NPL National Physical Laboratory

Quality Assurance of EO-based fire products

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(Climate Earth Observation Group)

5th GWIS and GOFC-GOLD Fire IT meeting, 21st-23rd June 2022, Ispra, Italy

Measurement/observation/product Quality characteristics?

consistency	model/algorithm/instrument/spatial/temporal
comparability	define the measurand, traceability to ref.
completeness	verification/validation, format
accuracy	uncertainty, confidence
transparency	documentation

Standards & Good practice guides

QMS & Quality indicators

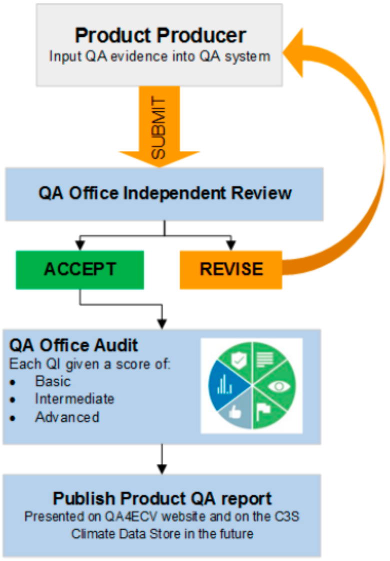
QA4EO Principle

"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**."

QA Framework Heritage

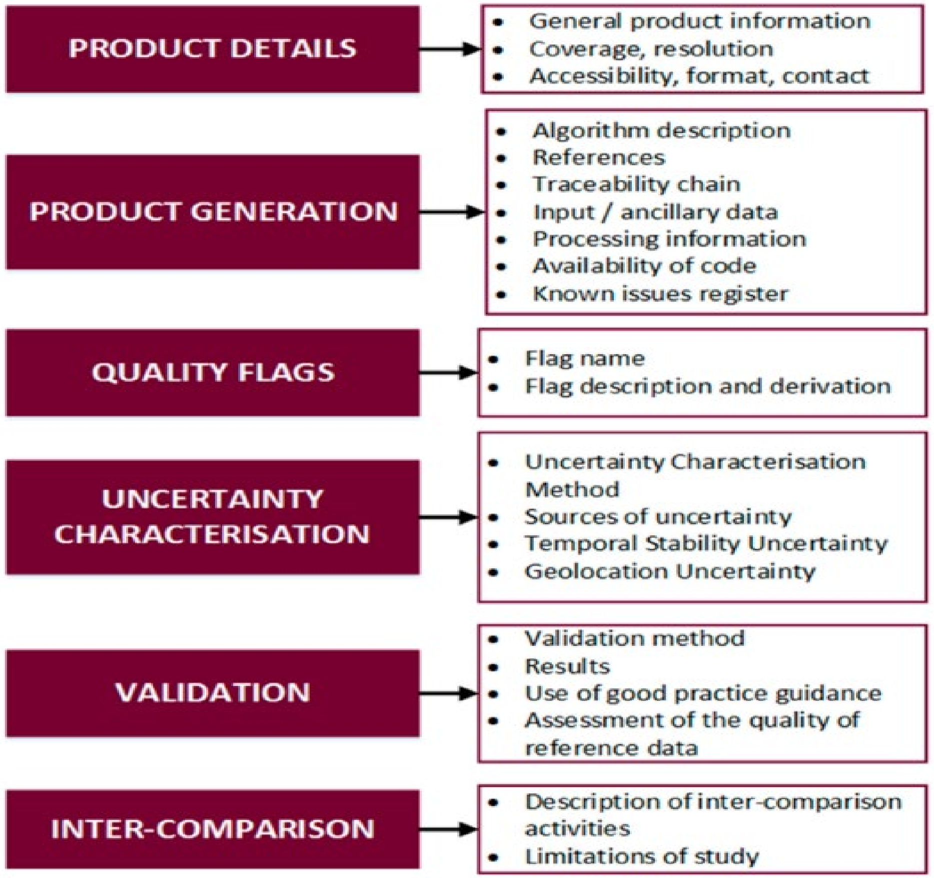
QA4ECV Project

J. Nightingale *et al.*, *Remote Sens.*, vol. 10, no. 8, Aug. 2018.



C3S EQC Project

J. Nightingale *et al.*, *Remote Sens.*, vol. 11, no. 8, Aug. 2019.

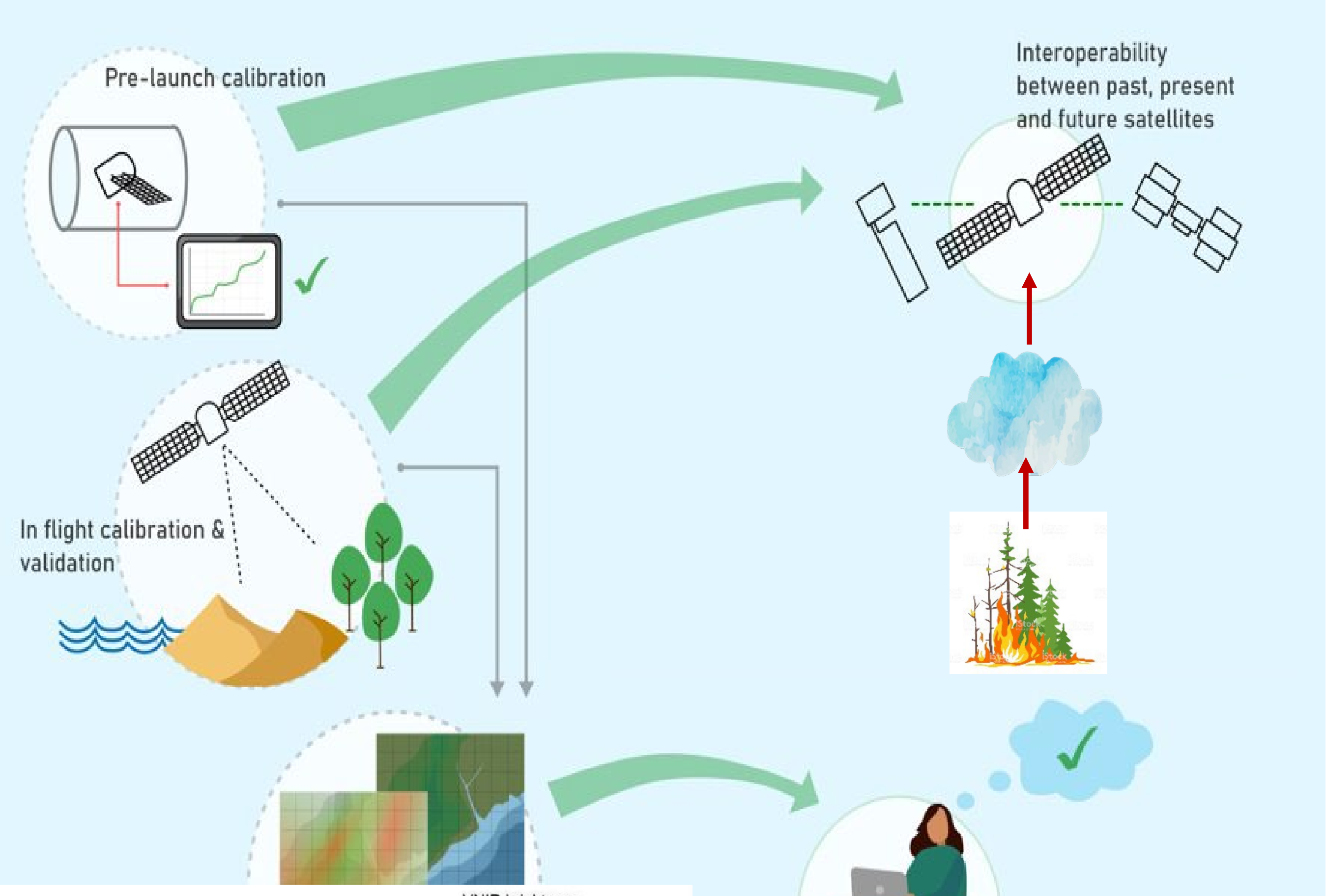


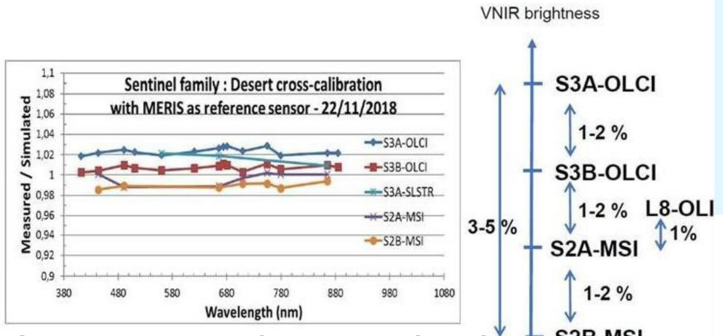
EDAP

Details	Generation	Quality flags	Uncertainty Characterisation	Validation	Inter-comparison
Product Information	Input data and uncertainties	Quality Flags	Uncertainty Characterisation Method	Reference data representativeness	Scale of inter-comparison activities
Product Description	Sensor Calibration		Uncertainty sources included	Reference data uncertainty inclusion	Inter-comparison method
Coverage and Resolution	Algorithm method		Uncertainty values provided	Validation method	Product uncertainties inclusion
Data gaps	Algorithm tuning to reference data		Temporal stability	Validation results	Discrepancy between products identified and, if possible, resolved
Data set limitations and target applications	Sensitivity analysis		Geolocation uncertainty		
Documentation	Internal Processes				
	Traceability				

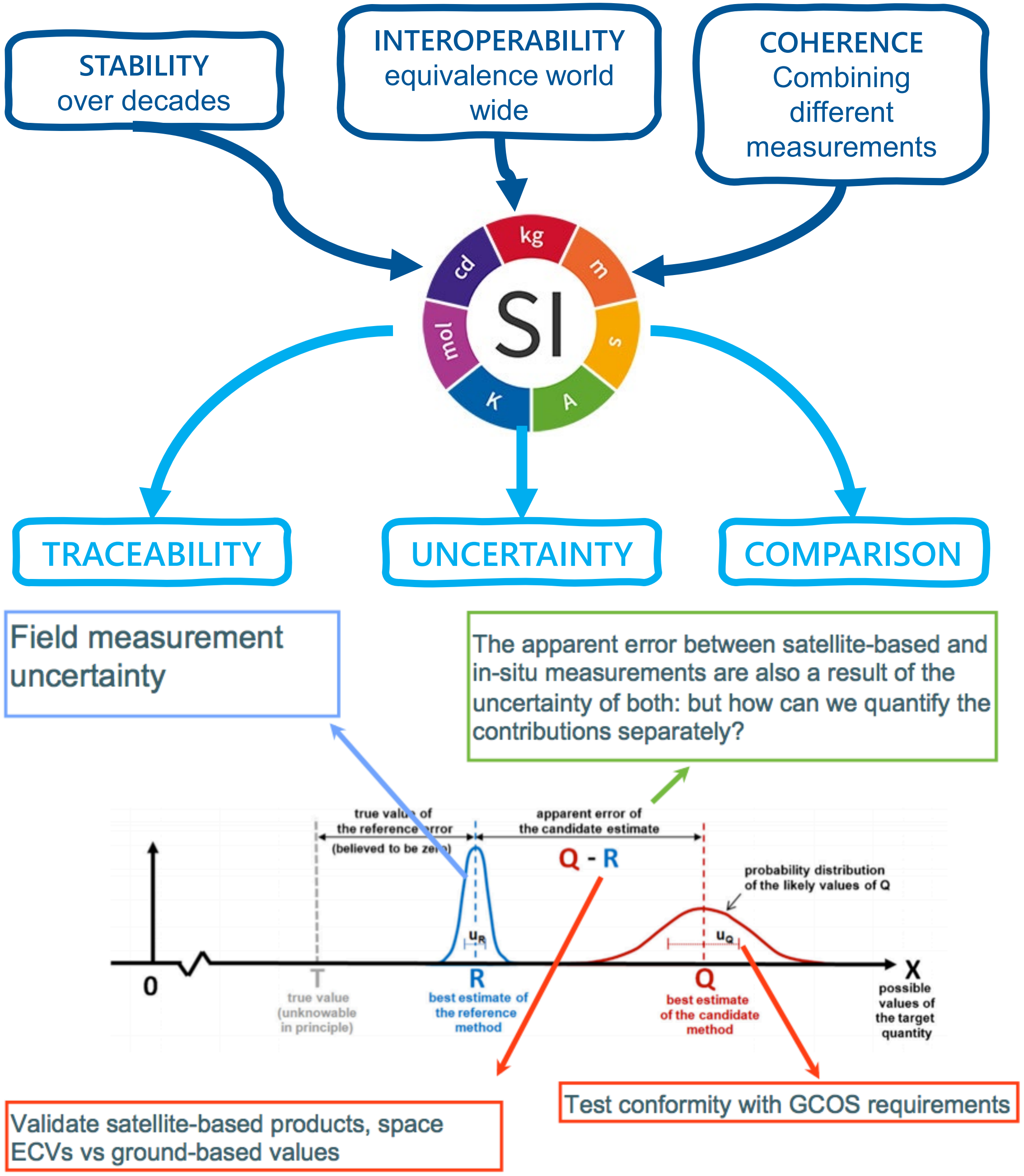
Key
Basic
Intermediate
Good
Excellent

Role of Metrology in EO





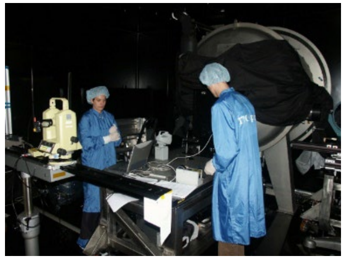
Graph courtesy of Meygret, CNES



Improvement / validation / down stream

Generate metrologically-rigorous data products

National Physical Laboratory



Pre-flight radiometric calibration

Raw satellite data (L0)

Calibrated radiances (L1)

Climate data record (L2)

Gridded CDR (L3)

Analysed / processed (L4+)

Climate index / information

In-flight calibration test sites and field work

Fiducial Reference Measurements (FRM)

Validation of ECV through field work/models/comparison

Fundamental Data Record (FDR)

Thematic Data Product (TDP)

Propagation of uncertainties to gridded EO data products

- Decision
- Insurance
- Liability

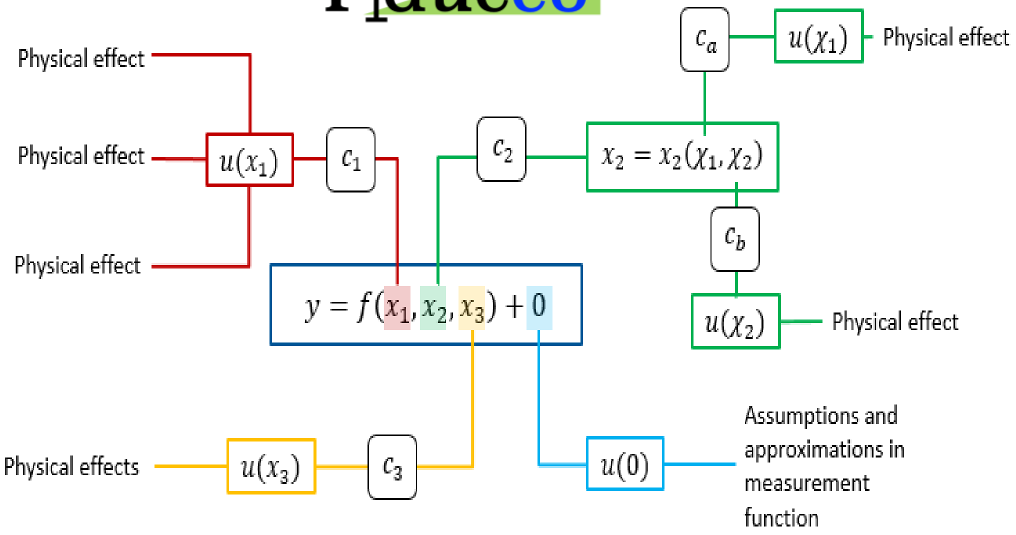
QA4EO

Resources at (www.qa4eo.org)

- Documents summarising the framework, and how it can be applied to your projects
- Introductions to metrology and uncertainty analysis
- Software tools for applying the QA4EO approach
- Case studies

Metrological concepts for EO

Earth observation metrology techniques developed within the H2020 FIDUCEO project (www.fiduceo.eu)

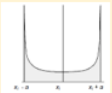


Uncertainty tree diagram

Effects tables

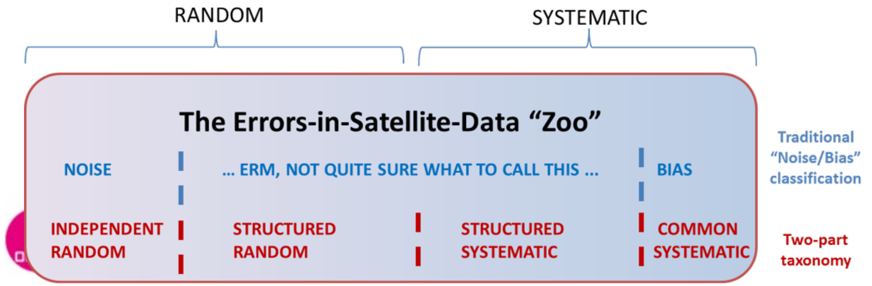
Table descriptor		Value/Parameter	Notes
Name of effect		A unique name to describe the effect	
Effect identifier		A unique number used to identify the position in the uncertainty tree or process chain	
Affected term in measurement function		Name and standard symbol of affected term	Usually an effect will only affect a single term, though there may be exceptions. The next higher-level identifier should be reported.
Maturity of analysis	Maturity of uncertainty estimate	0 – Effect identified, no quantification performed (no further information in cells below) 1 – Rough estimates only 2 – Some analysis performed to estimate values 3 – Rigorous analysis performed	This allows for the fact in the FDR/CDR we haven't thought everything through in detail and makes that very clear to users. If the maturity is low, we may still be able to estimate if it is negligible or minor, or if it's possibly significant (and therefore needs more work soon) Reference to the evidence for the maturity assessment, e.g. publication, report, weblink etc.
	Maturity of correlation scale estimate	0 – Not done 1 – Estimated 2 – Based on analysis, unsure about correlation shape 3 – Strong evidence	
	If maturity of estimate is 0 or 1, how significant do you expect this effect to be?	Negligible, Minor or Significant? For pixel level results and for long-term / large scale results	
Correlation type and form	From level xx	Select one of the types defined in §6.3 and Table 4	See §6.3 Define the level of analysis from, then to, e.g. level 0 to level1, and the relevant scales, e.g. per scan, orbit, calibration cycle etc. If there is a correlation with another effect, state its identifier.
	temporal scale type & form [time]		
	spatial scale type & form [geospatial coordinates]		
	Spectral type & form		
Correlation scale	From level xx	What is the correlation scale	See §6.4
	temporal scale [time]		
	spatial scale [geospatial coordinates]		
	Spectral scale		
Uncertainty	PDF shape	Functional form of estimated error distribution for the term, see Table 3	
	units	Units in which PDF shape is expressed (units of term, or can be as percentage etc)	See comment in §5.3.1 where uncertainty and sensitivity cannot be separated
	magnitude	Value(s) or parameterisation estimating width of PDF	
Sensitivity coefficient		Value, equation or parameterisation of sensitivity of measurand to term Can also flag "included in uncertainty" (by making this equal 1)	Where the uncertainty and sensitivity coefficient cannot be separated the sensitivity coefficient should be one and the uncertainty is in units of the measurand.
Validation		A description of any validation of the uncertainty at effect level.	The source of the uncertainty information and validation should also be identified.

uncertainty distribution

PDF shape	What is the standard uncertainty	Description
Gaussian 	$u = \sigma$	Be careful when using published literature, or a calibration certificate, to provide u. If an expanded uncertainty is quoted, then it's important to divide by k (often k=2 in certificates).
Digitised Gaussian	Unknown	The most appropriate standard uncertainty for a digitised Gaussian has not been fully evaluated. Please treat as a Gaussian, but keep this option open for the future
Rectangle 	$u = a/\sqrt{3}$ where a is the half width	Useful for when we know a quantity must be in a range $\pm a$, but it's equally likely to be anywhere in that range, e.g. digitisation
Triangular 	$u = a/\sqrt{6}$ where a is the half base	Useful for where we know there is a range a quantity is in but it's more likely to be in the middle of that range (e.g. when a quantity is the difference between two digitised values)
U-distribution 	$u = a/\sqrt{2}$ where a is the half base	Useful for where we know there is a range a quantity is in but it's more likely to be at the edges of that range (e.g. where there is a feedback loop that switches on and off and encourages drift to the two ends of a temperature range)
Other		If the PDF is not one of these, but a standard uncertainty can be provided, then this is also acceptable, a note should be added in documentation.

Error-covariance structure

$$S_{com}(y) = CS_i(x)C = \sum_i C_i U_i R_i U_i C_i$$



H2020 Copernicus Cal/Val Solution
CCVS

https://ccvs.eu

To define a holistic solution for all Copernicus Sentinel missions (op. or pl.) to overcome current limitations of Cal/Val activities.

- **Copernicus Cal/val Solution**
- **WP 5** Management
- **WP 1** Sentinel Cal/val Requirements
  - T1.1 Optical Missions
  - T1.2 Altimetry missions
  - T1.3 Radar and Micro-wave imaging missions
  - T1.4 Atmospheric composition missions
- **WP 2** Existing Cal/Val sources
  - T2.1 On-board calibration
  - T2.2 Vicarious methods on natural targets
  - T2.3 Inter-satellite comparisons
  - T2.4 Systematic ground-based measurements
  - T2.5 Field and aerial campaigns
  - T2.6 Cal/Val data distribution services
- **WP 3** Gap Analysis and Copernicus Cal/Val solution
  - T3.1 Instrumentation technologies
  - T3.2 Cal/val Methods
  - T3.3 Measurement networks and supersites
  - T3.4 Data distribution
  - T3.5 Performance analysis and Level 3 impact
  - T3.6 Copernicus Cal/val Solution
- **WP 4** Reference Scenario for Implementation
  - T4.1 Coordination with European agencies
  - T4.2 Coordination with measurement networks
  - T4.3 Coordination with Copernicus Services
  - T4.4 Coordination with international agencies
  - T4.5 Roadmap and sustainability analysis
  - T4.6 Reference Scenario for Implementation

An analysis phase: collection of the Cal/Val requirements for current and future Sentinel missions and survey of existing or planned sources of calibration and validation data

A synthesis phase: Recommendations and Solution for the Copernicus program and elaboration of reference scenario for the implementation of this solution.

ACRI ST · ARGANS France · University of Antwerp · NORCE · rayference · University of Tartu · Royal Netherlands Meteorological Institute, Ministry of Infrastructure and the Environment · NPL National Physical Laboratory · CLS · cnes · DLR · BIRA-IASB · ThalesAlenia Space · European Commission

Identified gaps in Cal/Val Methods

NPL National Physical Laboratory

Standards

- Definition of a **standard** for **classification confidence**, to allow for full product compatibility and comparability.
- Development of a community accepted standard for **geo-spatial uncertainties** for regrided/reprojected products.
- Define standard for thematic classification uncertainties.

Uncertainties

- Propagation of **per-pixel radiance uncertainty** (at L1/L2) to the final derived product (GUM).
- **Uncertainty propagation** **n**eeds to consider the **assumptions made by retrieval algorithms** and all **uncertainties** from input products (metrological approach)

intercomparisons

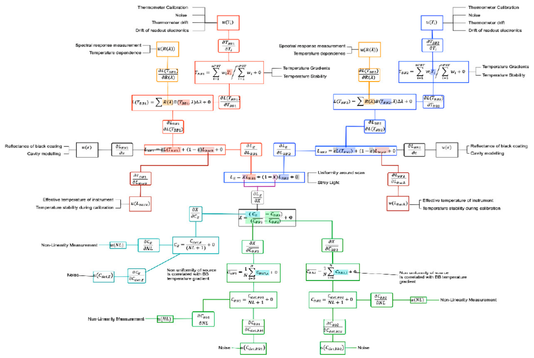
- For the inter-comparisons, comparisons need to be done in the context of their associated uncertainties and the need for the development of **robust statistical comparison methods** for **non-simultaneous products (FRP)**

Roadmap

- Develop a **framework** for the generation of **FRM fire** data by establishing protocols to ensure full traceability – a **CEOS approved good practice guide?**
- Define a **community-based roadmap** for FRP products to achieve CEOS Level-4 validation status.

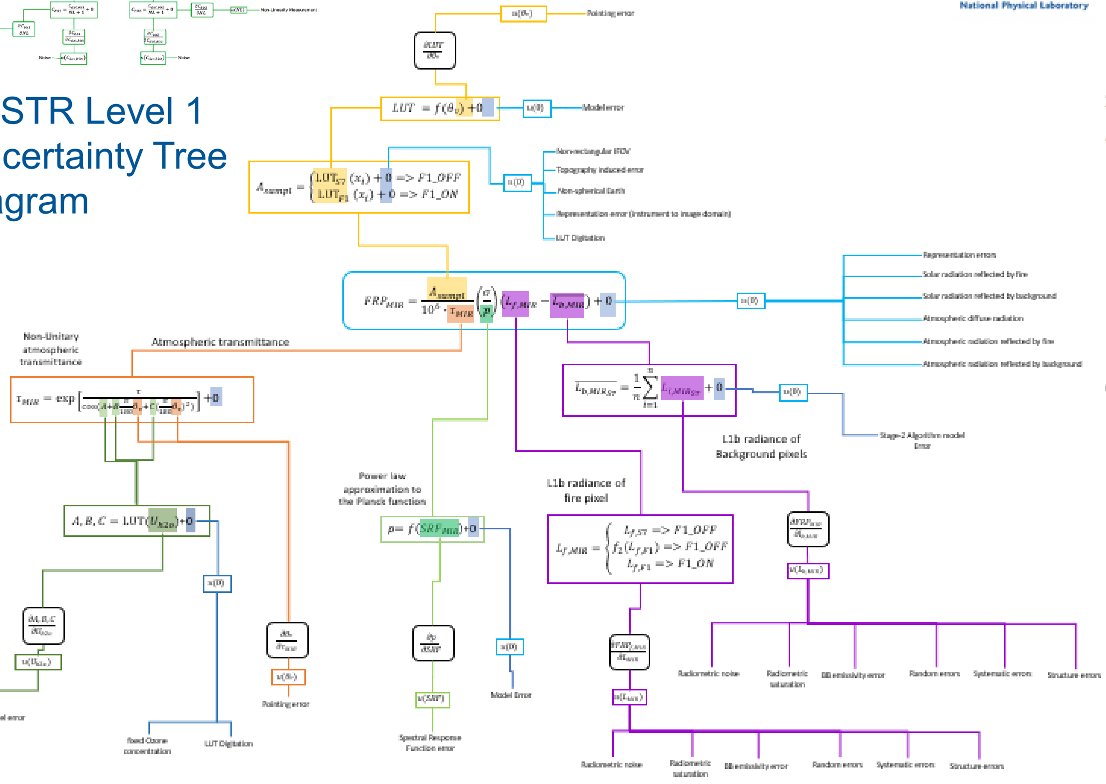
Uncertainty characterization of the Sentinel 3 L2 FRP product

by expanding the metrological concepts developed in the FIDUCEO project to L2 and L3 products

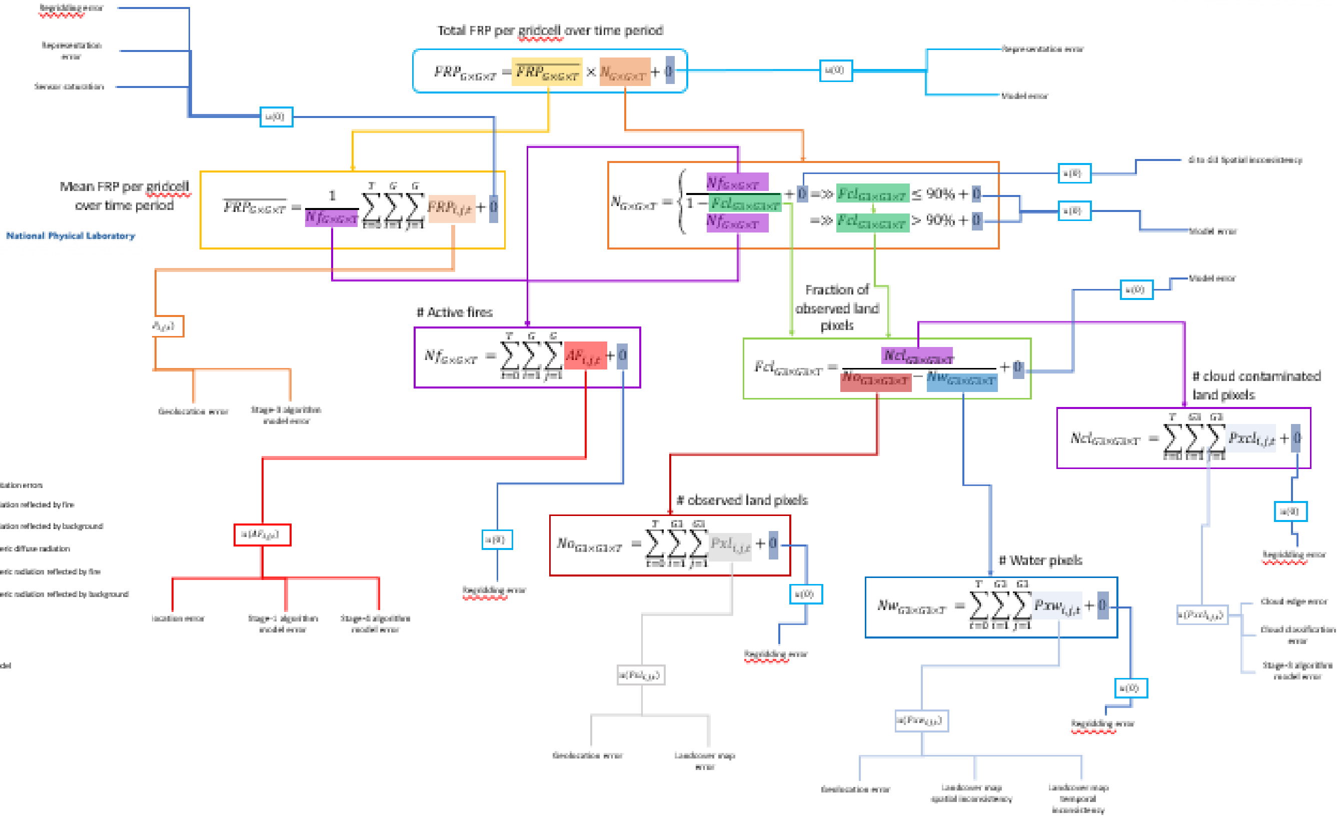


Courtesy of S. Hunt (NPL)

SLSTR Level 1 Uncertainty Tree diagram



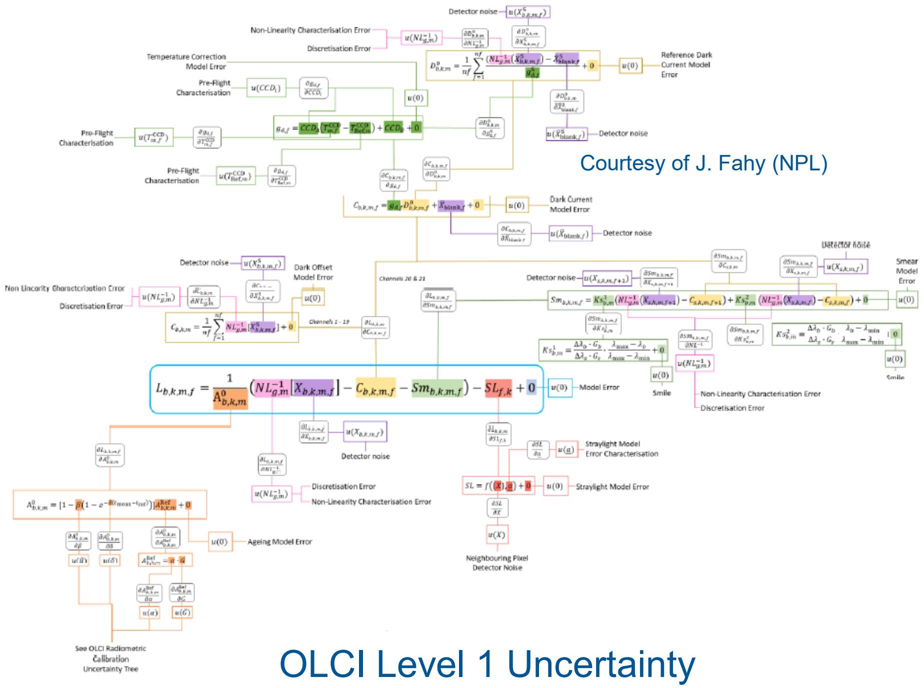
C3S FRP Level 2 Uncertainty Tree diagram



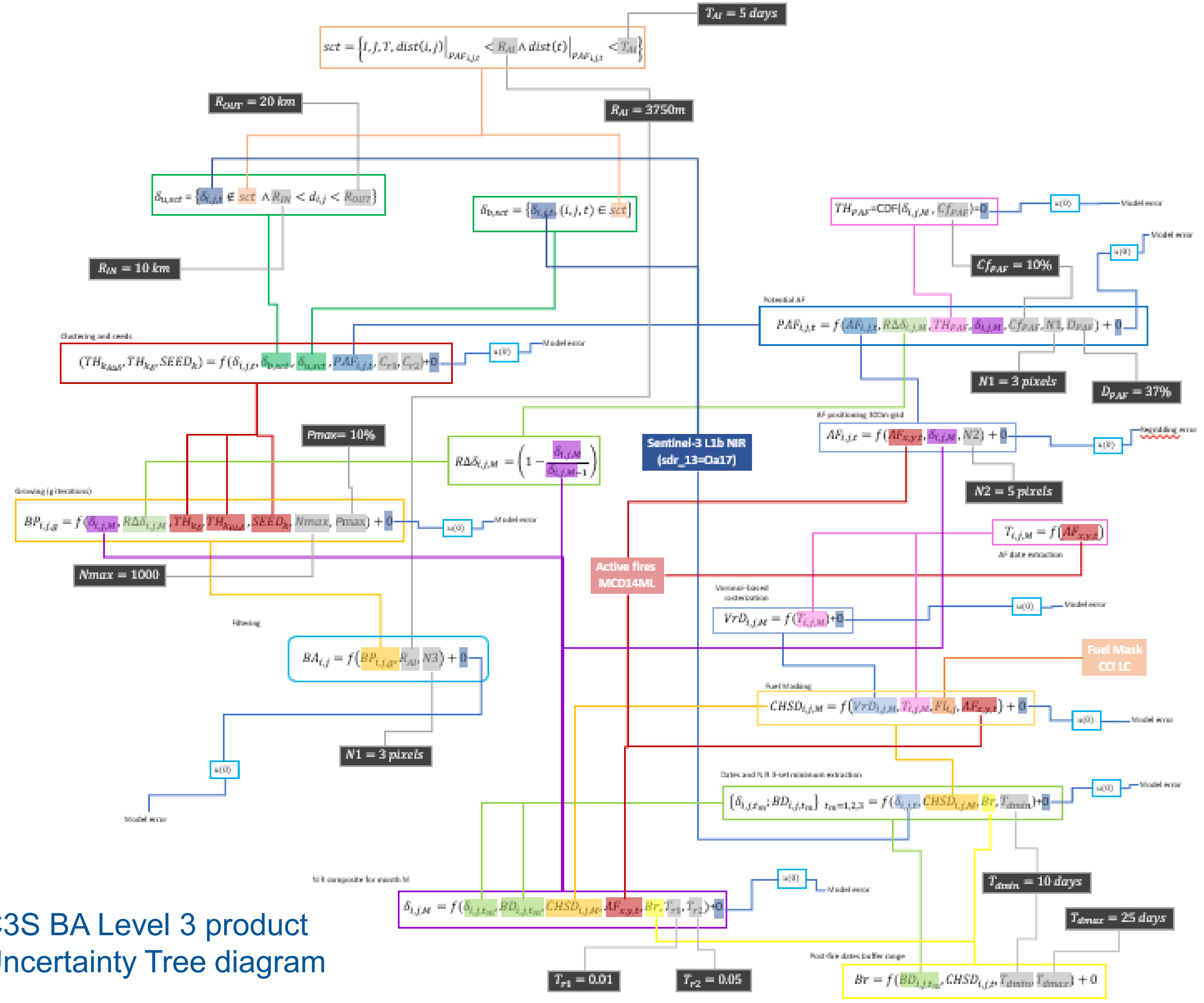
C3S FRP Level 3 Uncertainty Tree diagram

Uncertainty characterization of the Sentinel 3 L3 BA product

by expanding the metrological concepts developed in the FIDUCEO project to L2 and L3 products



OLCI Level 1 Uncertainty Tree diagram



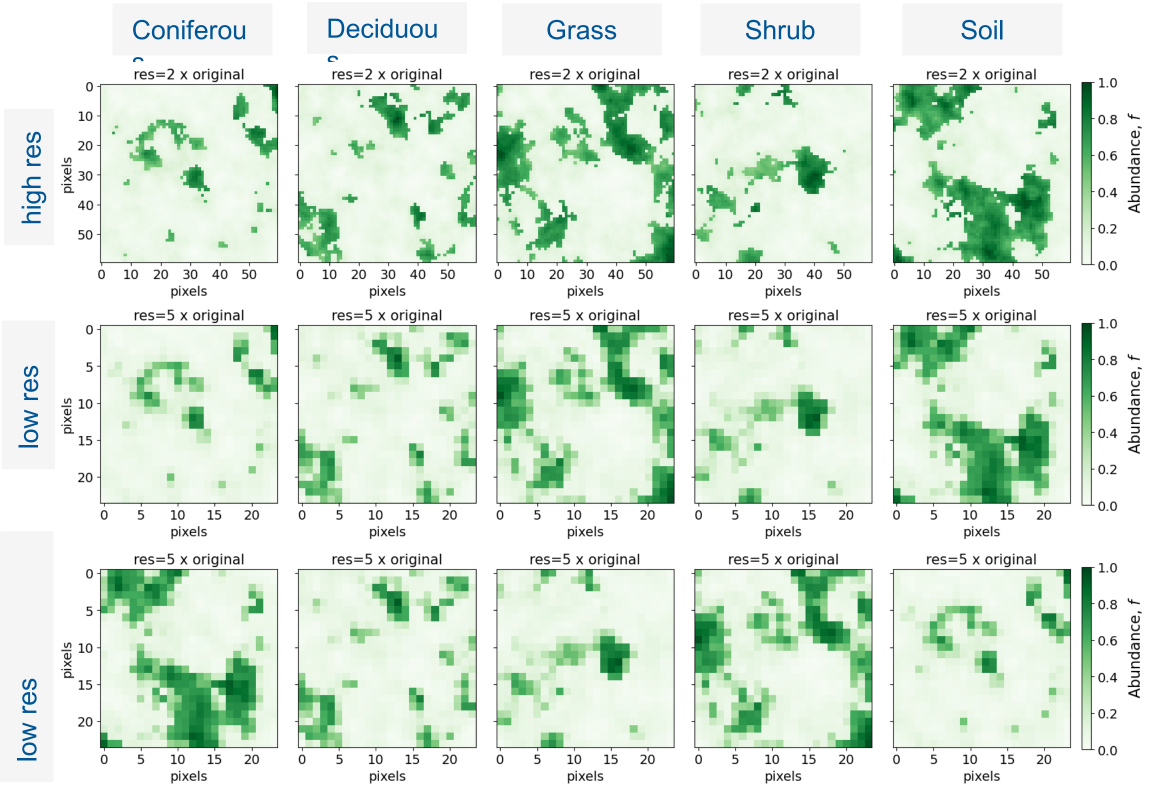
C3S BA Level 3 product Uncertainty Tree diagram

Framework to characterize the impact of uncertainty on LC abundance

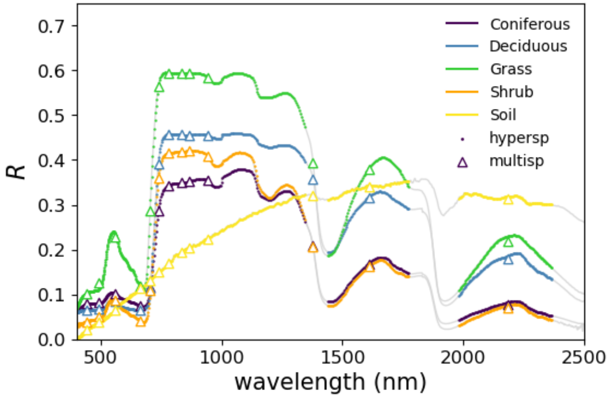
The scenarios are run for a range of random (x axis in the RMS plots in the Results section) and systematic (different line types in the RMS plots in the Results section) relative uncertainties for reflectance.

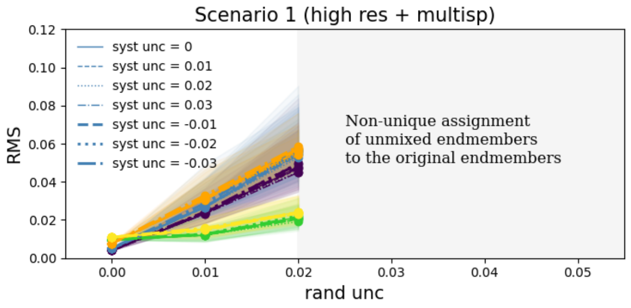
Other effects to consider:

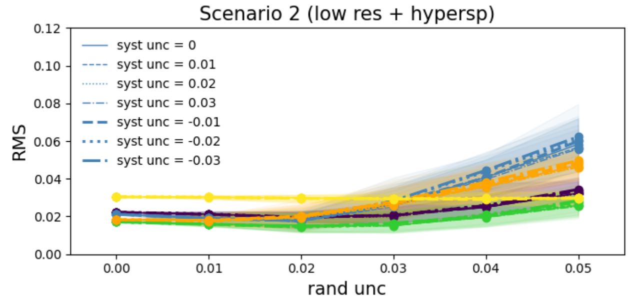
- Inter-class variability
- Geometric uncertainty
- PSF
- Atmosphere

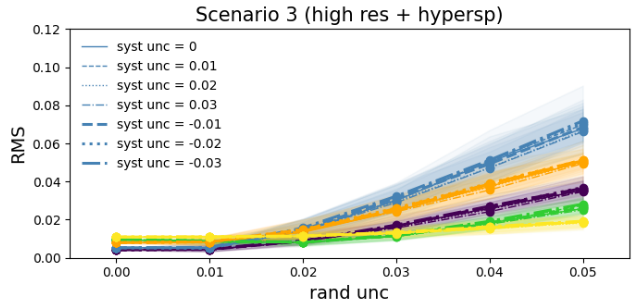


	Abund maps scenario	Spectral samplin g
Scenario 1	high res	multisp
Scenario 2	low res	hypersp
Scenario 3	high res	hypersp
Scenario 4	low res (reordered)	hypersp







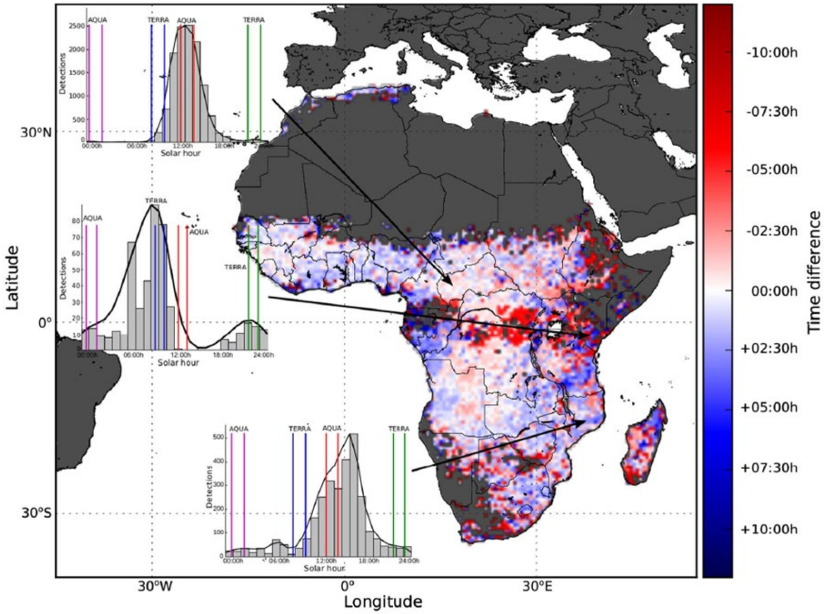


$$\mathrm{RMS} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(f_i^{\mathrm{unmixed}} - f_i^{\mathrm{original}}\right)^2}$$

RMS – root mean squared error of unmixing
f_i – abundance of an endmember in pixel i
N – total number of pixels in the scene

FRP inter-comparison Framework

(spatial context)

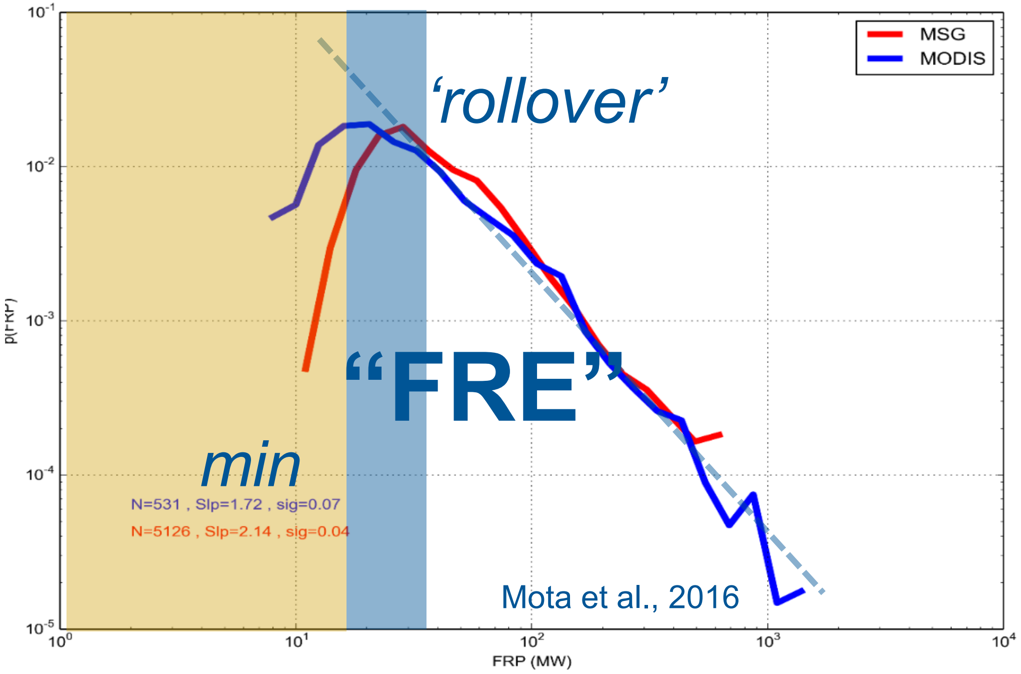


Mota and Wooster., 2018

In Polar mission products detections capture snapshots of the daily cycle -> lack of spatial consistency

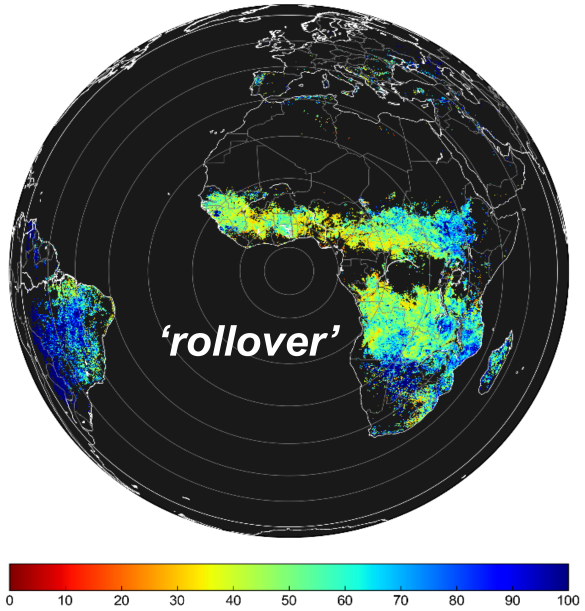
- Relation between the high-medium-low energy releases is the same, independent of #detections
- Area under the curve is Fire Radiative Energy (FRE) -> model for L4 FRP products

(temporal context)

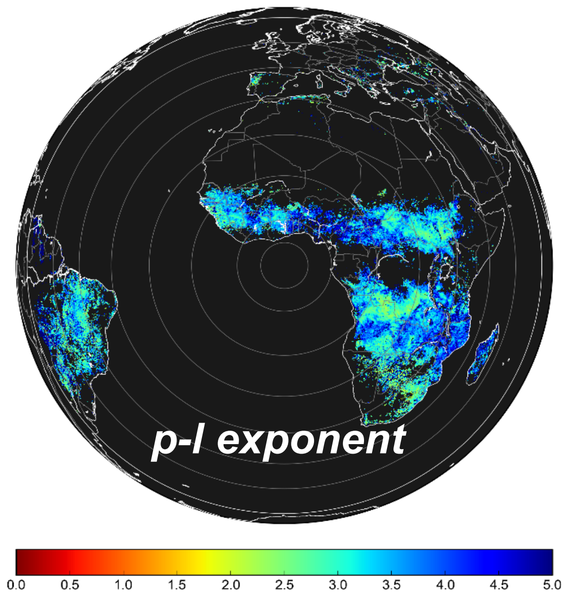


Probability density distribution function of MSG – SEVIRI FRP detection (red) and associated power law fit (black dash) and MCD14 (blue) for the period of (2009-2013) for a 3 by 3 MSG pixel size area over Central African Replublic.

Angular effects?

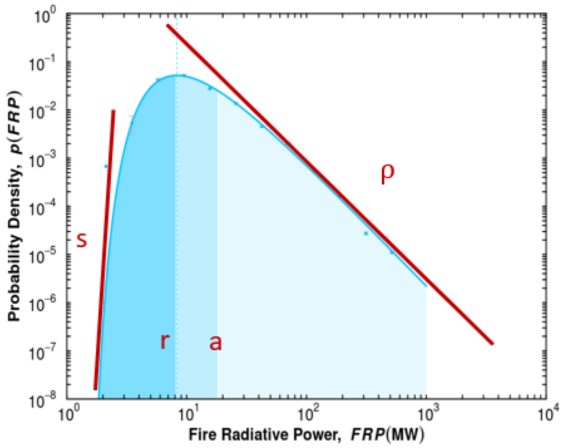


Landcover type dependent?



Ex: S3 L2 FRP evaluation

$$p(A_L \mid \rho, a, s) = \frac{1}{a\Gamma(\rho)}\left[\frac{a}{A_L - s}\right]^{\rho+1} \exp\left[-\frac{a}{A_L - s}\right]$$

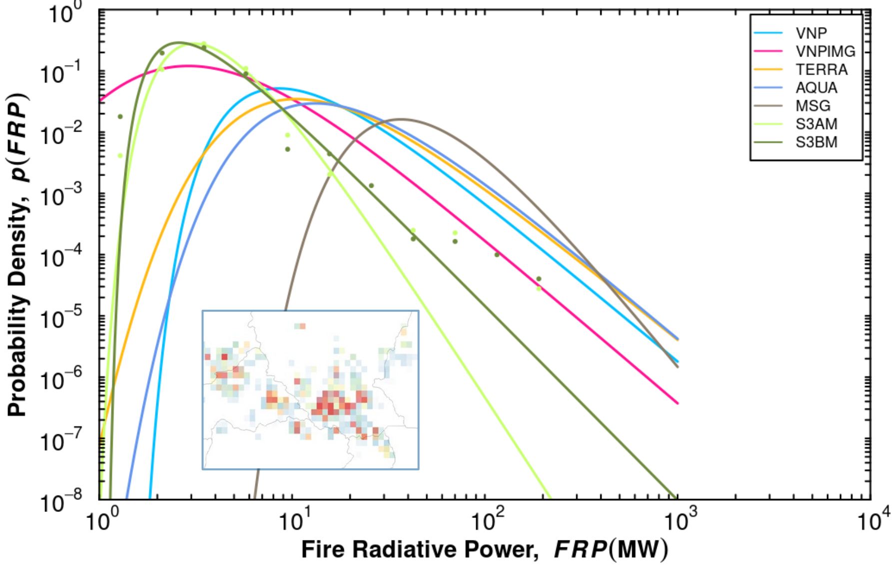


3 parameter inverse-gamma distribution fitting

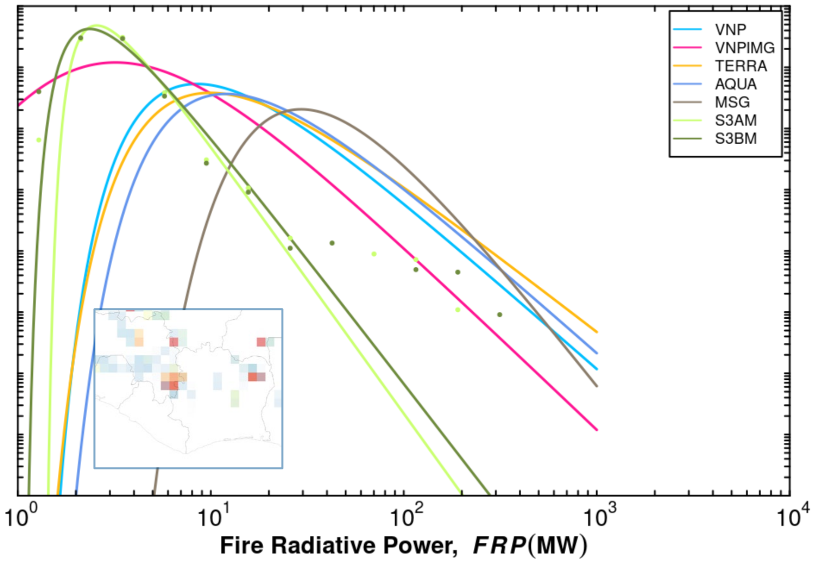
shape [ρ] – right tale power-law exponent
scale [a] – right tail distribution deviation from power-law
location [s] – left tail power law exponent
rollover [r] – maximum distribution frequency

PDF based on an Inverse gamma distribution

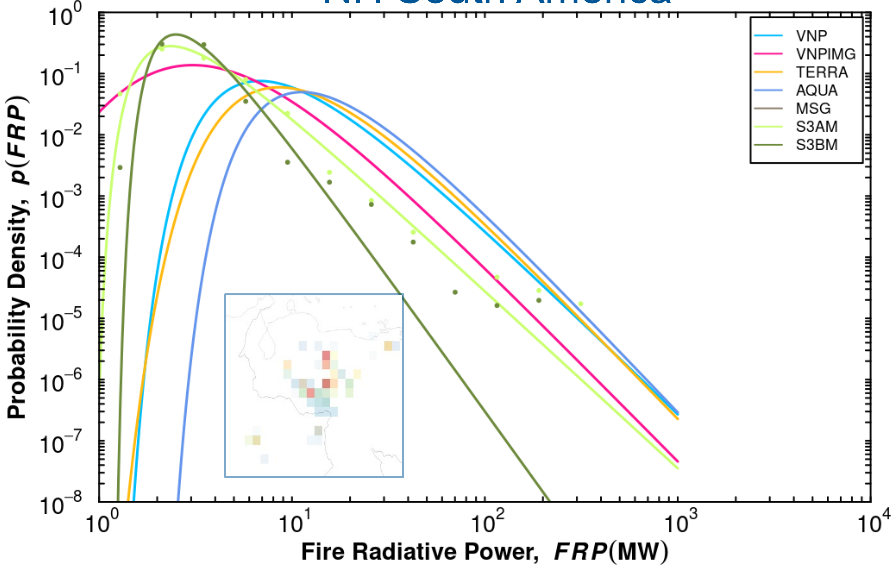
Northern Africa



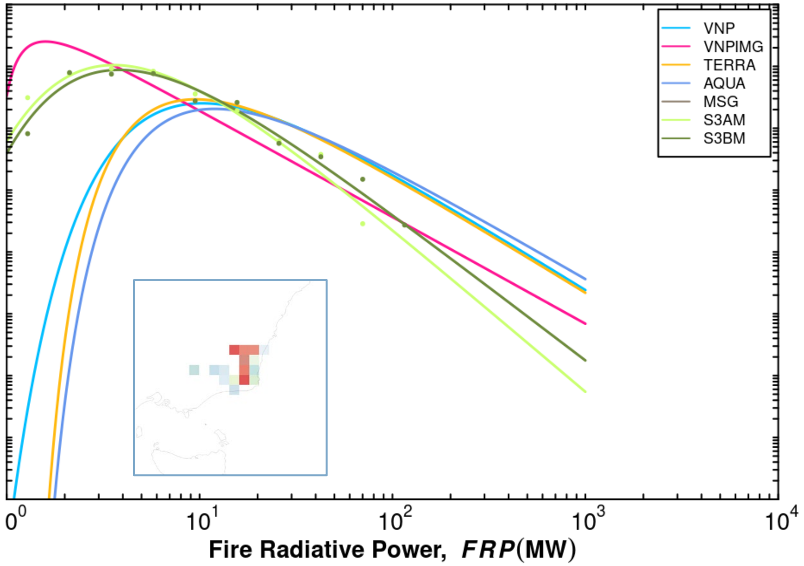
Western Africa



NH South America



Southeast Australia



(0.5 degree cells using only 3 month of outdated processing S3 FRP product)

The topics covered within the theme are listed in the table below.

Theme 1: Metrology in support of the physical science basis of climate change and climate observations	
Topic	**Items that could be covered within the topic include**
1. Atmospheric chemistry and physics	• Background and large-scale trend observations of stratospheric and tropospheric greenhouse gases, including ground and space-based total column observations and atmospheric composition products • Metrological characterisation of spectral parameters for chemical compounds (absorption cross-section, spectral line, solar spectral irradiance) • Surface and upper-air observations of temperature, pressure and humidity / water vapour, from reference networks and operational networks. • Reanalyses and the assimilation of atmospheric data and the utility of measurement and modelling uncertainties in reanalyses • Traceability of measurements in developing economies and for low-cost sensor networks. • Paleoclimatological studies of atmospheric composition and historical and pre-historical temperature records
2. Oceans and hydrology	• Ocean physics: measured in situ (e.g., temperature, surface and subsurface ocean currents) and remotely (e.g., sea surface temperature, sea level, colour, and sea state) • Ocean chemistry: pH, dissolved inorganic carbon, total alkalinity, partial pressure of carbon dioxide, salinity, nutrients, oxygen, and isotopes • Ocean and/or hydrological modelling and reanalysis • Hydrology: water quantity variables measured in inland waters (remote/space and in situ) such as flow, water elevations, channel bathymetry, flooded extent and other similar water quantity variables • Hydrology: water quality/chemistry variables in inland waters such as temperature, salinity, dissolved oxygen, pH, turbidity, nutrients, etc.
3. Earth Energy Balance	• SI-traceable Earth-observing satellites measuring outgoing radiation • Earth albedo estimates and variability • Cloud cover and cloud radiative forcing estimates • Energy uptake estimates and uncertainties • Global and regional ocean temperature, circulation, and sea-level measurements • Ice-mass measurements and loss rates • Heat-flux and evaporation measurements and models • Models, measurements, and requirements to improve Earth energy budget and imbalance estimates
4. Biosphere monitoring	• Forest biomass and properties (FAPAR, LAI, above ground biomass, soil carbon) • Fire monitoring and observation • Land surface temperature and albedo • Land cover classification • Ocean colour and phytoplankton
5. Cryosphere Monitoring	• In situ and satellite of the marine cryosphere (area, thickness, snow cover, motion, temperature, albedo, age) • In situ and satellite observations of polar ice sheets and glaciers, high mountains and the third pole (extent, thickness, mass balance, motion, temperature, albedo) • In situ and satellite observations of snow cover (area, thickness, precipitation, albedo, duration) • Observations of permafrost (area, thickness, temperature, active layer depth)

BIPM-

National Physical Laboratory

METROLO
CLIMATE
26–30 SEPTEMBER 202

Participation

The workshop is op ... easurement
science willing to co

Workshop Ai

The aims of the wo

- Present progre ... supporting
the physical sci
- Identify stakeh ... greenhouse
gas emissions

The output of the w

This workshop follo ... ing and the
second in 2015 on

THANK YOU

The Quality Assurance framework for Earth Observation (QA4EO) was established by the Committee on Earth Observation Satellites (CEOS) to define processes and procedures to achieve the QA4EO principle.

generate metrologically-rigorous data products applicable to:

MEASURAND — Define the measurand and measurement model

TRACEABILITY — Establish the traceability with a diagram

UNCERTAINTY — Evaluate each source of uncertainty and fill out an effects table

CALCULATE — Calculate data product and uncertainties

STORE — Store relevant information for present and future users

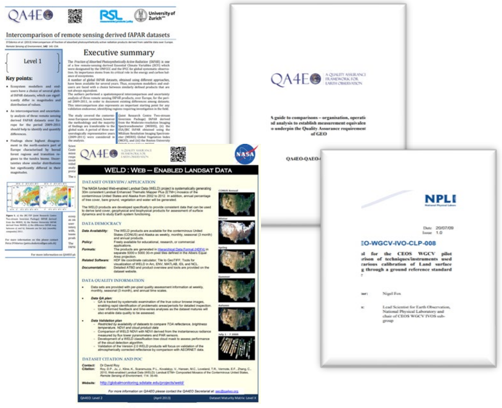
"**Fiducial Reference Measurements (FRMs)** are a suite of independent, fully characterised, and traceable sub-orbital measurements that follow the guidelines outlined by the GEO/CEOS Quality Assurance framework for Earth Observation (QA4EO) and have value for space-based observations."

"**Fundamental Data Records (FDRs)** is a record, of sufficient duration for its application, of uncertainty-quantified sensor observations calibrated to physical units and located in time and space, together with all ancillary and lower-level instrument data used to calibrate and locate the observations and to estimate uncertainty."

"**Thematic Data Products (TDPs)** is a record, of sufficient duration for its application, of uncertainty-quantified retrieved values of a geophysical variable, along with all ancillary data used in retrieval and uncertainty estimation."

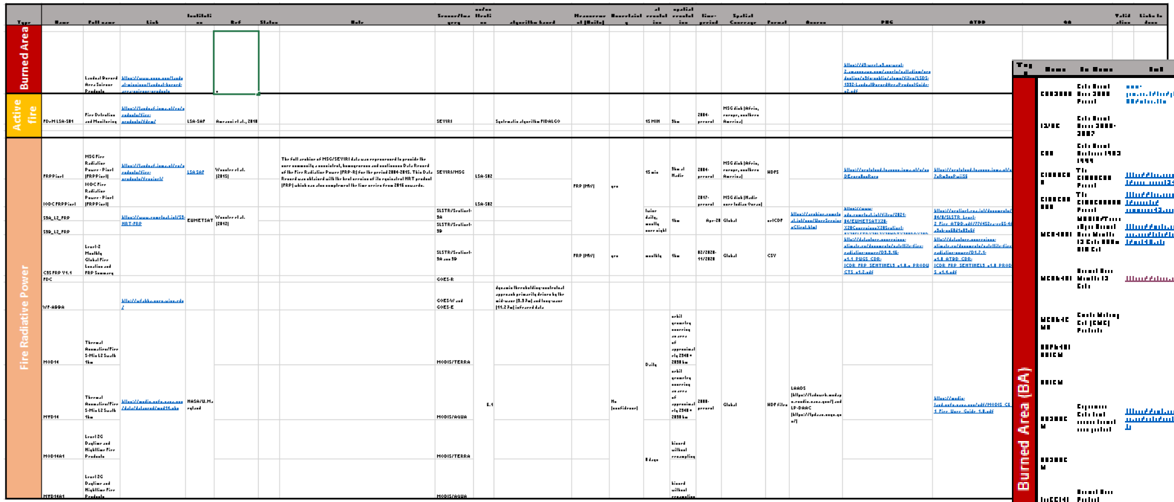
Resources at (www.qa4eo.org)

- Documents summarising the framework, and how it can be applied to your projects
- Introductions to metrology and uncertainty analysis
- Software tools for applying the QA4EO approach
- Case studies

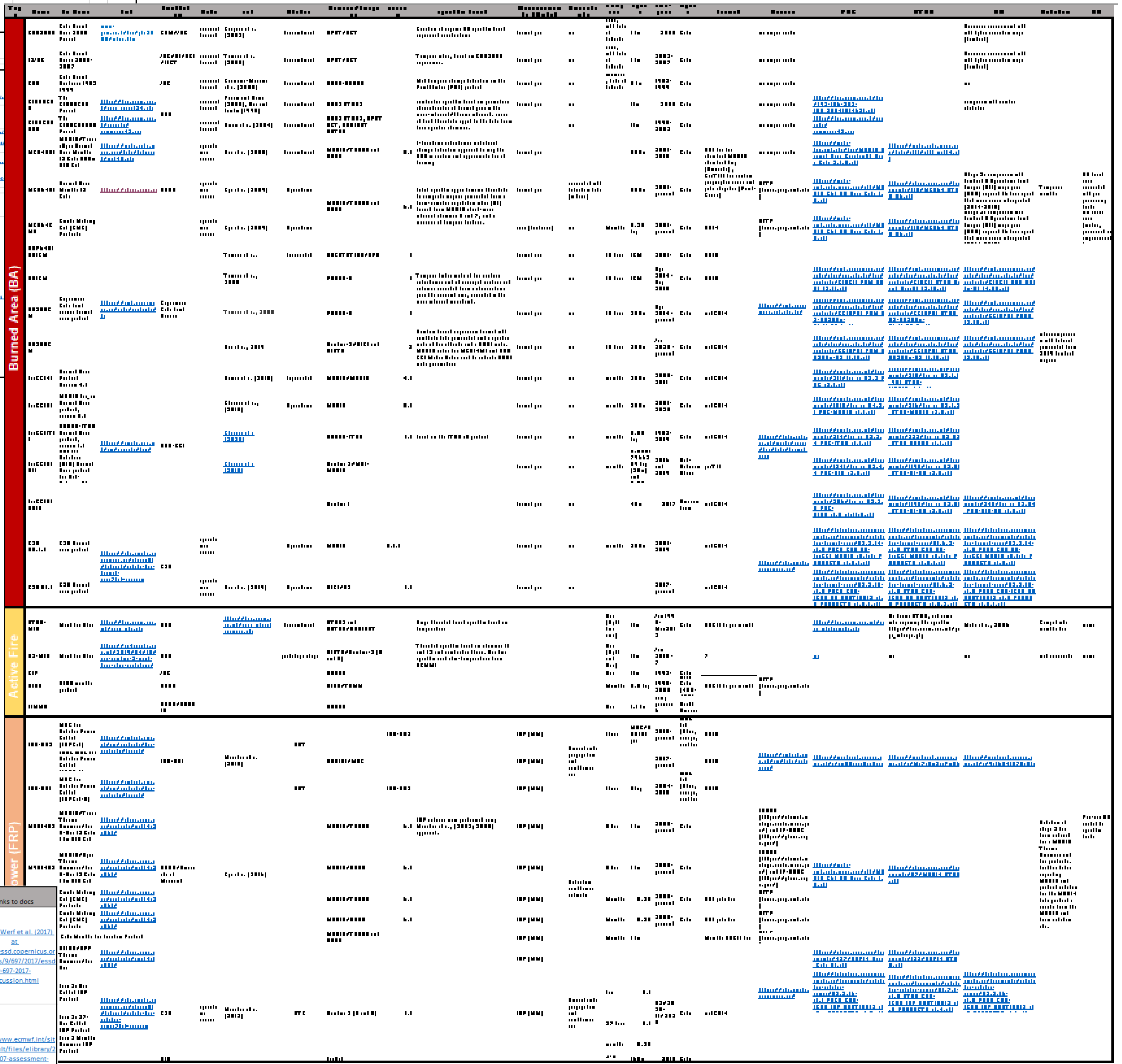


CoMet

L2



L3



Identified 52 fire products (BA, AF, FRP), global or hemispherical cover), analysis focused only the operational (NRT, NCT)

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

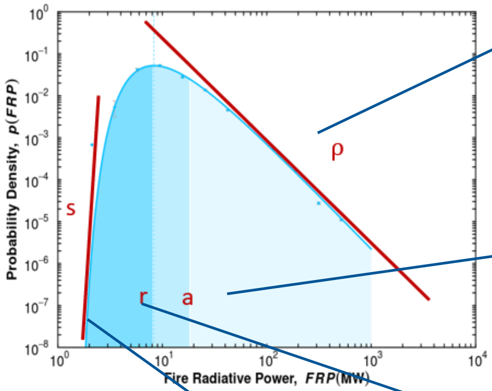
L4

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

FRP inter-comparison Framework

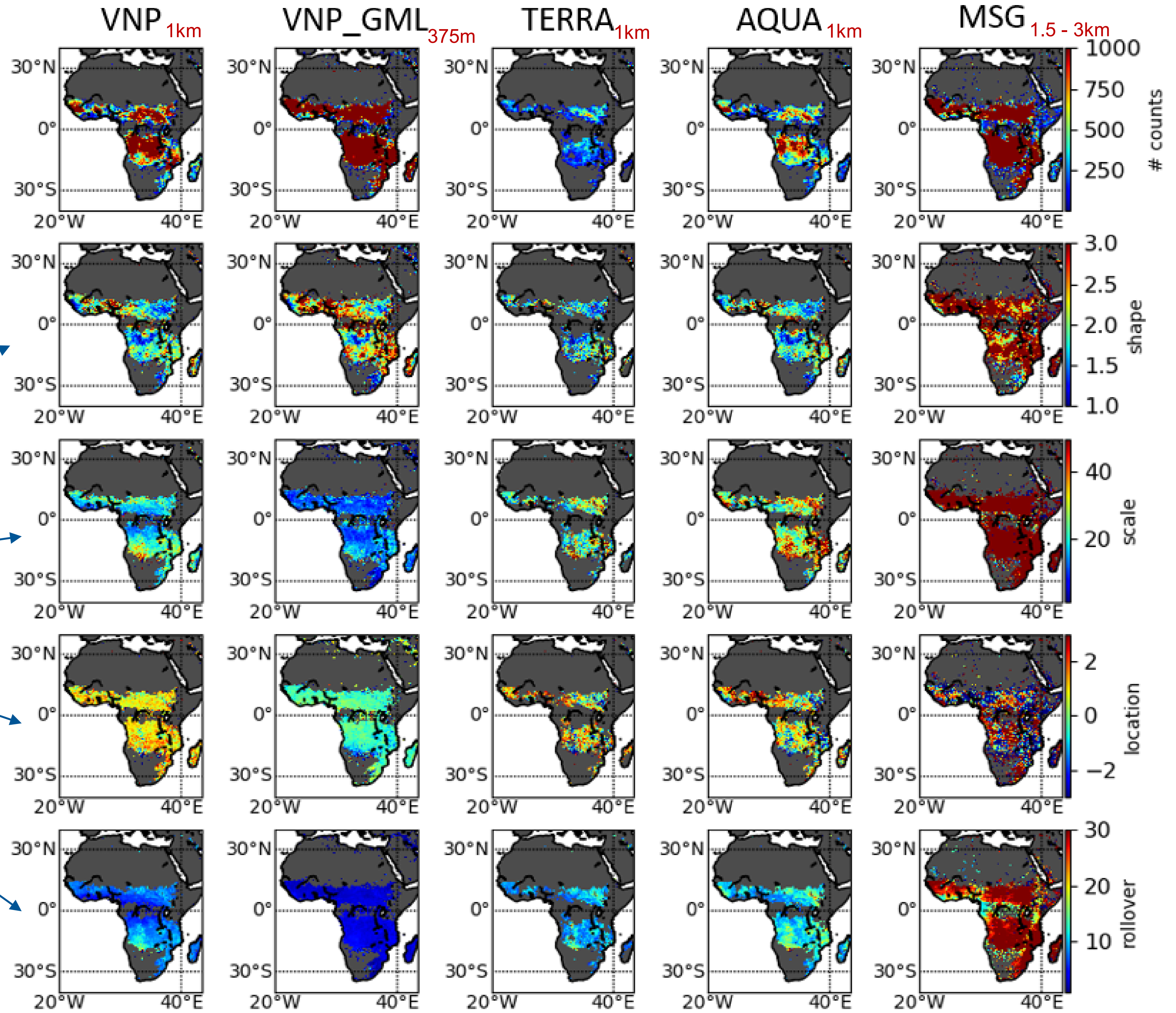
(2012-2019 climatology)

$$p(A_L \mid \rho, a, s) = \frac{1}{a\Gamma(\rho)}\left[\frac{a}{A_L - s}\right]^{\rho+1} \exp\left[-\frac{a}{A_L - s}\right]$$



3 parameter inverse-gamma distribution fitting

shape [ρ] – right tale power-law exponent
scale [a] – right tail distribution deviation from power-law
location [s] – left tail power law exponent
rollover [r] – maximum distribution frequency



PDF based on Single power-law Double Pareto