CEOS LPV: Fire Disturbance

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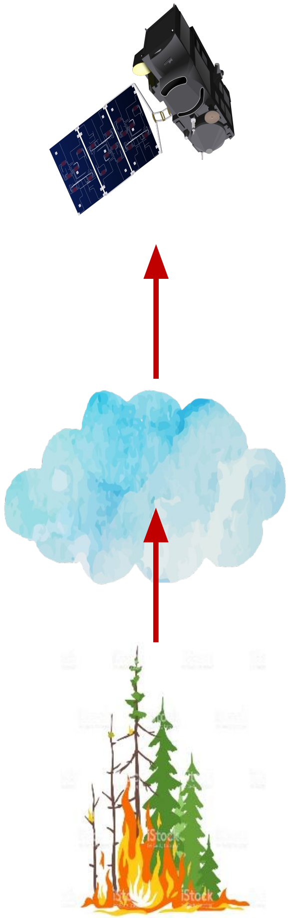
CEOS LPV Plenary: 26 June 2025

Fire Disturbance - Outline

- Review of fire disturbance products, GCOS requirements and validation stages and general QA issues
- Burned area validation
  - Status of the BA protocol (setbacks, gap and time frames)
  - Validation challenges (very high resolution in the context of developing a FRM)
- Active Fire and FRP validation
  - Current product developments
  - Validation challenges and progress (talk about FRM4Fire)
  - CEOS LPV AF & FRP validation protocol (status, timeframe)

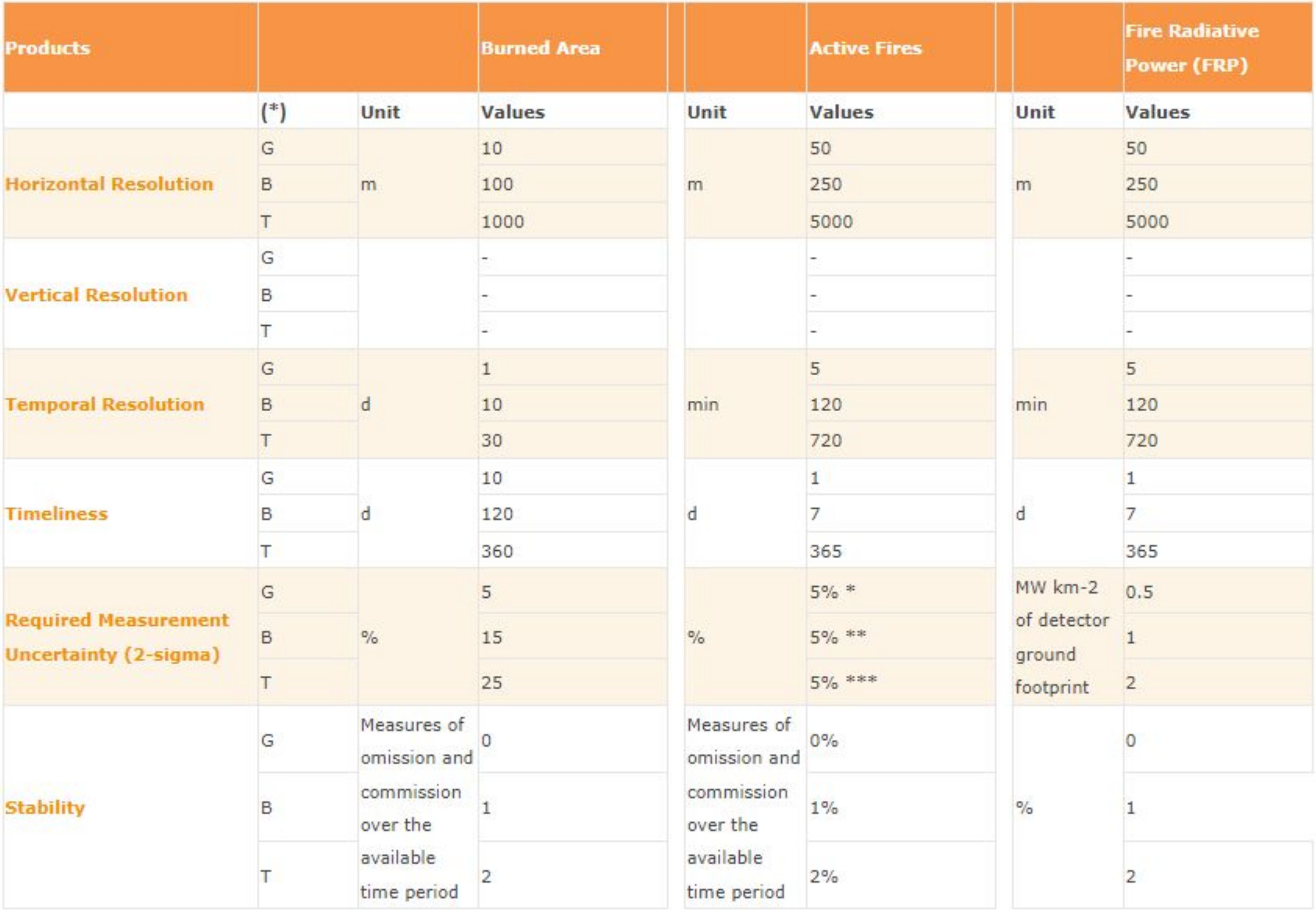
Open discussion on some questions:

  - Use of AI
  - FRP validation-stage limitations



Fire Disturbance

Active fire detection, FRP, and burned area comprise three separate GCOS Essential Climate Variables (ECVs).



Products			Burned Area		Active Fires		Fire Radiative Power (FRP)
	(*)	Unit	Values	Unit	Values	Unit	Values
Horizontal Resolution	G	m	10	m	50	m	50
	B		100		250		250
	T		1000		5000		5000
Vertical Resolution	G		-		-		-
	B		-		-		-
	T		-		-		-
Temporal Resolution	G	d	1	min	5	min	5
	B		10		120		120
	T		30		720		720
Timeliness	G	d	10	d	1	d	1
	B		120		7		7
	T		360		365		365
Required Measurement Uncertainty (2-sigma)	G	%	5	%	5% *	MW km-2 of detector ground footprint	0.5
	B		15		5% **		1
	T		25		5% ***		2
Stability	G	Measures of omission and commission over the available time period	0	Measures of omission and commission over the available time period	0%	%	0
	B		1		1%		1
	T		2		2%		2

To come:

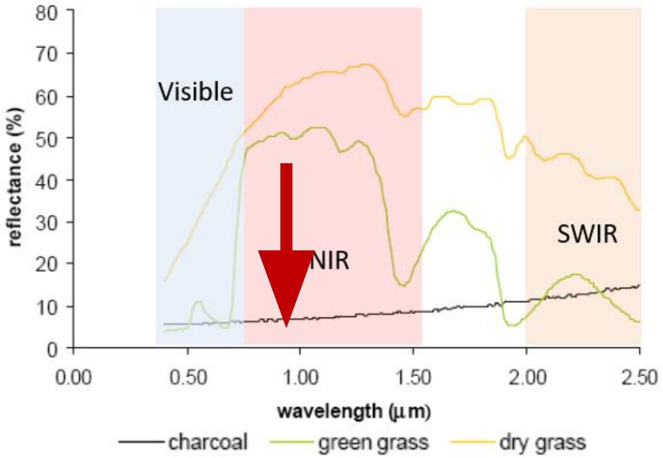
Combustion Completeness (CC)

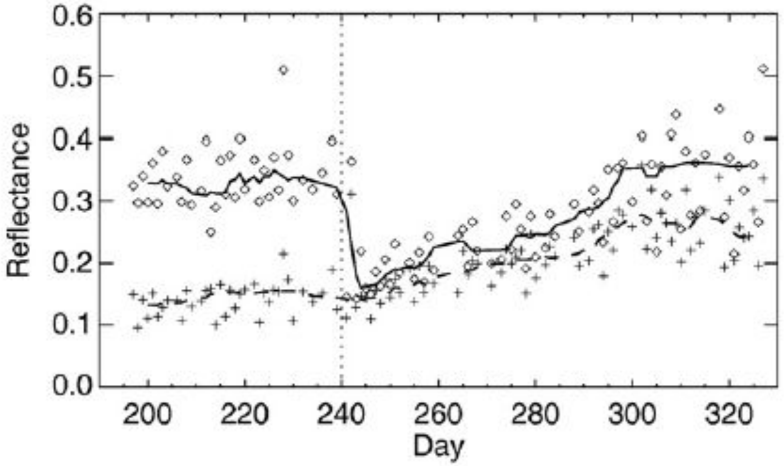
https://gcos.wmo.int/en/essential-climate-variables/fire

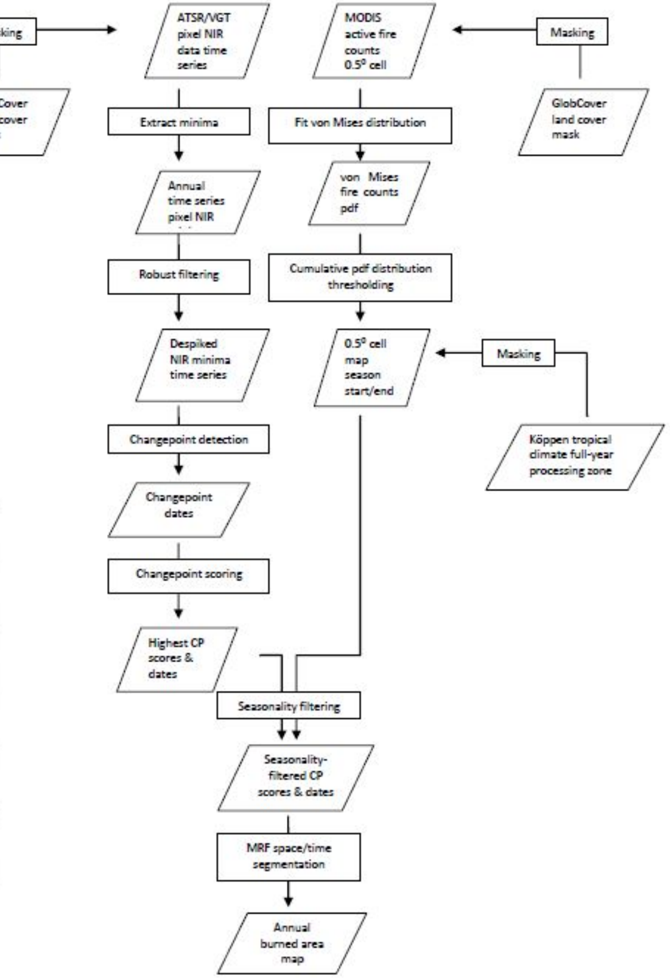
Fire Disturbance - Burned area

Burned Area [km^2] - product characteristics

- *Retrospective mapping of cumulative burned area extent*
- Typically includes date of burn
- Mostly relies on the NIR in spectral indices
- Can incorporate AF information (e.g., seeds)
- No L2 products
- No physically-based measuring function



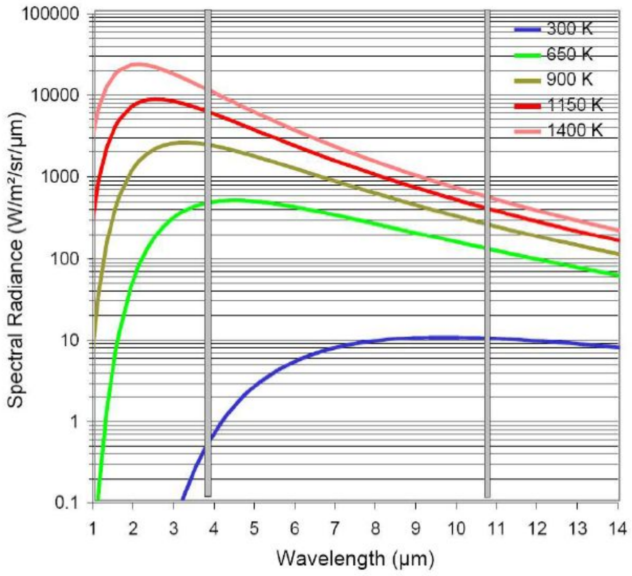




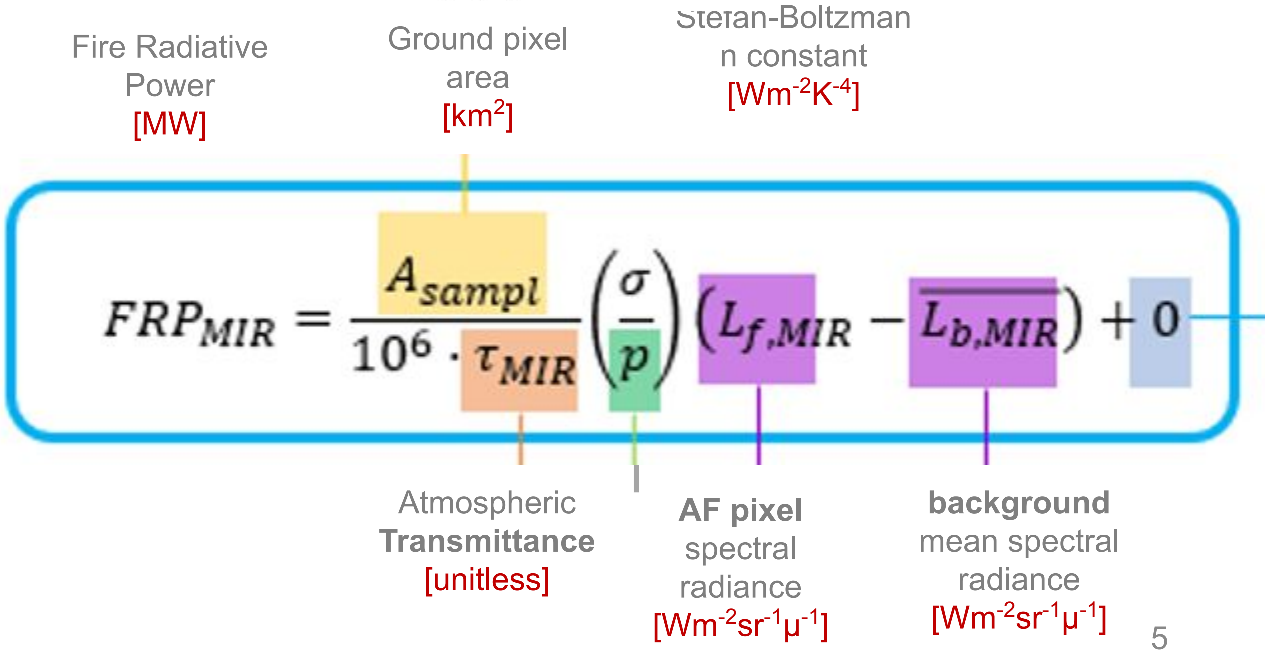
Fire Disturbance - Fire Radiative Power

Fire Radiative Power [MW]

- *Based on Active Fire products*
- Measure the amount of energy that is being released by an ongoing fire.
- Mostly relies on the MWIR band difference between the fire pixel and its background (physical based function)
- Uncertainty characterization in its initial stages (some effects considered and being revised –FRM4Fire)
- Challenge to produce L3/L4 products spatially and temporally consistent
- No validation standard exist.



MWIR (3-5 µm): spectral window where fires radiant intensity is greatest in this even for very small fires compared to the sensor spatial resolution (10^{-3}



Fire Radiative Power [MW]

Ground pixel area [km^2]

Stefan-Boltzman n constant [$Wm^{-2}K^{-4}$]

$$FRP_{MIR} = \frac{A_{sampl}}{10^6 \cdot \tau_{MIR}} \left(\frac{\sigma}{p}\right) \left(L_{f,MIR} - \overline{L_{b,MIR}}\right) + 0$$

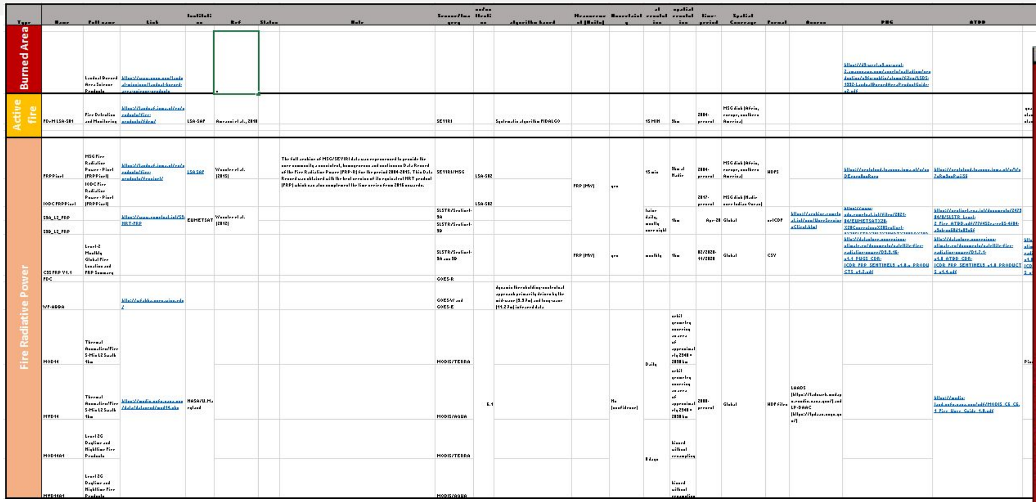
Atmospheric **Transmittance** [unitless]

AF pixel spectral radiance [$Wm^{-2}sr^{-1}\mu^{-1}$]

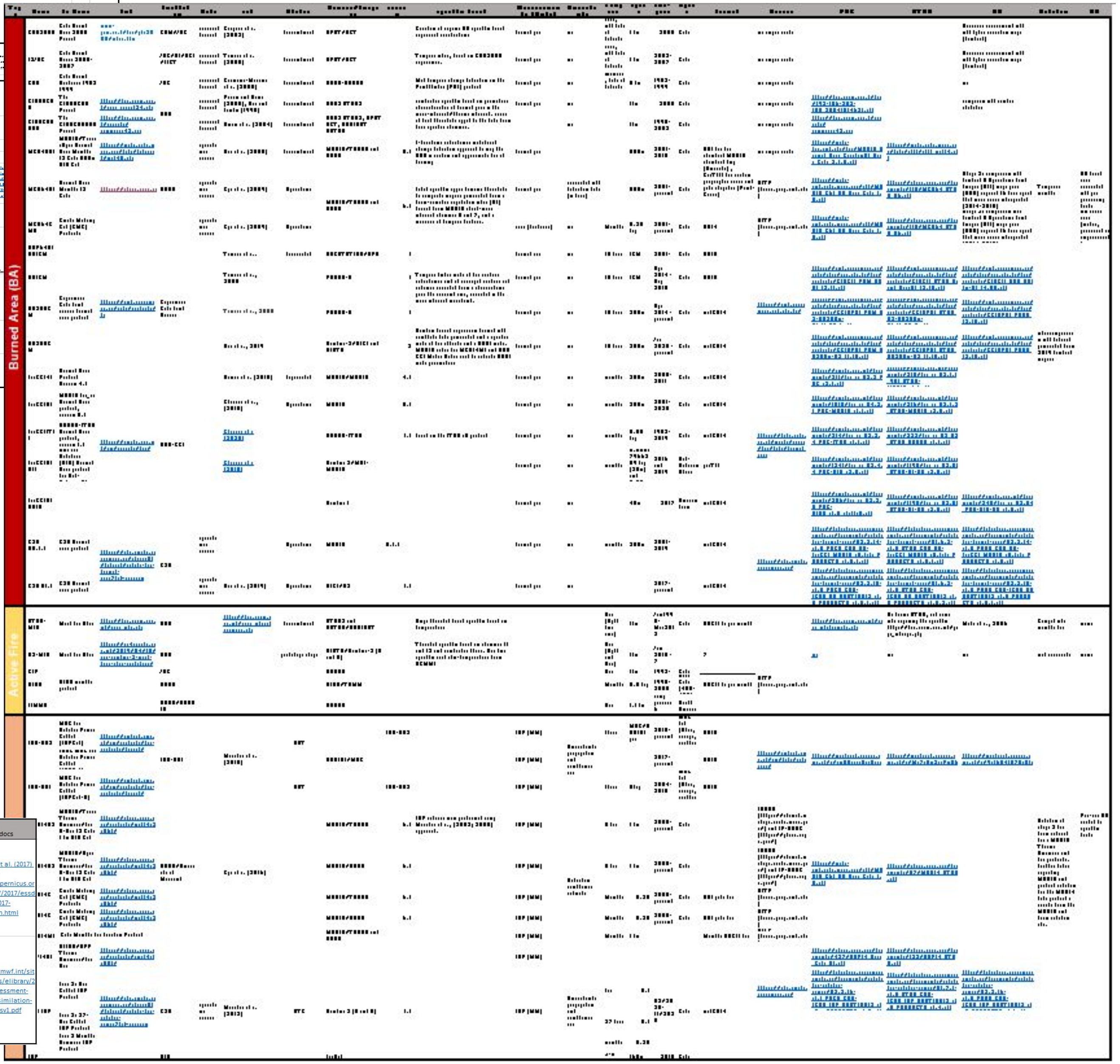
background mean spectral radiance [$Wm^{-2}sr^{-1}\mu^{-1}$]

Fire Disturbance EO products status

L2



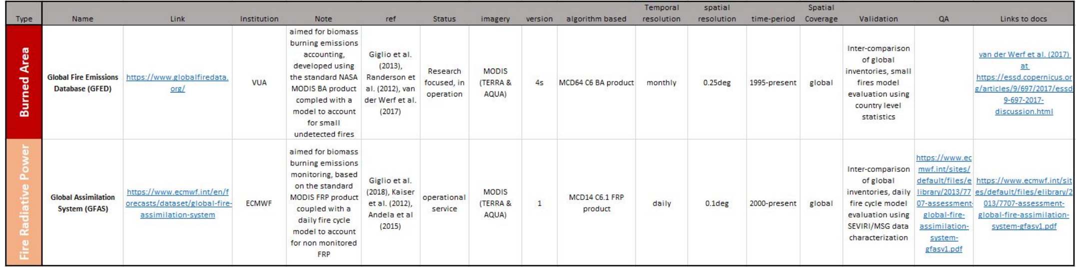
L3



Identified 52 fire products (BA, AF, FRP), global or hemispherical cover, NRT,NTC)

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

L4



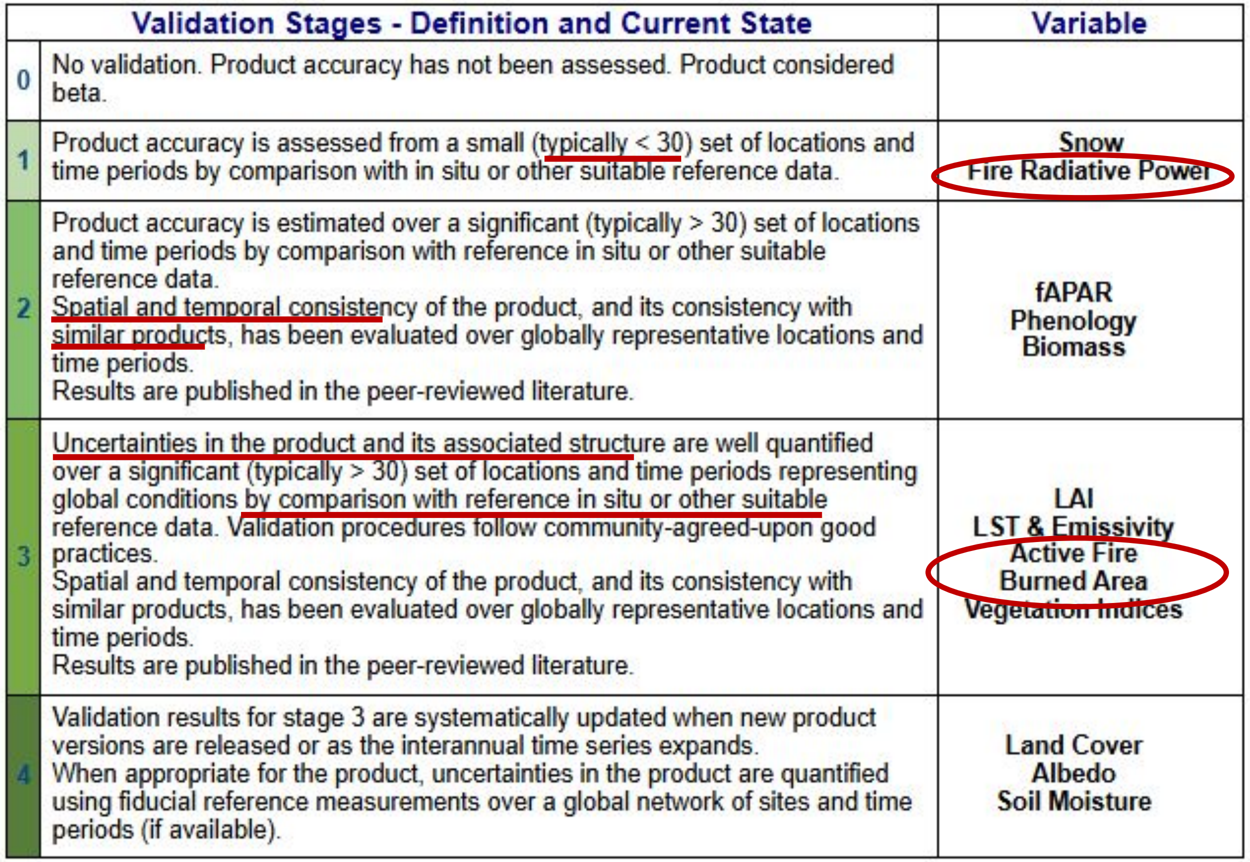
Type	Name	Link	Institution	Note	ref	Status	imagery	version	algorithm based	Temporal resolution	spatial resolution	time-period	Spatial Coverage	Validation	QA	Links to docs
Burned Area	**Global Fire Emissions Database (GFED)**	https://www.globalfiredata.org/	VUA	aimed for biomass burning emissions accounting, 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

Fire Disturbance - Cal/Val gaps of fire products

https://ccvs.eu

- Definition of what entails each fire product processing level (L2/L3/L4).
- Definition of a **standard method** for estimating thematic **classification confidence**, to allow for full product compatibility and comparability.
- Development of method/models to allow for **conversion** between classification **confidence and uncertainty**.
- Development of a community accepted standard for **geo-spatial uncertainties** for regrided/reprojected products.
- Development of **product uncertainties** considering the **assumptions made in retrieval algorithms** and **uncertainty propagation** from input products (metrological approach) to assure compliance with Thematic Data Records (TDP).
- Propagation of **per-pixel radiance uncertainty** (at L1/L2) to the final product (GUM).
- For the intersatellite inter-comparisons, further investigations are required over **multiple sources of uncertainty**.
- Development of robust statistical methods for **non-simultaneous products**.
- Develop a **framework** for the generation of **FRM fire** data by establishing the required protocols to ensure full traceability – a **CEOS approved good practice guide**.
- Define a **community-based roadmap** and all the requirements, in order for FRP products to achieve CEOS Level-4 validation status.
- Define a community agreed **validation strategy** for classification-based mapping that ensures representativeness, in terms of landscape, in time, space and severity.

Fire Disturbance - products validation stage status

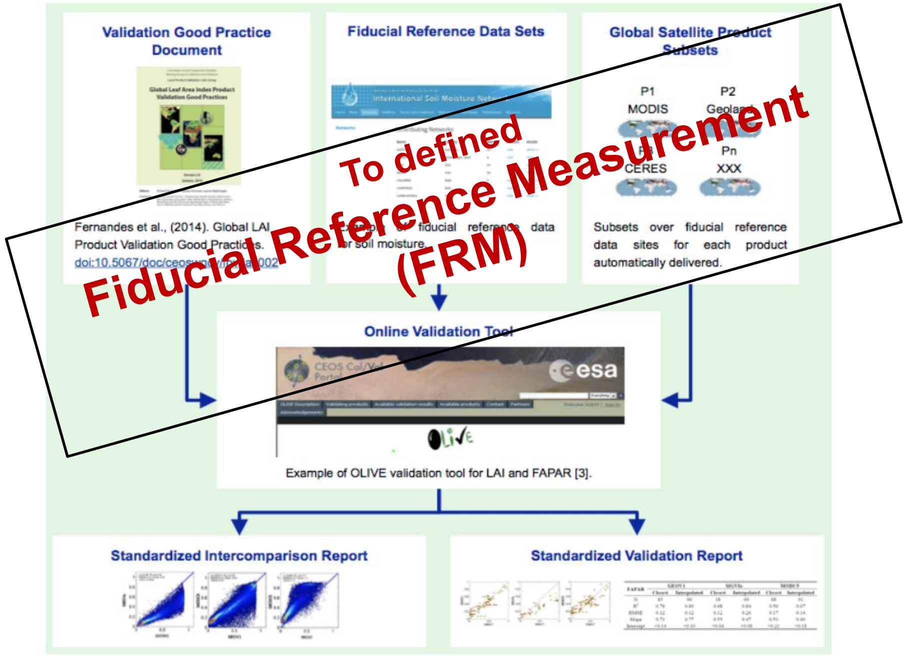


	Validation Stages - Definition and Current State	Variable
0	No validation. Product accuracy has not been assessed. Product considered beta.	
1	Product accuracy is assessed from a small (typically < 30) set of locations and time periods by comparison with in situ or other suitable reference data.	Snow Fire Radiative Power
2	Product accuracy is estimated over a significant (typically > 30) 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 its consistency with similar products, has been evaluated over globally representative locations and time periods. Results are published in the peer-reviewed literature.	fAPAR Phenology Biomass
3	Uncertainties in the product and its associated structure are well quantified over a significant (typically > 30) set of locations and time periods representing global conditions by comparison with reference in situ or other suitable reference data. Validation procedures follow community-agreed-upon good practices. Spatial and temporal consistency of the product, and its consistency with similar products, has been evaluated over globally representative locations and time periods. Results are published in the peer-reviewed literature.	LAI LST & Emissivity Active Fire Burned Area Vegetation Indices
4	Validation results for stage 3 are systematically updated when new product versions are released or as the interannual time series expands. When appropriate for the product, uncertainties in the product are quantified using fiducial reference measurements over a global network of sites and time periods (if available).	Land Cover Albedo Soil Moisture

FRP Validation at stage 1: The main challenge to validate fire products is the **generation of reference data** due to the **ephemerity** of the phenomenon to be mapped and the current **revisiting times** of moderate-high spatial resolution observing systems. Therefore, reference data samples are scarce and not coincident with product estimates.»

***In-situ* generated reference data**

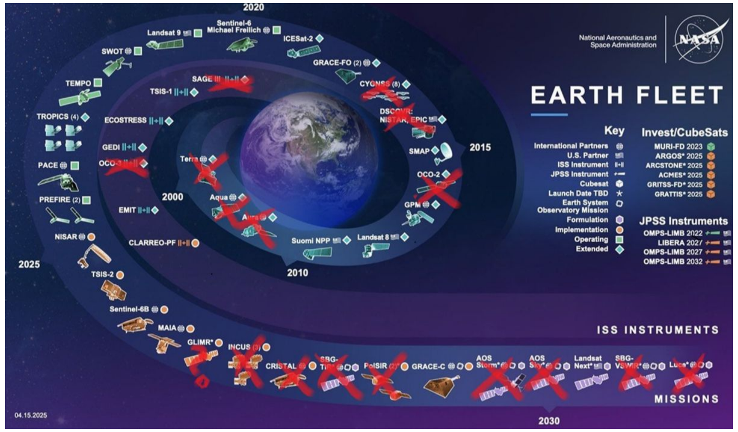
- **Coincident** measurements currently are not routinely available, even opportunistic experiments used **airborne thermal** imaging systems.
- A field experiments **scarce** and limited to **controlled environments**



Example of OLIVE validation tool for LAI and FAPAR [3].

Burned area validation *now routinely achieves Stage-3 and sometimes Stage-4.*

Satellite/Product status



- WH proposed decommission of MODIS
  - VIIRS only afternoon overpass

- Landsat NEXT (uncertainty)?

- Recent news: Wildfire sat operational in the spring of 2029 it will begin providing data globally, the fire products will be shared publicly in NRT with the L-1B data trailing by ~24 hrs.

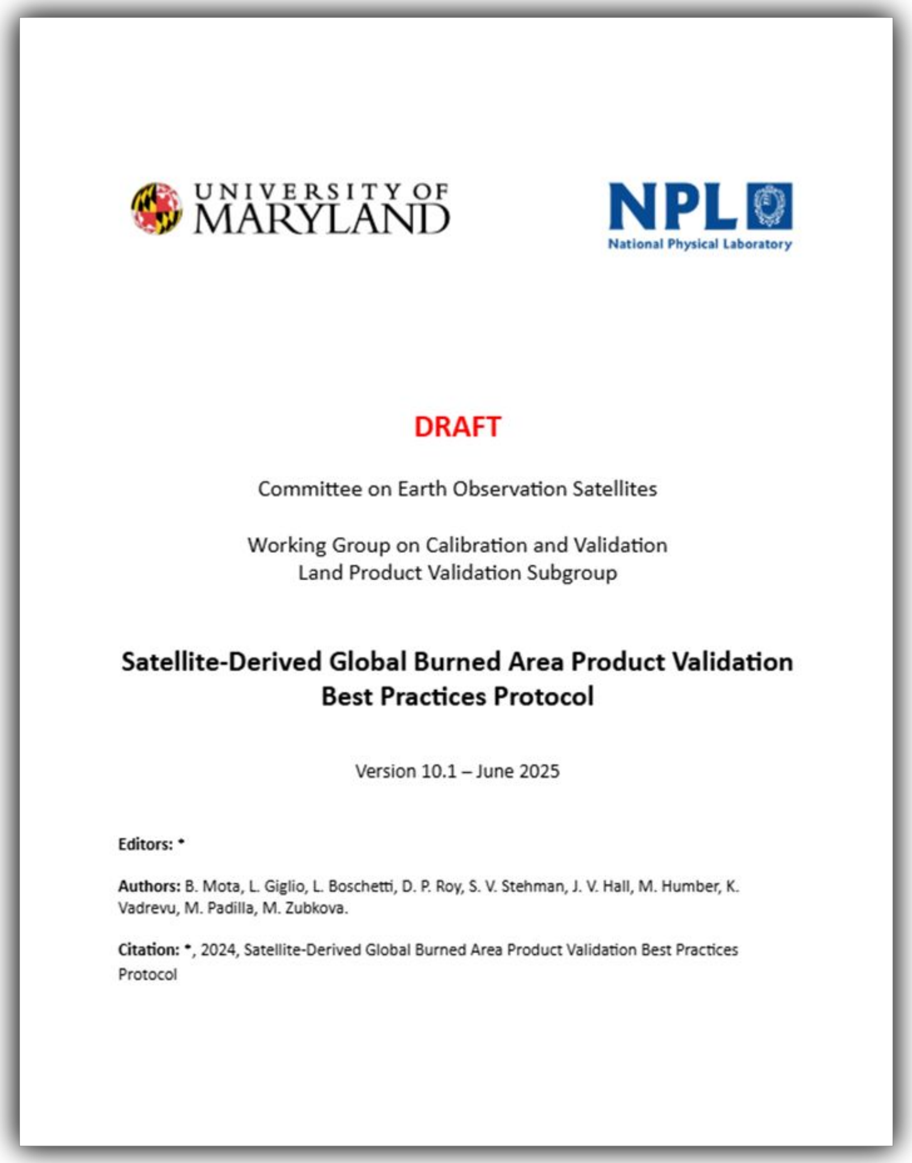
WildFireSat
La mission GardeFeu

- Non-science, commercial systems are being planned to replace some of the services provided by the space agencies (NRT) - Earth Fire Alliance (EFA) FireSat Constellation that will provide a full suite of products (AI based). QA plan is unknow.

- FIRMS NRT BA and experimental fire perimeters based on AF

Fire Disturbance – Burned area validation protocol

- Continuing to update the current draft, that was based on the 2010 burned area validation note
- Still some disagreement within the community regarding the required sample sizes, metrics and use of ‘long units’
- Needs updating on coarse resolution validation and on the use and role of “future space”
- Promote final discussion at the next GOFC Fire Implementation Team meeting (still unknown when and where, but not US)



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DRAFT

Committee on Earth Observation Satellites

Working Group on Calibration and Validation
Land Product Validation Subgroup

Satellite-Derived Global Burned Area Product Validation Best Practices Protocol

Version 10.1 – June 2025

Editors: *

Authors: B. Mota, L. Giglio, L. Boschetti, D. P. Roy, S. V. Stehman, J. V. Hall, M. Humber, K. Vadrevu, M. Padilla, M. Zubkova.

Citation: *, 2024, Satellite-Derived Global Burned Area Product Validation Best Practices Protocol

Fire Disturbance - Burned area

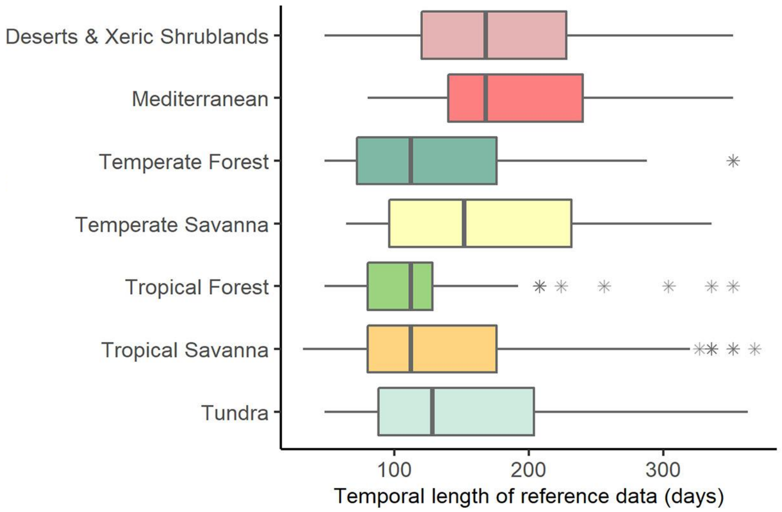
Validation Challenges

- How to validate growing pool of moderate-resolution (20 – 30 m) burned area products?
  - Appealing to high resolution (~1–10 m) commercial imagery is constrained by spatial and spectral coverage + cost
- Validation alone is not enough – also required is **quality assurance**
  - *“Product quality assessment is necessary for global products given the large number of factors that can adversely affect their quality... and because over large areas product quality issues, such as stripes at input image . . . boundaries, or anomalous temporal and spatial burning patterns... may remain undetected by validation activities that necessarily rely on a limited sample of independent reference data.”* (Boschetti et al., 2019)

Fire Disturbance - Burned area

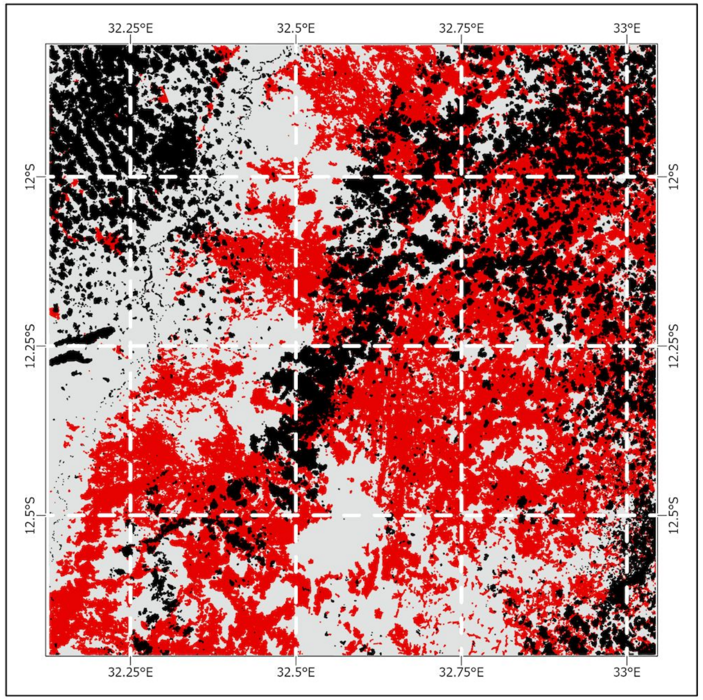
Burned Area Validation: Issues to Address

- "Long" validation units
  - Lack of consensus re. maximum permissible time between first and last images used to derive reference maps
- Coarse-resolution BA product validation
  - Level-4 coarse-resolution BA products (e.g., GFED) **typically assessed to less stringent standards** than purely satellite-based BA products
  - More appropriate rigorous approach under development (Giglio & Mota, in prep.)



Long-unit periods ideally do not exceed vegetation regrowth + other post-burn disturbance time frames.

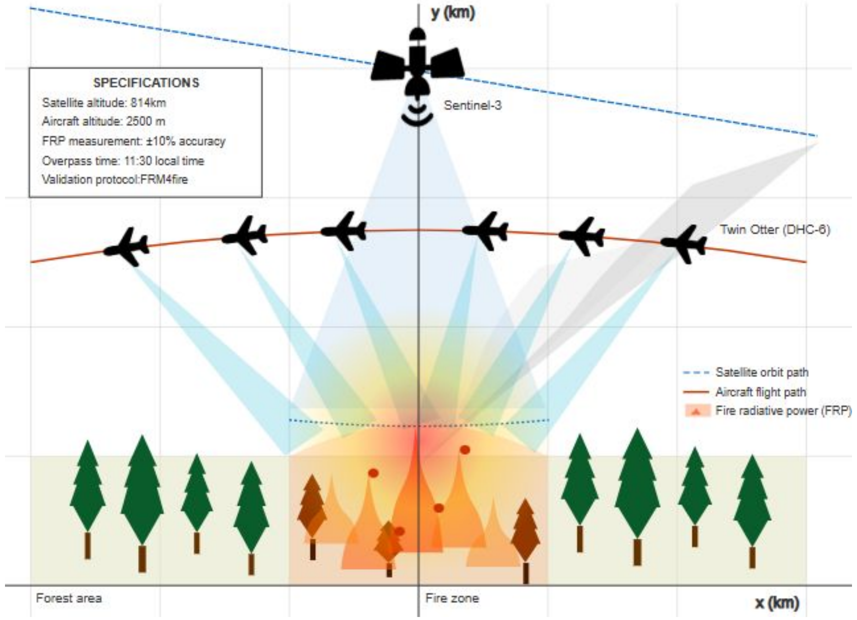
Franquesa et al., (2022)



🟥 burned ⬜ unburned ⬛ unobserved

Example of Stroppiana et al. (2022) Sentinel-2 reference map for site in Africa superimposed with 0.25° GFED grid.

FRPM Validation



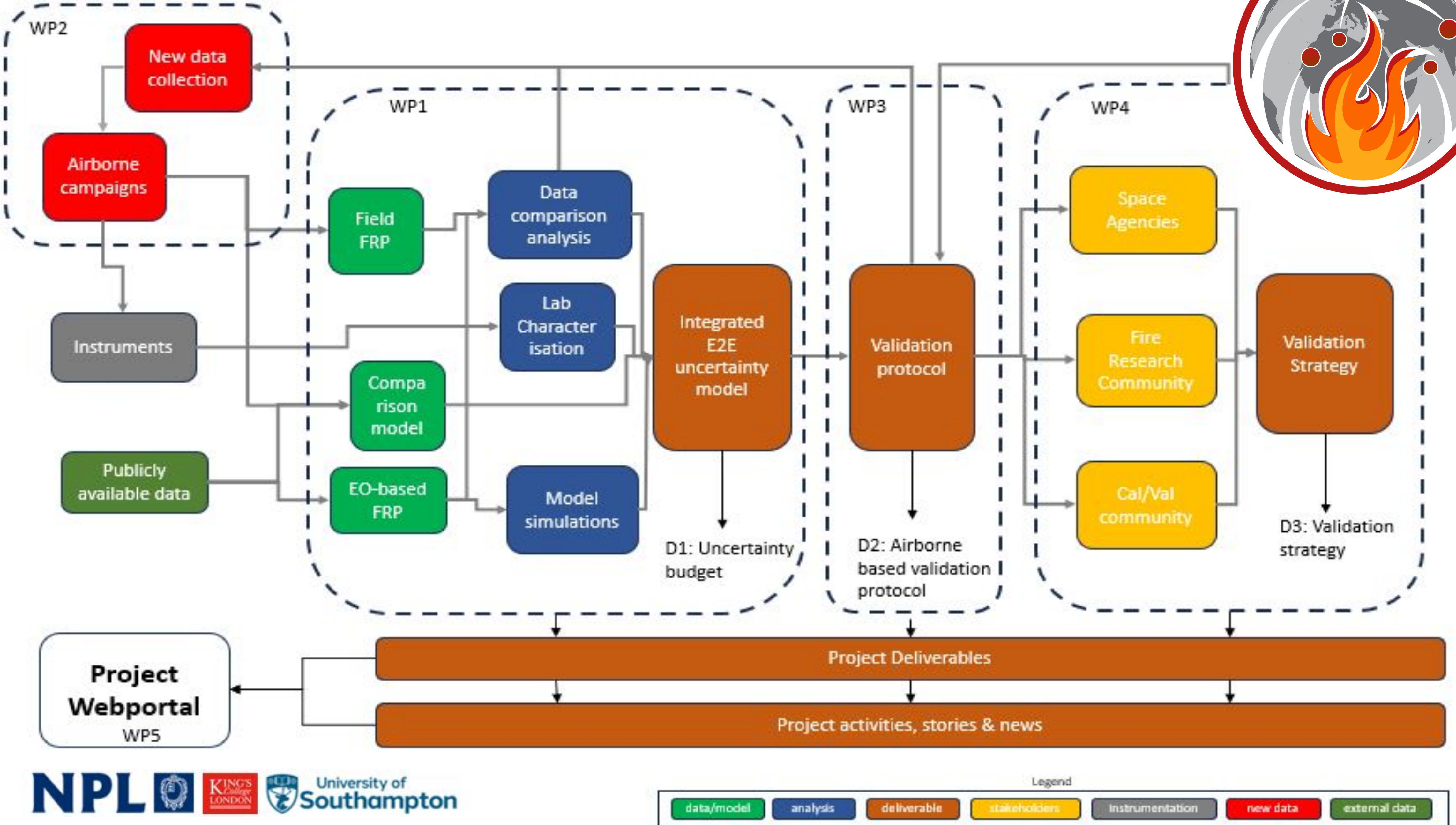
Spaceborne retrieval are based on the comparison with airborne-based reference measurements

Spaceborne: instantaneous measurement of the radiative power associated with ongoing fire activity within a pixel area
[units: MW]

Airborne: measurement of the radiative power from a particular fire event of a certain size during at a particular instance.
[units: MW]

Comparison challenge:
- spatial scale: km vs 100’s meters,
- temporal range: $^{1}/_{10}$ s vs min.,
    - as well as the observational conditions (environmental & technical)

FRM4Fire project framework – phase 1



WP2

New data collection

Airborne campaigns

Instruments

Publicly available data

WP1

Field FRP

Compa rison model

EO-based FRP

Data comparison analysis

Lab Character isation

Model simulations

Integrated E2E uncertainty model

D1: Uncertainty budget

WP3

Validation protocol

D2: Airborne based validation protocol

WP4

Space Agencies

Fire Research Community

Cal/Val community

Validation Strategy

D3: Validation strategy

Project Deliverables

Project activities, stories & news

Project Webportal
WP5

Legend

data/model | analysis | deliverable | stakeholders | instrumentation | new data | external data

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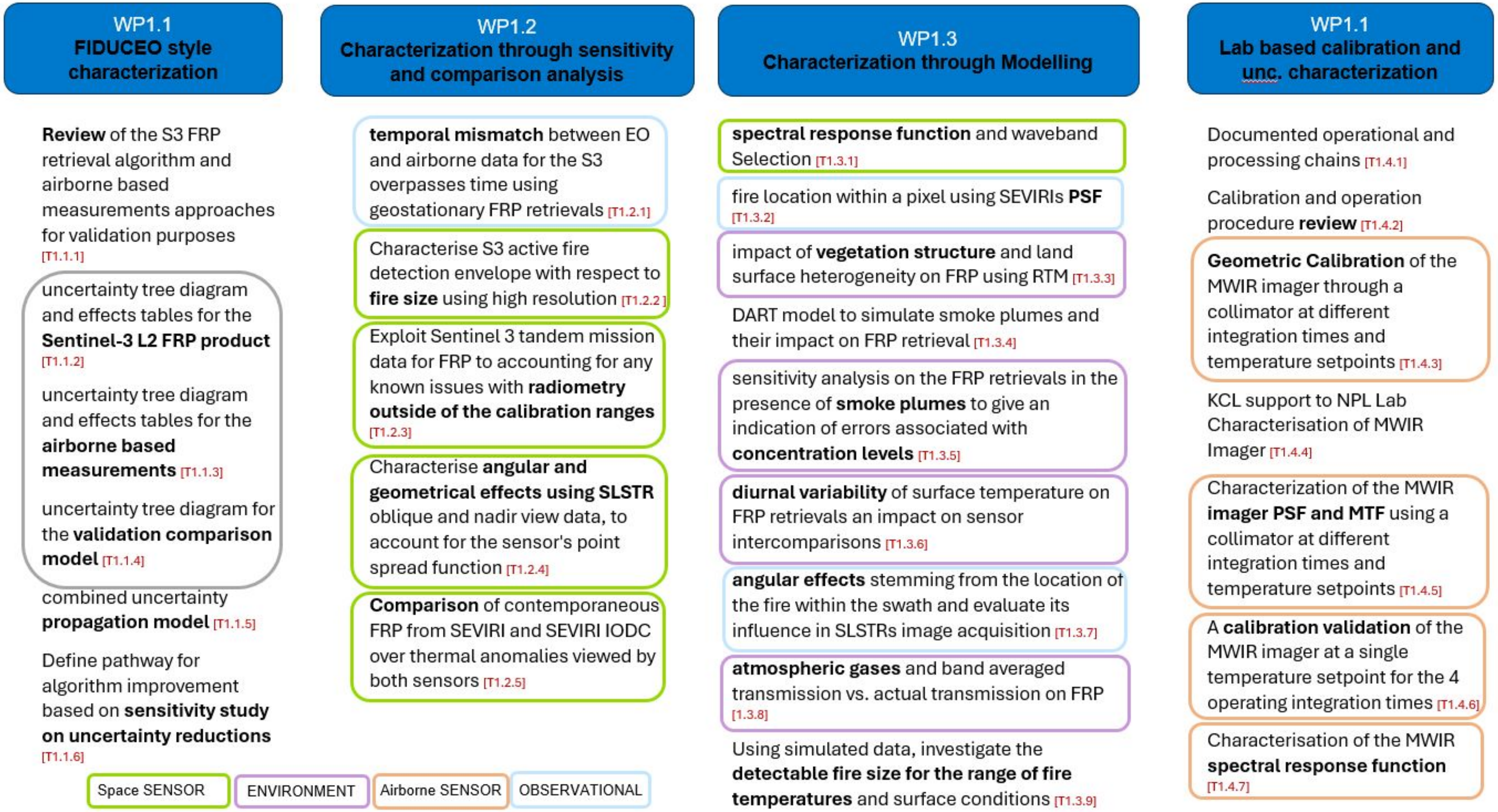
FRM4Fire – analysis to characterize uncertainties



WP1.1
FIDUCEO style characterization

Review of the S3 FRP retrieval algorithm and airborne based measurements approaches for validation purposes [T1.1.1]

uncertainty tree diagram and effects tables for the **Sentinel-3 L2 FRP product** [T1.1.2]

uncertainty tree diagram and effects tables for the **airborne based measurements** [T1.1.3]

uncertainty tree diagram for the **validation comparison model** [T1.1.4]

combined uncertainty **propagation model** [T1.1.5]

Define pathway for algorithm improvement based on **sensitivity study on uncertainty reductions** [T1.1.6]

WP1.2
Characterization through sensitivity and comparison analysis

temporal mismatch between EO and airborne data for the S3 overpasses time using geostationary FRP retrievals [T1.2.1]

Characterise S3 active fire detection envelope with respect to **fire size** using high resolution [T1.2.2]

Exploit Sentinel 3 tandem mission data for FRP to accounting for any known issues with **radiometry outside of the calibration ranges** [T1.2.3]

Characterise **angular and geometrical effects using SLSTR** oblique and nadir view data, to account for the sensor's point spread function [T1.2.4]

Comparison of contemporaneous FRP from SEVIRI and SEVIRI IODC over thermal anomalies viewed by both sensors [T1.2.5]

WP1.3
Characterization through Modelling

spectral response function and waveband Selection [T1.3.1]

fire location within a pixel using SEVIRIs **PSF** [T1.3.2]

impact of **vegetation structure** and land surface heterogeneity on FRP using RTM [T1.3.3]

DART model to simulate smoke plumes and their impact on FRP retrieval [T1.3.4]

sensitivity analysis on the FRP retrievals in the presence of **smoke plumes** to give an indication of errors associated with **concentration levels** [T1.3.5]

diurnal variability of surface temperature on FRP retrievals an impact on sensor intercomparisons [T1.3.6]

angular effects stemming from the location of the fire within the swath and evaluate its influence in SLSTRs image acquisition [T1.3.7]

atmospheric gases and band averaged transmission vs. actual transmission on FRP [1.3.8]

Using simulated data, investigate the **detectable fire size for the range of fire temperatures** and surface conditions [T1.3.9]

WP1.1
Lab based calibration and unc. characterization

Documented operational and processing chains [T1.4.1]

Calibration and operation procedure **review** [T1.4.2]

Geometric Calibration of the MWIR imager through a collimator at different integration times and temperature setpoints [T1.4.3]

KCL support to NPL Lab Characterisation of MWIR Imager [T1.4.4]

Characterization of the MWIR **imager PSF and MTF** using a collimator at different integration times and temperature setpoints [T1.4.5]

A **calibration validation** of the MWIR imager at a single temperature setpoint for the 4 operating integration times [T1.4.6]

Characterisation of the MWIR **spectral response function** [T1.4.7]

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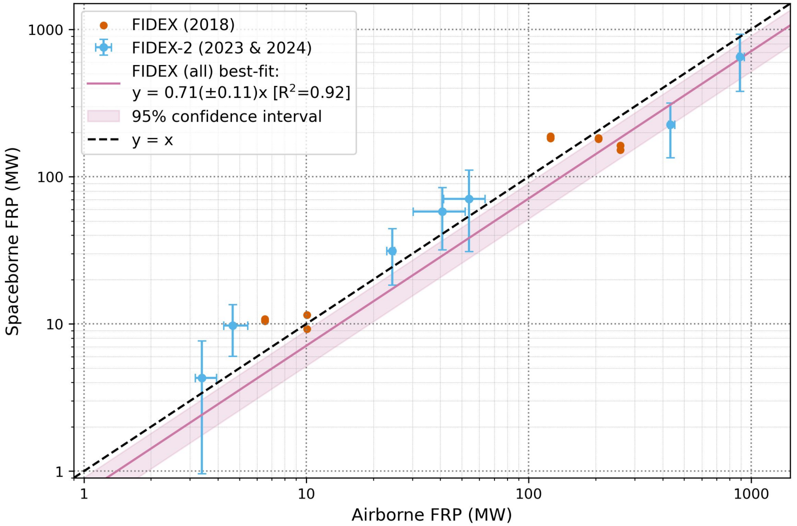
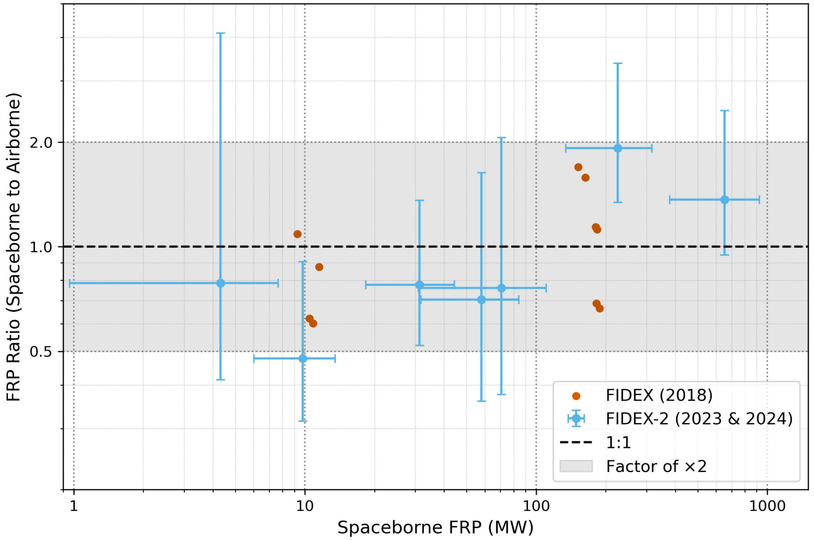
FRM4fire presentation at LPS25, Friday at 2:30 C.06.02 “Advances in Calibration and Product Validation for Optical Sensors”

Recent airborne validation campaigns

- FIDEX-2 (August 2023 – Ontario, Canada) – Matchup with S3A&B:
  - All points collected within the ‘factor of x2’ uncertainty resulting from the PSF and overlapping pixels of SLSTR
  - Higher airborne-derived than satellite-derived FRP for >200MW fires
  - Suggests future campaigns should investigate large fires, possibly by flying higher





Validating Fire Radiative Power

FRM4Fire: Early recommendations for the characteristics and quality of airborne reference data used for satellite fire product evaluation

Farrer Owsley-Brown[1,2,3], Martin Wooster[1,2,3], Bernardo Mota[4], Gareth Roberts[5], Dirk Schüettemeyer[6], Callum Middleton[1,2], Weidong Xu[1,2], Toby Wainwright[1,2,3]

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[2]National Centre for Earth Observation, United Kingdom
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[4]National Physical Laboratory, United Kingdom
[5]School of Geography and Environmental Science, University of Southampton, United Kingdom
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1. Airborne Platform

Enables large-scale data collection

Fixed-wing aircraft, such as the BAS De Havilland Twin Otter deployed in Canada (above), and rotorcraft, such as the Robinson R66 helicopter used in Kruger National Park, South Africa (left).

2. Instrumentation

Thermal sensor deployed should
- match spectral channel of the satellite sensor being validated
- have sufficient dynamic range

Navigation data required to georeference airborne data

Spectral filter allows MIR thermal camera to replicate SLSTR S7/F1 channel (left); EO sensors installed on Twin Otter (right)

3. Planning Data Collection

Identify suitable fire

Determine satellite overpass(es)

Ensure cloud-free

Plan survey

4. Fly over a fire

Collect near-simultaneous measurements with satellite

Wildfire surveyed during two Sentinel-3 nighttime overpasses in Ontario (above) and two Sentinel-3 daytime overpasses in Saskatchewan (right).

5. Airborne Data Processing

Georeference using navigation data and per pixel view vectors (from geometric calibration of optics)
Apply atmospheric correction

6. Comparison with Satellite FRP

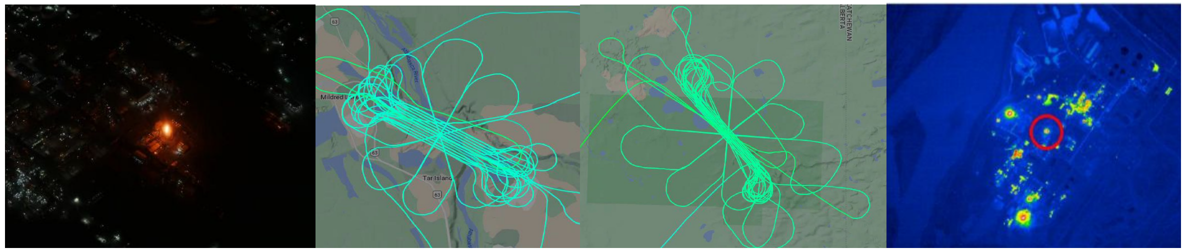
Total FRP should be measured for entire fire clusters, rather than per pixel, to reduce the impact of georeferencing inaccuracies in the satellite data.

As part of the FIDEX project, 19 fires were measured during S3 overpasses.
A strong linear correlation was observed between airborne and satellite-derived FRP. Most data points fall within expected uncertainty, though the airborne-derived FRP tended to be larger than the satellite-derived for more intense fires (>150 MW). This suggests future efforts should prioritise larger fires and, therefore, consider higher-altitude flights.

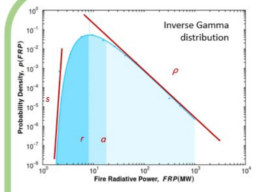
fiducial reference measurements for fire

Courtesy of Farrer Owsley-Brown, KCL

- CarbonARA (September 2024 – Aberta, Canada):
  - FRP from matchups (S3A&B) currently being processed
  - Measured FRP over gas flares to assess angular effects (vegetation and sensor)



FRP Product Intercomparison Framework



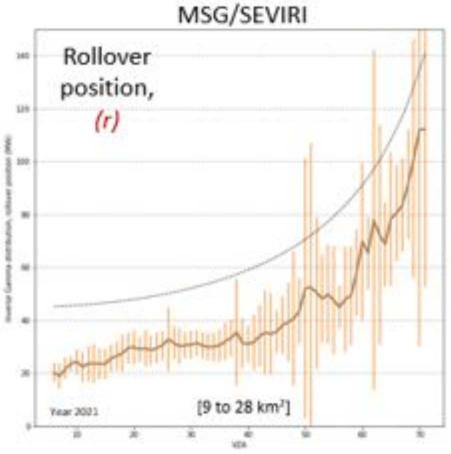
$$p(FRP\,|\,\rho, a, s) = \frac{1}{a\Gamma(\rho)}\left[\frac{a}{FRP - s}\right]^{\rho+1} \exp\left[-\frac{a}{FRP - s}\right]$$

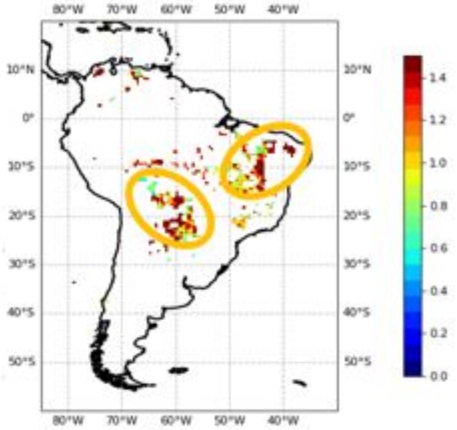
Shape parameter, (ρ)
Right hand side exponent associated with events. power-law relation associated with nature's self-organized critical behaviour.

Location parameter, (a)
Identifies the FRP threshold below which detection relations detach from a power-law relation

Rollover parameter, (r)
Identifies the FRP threshold below which a detection algorithm/sensors are limited

Scale parameter, (s)
Left hand size exponent associated with the rate of decay of detections



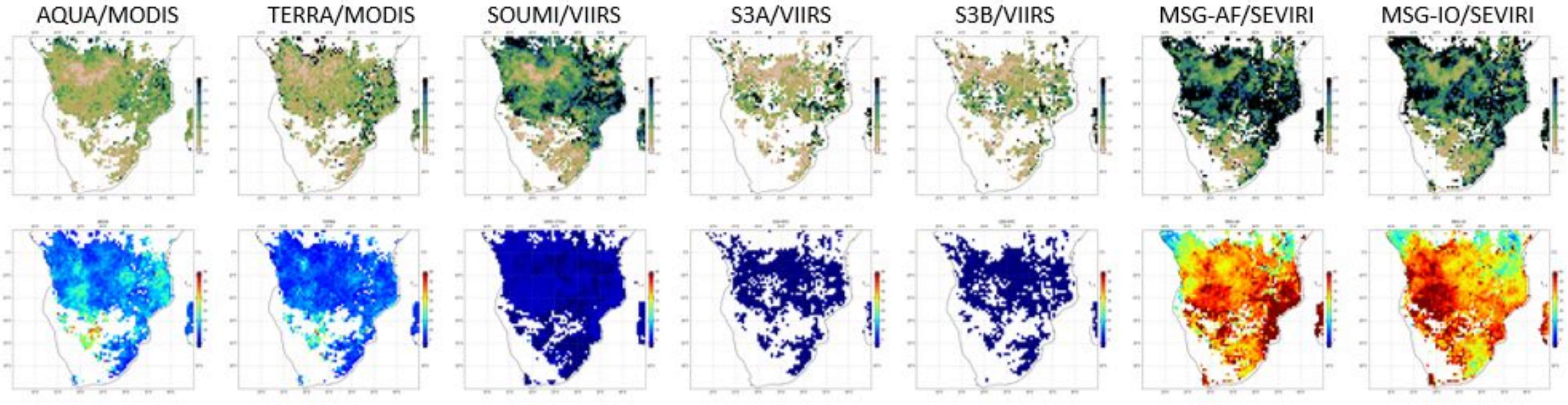


Robust statistical analysis based on non-concurrent detections (*pdf),* allows for*:*

- algorithm detectability underperformance (lower range)
- Sensor saturation impacts
- Spatial and temporal consistency
- False or non-fire detections

shape parameter

rollover parameter



Fire Disturbance - – AF & FRP validation protocol

- Drafted the outline
- Will include protocol section on airborne FRP measurements developed from FRM4fire
- Include section on product inter-comparisons (simultaneous and non-simultaneous)
- 1st Draft end-2025?

DRAFT

Committee on Earth Observation Satellites

Working Group on Calibration and Validation
Land Product Validation Subgroup

Satellite-Derived Global Active Fire Product Validation Best Practices Protocol

Version 1.0 – January 2025

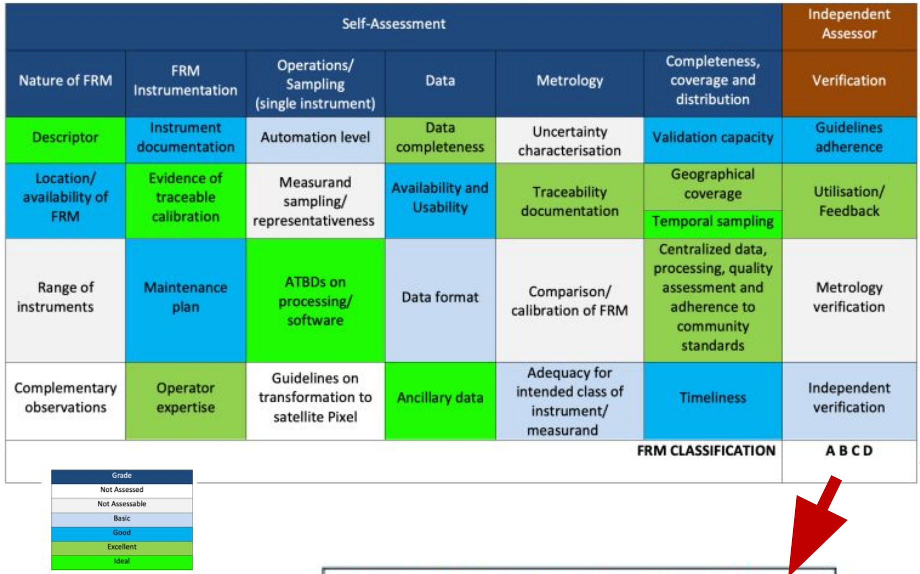
Editors: *

Authors: B. Mota, L. Giglio, ...

Citation: *, 2025, Satellite-Derived Global Active Fire Product Validation Best Practices Protocol

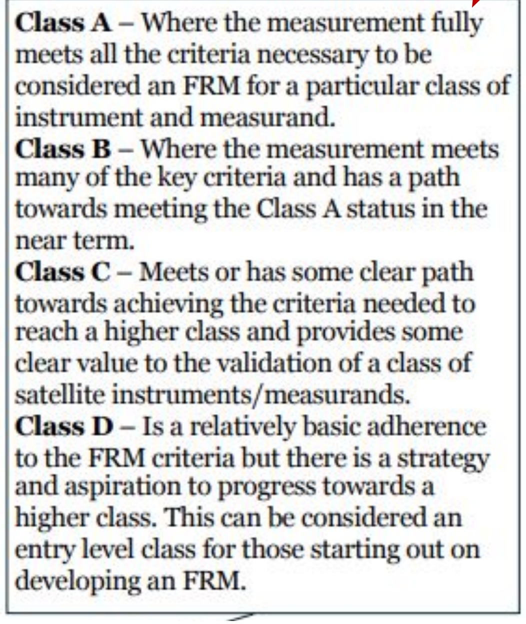
Final note: Long-term strategy – FRM maturity

characteristic	description
Traceability	documented evidence of their traceability to a community agreed reference ideally tied to the International System of units, SI
Independence	measurements are independent from the satellite geophysical retrieval process
Uncertainty budget	comprehensive uncertainty budget for all instruments and processed measurements (transformation of the measurand to match the measurand of the satellite product)
Documented protocols	measurement protocols, procedures and communitywide quality management practices (measurement, processing, archive, documents, etc.) are defined
Accessibility	datasets, including metadata and reports documenting processing, are accessible to other researchers, allowing independent verification of processing
Representativeness	representativeness of the FRM to that of the satellite observation as well as the satellite to FRM comparison process are thus required to be documented and the uncertainty assessed
Adequacy of Uncertainty	uncertainty of the FRM, including the comparison process, must be commensurate with the requirements of the class of satellite sensor they are specified to support
Utility	are designed to apply to a class of satellite missions. They are not mission-specific



Self-Assessment						Independent Assessor
Nature of FRM	FRM Instrumentation	Operations/ Sampling (single instrument)	Data	Metrology	Completeness, coverage and distribution	Verification
Descriptor	Instrument documentation	Automation level	Data completeness	Uncertainty characterisation	Validation capacity	Guidelines adherence
Location/ availability of FRM	Evidence of traceable calibration	Measurand sampling/ representativeness	Availability and Usability	Traceability documentation	Geographical coverage Temporal sampling	Utilisation/ Feedback
Range of instruments	Maintenance plan	ATBDs on processing/ software	Data format	Comparison/ calibration of FRM	Centralized data, processing, quality assessment and adherence to community standards	Metrology verification
Complementary observations	Operator expertise	Guidelines on transformation to satellite Pixel	Ancillary data	Adequacy for intended class of instrument/ measurand	Timeliness	Independent verification
					FRM CLASSIFICATION	A B C D

Grade
Not Assessed
Not Assessable
Basic
Good
Excellent
Ideal



Class A – Where the measurement fully meets all the criteria necessary to be considered an FRM for a particular class of instrument and measurand.
Class B – Where the measurement meets many of the key criteria and has a path towards meeting the Class A status in the near term.
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.
Class D – Is a relatively basic adherence to the FRM criteria but there 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.

Open issues

- For BA , and some extent AF, the use of ML (as opposed to AI) and traceability challenge it represents
- Definition of what is BA
- FRM for BA validation to be defined what it is

- FRP validation-stage limitations
  - Are the defined stages adaptive to validation that requires airborne campaigns?