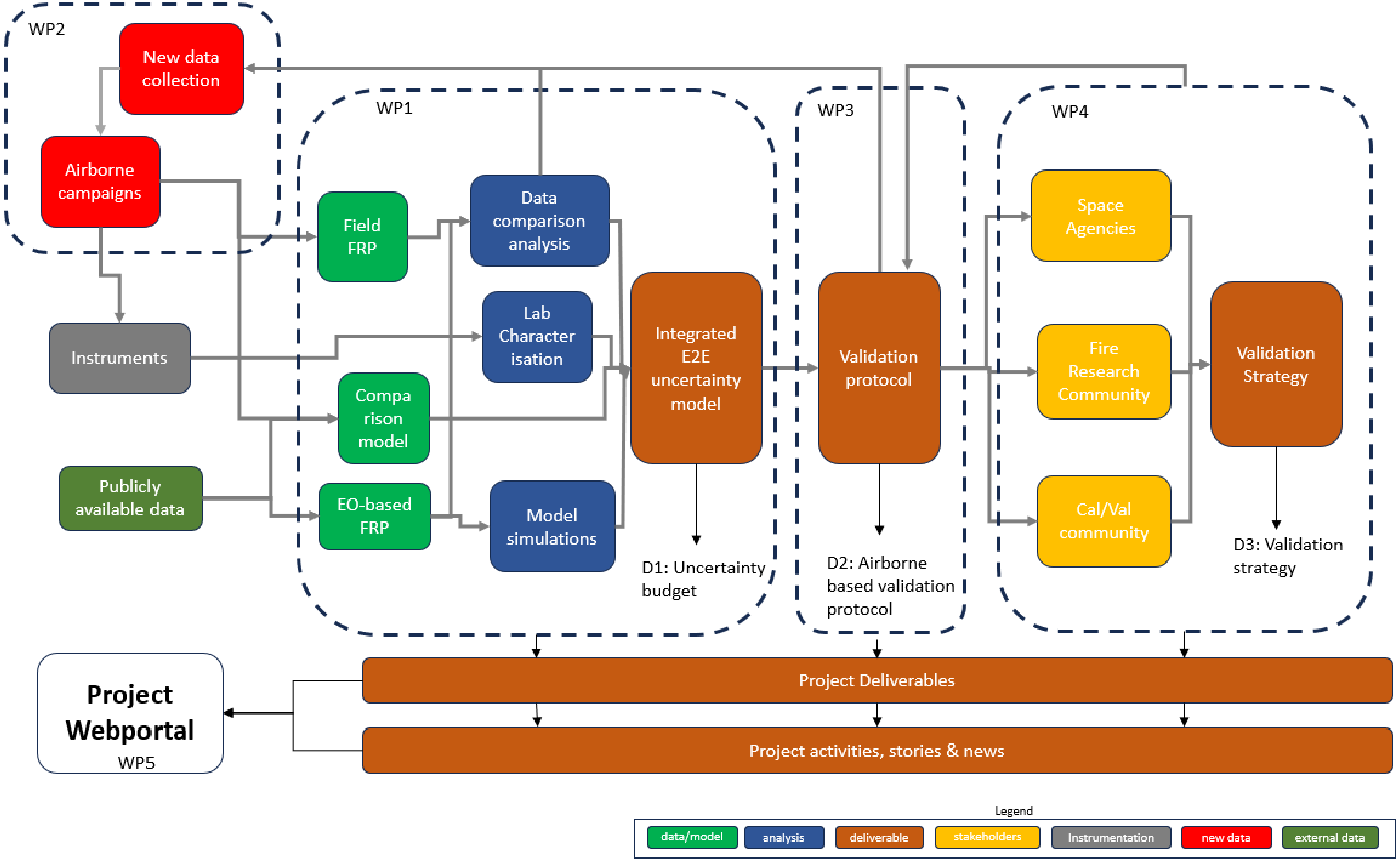
CHALLENGE: VALIDATION OF FRP PRODUCTS

FRM4fire project

Characterize sources of uncertainty in:
a) EO data retrievals
b) In situ measurements
c) Comparison model

Experiments to look at:
Environmental related sources
- Thermal diurnal variability
- Atmosphere
- Fire geometry and size

Sensor related sources
- Radiometry
- Viewing geometry
- Fire location
- geometric



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