



FLEX DISC

FLUORESCENCE EXPLORER DATA INNOVATION AND SCIENCE CLUSTER

CALIBRATION/VALIDATION PLAN OVERVIEW

Document Information

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1. Introduction

1.1. Scope of the document

This document provides an overview of the overall FLuorescence EXplorer (FLEX) strategy for the calibration and validation (cal/val) of the satellite's operational Level 1 and Level 2 science data products. This document introduces common information and lays the foundations for specific documents related to the validation of the different mission's products.

This document can be considered as the master "umbrella" document, containing basic information on cal/val topics related to the FLEX mission. The validation plan of FLEX is therefore structured with the following logic and, besides this document, it includes specific ESL cal/val documents for each product level to be validated:

1. FLEX cal/val plan master document (this document);
2. Validation plan for L1C/L2, Geolocation grid [RD-17];
3. Validation plan for L1C including, radiometric, spectral validation, and cross calibration between OLCI and FLORIS [RD-16];
4. Validation plan for L2A (apparent surface reflectance, at-surface irradiance) and AOD, ÅNG, CWV, ASY, (SSA) [RD-18];
5. Validation plan for L2B (fluorescence and scalar metrics) [RD-19];
6. Validation plan for L2C (direct and indirect validation of LAI, fAPAR, LCC, APAR (APAR_chl, LCARC, ETR, NPQ, FQE, Fesc) [RD-20];
7. Validation plan for L2C LST [RD-21].

In this document and elsewhere we use the term "L2 product" to refer to the Level 2 physical product as described in the L1C & L2 IPF Product Format Definition [RD-15]. The L2 product contains three logical products as follows (see [RD-15]):

- L2A: the group of L2 Atmospheric products,
- L2B: the group of L2 Fluorescence products, and
- L2C: the group of L2 Vegetation products.

Hereafter, we use the terms "L2A Product", "L2B Product", and "L2C Product" to refer to the corresponding group of parameters in the L2 Product.

The 7 separate documents describe different issues related to the validation approach, details of test sites, in situ instrumentation, cal/val tools and algorithms description that will be used for the validation activities for each mission product.

At a later stage, activities mentioned in the Instrument Calibration and Characterization documents provided by Industry will be merged with this validation plan for the Phase E2 of the mission. Besides this set of Cal/Val Plans, it should be noted that there are companion documents, in particular the "Validation Database Definition Document", the

“Quality Control Monitoring Baseline Document (MBD)” and the “FLEX DISC cal/val activities – Preparation and Commissioning”. Taken together, all these documents provide a comprehensive understanding of the entire and complex architecture of FLEX product validation.

It is to be noted that all these documents highlight main activities to be done. They will be regularly updated in coordination with ESA.

1.2. Related documents

1.2.1. Applicable documents

Id.	Ref.	Description	Issue
[AD-01]	ESAEOP-SM/2221/MDru-md	FLEX EE8 Mission Requirements Document	3.1
[AD-02]	FLX-TN-ESA-SYS-0032	FLEX Mission Architecture and Operations Concept	2.0
[AD-03]	FLX-ADD-GMV-FIPS-GPP	FLEX L2 E2E Mission Performance Assessment - Architecture Design Document	2.2.2
[AD-04]	FLX-ICD-GMV-FIPS-GPP	FLEX L2 E2E Mission Performance Assessment - Interfaces Control Document	2.2.3
[AD-05]	ESA-EOPG-PR-0005	EOP-G Security operating procedure (SECOPS) framework	1.0
[AD-06]	GMGT-SENE-EOPG-PD-12-0011	EOP-G Security Incident Handling Policy	1.1
[AD-07]	ESA-EOPG-EOEP-DD-0003	FLEX PDGS System Architecture Document	3.3
[AD-08]	ESA-EOPG-EEGS-ID-0083	Generic Processor ICD	1.4
[AD-09]	ESA-EOPG-EOEP-ID-0009	FLEX PDGS CPF-IPF Interface Control Document	1.9
[AD-10]	ESA-EOPG-EOEP-TN-0015	FLEX PDGS Products Naming Convention and Definition	2.17
[AD-11]	ESA-EOPG-EOEP-TN-0025	FLEX PDGS Main Product Header Definition	1.5
[AD-12]	ESA-EOPG-EOEP-TN-0014	FLEX PDGS Production Model	1.4
[AD-14]	ESA-EOPG-EOPGMQ-SOW-43	FLEX DISC Statement Of Work	1.0

1.2.2. Reference documents

Id.	Ref.	Description	Issue
[RD-01]	EOP-SM-3044-MDru-mdru	FLEX Mission Product Tree & Product Definition	2.0
[RD-02]	EOP-SM/2776	Scientific Readiness Levels (SRL) Handbook	1.1
[RD-03]	FLX-LI-ESA-SYS-0017	FLEX Acronyms, Terms and Definitions (ATD)	1.3
[RD-04]	ECSS-E-HB-40-01A	Agile software development handbook	1.0
[RD-05]	ESA-EOPG-EOEP-TN-0013	FLEX PDGS Product Baseline Definition and Usage	1.1
[RD-06]	ESA-EOPG-EOEP-TN-0026	FLEX PDGS Auxiliary Product Format Definition	2.3

[RD-07]	ESA-EOPG-EOEP-TN-0027	FLEX PDGS RAW Products Format Definition	2.10
[RD-08]	ESA-EOPG-EOEP-TN-0022	FLEX PDGS Level-0 Product Format Definition	2.7
[RD-09]	ESA-ESO-PR-2020-0039	Instructions Regarding the Common Protection of Unclassified Programme/Project Information	2.0
[RD-10]	ISO/IEC 15408D	Common Criteria for Information Technology Security Evaluation	
[RD-11]	FLX-RS-ESA-GS-0043	FLEX Ground Segment Requirements Document (GSRD)	2.1
[RD-12]	MAG-23-PTF-86-Vol1	FLEX DISC Technical Proposal	2.1
[RD-13]	FLEXDISC-PMP-MAG-002	FLEX DISC Project Management Plan	1.1
[RD-14]	ESA-EOPG-EOPGMQ-PL-001	FLEX Validation Plan (Draft)	1.0
[RD-15]	FLEXDISC-IPF-PFD-MAG-016	L1C & L2 IPF Product Format Definition	1.4
[RD-16]	FLEXDISC-CALVAL-PLAN-MAG-058	L1C Vicarious Validation Plan	1.0
[RD-17]	FLEXDISC-CALVAL-PLAN-MAG-105	L1C L2 Geolocation Validation Plan	1.0
[RD-18]	FLEXDISC-CALVAL-PLAN-FMI-059	L2A Validation Plan	1.0
[RD-19]	FLEXDISC-CALVAL-PLAN-UMB-060	L2B Validation Plan	1.0
[RD-20]	FLEXDISC-CALVAL-PLAN-ITC-061	L2C Validation Plan	1.0
[RD-21]	FLEXDISC-CALVAL-PLAN-ULE-062	L2A LST Validation Plan	1.0
[RD-22]	FLEXDISC-CALVAL-L1BGA-MAG-037	The Gap analysis of L1B calibration validation	1.1

1.2.3. Other related documents

Id.	Ref.	Description	Issue
	(DEFLOX CCN4)	Strategy for the uncertainty budget of SIF Ground measurements	
	ESA -MAG FLEX	PRELIMINARY GUIDELINES FOR CAL/VAL ACTIVITIES IN THE CONTEXT OF THE FLEX MISSION	
	ESA ESTEC Contract No. 4000112341/14/NL/FF/gp	FLEX-BRIDGE REPORT CAL/VAL	
	ESA-EOPSM-FLEX-RS-3424	FLEX Validation Site Requirement Baseline Document	
	[CALVAL-PE]	Sentinel-3-CalVal-Plan-V2.0	
		DIMITRI SUM	
	ESA Contract No. 4000125402/18/NL/NA	FLEXSENSE 2018 Final Report	
	ESA Contract No. 4000125402/19/NL/NA	FLEXSENSE 2019 Final Report	
	ESA-DISC	FLEX DISC cal/val activities – Preparation and Commissioning	1.4
	FLEXDISC-QC-MBD-MAG-053	Quality Control Monitoring Baseline Document (MBD)	3.1
	FLEXDISC-CALVAL-TN-FZJ-081	Validation Database Definition Document	3.0

1.2.4. Definitions and Acronyms

The FLEX Acronyms, Terms and Definitions are listed in [RD-03]. Additional definitions and acronyms not covered in [RD-03] are listed below.

Acronym	Description
ADF	Auxiliary data file
ANC	Ancillary data
CAL	Calibration
CP	Collaborative Platform
DISC	Data Innovation and Science Cluster
ECSS	European Cooperation for Space Standardization
EO	Earth Observation
EOF	Earth Observation File
EOM	End Of Mission
ESA	European Space Agency
FLEX	Fluorescence Explorer
FLEX-VT	FLEX Validation Team
FOS	Flight Operations Segment
FP	Focal Plane
GPP	Ground Processor Prototype
GS	Ground Segment
HR	High Resolution
HRE1	High Resolution 1

HRE2	High Resolution 2
ICD	Interface Control Document
ICU	Instrument Control Unit
INSTTM	Instrument Telemetry
IPF	Instrument Processing Facility
ISP	Instrument Source Packet
L0	Level-0 Products
L1	Level-1 Products
L2	Level-2 Products
L2RM	Level 2 Retrieval Module
LR	Low Resolution
LRES	Low Resolution
LST	Land Surface Temperature
MAAP	Mission Analysis and Algorithm Platform
MPH	Main Product Header
NetCDF	Network Common Data Format
OLCI	Ocean Land Colour Imager (Sentinel-3)
PDGS	Payload Data Ground Segment
PDHU	Payload Data Handling Unit
RD	Reference Document
SAT	Satellite
SIF	Sun Induced chlorophyll Fluorescence

SLSTR	Sea Land and Surface Temperature Radiometer (Sentinel-3)
SP	Source Packet
SW	Software
TBC	To Be Confirmed
TBD	To Be Defined
TBW	To be written
TOA	Top Of Atmosphere
UTC	Universal Time Coordinated
VAU	Video Acquisition Unit
VC	Virtual Channel
VDBRD	Validation Database Requirements Document
XML	eXtended Markup Language

Table 1: List of Acronyms

Term	Description
Agency	European Space Agency (ESA)
Ancillary Data	Data acquired on-board in support of the observation data, both for the instrument and the platform, such as calibration and timing data
Ancillary Products	All data generated by Ground Processor(s) from input ancillary data generated by onboard instrument and platform.
Auxiliary Data	Supporting data sets provided outside the Space Segment data stream used to apply corrections to the Space Segment sensor data. Examples include previously derived calibration parameters, ground control data, NWP data, external imager data.
Calibration Event	Each continuous uninterrupted sensing activity in calibration mode

Calibration ID	Unique identifier of each individual Calibration Event, uploaded from ground using the dedicated command and copied by the instrument in the dedicated field of the Data Field Header of the CCSDS packets (the CCSDS field is shared with the Data Take ID)
Calibration Products (CAL)	All calibration data generated by Ground Processor(s) from input raw data generated by onboard instrument.
Earth Observation Products (EO)	All measurements data generated by Ground Processor(s) from input raw data generated by onboard instrument.
Navigation Data	All data issued by the Navigation function after processing of GNSS Measurement data: they are mainly position and velocity of the satellite in one or several reference frames. The Navigation function is jointly assured by the GNSS receiver itself and by the AOCS software (in SMU).
Observation Mask	It is used for the planning of FLEX instrument observations activities and it indicates the actual area to be observed (i.e. land, including islands greater than 100 sqkm, and coastal areas).
Planning Data	All mission planning data issued by FOS and/or PDGS Mission Planning that are exchanged within the Ground Segment between ESOC and ESRIN.
Slicing Grid	Fix geographical-grid aligned to the ANX, defined to cut FLEX products. The cut in time is performed considering the reference scenario orbit file considering identified configurable margins, and data overlapping between consecutive Level-0 products. This cutting rule grants that the products generated along a given orbit are cut on sensing time basis to overlap the same geographical area of corresponding FLEXLevel-1 data.
Slicing Grid Frame	(or simply Slicing Frame) The interval in between two consecutive “cut times” defined by the Slicing Grid

Table 2: List of Definitions

2. Science and Mission Overview

2.1. Background and mission objectives

The FLuorescence EXplorer (FLEX) is ESA's 8th Earth Explorer mission. On November 19, 2015, ESA announced that its Member States had selected FLEX as the eighth Earth Explorer mission, upon recommendation from the Advisory Committee for Earth Observations. FLEX is designed to be compatible with Vega-C launcher. FLEX will provide, for the first time, the full fluorescence spectra and physiological-related parameters at high spatial resolution.

The FLEX mission in ESA's Living Planet Programme aims to provide global maps of vegetation fluorescence that can reflect photosynthetic activity, plant health and stress. This will provide a completely new possibility to assess the dynamics of actual photosynthesis through sun-induced fluorescence, which offers a great advancement over current capabilities that can only detect potential photosynthesis as derived in passive reflectance measurements by conventional land surface monitoring satellites. In turn, this is not only important for a better understanding of the global carbon cycle, but also for agricultural management and food security.

The conversion of atmospheric carbon dioxide and sunlight into energy-rich carbohydrates through photosynthesis is one of the most fundamental processes on Earth - and one on which we all depend. Information from FLEX will improve our understanding of the way carbon moves between plants and the atmosphere and how photosynthesis affects the carbon and water cycles. In addition, information from FLEX will lead to better insight into plant health and stress. This is of unique relevance since the growing global population is placing increasing demands on the production of food and animal feed.

From space, FLEX proposes to measure fluorescence as an indicator of photosynthetic activity together with the necessary parameters for deriving the amount of carbon assimilated by plants.

2.2. Tandem with Sentinel 3 and measurement approach

The FLEX mission concept foresees a small satellite flying in tandem with Sentinel-3 (Figure 1). The combination of FLORIS and Sentinel-3's OLCI and SLSTR instruments allows for an integrated package of measurements providing all the necessary auxiliary information to retrieve the fluorescence signal. FLEX instruments will provide information related to the atmospheric state and land-surface characterization needed for fluorescence retrieval covering the visible spectrum with OLCI and dual-angle visible / infrared and thermal infrared with SLSTR.

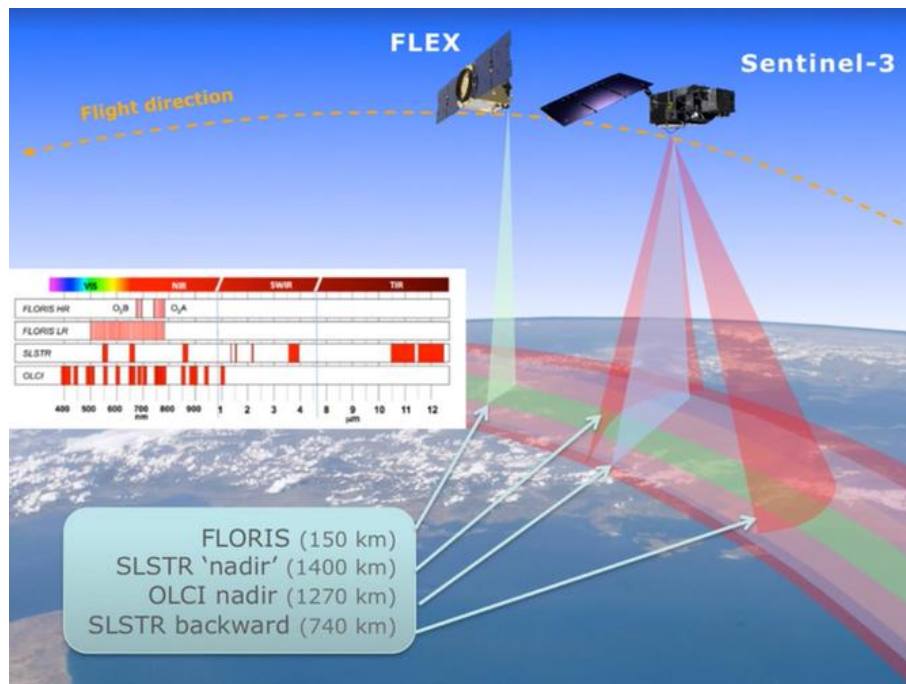


Figure 1: FLEX—Sentinel-3 formation indicating the different swath widths (credit Drusch et al., 2017).

The acquisitions of measurements for the same scene from FLORIS and the OLCI and SLSTR instruments shall be made within 6 s (G) and 15 s (T) and the coverage is from 56° S to 75° N. Overall, the nominal lifetime is 3.5 (5) years.

2.3. FLORIS instruments

The FLEX space segment consists of a single satellite carrying a high-resolution imaging spectrometer. The instrument, referred to as FLuOREscence Imaging Spectrometer (FLORIS), will acquire data in the 500-780 nm spectral range.

The FLORIS instrument baseline architecture is based on a push broom spectrometer obtained with matrix detectors, where one direction is used for swath and the other for spectral separation.

Acquisition of multi-frames of detector matrix during satellite movement permits to produce a 2D Earth scene image in two different spectral channels, called Low Resolution (LR) and High Resolution (HR). The operative spectral regions are: 500–760 nm for LR and 677–780 nm for HR. The overlapped spectral range has been introduced to simplify the inter-band co-registration between the two spectrometers.

The pupil diameter to comply with the SNR requirement is 75.7 mm for HR and 36.1 mm for LR. The optical design foresees a single telescope (234.5 mm of focal length, and f-number 3.1) used to collect the radiation coming from two single strips of 292 m*153 Km (at 815 km altitude) onto 2 identical slits (84 μm *44.1 mm) placed in its focal plane and separated by a distance of 4.5mm.

In front of the telescope a baffle and a dual Babinet scrambler are placed to reduce the out of field stray-light and to achieve the polarisation sensitivity requirements with negligible impact on the image quality. The operative instrument spectral band (500 -780 nm) is selected by a band pass filter placed in front of the scrambler.

Three identical low noise backside illuminated frame transfer 1050*430 (42 μm *28 μm) CCD detector units, cooled by radiator (-35°C), permit to reach the required SNR by means of a 42.8 msec integration time without saturation (1.25 Me- for each pixel), < 3 MHz readout frequency, 2 or 4 ports and x2 pixel binning along the spatial direction at the CCD level. A further binning along the spectral direction (x3 or x5) is provided in some spectral channels by the VAU Video Acquisition Unit.

An active thermal control using heaters on the detectors in closed loop with DU temperature sensors has been considered to maintain the temperatures around -35°C with a stability of $\pm 0.1^\circ\text{C}$.

Separated Video Acquisition Units (VAUs) are used to read the detector outputs, to bias and to drive them with correct sequencing and voltage levels, to convert the analogue signal to digital format, to perform binning, to transmit the digital signal to the Instrument Control Unit (ICU), to receive and execute the commands from ICU. A two-point radiometric calibration is achieved by means of sun and dark calibration.

Considering the high FLORIS spectral sampling and resolution, the spectral calibration can be performed by vicarious calibration using the narrow atmospheric absorption lines.

The FLORIS instrument is based on a common optical bench (OB) providing support to optical assemblies, and focal plane assemblies. The optical bench is supported over the Payload Interface Module by means of isostatic mounts. Passive radiators to cool the FPAs are placed on the OB external side looking at cold space. Also, the VAU box is supported on the OB external side looking into cold space. To maintain the required optical quality and spectral stability, the whole instrument's operative temperature is actively controlled in a range of $22^\circ\text{C} \pm 1^\circ\text{C}$.

Due to the needed instrument thermal stabilisation, the VAU box is mounted onto the external OB side looking to cold space. The VAU box shall dissipate its thermal power towards the cold space by exposing dedicated portions of its external surfaces or by dedicated radiators, according to Contractor design. Furthermore, the VAU will be thermally insulated from the OB by means of suitable insulator supports and suitable coatings/MLI blankets.

2.4. Mission Requirements and Science Data Products

The objective of FLEX is to provide estimates of the photosynthetic activity on large spatial and temporal scales, with uncertainties lower than 30% in photosynthesis efficiency for environmental conditions resulting in low and high values of regulated heat dissipation, respectively. The mission requirements are related to this main goal, and they are fully described in the MRD document [AD-01].

The overall FLEX strategy and plan for the validation of the satellite's operational products uses a requirements-based approach to ensure by traceability to the mission requirements that all parameters relevant for the operational product validation have been adequately covered. The mission requirements cover the end-to-end Earth observation system including high-level requirements, mission operations, data product development and processing, data distribution and data archiving.

The approach proposed is to identify from the requirements, the relevant error sources and associated related activities needed to ensure that products and services are adequately validated. The traceability from Mission Requirements Baseline/metrics is shown in the specific ESL validation documents.

Figure 2 shows the general structure of the different FLEX products:

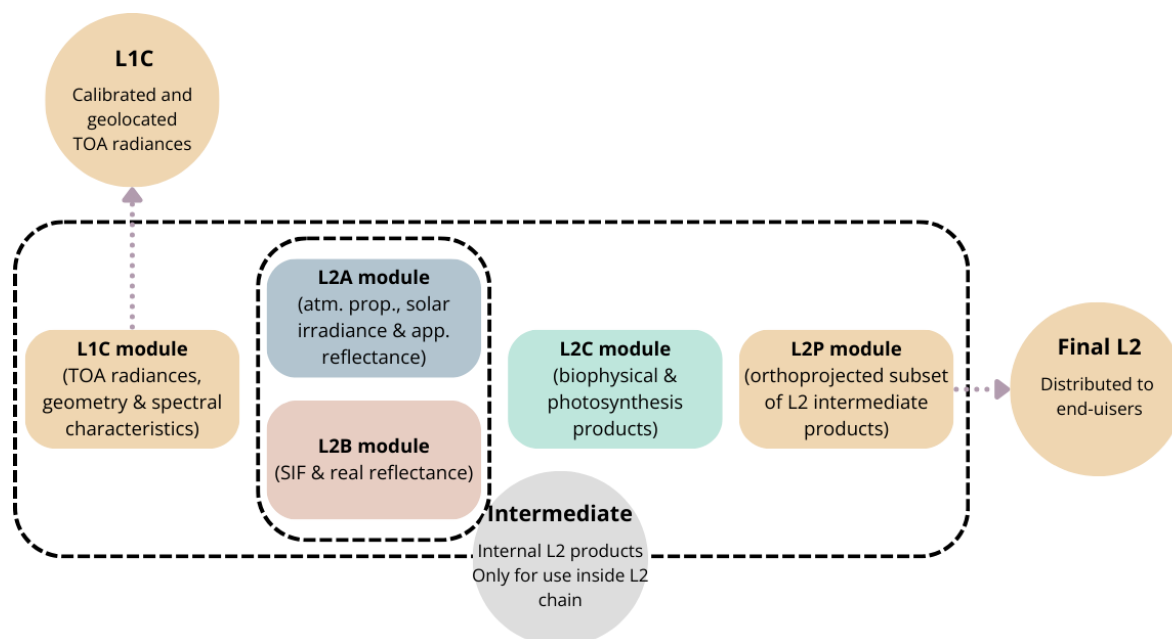


Figure 2: FLEX L2 Processing Chain

According to the L1C & L2 IPF product Format Definition [RD-15], FLEX Mission will generate the following L1C and L2 products (Table 3):

Product	High-level description
L1C	Radiometrically and spectrally calibrated TOA radiances for the FLORIS (HR and LR), OLCI, and SLSTR (nadir and oblique) spatially resampled and projected into the FLORIS-HR focal plane geometry with appended information (quality flags, surface topography, geometry, spectral characteristics).
L2	• Surface apparent reflectance for the FLORIS instruments. • At-surface solar irradiance (direct and diffuse) at FLORIS spectral resolution • Cloud probability mask • Land Surface Temperature (LST) • SIF and surface real reflectance spectra • Biophysical parameters • Photosynthesis-related parameters Note: all products are provided with appended uncertainties.

Table 3: High-level description of FLEX L1C/L2 products

It should be noted that the contingency plan in case of absence of Sentinel-3 is to replace AOD and water vapor originally derived from Sentinel-3 by the Copernicus Atmosphere Monitoring Services (CAMS) data. In this case the FLEX L1C/L2 products could be of a lower quality than when S3 data is used.

3. Interactions and cal/val teams

3.1. Roles and Responsibilities

The FLEX Cal/Val Plan is developed by ESA and the FLEX DISC with feedback from the FLEX MAG. In general, all established Cal/Val teams can be classified as:

- ESA Flight Operation Segment (FOS) team and ESA PDGS team: •Primary source for accessing the telemetry data (HKTM / GNSS Packet Stores / TC History Files). Access to L1/L2 data from the PDGS L1/L2 PFs hosted in MAAP. L1/L2 data will also be available on the DISC Collaborative Platform for external users (e.g. External Validation Team).
- DISC ESLs Team (Internal Expert): Expert Support Laboratory (ESL) on Calibration and Validation, as a part of the DISC project.
- Scientific Core Validation Team (SCVT): This team corresponds to the scientific groups involved in ESA founded campaigns.
- FLEX Scientific External Validation Team (SEVT): This validation team is built through the Announcement of Opportunity (AO) and will be composed of users from the scientific community that will perform validation of the FLEX data products. The VT will have access to the L1/L2 data and the Cal/Val tools on the DISC Collaborative Platform. They may also provide validation data that may be used by the DISC for its validation activities.
- Quality Working Group (QWG) (Expert Group): This group will be set up by the Data Quality Manager (ESA) and includes members of the MAG, industry experts and members of the DISC.

The responsibilities between the FLEX cal/val specific phases is split as follows:

- the Space Segment Commissioning phase, including all its cal/val activities, is led by the FLEX ESA satellite project, with the support of other ESA teams for the validation activities (e.g. DISC ESLs on cal/val);
- the Routine Operations phase, including all its cal/val activities, is under the responsibility of the FLEX Mission Management.

All the teams will include all necessary expertise for calibration and validation:

1) Calibration tasks

- full in-flight calibration and (re)characterisation of all instruments;
- comprehensive verification of Level 1 data processors (tuning of all relevant processing parameters, regeneration of all L1 auxiliary products);
- prepare and advise on necessary Level 1 processor updates;
- routine calibration monitoring and assessment after the end of the Commissioning Phase.

2) Validation tasks

- In Commissioning Phase, Level 2 algorithm verification for all L2 “baseline” products (tuning of all relevant processing parameters, regeneration of all L2 auxiliary products);
- Level 2 algorithm validation starting during Commissioning Phase and continued in Phase E2;
- Quantifying error estimates for L1 and L2 products;
- Long term monitoring for consistency and constant quality of geophysical products;
- Advice on re-processing campaigns.

Team structure and objectives are described separately for Phase E1 and E2. However, there will be a natural transition of team structures from E1 to E2, as key members and functions will remain.

The DISC project actively contributes to the improvement of the Validation Plan Draft [RD-14], preparing all the cal/val driving documents for each FLEX product. With regards Figure 3, the satellite-platform and instrument-level characterization, calibration and verification will rely on intense involvement of the FLEX prime contractor instrument suppliers. Some independent (with respect to the instrument developers) DISC scientific algorithm experts from the ESL will also support the in-orbit verification of the payload calibration and the Level 1 algorithms; these scientific experts will also perform Level 2 algorithm verification. Similarly, for the ground segment, individual verification plans are applicable to the Flight Operations Segment and the Payload Data Ground Segments. Here the verification will include involvement of the relevant subsystem developers. The DISC ESL Validation will take care of the FLEX scientific validation plan and will exchange information, with ESA and with the Validation Teams (after the Announcement of Opportunity) and with the industry.

The DISC scientific algorithm ESL will provide the algorithms and interact with engineers that provide simulated data. The payload engineers will inform the ESL validation when the instrument configuration is sufficiently stable to begin collocated measurements and campaigns. The Validation Database Requirements Document (VDBRD) will serve as a basis to identify simulation data to be used by the ESL validation and algorithms for assessing the quality of the retrieval and to set-up the validation software tools.

The ESL validation and the Validation Teams will perform correlative analysis, intercomparing independent data with FLEX products, considering as far as possible any transformation that would make the comparison more accurate. Also, the campaign data are uploaded to the Collaborative Platform (CP) data centre.

3.1.1 Cal/Val teams during Preparation activities

For pre-launch activities a specific “technical instrument calibration team” is defined comprising ESA staff and industry experts only. In pre-launch, Quality Control/Quality Indicators/Quality assessment tools (QC/QI/QA) and cal/val tools will be developed, tested

and integrated in the Collaborative Platform (CP). L1 Cal/Val tools developed by industries will be tested before launch and used during Commissioning to calibrate the FLORIS instrument and validate its performance and L1b products.

3.1.2 Cal/Val teams during Commissioning Phase

The Cal/Val teams during the Commissioning phase (E1 - 3 months) will be grouped as FLORIS Cal/Val E1-Commissioning Phase Team including:

- ESA staff members that are part of the project team;
- ESA staff members that are part of the PDGS development team;
- Specialists from the Industry Support Team (for calibration and characterisation tasks), with selected specialists from the satellite prime contractor and payload subcontractors;
- DISC Expert Support Laboratories on Cal/Val.

These teams will report to the Commissioning Phase Management Team.

The FLORIS Cal/Val E1 - Commissioning Phase team might as well be complemented by experts that will concentrate on the synergy L1C_SYN product, with a focus on the specific issues like geometrical co-registration.

Expert user feedback from the CP should be included in validation activities. As experience from other operational missions FLEX data streams already in a Commissioning Phase can provide valuable product quality feedback. A detailed strategy of the validation of L1C and L2 products is outlined in the FLEX DISC cal/val activities – Preparation and Commissioning Document.

3.1.3 Cal/Val teams during Routine Operations

ESA will oversee the routine quality control, the calibration analysis and the validation analysis in a continuous manner during the Routine Operations. This also includes details on control and update mechanisms for product algorithms.

On system level the following framework elements for Phase E2 Cal/Val are considered:

- An ESA contractual framework for FLEX Data Innovation and Science Cluster (DISC)
- A set of technical and scientific boards (part of the DISC) to advise Mission Management how to ensure consistent product quality throughout the mission lifetime.
- An independent Validation Team FLEX-VT which will be identified with a specific Announcement of Opportunity.

The FLEX-VT will include subgroups dedicated to data products and may be extended with further expertise.

It is expected that teams defined for Phase E1 will be transferred to the Phase E2 under a new management structure to be defined by ESA. The FLEX-VT established in Phase E1

will continue their support with in-situ measurements and product analysis. All these possible groups are referred to as "FLEX Validation Teams" in this document.

The FLEX CP will include necessary tools, and a dedicated team of CP operators will provide regular monitoring of the data quality.

4. Terminology and Validation stages

To clarify this cal/val document and its relation to other documents and plans, it is important to define the following key terms:

- **Characterization** is the process of probing the properties of a system as a function of expected operating conditions. For example, characterization of degradation and non-linearity are common activities that need to be addressed by most missions. The characterization outputs are applied among others to the subsequent step of calibration.
- **Calibration** is the process of quantitatively defining the system response to known controlled signal inputs (CEOS definition). This involves establishing, under specified conditions, the relationship between values indicated by a measuring instrument (engineering units) and the corresponding known values of a standard (physical units).

This relation is applied in the data processing chain ("product calibration") and/or to an on-board instrument or platform configuration ("instrument/platform calibration"). An example is radiometric calibration, which assigns, for various levels of incident radiation, the relation between charge readout from a detector and radiance in SI units. Two special cases of calibration are:

-External Calibration is a special case where measurements from other (often sub-orbital) independent instruments are used to corroborate this relation. It can be considered a form of verification.

-Vicarious Calibration is a special case of product calibration, where measurements from other independent instruments are needed to establish this relation. This typically involves the satellite sensor observing the target area that has been characterised by the independent sensor (e.g. a desert).

Initial calibrations are performed to establish a baseline for the mission. A subset of calibrations needs to be repeated at regular intervals in case the relation between engineering and physical units is time dependent, e.g. in case of degradation.

Once the initial mission characterization and calibration baseline has been established, the product verification can begin.

- **Verification** is the process of assessing whether a system or product meets its specification. In line with the IEEE, (Algorithm) Verification will exclude any assessment that involves independent data (i.e. from instruments external to the mission). Mission verification is a broad activity which addresses the platform and payload, including thermal, mechanical and electronic aspects although this document will focus on verification of the geophysical performance.
- **Validation** is the process of assessing by independent means the quality of the data provided (CEOS). These independent means are datasets from instruments external to the

mission, e.g. surface-based instrumentation measuring the same geophysical quantity as the satellite sensor that is being validated.

Correlative measurements and correlative datasets refer to the “independent means” in the definition of validation. These are the data from instruments that are independent from those on-board the FLEX satellite, typically from other satellites or sub-orbital data (i.e. from airborne or ground-based (fixed or mobile instruments)).

- **Commissioning** is the process of assessing that all systems have first survived the launch then can be operated according to the mission requirements including the fulfilment of the scientific performance of the mission. Commissioning will encompass in-orbit check-out (switch-on of various equipment/sub-system and instrument followed by some operational health checks), characterization, calibration, verification and validation. Results of the commissioning will be presented and evaluated during the In-Orbit Commissioning Review (IOCR).

The main authority that guides validation activities for satellite retrieved data of biogeophysical variables is the Committee on Earth Observation Satellites (CEOS) Working Group on Calibration and Validation (<http://ceos.org/ourwork/workinggroups/wgcv/>). The CEOS LPV defines four validation stages that represent the level of sophistication of validation protocols employed for a particular data product.

For FLEX, as an Earth Explorer mission, we propose to follow the validation stages below (NASA MODIS). ‘Beta’ and ‘Provisional’ stages shall be achieved by the end of Phase E1, the ‘Stage 2 Validation’ shall be targeted for the operations phase E2. Due to the mission lifetime of 3.5 years, it is uncertain if ‘Validation Stage 3’ can be achieved. However, elements of ‘Validation Stage 3’ should be assessed in Phase F. The FLEX core products are expected to reach stage 3 (and 4) of the CEOS Validation by the end of Phase E2 (see for example CEOS LAI validation framework for the CEOS definitions).

According to the CEOS Hierarchy of Validation, used to define the maturity level, we can consider the following definitions:

Beta: Products intended to enable users to gain familiarity with the parameters and the data formats. It includes: i) early release product, minimally validated and may still contain significant errors, ii) available to allow users to gain familiarity with data formats and parameters and iii) product is not appropriate as the basis for quantitative scientific publications

Provisional: Product was defined to facilitate data exploration and process studies that do not require rigorous validation. These data are partially validated and improvements are continuing; quality may not be optimal since validation and quality assurance are ongoing. It includes: i) product quality may not be optimal, ii) incremental product improvements are still occurring, iii) general research community is encouraged to participate in the QA and validation of the product, but need to be aware that product

validation and QA are ongoing, iv) users are urged to contact science team representatives prior to use of the data in publications, v) may be replaced in the archive when the validated product becomes available

Validated: Products are high quality data that have been fully validated and quality checked, and that are deemed suitable for systematic studies such as climate change, as well as for shorter term, process studies. These are publication quality data with well-defined uncertainties, but they are also subject to continuing validation, quality assurance, and further improvements in subsequent versions. Users are expected to be familiar with quality summaries of all data before publication of results; when in doubt, contact the appropriate instrument team. It includes: i) product uncertainties are well defined over a range of representative conditions, ii) ready for use in scientific publications, and by other agencies, iii) there may be later improved versions.

According to the CEOS Hierarchy of Validation there are four validation stages:

- *Stage 1 Validation:* Product accuracy has been estimated using a small (typically < 30) number of independent measurements obtained from selected locations and time periods and ground-truth/field program effort.
- *Stage 2 Validation:* Product accuracy has been assessed over a widely distributed set of locations and time periods via several ground-truth and validation efforts. Spatial and temporal consistency of the product and with similar products has been evaluated over globally representative locations and time periods. Results are published in the peer-reviewed literature
- *Stage 3 Validation:* Product accuracy has been assessed and the uncertainties in the product well established via independent measurements in a systematic and statistically robust way 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
- *Stage 4 Validation:* Validation results for stage 3 are systematically updated when new product versions are released and as the time-series expands.

The FLEX products are expected to reach different stages of the Validation by the end of Phase E1 with an early L2 product validation that is expected in the Commissioning Phase. All parameters will be updated throughout the lifetime of this document and the companion validation plans.

5. FLEX Product categories

An important step has been to define FLEX Product categories according to the following definitions:

- **FLEX Core Science Data (CSD)**

CSDs are essential to address the mission objective and the scientific goals.

CSDs are directly traceable to the mission objectives and are driving the requirements including performances.

CSD products requirements (including uncertainties) are spelled out in the MRD and shall be validated and verified.

Algorithms for the retrieval of CSDs are being developed by ESA and included in the E2E simulator.

ATBDs for CSD products exist and are being maintained.

CSDs are generated continuously in the PDGS, their quality is being monitored, and ESA is responsible for timely dissemination.

The CSD products are fully captured and detailed in the Cal/Val plan.

The validation infrastructure developed for the mission is tailored to the CSD products.

Full validation to CEOS Stage 3 is targeted for Phase E2.

- **FLEX Supporting Science Data (SSD)**

Data that contribute to addressing the mission objective and/or the scientific goals.

Algorithms for SSDs are well established, and similar products are provided through other missions, albeit with different spatial resolution and/or temporal sampling and /or uncertainties, etc.

A limited number or no requirements are spelled out in the MRD.

ATBDs or similar documentation describing the retrieval algorithm exist and are being maintained.

SSD data are generated continuously in the PDGS and disseminated to the users.

The validation infrastructure is either existing or provided within the framework of dedicated campaigns.

Validation to CEOS stage 2 is targeted for Phase E2.

SSDs are addressed in the Cal/Val plan at least through references to complementing documents, e.g. the Sentinel-3 Cal/Bal plan or similar documents.

- **FLEX Experimental Science Data (ESD)**

Data products that support the scientific goals of the mission.

Algorithms are novel and/or under development and will continuously be refined during Phase E2.

ATBDs are incomplete and/or under development.

Data product requirements (including uncertainties) are partly spelled out in the MRD and should be verified and validated.

ESD can be generated in a DISC framework but may be not generated continuously with full global coverage meeting the latency requirements.

The validation infrastructure is partly in place and/or under development and/or will be provided within the framework of dedicated campaigns within Phase E2.

Validation to CEOS stage 1 is targeted for phase E2.

- **FLEX Ancillary Science Data (ASD)**

Data products that are direct outputs from the processors or derived geophysical variables.

Data products requirements (including uncertainties) are not or only partly provided in the MRD.

There is no or only indirect traceability to the mission objectives.

Non validation is foreseen (CEOS stage 0 is acceptable for Phase E2).

The ASDs can be made available to the users on request.

According to these categories, the list of FLEX products was defined associated with their validation stage during the mission (Table 4/1 and 4/2). Moreover, Table 4 shows the traceability of the validation according to the MRD v3.0 requirements and finally reports the preliminary uncertainty that can be expected in field data in the case of FLEX CSD. The reported uncertainty is only related to ground instruments and retrieval scheme only, without considering the spatial representativeness within the FLEX kernel. The ground measurements and the overall uncertainty will follow a metrological approach (ideally SI-traceable) exploiting the Fiducial Reference Measurements (FRM) protocols by a suite of independent, fully characterized, and traceable ground measurements outlined by the GEO/CEOS Quality Assurance framework for Earth Observation (<https://qa4eo.org/>). These criteria include the establishment of documented evidence of uncertainty with respect to a community-agreed reference and specific tailoring to the needs of a satellite mission and are good cal/val practices adopted in ESA satellite missions.

Data type	Product Level	Variable Type	FLEX L1C/L2 variable	Units	Product Uncertainty (y/n)	Validation (y/n)	Validation Category	CEOS stage	MRD traceability (v 3.0)
Core Science Data	L1B	L1	floris_toa_reflectance (from L1B radiance)	-	-	y	B, C	2/3	MR-FLEX-190, MR-FLEX-200, MR-FLEX-210
	L1C	L1	floris_toa_radiance	mW.m ⁻² .sr ⁻¹ .nm ⁻¹	y	n	-	-	MR-FLEX-190, MR-FLEX-210
	L2A	L2	floris_apparent_reflectance	-	y	y	A	2/3	MR-FLEX-680
	L2B	L2	total_integrated_sif	mW.m ⁻² .sr ⁻¹	y	y	A	2/3	MR-FLEX-010
	L2B	L2	sif_peak_positions	nm	y	y	A	2/3	MR-FLEX-020
	L2B	L2	sif_peak_values	mW.m ⁻² .sr ⁻¹ .nm ⁻¹	y	y	A	2/3	MR-FLEX-020
	L2B	L2	sif_O2_bands_values	mW.m ⁻² .sr ⁻¹ .nm ⁻¹	y	y	A, C	2/3	MR-FLEX-030
	L2B	L2	sif_emission_spectrum	mW.m ⁻² .sr ⁻¹ .nm ⁻¹	y	n	-	2/3	-
Supporting Science Data	L2A	L2	direct_irradiance	mW.m ⁻² .nm ⁻¹	y	y	A	2/3	MR-FLEX-680
	L2A	L2	diffuse_irradiance	mW.m ⁻² .nm ⁻¹	y	y	A	2/3	MR-FLEX-680
	L2C	L2	leaf_chlorophyll_content	µg.cm ⁻²	y	y	A,B,C	1/2	-
	L2C	L2	fraction_of_absorbed_photosynthetically_active_radiation	µmol.µmol ⁻¹	y	y	A,B,C	2	-
	L2C	L2	fapar_chlorophyll	µmol.µmol ⁻¹	y	y	B	1/2	-
	L2C	L2	apar_chlorophyll_photons	µmol.photons.m ⁻² .s ⁻¹	y	y	B	2	MR-FLEX-060
	L2C	L2	leaf_area_index	m ² .m ⁻²	y	y	A,B,C	3	-
	L2C	L2	leaf_carotenoid_content	µg.cm ⁻²	y	y	A,B	1/2	-
	L2A	L2	land_surface_temperature	K	y	y	A	2/3	MR-FLEX-040
	L2A	L2	aerosol_optical_thickness	-	y	y	A	3	-
Experimental Science Data	L2A	L2	columnar_water_vapor	g.cm ⁻²	y	y	A	3	-
	L2C	L2	reversible_energy_dissipation	µmol.m ⁻² .s ⁻¹	y	y	A	1/2	MR-FLEX-050
	L2C	L2	fluorescence_quantum_efficiency	µmol.µmol ⁻¹	y	y	A,B	1/2	-
	L2C	L2	electron_transport_rate	µmol.m ⁻² .s ⁻¹	y	y	A	1/2	-
	L2C	L2	fluorescence_escape_probability	-	y	y	B	1/2	-
	L2C	L2	PSI_PSIII_relative_contribution	-	y	n	-	-	-
	L2A	L2	angstrom_exponent	-	y	y	A	3	-
Ancillary Science Data	L2A	L2	asymmetry_parameter	-	y	y	A	3	-
	L2B	L2	floris_real_reflectance	-	y	n	-	-	-
	L2A	L2	integrated_par	µmol.photons.m ⁻² .s ⁻¹	y	n	-	-	-
	L1C	L1	crosscalibration_coefficients	-	y	y (calibration)	C	-	-
	L1C	L1	floris_spectral_channel_central_wavelengths	nm	y	y	B	2/3	MR-FLEX-220, MR-FLEX-330, MR-FLEX-550, MR-FLEX-560, MR-FLEX-570
	L1C	L1	floris_spectral_channel_fwhm	nm	y	y	B	2/3	MR-FLEX-230, MR-FLEX-240, MR-FLEX-340, MR-FLEX-550, MR-FLEX-560, MR-FLEX-580
	L1C & L2	L1/L2	longitude	deg	y	y	C	2/3	MR-FLEX-290, MR-FLEX-320
	L1C & L2	L1/L2	latitude	deg	y	y	C	2/3	MR-FLEX-290, MR-FLEX-320
	L1C	L1	olci_toa_radiance	mW.m ⁻² .sr ⁻¹ .nm ⁻¹	y	n	-	-	-
	L1C	L1	slstr_nadir_toa_radiance	mW.m ⁻² .sr ⁻¹ .nm ⁻¹	y	n	-	-	-
	L1C	L1	slstr_oblique_toa_radiance	mW.m ⁻² .sr ⁻¹ .nm ⁻²	n	n	-	-	-
	L1C	L1	slstr_nadir_tir_toa_radiance	mW.m ⁻² .sr ⁻¹ .nm ⁻³	n	n	-	-	-
	L2A	L2	olci_apparent_reflectance	-	n	n	-	-	-
	L2A	L2	slstr_apparent_reflectance	-	n	n	-	-	-

Table 4/1: FLEX product categories and main characteristics of the L1C/L2 mission products subject to validation. CEOS validation stage, MRD requirements, uncertainty of ground measurements for some products is also indicated for some products. Cal/val tools names are also indicated

FLEX DISC
Cal/Val Plan Overview

Ref. : FLEXDISC-CALVAL-PLAN-UMB-030
Date : 31/03/2026
Issue : 3.0

Data type	Product Level	Variable Type	FLEX L1C/L2 variable	Units	Ground data Instrument/retrieval uncertainty (single point)	Cal/Val tool name
Core Science Data	L1B	L1	<i>floris_toa_reflectance (from L1B radiance)</i>	-	VICALOPS uncertainty in reflectance on order of 5%	VICALOPS
	L1C	L1	<i>floris_toa_radiance</i>	mW.m ⁻² .sr ⁻¹ .nm ⁻¹	-	-
	L2A	L2	<i>floris_apparent_reflectance</i>	-	HYPERNETS uncertainty on order of 3%; FLOX reflectance uncertainty TBD	L2A_AtmCorr
	L2B	L2	<i>total_integrated_sif</i>	mW.m ⁻² .sr ⁻¹	In progress for FLoX (FRM4FLUO project)	L2B_SIF_SinglePoint/L2B_SIF_MultiplePoints/L2B_SIF_Airborne
	L2B	L2	<i>sif_peak_positions</i>	nm	In progress for FLoX (FRM4FLUO project)	L2B_SIF_SinglePoint/L2B_SIF_MultiplePoints/L2B_SIF_Airborne
	L2B	L2	<i>sif_peak_values</i>	mW.m ⁻² .sr ⁻¹ .nm ⁻¹	In progress for FLoX (FRM4FLUO project)	L2B_SIF_SinglePoint/L2B_SIF_MultiplePoints/L2B_SIF_Airborne
	L2B	L2	<i>sif_O2_bands_values</i>	mW.m ⁻² .sr ⁻¹ .nm ⁻¹	In progress for FLoX (FRM4FLUO project)	L2B_SIF_SinglePoint/L2B_SIF_MultiplePoints/L2B_SIF_Airborne/L2B_SIF_Satellite (only A)
	L2B	L2	<i>sif_emission_spectrum</i>	mW.m ⁻² .sr ⁻¹ .nm ⁻¹	-	-
Supporting Science Data	L2A	L2	<i>direct_irradiance</i>	mW.m ⁻² .nm ⁻¹	HYPERNETS uncertainty on order of 3%; FLOX irradiance uncertainty TBD	L2A_AtmCorr
	L2A	L2	<i>diffuse_irradiance</i>	mW.m ⁻² .nm ⁻¹	-	-
	L2C	L2	<i>leaf_chlorophyll_content</i>	µg.cm ⁻²	Difficult to specify, as the reference data can be collected using a variety of field instruments	L2C_Bio_Campaign/L2C_Veg_RTM/L2C_Veg_Satellite
	L2C	L2	<i>fraction_of_absorbed_photosynthetically_active_radiation</i>	µmol.µmol ⁻¹	Difficult to specify, as the reference data can be collected using a variety of field instruments	L2C_Bio_Campaign/L2C_Bio_network/L2C_Veg_RTM/L2C_Veg_Satellite
	L2C	L2	<i>fapar_chlorophyll</i>	µmol.µmol ⁻¹	-	L2C_Veg_RTM
	L2C	L2	<i>apar_chlorophyll_photons</i>	µmol.photons.m ⁻² .s ⁻¹	-	L2C_Veg_RTM
	L2C	L2	<i>leaf_area_index</i>	m2.m ⁻²	Difficult to specify, as the reference data can be collected using a variety of field instruments	L2C_Bio_Campaign/L2C_Bio_network/L2C_Veg_RTM/L2C_Veg_Satellite
	L2C	L2	<i>leaf_carotenoid_content</i>	µg.cm ⁻²	Difficult to specify, as the reference data can be collected using a variety of field instruments	L2C_Bio_Campaign/L2C_Veg_RTM
	L2A	L2	<i>land_surface_temperature</i>	K	Radiometer uncertainty ~0.3K, point retrieval uncertainty ~0.3K to 0.8K	L2A_LST
	L2A	L2	<i>aerosol_optical_thickness</i>	-	0.01 - 0.02	L2A_AtmChar
Experimental Science Data	L2A	L2	<i>columnar_water_vapor</i>	g.cm ⁻²	c. 10%	L2A_AtmChar
	L2C	L2	<i>reversible_energy_dissipation</i>	µmol.m ⁻² .s ⁻¹	Expected uncertainty of the reference data from PAM will be added after the completion of FRM4FLUO	L2C_Photosyn_campaign
	L2C	L2	<i>fluorescence_quantum_efficiency</i>	µmol.µmol ⁻¹	Expected uncertainty of the reference data from PAM will be added after the completion of FRM4FLUO	L2C_Photosyn_campaign/L2C_Veg_RTM
	L2C	L2	<i>electron_transport_rate</i>	µmol.m ⁻² .s ⁻¹	Expected uncertainty of the reference data from PAM will be added after the completion of FRM4FLUO	L2C_Photosyn_campaign
	L2C	L2	<i>fluorescence_escape_probability</i>	-	-	L2C_Veg_RTM
	L2C	L2	<i>PSII_PSII_relative_contribution</i>	-	-	-
	L2A	L2	<i>angstrom_exponent</i>	-	c. 0.03-0.04	L2A_AtmChar
Ancillary Science Data	L2A	L2	<i>asymmetry_parameter</i>	-	c. 3-5%	L2A_AtmChar
	L2B	L2	<i>floris_real_reflectance</i>	-	-	-
	L2A	L2	<i>integrated_par</i>	µmol.photons.m ⁻² .s ⁻¹	-	-
	L1C	L1	<i>crosscalibration_coefficients</i>	-	Calibration via RadCal tool	L1C_RADCAL
	L1C	L1	<i>floris_spectral_channel_central_wavelengths</i>	nm	-	L1C_SPECAL
	L1C	L1	<i>floris_spectral_channel_fwhm</i>	nm	-	L1C_SPECAL
	L1C & L2	L1/L2	<i>longitude</i>	deg	-	L1C_GEOLOC/L2_GEOLOC
	L1C & L2	L1/L2	<i>latitude</i>	deg	-	L1C_GEOLOC/L2_GEOLOC
	L1C	L1	<i>olci_toa_radiance</i>	mW.m ⁻² .sr ⁻¹ .nm ⁻¹	-	-
	L1C	L1	<i>slstr_nadir_toa_radiance</i>	mW.m ⁻² .sr ⁻¹ .nm ⁻¹	-	-
	L1C	L1	<i>slstr_oblique_toa_radiance</i>	mW.m ⁻² .sr ⁻¹ .nm ⁻²	-	-
	L1C	L1	<i>slstr_nadir_tir_toa_radiance</i>	mW.m ⁻² .sr ⁻¹ .nm ⁻³	-	-
	L2A	L2	<i>olci_apparent_reflectance</i>	-	-	-
	L2A	L2	<i>slstr_apparent_reflectance</i>	-	-	-

Table 4/2: FLEX product categories and main characteristics of the L1C/L2 mission products subject to validation. CEOS validation stage, MRD requirements, uncertainty of ground measurements for some products is also indicated for some products. Cal/val tools names are also indicated

6. Introduction to the validation plan documents

As mentioned in the introduction a set of 6 documents are submitted to ESA along with this overview document, defining the validation strategy for each FLEX product. This brief chapter aims to introduce the validated products and refers to specific ESL cal/val documents for a more detailed description.

The validation plans presented by different ESLs describe in detail the different products to be validated during the FLEX mission, the validation procedures, available sites, field instruments, and the overall preliminary planning for commissioning. These documents are considered living documents and will be updated as needed during the mission.

All plans are focused on validation, except for the L1C which also considers calibration in relation to S3 OLCI and FLEX FLORIS.

In summary, the ESL cal/val documents are:

- L1C/L2: Geolocation at L1C and L2;
- L1: Vicarious validation of the radiometric and spectral calibration and FLORIS/OLCI cross calibration coefficients; VICALOPS is used to validate L1B radiances;
- L2 (L2A): Atmospheric characterisation (CWL, AOD, ANG, ASY) and atmospheric correction parameters (surface apparent reflectance and at-surface solar irradiance) , Land Surface Temperature;
- L2 (L2B): Fluorescence parameters;
- L2 (L2C): Biophysical and photosynthesis-related parameters;
- Validation Database Definition Document, which describes the format and type of input data of sensor networks and field campaign data to properly collect data and run the cal/val tools.

In addition to the above documents, additional calibration/validation plan for L1B products is expected to be defined and conducted by the instrument's prime contractor (Leonardo) prior to the operational phase and then conducted by the FLEX DISC lead by Magellium during the operational phase.

Below, is a summary of the validations carried out by various DISC ESLs:

L1 Vicarious Cal/Val Plan	
Monitored variables	L1B radiance (in term of TOA reflectance)
Method	Use of VICALOPS service using PICS (Pseudo-Invariant Calibration Sites)
Monitored variables	Calibration of S3 OLCI radiometry coefficient at L1C
Method	Cross calibration of S3 OLCI and FLEX FLORIS using a stand-alone tool.
Monitored variables	FLORIS wavelengths and FWHM at L1C
Method	Determination of spectral shift (barycenter) and band broadening (FWHM) by comparison against simulated TOA radiances over selected bare-soil targets.
L1C/L2 Cal/Val Plan	
Monitored variables	L1C co-registration
Method	Correlation FLORIS vs OLCI on common spectral bands Correlation FLORIS HR vs LR on common spectral bands
Monitored variables	L2 geolocation
Method	Correlation FLORIS LR vs reference Sentinel-2 L1C on common spectral bands
L2 (L2A) - Atmosphere - Validation Plan	
Monitored variables	L2: Columnar water vapor (CWV), Aerosol optical depth (AOD), Angstrom exponent (ANG), Asymmetry parameter (ASY), [Single scattering albedo (SSA)] (not retrieved, taken from climatology)

Method	Comparison with AERONET direct products (AOD, ÅNG, CWV) and inversion products (ASY, SSA): • Typical procedure of satellite aerosol product validation against AERONET is used (e.g. Ichoku et al. 2002) • Satellite data is spatially sampled (averaged) near the AERONET site (within e.g. 0.5° or 50 km) • AERONET data is temporally sampled around the satellite overpass time (e.g. ±30 min)
Monitored variables	L2: apparent surface reflectance, at-surface irradiance
Method	Comparison FLEX L2A products with LANDHYPERNET (desert, forest, agricultural) and INSIF networks

L2 (L2B) – Fluorescence - Validation Plan	
Monitored variables	L2: Full SIF spectra and SIF metrics
Method	1. Direct comparison of satellite L2B products with in-situ measurements (INSIF networks), Upscaling based on bottom-up approach using higher spatial resolution data (e.g., Sentinel 2) 2. Multiple points based on spatial sampling, 3. Validation with airborne data 4. Comparison with satellite data

L2C – Vegetation - Validation Plan	
Monitored variables	Traditional variables (direct approach): Effective leaf area index (LAI) [m² m⁻²], fraction of absorbed photosynthetically active radiation (fAPAR) [-], Leaf chlorophyll content (LCC) [µg m⁻²], Leaf carotenoid content (LCARC) [µg m⁻²]
Method	Option 1: direct non-destructive in-situ sampling • Field campaigns required during commissioning and operational phases Option 2: use of existing networks • See ESL Biophysical variables document (indirect)

Monitored variables	Advanced products (direct approach): absorbed photosynthetically active radiation by chlorophyll ab (APAR_chl) [photons m⁻² s⁻¹], Electron transport rate (ETR), Reversible Energy Dissipation (RED), Non-photochemical quenching (NPQ), Fluorescence quantum yield (FQE), Fluorescence escape probability (fesc) [-]
Method	- PSI/PSII: using Dual-PAM instrument - NPQ, FQE: Measurements with active fluorescence (such as moni-PAM) - APAR_chl: using light interception (ceptometers), - RED and ETR, estimated from NPQ, FQE and APAR_chl using a scaling function from leaf to FLORIS spatial resolution.
Monitored variables	Traditional variables (indirect approach): Effective leaf area index (LAI) [m² m⁻²], fraction of absorbed photosynthetically active radiation (fAPAR) [-], Leaf chlorophyll content (LCC) [µg m⁻²], Leaf carotenoid content (LCARC) [µg m⁻²], Advanced products (indirect approach): absorbed photosynthetically active radiation by chlorophyll ab (APAR_chl) [photons m⁻² s⁻¹], Electron transport rate (ETR), Non-photochemical quenching (NPQ), Fluorescence quantum yield (FQE), Fluorescence escape probability (fesc) [-]
Method	Method 1: Satellite product inter-comparison - LAI, fAPAR: comparison to existing datasets (e.g., C3S, CLMS, MODIS, LSA-SAF) - LCC: Chlorophyll proxy products (C3S) Method 2: Indirect validation through inversion of FLoX data RTM inversions from reflectance and SIF FLoX data (either full inversion or using reflectance indices), if available combined with direct method with PAM fluorescence (see above) For classical biophysical parameters + LCARC + APAR_chl - PROSAIL inversion from FLOX and Sentinel-2 For fesc, FQE, NPQ/iPRI and ETR - fesc: From FLoX reflectance using spectra reflectance indices or SCOPE inversion - FQE: From FLoX reflectance and SIF using spectra reflectance indices or SCOPE inversion - NPQ: Using DeltaPRI from FLoX or spectral fitting of diurnal reflectance in the 500-600 nm range - ETR: inversion of FLoX data and use of PAM data in forward modeling (such as SCOPE)

L2A – LST - Validation Plan	
Monitored variables	L2: Land Surface Temperature (LST) [uncertainty of $\pm 1K$ (G) and $\pm 2K$ (T)]
Method	• Temperature-based validation, which is comparison of satellite-retrieved LST with in situ measurements collected from radiometers sited at a number of stations spread across the Earth (SURFRAD, USCRN, ARM, BSRN, Copernicus LAW), for which the highest-quality validation can be achieved. • Radiometric-based validation, which offers an alternative to validation with in-situ LST measurements as it does not require measurements of LST on the ground, and can provide a viable alternative for long-term, operational LST product evaluation at the global scale; • Inter-comparisons with similar LST products from other sources, which give important quality information with respect to spatial patterns in LST deviations; • Time series analysis to quantify trends and to identify potential instrument drift or persistent cloud contamination.

7. Cal/val plans overview

Overall, to perform a proper validation of the FLEX products, it is necessary to consider that the FLORIS sensor will acquire data in the 500 - 780 nm spectral range with a spectral resolution between 0.3 nm (High Resolution, HR) and 1.8 nm (Low Resolution, LR). Spectral sampling interval/spectral binning will be from 0.1 nm in the oxygen absorption bands (748-769 nm and 686-697 nm) up to 2 nm outside the atmospheric absorption bands. Data will be provided at a spatial resolution of 300 m, and the observation time will be around 10:00 local time, with a 150 km swath and 27 days repeat cycle. FLEX will fly in tandem with Sentinel-3. FLORIS will operate synchronously with Sentinel-3 camera 4, covering a 14 degrees field of view. Therefore, the ground/airborne instruments used for validation, should be in line with the specific characteristics of FLEX and the final aggregated data should be identified with the associated uncertainty at each wavelength. In general, an area of 2x2 or 3x3 pixels could be considered for the validation approaches.

The validation plan of FLEX is made of different components, organised to provide a useful roadmap for evaluating the overall quality of the mission's core products. Overall, FLEX Validation activities should address three main objectives, which can be reached at different times of the mission:

a) to provide a comprehensive initial assessment of product validity and quality at the end of commissioning activities with documented and associated traceable uncertainty estimates. In this context, it is necessary to develop and prepare documentation, guidelines, and tools for validation of products before the Commissioning Phase.

b) to gain knowledge on the sensor performance and the algorithms characteristics to improve their quality and reliability. To monitor the stability and the quality of the products throughout the operational phase of the mission;

c) to continuously improve the quality of the products throughout the operational phase of the mission following the evolving user requirements.

The validation document includes all the necessary activities to define and develop Cal/Val tools, including data and plans to be used in Phase E2:

- identification of the validation data;
- definition and development of the tools needed for the calibration activities;
- definition of the planning of the calibration activities;
- definition and development of the tools needed for validation activities;
- definition of the planning of the validation activities.

This Plan defines the scope of the activities that will validate the data products generated operationally and disseminated by the PDGS centres. In the following section we present the general framework of the FLEX cal/val activities. Instruments requirements, optimal strategy for sampling, processing methods and tools and implementation practices are fully described in the specific cal/val documents of each ESL.

7.1. Pillars for upscaling FLEX products and cal/val components

Different components should be considered in the FLEX validation plan. Basically, these can be summarised as follows:

- i. Definition of the FLEX products to be validated;
- ii. Definition of the validation approaches, sites classification and sampling approach;
- iii. Instruments requirements and essential measurements type for temporal and spatial sampling;
- iv. Site definition requirements and site selection;
- v. Definition of the upscaling approach, identification of possible validation strategies;
- vi. Set-up of cal/val toolbox.

A valuable lesson learned in global land imaging has been that validation is critical for accurate and credible product usage. It must be based on quantitative estimates of uncertainty for all products. For satellite-based retrievals, this should include direct comparison with independent correlative measurements. The assessment of uncertainty

must also be conducted and presented to the community in normally used metrics to facilitate acceptance and implementation. Overall, FLEX will utilise a wide range of methodologies in calibrating and validating the mission science products, these include:

- In situ networks;
- Tower, drone, and airborne-based;
- Natural targets;
- Satellite products;
- Model-based products;
- Field experiments
- Simulated scenes (in Development Phase only)

Some of these instruments/platforms and methodologies will be better suited to a specific product than others. Matching these to FLEX products is addressed in the specific ESL cal/val documents, while within the Field Database document a specification of the data is presented and linked with the document related to the CP. Here, we remark the importance of having a traceable database of ground measurements and overall, the ground value uncertainty should be less than the satellite product uncertainty.

Another important consideration in developing the Cal/Val Plan is that FLEX will provide global products. Therefore, product validation should be representative of a wide range of global climate and vegetation conditions. Obviously, the logistics and potential costs of conducting a fully comprehensive program may be beyond the capabilities available. Success will require partnerships that leverage ongoing programs, both within the EU and internationally.

Validation schemes and letters in Figure 3, refer to the type of validation approach and, for FLEX missions, we can consider different categories. Regarding the sampling approach, the different shapes in Figure 4 are related to the different type of measurements that can be done encompassing field spectroscopy or image systems. Regarding the instruments and the measurements, we should consider SIF-p: Ground spectrometers for Top of canopy radiance, reflectance and fluorescence; At: Instruments for atmospheric characterization; Dr: UAV (or robotic) spectroscopy; Air: Airborne sensors; €: Additional instruments for environmental measurements (spectral, ecological...); EO: Earth Observation data. We can think of a constellation of different sites (core, support ...), which provide data suitable for the different validation schemes. For example, the key in Figure 3 indicates the core site's typology. Finally, the target type should be classified according to site requirements and ecosystem shape, evaluating spatial characteristics.

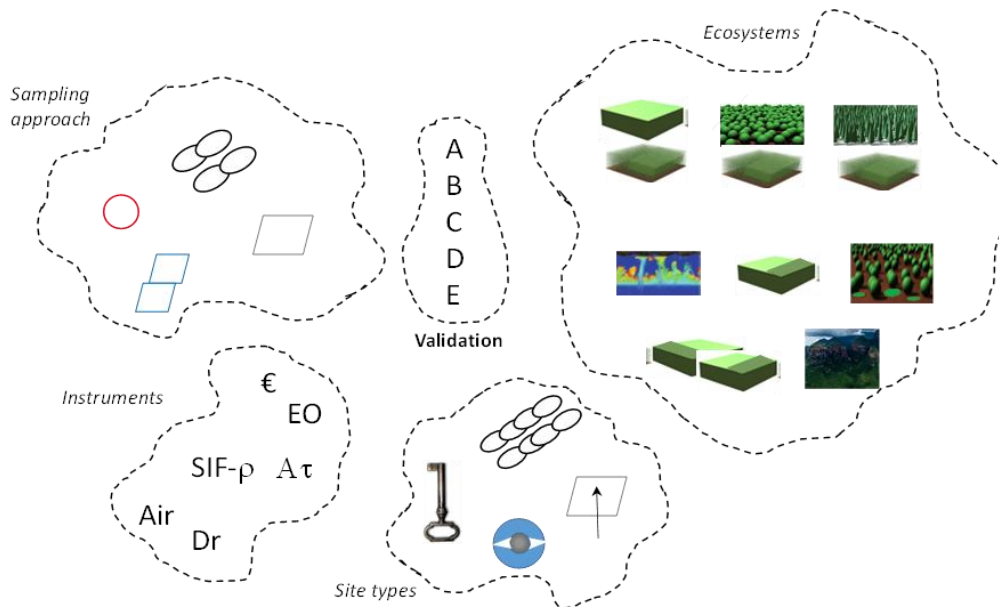


Figure 3: Main components of the FLEX validation process

Another view of the cal/val components is presented in Figure 4. Different measurements can be collected in the different phases of the mission, with point data collected at leaf and canopy scale and covering the spatial domain.

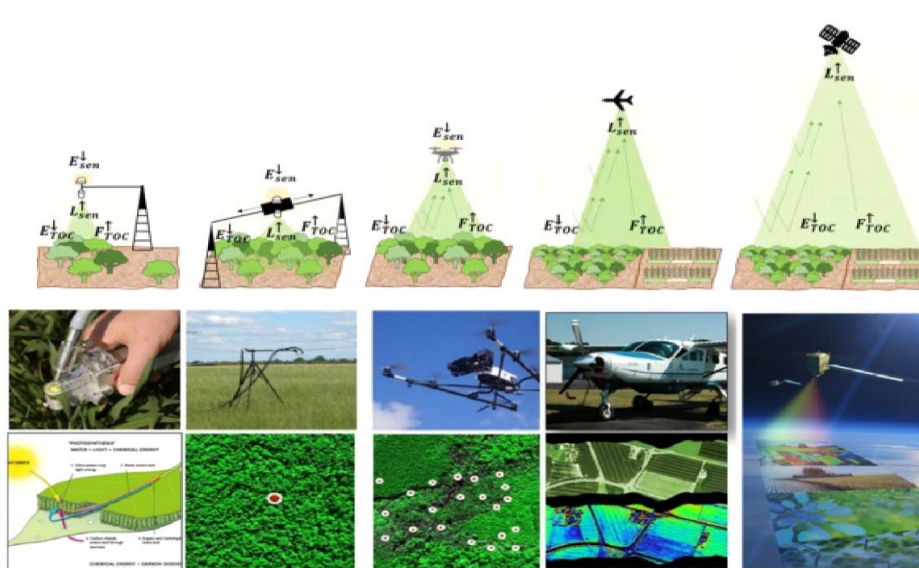


Figure 4: Main components of the FLEX validation process for reflectance, fluorescence and higher-level products

7.2. Validation approaches

Different studies, research and national and international efforts have been pursued and currently running for defining appropriate validation schemes of both radiance products, reflectance and higher-level products (e.g. thematic maps of bio/geophysical variables) (e.g. Guillevich et al., 2014). For the FLEX mission, the following categories are considered.

Category A: Comparison of satellite with in-situ measurements: This is the traditional and most straightforward approach to validating any given parameter. It involves a direct comparison of satellite-derived value with collocated and simultaneously acquired measurement from ground-based instruments. The approach is basically a direct validation using a bottom-up approach (e.g. Morissette et al. 2006). This type of validation should be performed over core and support sites, using single spot spectral measurements, multiple points or mapping measurements with well-characterised instruments and defined uncertainty of the retrieval.

Category B: Indirect validation through numerical RTMs (i.e., radiance-based validation technique). This approach can be exploited where availability of fluorescence monitoring is limited or absent, but also at core and support sites. This technique uses top-of-atmosphere (TOA) data in conjunction with a radiative transfer model to simulate ground SIF using field data and atmospheric profiles of air temperature and water vapour content.

Category C: Inter-comparison with space products. A wide variety of airborne and spaceborne instruments collect similar data and many provide operational products. Inter-comparison of products from different satellite instruments can be valuable for determining the accuracy of a parameter, given that all the systems use the same (or compatible) retrieval algorithms.

Category D: Time series analysis. Analysing time series of satellite data over a temporally stable target site allows for identification of potential calibration drift or other issues of the instrument that manifest themselves over time. Furthermore, problems associated with cloud contamination for example may be identified from artefacts evident in the time series. Care must be taken in distinguishing between instrument-related issues such as calibration drift and real geophysical changes of the target site or the atmosphere.

Category A and B represent the most important approaches to be used for FLEX.

Category C is not fully considered for fluorescence, since the main fluorescence products from FLEX do not have similar counterparts in other satellite products to compare against. Lack of similar or higher spatial resolution satellite fluorescence data do not allow to apply a full bottom-up approach strategy. FLEX will collect data at an unprecedented spatial resolution, and it may become a future benchmark for evaluating other fluorescence

products derived from other space missions. A network of sites of vegetated areas distributed worldwide could be harmonised with, for example, TROPOMI and OCO-2 estimates for time series/stability comparison. However, this comparison approach can be also done for larger areas (such as corn belt, forest, savannah type...) to evaluate consistency in terms of spatial pattern, bias, completeness etc.

Finally, due to the low temporal resolution of FLEX, the Category D may not be fully adequate for L2B product validation.

For FLEX L2A reflectance product perspectives, core sites are used for validation and comparison and all categories A, B and C should be pursued.

For FLEX L2A surface solar irradiance product perspectives, we should introduce a network of sites (e.g. SolarSites), which can initially grow up around the current FLOX location. This should allow characterising spectrally resolved solar irradiance in different geographic contexts. These sites can be defined as SolarSites and the category A can be easily performed. To a certain extent, also the SURFRAD (Surface Radiation Budget) Network at <https://gml.noaa.gov/grad/surfrad/> can be evaluated.

7.3. FLEX products validation procedures

The methodology and the preliminary information for implementation for the validation of the different FLEX products are described in the specific ESL validation documents, as well as the input data and the instrument's requirements.

7.4. Site classification

For FLEX, we propose to have a constellation of different sites, which provides data suitable for the different validation approaches. The sites should satisfy site characteristics and instrument requirements to become core sites and peripheral sites are needed to improve the overall validation quality. The sites' description and locations are presented in the different ESLs validation documents.

RadSites, SpecSites and CrossCalSites. These are non-fluorescent sites to address radiometric cal/val, of L1B, L1C and L2A and include RadCal network and CEOS VICALOPS sites; Desert locations; sites devoted to determining baseline and offset error (zero fluorescence) and to evaluate the FLORIS performance characterisation and recalibration.

GeolocSites. These sites will be used for co-registration and geolocation validation. In particular for L1C FLORIS TOA radiance vs OLCI geolocation validation and for L2 FLORIS reflectance vs Sentinel 2 geolocation validation.

AtmoSites. These sites correspond to AERONET sites, and they are used for direct validation A of atmospheric parameters at L2A.

SolarSites. These sites are established according to the current worldwide distribution of the HYPERNETS and FLOX instruments. Direct comparison according category A can be performed to evaluate solar irradiance products.

RefSites. These sites are used for the direct validation A of apparent reflectance and currently they correspond to the LAND HYPERNET and FLOX sites. However, FLOX sites are still under evaluation. Currently, we still don't know which SIF sites are involved because the INSIF network (International Network of Sun Induced Chlorophyll Fluorescence) is not in place yet, whereas the Hypernet network is already established and the sites are known.

FluoSingleSites. These sites are core sites for fluorescence products, and they belong to the INSIF network. They are established research sites explicitly dedicated to continuous monitoring of solar-induced SIF (and reflectance), with financial support to assure their availability, maintenance and calibration during the mission operative lifetime. Core sites are defined as core when they have located a permanent and well-defined set-up of traceable ground fluorescence and atmospheric instruments for continuous measurements during the FLEX mission. They should be the Cal/Val sites with high performance and calibrated ground instruments providing point and spatial uncertainty. These sites can be also used for satellite data inter-comparison validation activities. They can be homogeneous or heterogeneous, with different sampling approaches (i.e. field spectroscopy, multiple spots, and mapping), encompassing sites with or without equipment from existing ecological/radiance networks and with field/site facilities devoted to different experiments and research questions. These sites should provide the highest accuracy and best error budget. These sites will allow validation approaches for L2A, L2B and L2C according to the categories A, B (and C for some biophysical parameters) and could match with other networks sites (e.g. ICOS, S3 networks). These sites should be characterised in terms of spatial representativeness using geo-statistical tools for assessing spatial uncertainty. Some indications about how to infer spatial representativeness are presented in Section 7.6. Continuous measurements of biophysical and functional parameters could be useful to be measured at core sites and a link with existing networks can benefit the choice of the core sites. Basically, instrument requirements and landscape characteristics drive the choice to become a core site.

FluoMultiSites. correspond to sites where the validation is performed by using multiple points measurements collected by field spectroscopy techniques in dedicated campaigns, with instruments on board of AirFlox-like platforms (category A based on drones-like systems).

FluoImageSites and FluoSatSites. correspond to sites where the validation is performed by using an airborne system (category A) in dedicated campaigns or other satellite data. These sites can correspond to FluoSingleSites and FluoMultipleSites in case they are covered by an airborne acquisition. are basically a network of worldwide distributed check pixels without any ground instrumentation that would help to determine

baseline error and offset in the retrieval algorithm to make estimations over non-vegetated regions and evaluate the consistency of SIF over vegetated surfaces. Satellite sites respond to the validation approach by category C (mainly by using TROPOMI) and may be selected based on existing networks with different purposes.

BioDirectSites, BioIndirectSites and BioImageSites dealing with biophysical or functional vegetation parameters (L2C). **BioDirectSites correspond to LANDVAL and GBOB networks and allow for Validation A.** *BioIndirectSites* correspond to FLOXsites and can be used for validation A, B, while *BioImageSites* approximately correspond to **FluoSatSites** and allow for Validation category C.

BioCampSites. Correspond to sites used for the validation of vegetation L2 products collected in specific field/airborne campaigns.

LSTSites are used for L2A - LST validation. Ground instrument uncertainty is provided, and validation A will be conducted

SupportSites are sites defined on demand after AO. These sites can address different types of validation and can become new sites linked to structured networks, or new sites where campaigns are carried out. Specifically, for campaign sites, they could for example become FluoMultiSites, FluoImageSites, Biosites, or new LSTCampSites or new RefCampSites. Ground spectral instruments are set-up and running without having the need to collect data continuously. These sites can be equipped for long term temporal fluorescence measurements but without satisfying criteria to become core sites (e.g. due to their heterogeneity, only single point measurements or with only one instrument in complex ecosystems or fragmented terrain). They can include a variety of purposes for short-term/one-shot experiments, manipulations, etc. As core sites, they should be equipped with ground spectrometers and will mainly serve for A and B validation approaches. These sites should be linked with existing networks. These

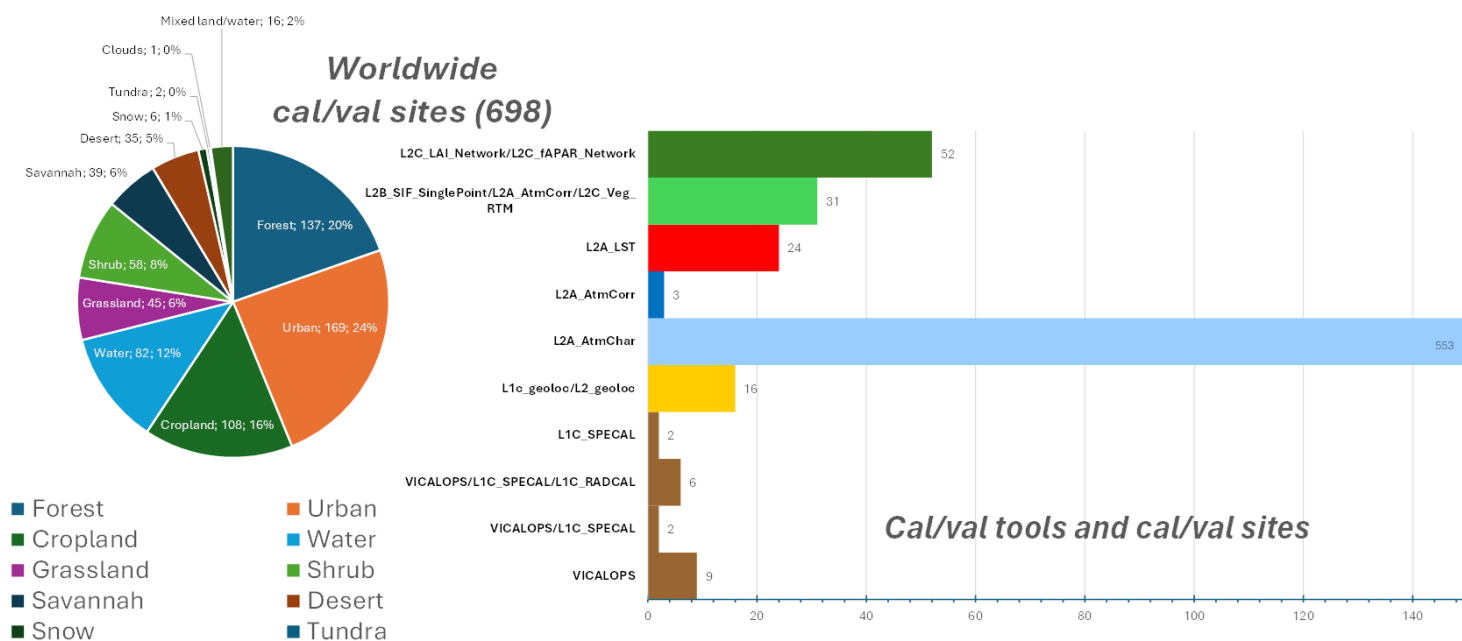
QASites are sites used to perform a qualitative evaluation (Qualitative Assessments, QA) of different products, according to the quality indicators defined for each product. The evaluation is conducted in a large region of interest at image level.

Overall, according to this scheme the sites can be used for different stages of validation and therefore afford a more exhaustive strategy of Cal/Val of FLEX. Validation should extend globally over relevant biomes and latitudes, continuously over seasonal changes, and it should contemplate the accuracy and precision of the different mission products. Data from the different validation sites should be compiled in a homogenised database for easy and consistent processing within the collaborative platform.

Having a supersite equipped with all the instrumentation for validating all the products is still challenging. Currently, we do not have a supersite where all relevant parameters are measured simultaneously. Some sites are designated for reflectance and fluorescence measurements and will be used for inversion techniques to retrieve vegetation parameters. However, these locations do not yet support direct measurements of

vegetation properties or land surface temperature. Following the AoO, we will assess whether new sites can be made available to expand the measurement capabilities.

At the current stage, 698 sites have been identified. Figure 5 shows a chart illustrating the distribution of the sites by land cover and the number of sites as a function of the specific cal/val tool associated with a given product. Most of the sites are used for validating the characterization of atmospheric parameters through the L2A_AtmoChar tool, which relies on data from the AERONET network. It should be noted that the INSIF network is still ongoing, and the number of sites is preliminary and needs to be reviewed.



- Rad Sites [VICALOPS]
- Rad Sites, Spec Sites [VICALOPS, L1C_SPECAL]
- Spec Sites [L1C_SPECAL]
- Rad Sites, Spec Sites, Cross Sites [VICALOPS/L1C_SPECAL/L1C_RADCAL]
- Atmo Sites [L2A_AtmoChar]
- Geoloc sites [L2_geoloc/L1c_geoloc]
- FluoSingle Sites, Solar Sites, RefSites, BioindirectSites [L2B_SIF_SinglePoint/L2A_AtmoCorr/L2C_Veg_RTM]
- BioDirect Sites [L2C_Bio_Network]
- LST Sites [L2A_LST]
- Solar Sites, RefSites [L2A_AtmoCorr]

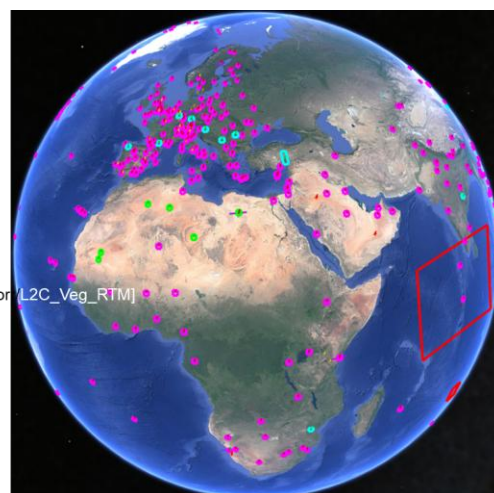


Figure 5: Top: distribution of the sites by land cover and number of sites for each cal/val tool. Bottom: distribution of the sites based on the type of FLEX product to be validated and corresponding cal/val tool

7.5. Sampling and scaling approaches

The terminology related to the field sampling approach can be defined according to the following criteria. **Single spot** field spectroscopy measurements (tower-based, at different heights) with continuous non-imaging systems to cover the temporal domain at the core site; **Multiple spot** measurements (e.g., from UAVs spectroscopy, helipod or other robotised platforms) would be useful for acquisition of sparse measurements; **Mapping measurements** (e.g. from airborne or intermediate platforms with imaging systems) to cover relatively large areas. Alternatively, RTMs may be used to build reference data over whole targets by utilising a tool such as the scene generator (SGM) developed for the FLEX. **ROI pixels** are instead expected for satellite intercomparison or for the qualitative products evaluation at the Image Sites.

In situ observations are usually made pointwise and the problem in using point measurements for the validation of a measurement over a sizable footprint is the representativeness of those point measurements with respect to the larger footprint measurement. To use point measurements for the validation of larger satellite footprint measurements a scaling methodology will be used. Scaling strategies can be different for each FLEX product, and they are addressed and detailed in the ESLs specific cal/val documents of each product.

7.6. Site requirements, characterization and recommendation for selection

The selection of the sites is in progress. Here, we underline some guidelines that should be followed to define suitable sites for validation especially relevant for direct validation (category A) of reflectance, fluorescence and vegetation biophysical parameters. The criteria to select the site are presented in Table 5.

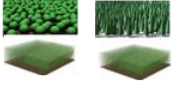
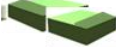
Furthermore, sites located in the northern and southern hemisphere should be included. This will allow performing the validation activities of different FLEX products, during commissioning phase, independently of the period of the year FLEX will be launched. Moreover, different Plant Functional Types (PFT) should be considered, to include different vegetation types and a wide range of fluorescence.

When FLEX will be in orbit, there will be different sites characterised by different sampling approaches (see Section 7). Some sites will be equipped for continuous acquisition of FLoX-like data (to guarantee temporal dynamics, heterogeneous or two components' sites will require the use of multiple radiometers, at least one for each) other sites can be occasionally sampled by imaging system or by spatial sampling techniques (performed manually or UAV based) to capture spatial variability during the satellite overpasses. Eventually, some core sites can have all these components. Thus, the sites will be selected keeping into account different site equipment, different sampling approaches, different validation schemes, network, facilities and site manager efficiency. Aside the core sites, auxiliary will be also included, encompassing simple, large homogeneous crop sites, different biomes and two/three vegetation component sites (beside traditional Pseudo Invariant Calibration Sites for L1).

Key aspects for the site selection criteria are explained below and summarised in Table 5.

- *Site dimension, homogeneity and spatial representativeness.* Site dimension should be coherent with the FLORIS pixel size. Site cover homogeneity can be considered, in first approximation, the number of land cover types within the pixel, or using the species composition (numbers) and their respective proportion of land cover within the pixel size or referring to the coefficient of variation of a certain parameter. In principle, a single vegetation component, characterised by a turbid medium canopy, homogeneous over a large area, might represent the ideal site. To evaluate the homogeneity at the required spatial scale (1 km²) geo-statistical tools and vegetation indices like NIRv, FCVI or similar can be evaluated for fluorescence, making use of highly spatial resolved images, such as Landsat or Sentinel-2. Temporal evolution of spatial homogeneity is an important factor to be considered as well. In this context, we recommend exploiting the method proposed by Roman et al., (2009) to evaluate the spatial homogeneity and representativeness of the site. Overall, the sites should provide areas covered with vegetation that are large enough to include multiple moderate spatial resolution product pixels, particularly given positional errors and uncertainties related to the instrument's point spread function (PSF). An area of at least 2x2 or 3x3 pixels will enable misregistration errors between the moderate spatial resolution product and high spatial resolution imagery used in upscaling to be accounted for. The extent of the site should be on the order of several square kilometres to balance the need to validate multiple moderate spatial resolution product pixels with efficient in situ sampling.

After selecting the L2A, L2B and L2C sites at a dimension of about 1000x1000m, they could be classified according to the following simplified structure.

- 1)  Simple homogeneous crop type (e.g. planophyle crops on flat open terrain)
- 2)  Homogeneous, full cover single species forest (e.g. dec/needle)
- 3)  Homogeneous mixed forest (e.g. Sabaudia forest...)
- 4)  Two components agricultural type (e.g. large fields)
- 5)  Two vegetation components (e.g. trees/grassland, white spruce forest....).
- 6)  Fragmented agricultural landscape (e.g. small size fields)
- 7)  Rugged terrain (e.g. forest or crops)

This classification is still under evaluation, and it can be mainly used only for L2 products.

- *Land cover/plant functional type (PTF)*. The site has a high degree of representativeness based on distribution of that land cover type globally, high variability of expected SIF emission or a wide range of structural, biophysical, and biochemical characteristics. Typically, broadleaf forest, needle leaf forest, grasslands and crops are suggested PFT.

- *Topography*. Flat or almost flat sites could be preferred for different reasons. Projected shadow should eventually be considered. A threshold on slope/relief energy to define the topography of the site should be defined (e.g. slope lower than 10°, to prevent projected shadows happening during overpass).

- *Latitude*. This criterion refers to site position over the globe (i.e. affecting sun angles). Priority could be given to mid-latitude sites, but we should also consider that there is a benefit to using high-latitude site(s) because it allows for more frequent sampling by FLEX and thus temporal analyses of SIF.

- *Meteorology*. Sites with high probability of cloud cover can restrict the use of the temporal domain and hamper Cal/Val activities. In principle, cloud free areas are preferred, although it could be relevant to distribute some sites through ecosystems with different climatic/atmospheric conditions. Overall, to maximise data collection and validation opportunities, the sites should have a good probability of clear skies during the timing of the campaigns. The clear sky conditions can be for example analyzed based on Sentinel 2

OLCI data. Furthermore, an analysis of wind direction and intensity could also be important if spatial sampling with drones is planned.

- *Facilities, logistics, accessibility and link with other networks.* A consideration is the presence of existing Infrastructures, instruments and equipment, and also to have a contact point for each site. Management information in the case of agricultural areas or forest inventory in the case of forests should be readily accessible. Site accessibility and logistical support - such as availability of guesthouses with lab facilities - are also important for dedicated experiments. Availability of open areas to locate reference panels and points with known coordinates are also required. The sites should be easily accessible by road to enable access with relevant field equipment. In addition, permission for working at the site should be sought.

- *Flights.* This requirement deals with logistical practicalities for drone/airborne overpass campaigns. Flight permissions, restrictions, costs, site distance from airports should be considered. Of course, flight permissions are not related to the sites for cal/val and it is not mandatory to have flights in all the sites. However, the possibility to fly over a certain site can represent an advantage for the validation by using multiple spots, drone spectroscopy and airborne data with imaging systems.

	<i>Site requirements</i>	<i>Criteria</i>
1	Dimension, homogeneity and representativeness	Nr. of endmembers, size and statistical metrics
2	Land cover/FPT	Dominant species/ecosystem
3	Topography	Slope (°)
4	Latitude	Cos(θ)
5	Meteorology, wind	Cloud cover %
6	Facilities, logistic, accessibility	Yes/No
7	Flights	High risk/medium/low

Table 5: Recommendations for site selection

Furthermore, i) science questions, ii) position of the site (ground instrument) within the FLEX image (kernel), iii) possibility of performing manipulation experiments, iv) heritage of the site in term of previous campaigns and v) long term commitment by the sponsor/host and finally vi) maturity represent additional evaluations. The site should be well established and well-characterised sites with a legacy of scientific activity are preferred, particularly where research facilities are available and/or permanent instrumentation is installed, such as flux towers which collect measurements of biophysical

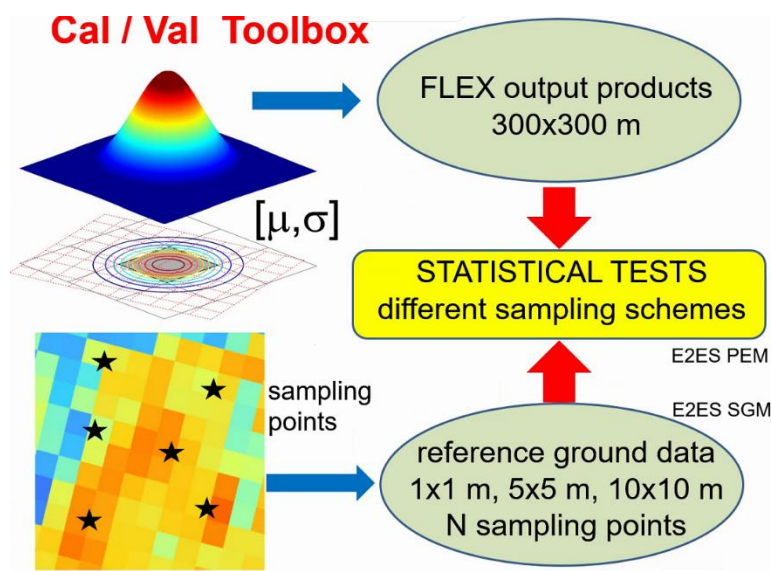
variables over extended periods of time. INSIF, RadCalNet, HYPERNET and S3 sites, could be beneficial for upscaling of the in situ measured variables.

The list of potential FLEX Validation Sites is presented on the specific ESL cal/val documents and will be available in the CP.

7.7. Introduction to the cal/val tools

The cal/val tools are automated tools that enable the calibration and validation of FLEX products within the CP. Processing chain, dataset, error metrics, traceability and uncertainty of the ground reference data are needed to design the cal/val tools. This component will be ready before the commissioning phase. This activity is dedicated to the preparation of cal/val tools, database and datasets needed for the cal/val activities. Of relevance is the link with the FLEX matchup database.

Potential interaction with external field campaigns will allow to refine protocols and to adapt database and cal/val tools. Results of the rehearsal activity can be used to provide recommendations for field activities and campaigns to guarantee the provision of in-situ reference data through the validation sites. Figure 4 shows a schematic and simplified overview of a possible comparison between ground and satellite data.



Conceptual models and algorithms on cal/val tools for assessing spatial and temporal performances of L1 and L2 products are described in the ESL specific documents. Previous validation approaches populate the FLEX Matchup database, and the developed tools will be able to manage multisource data and to provide different matchups (e.g. satellite vs in situ data (temporal vs spatial, point vs image systems) and satellite

inter-comparisons). The approach to perform the statistical tests and the metrics used to quantify the comparison between ground data and FLEX data are described in Section 7.9 and they are used for most of the product's validation.

The validation of the different products is under development, and each ESL is providing the conceptual flowchart and the corresponding code (in python language). An example of flowchart scheme for L2B is shown in Figure 6.

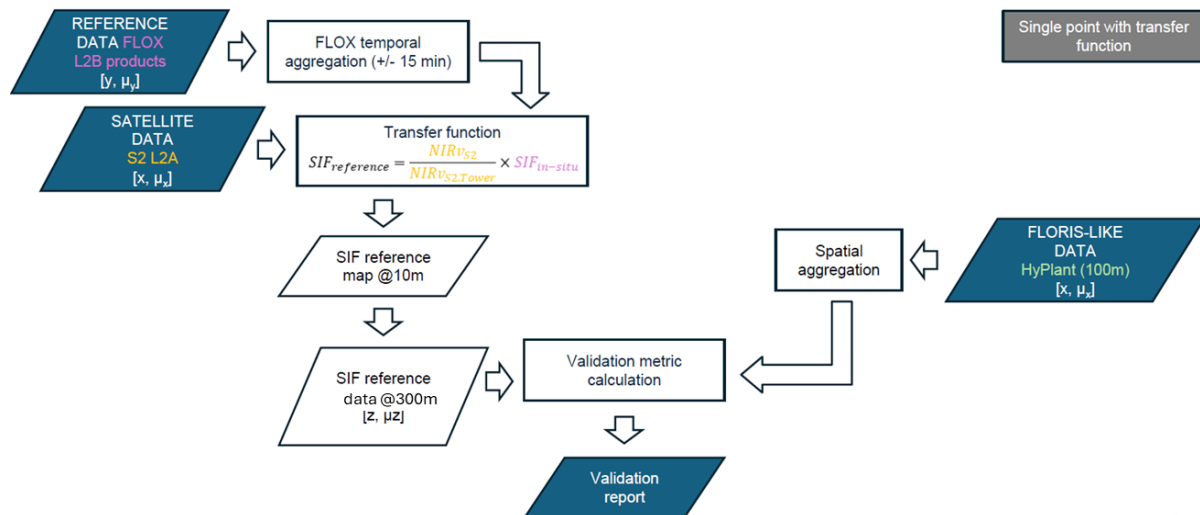


Figure 6: Example of Cal/Val tools (fluorescence - L2B_SIF_SinglePoint - Single-point tool with transfer function)

Beside VICALOPS, all the 17 developed cal/val tools will be integrated in the CP and available from the commissioning phase for the validation of L1B-L1C and L2 products. Cal/val tools can operate on reference networks as well as field/campaign data and will be assessed and verified during the rehearsal period. Cal/val tools include uncertainty estimates and follow a metrological approach. Spatial, temporal, angular and spectral uncertainties are considered wherever possible. The full description of the tools and algorithms used for the validation are described in each Cal/Val Plans document. Table 6/1 and 6/2, summarises the cal/val tools used in FLEX. It also provides the required input data and the sites used for the validation.

Cal/Val tool name	Cal/Val type	Product Level	Target	Cal/Val Description	Input Data
VICALOPS	V	L1B	L1B - Radiometric Validation	L1B Radiometric relative calibration and monitoring (FLORIS TOA reflectance via PICS and DCC)	PICS and DCC sites
L1C_SPECAL	V	L1C	L1C - Spectral Validation	L1C spectral (barycentre and FWHM) validation through vicarious methods	RadCalNet, PICS
L1C_RADCAL	C	L1C	L1C - Floris TOA Radiance cross calibration	L1C FLORIS/OLCI cross calibration through vicarious methods	PICS
L1C_GEOLOC	V	L1C&L2	L1C - Coregistration	L1C FLORIS TOA radiance vs OLCI geolocation validation	Sentinel-3
L2_GEOLOC	V	L1C&L2	L2 - Geolocation	L2 FLORIS reflectance vs Sentinel 2 geolocation validation	Sentinel-2
L2A_AtmChar	V	L2A	L2A - Atmospheric parameters	L2A atmospheric characterisation parameters (CWV, AOD, ANG, ASY)	AERONET
L2A_AtmCorr	V	L2A	L2A - Solar Irradiance and apparent reflectance	Single point comparison	HYPERNETS, INSIF, S2
L2A_LST	V	L2A	L2A - Land Surface Temperature	Validating LST using in-situ data from international networks	In-situ data: SURFRAD, USCRN, ARM, LAW, AStern; emissivity
L2B_SIF_FullSpec	V	L2B	L2B - Fluorescence products	Processing ground reference point data from radiances to L2B products.	Radiance data (e.g. from INSIF)
L2B_SIF_SinglePoint	V	L2B	L2B - Fluorescence products	Single point comparison	Output of L2B_SIF tool or external SIF data, Sentinel-2 L1C
L2B_SIF_MultiplePoints	V	L2B	L2B - Fluorescence products	Multiple sampling points tool	FLOX, AirFLOX, Sentinel-2 L1C
L2B_SIF_Airborne	V	L2B	L2B - Fluorescence - Red&FarRed	Airborne tool	Airborne image data
L2B_SIF_Satellite	V	L2B	L2B - Fluorescence-FarRed	Comparison between FLORIS L2B data and TROPOMI L3 SIF products	Sentinel-5P TROPOMI
L2C_Bio_Campaign	V	L2C	L2C - Vegetation Biophysical	Validating fAPAR, LCC, LCAR, LAI using in-situ from field campaigns	In situ measurements, Sentinel-2 L1C data, ROI
L2C_Bio_Network	V	L2C	L2C - Vegetation Biophysical	Validating LAI and fAPAR using in-situ from international networks	GBOV LP03 and GBOV LP04 reference data
L2C_Photosyn_Campaign	V	L2C	L2C - Novel Photosynthesis Parameters	Validating FQE, ETR, RED using in-situ from field campaigns	PAM measurements, FloX measurements, ROI
L2C_Veg_Satellite	V	L2C	L2C - Vegetation Biophysical - LAI and FAPAR	Validating L2C vegetation parameters using other satellite data	CLMS, Sentinel-2 L2A
L2C_Veg_RTM	V	L2C	L2C - Vegetation Biophysical - LAI, FAPAR, REP, FQE	Validating L2C vegetation parameters using reference data generated by RTMs	INSIF

Table 6/1: Cal/val tools, target variables and cal/val tools description

FLEX DISC
Cal/Val Plan Overview

Ref : FLEXDISC-CALVAL-PLAN-UMB-030
Date : 31/03/2026
Issue : 3.0

FLEX L1C/L2 variable	Cal/Val tool name	FLEX Sites name	#Sites
floris_toa_reflectance (from L1B radiance)	VICALOPS	RadSites	17
crosscalibration_coefficients	L1C_RADCAL	CrossCalSites	6
floris_spectral_channel_central_wavelengths	L1C_SPECAL	SpecSites	10
floris_spectral_channel_fwhm	L1C_SPECAL	SpecSites	10
longitude	L1C_GEOLOC/L2_GEOLOC	GeolocSites	16
latitude	L1C_GEOLOC/L2_GEOLOC	GeolocSites	16
aerosol_optical_thickness	L2A_AtmChar	AtmoSites	553
columnar_water_vapor	L2A_AtmChar	AtmoSites	553
angstrom_exponent	L2A_AtmChar	AtmoSites	553
asymmetry_parameter	L2A_AtmChar	AtmoSites	553
floris_apparent_reflectance	L2A_AtmCorr	SolarSites/FluoSingleSites	34
direct_irradiance/diffuse_irradiance	L2A_AtmCorr	RefSites/FluoSingleSites	34
land_surface_temperature	L2A_LST	LSTSites	24
total_integrated_sif	L2B_SIF_SinglePoint/L2B_SIF_MultiplePoints/L2B_SIF_Airborne	FluoSingleSites, FluoMultiSites, FluoImageSites	31
sif_peak_positions	L2B_SIF_SinglePoint/L2B_SIF_MultiplePoints/L2B_SIF_Airborne	FluoSingleSites, FluoMultiSites, FluoImageSites	31
sif_peak_values	L2B_SIF_SinglePoint/L2B_SIF_MultiplePoints/LsB_SIF_Airborne	FluoSingleSites, FluoMultiSites, FluoImageSites	31
sif_O2_bands_values	L2B_SIF_SinglePoint/L2B_SIF_MultiplePoints/L2B_SIF_Airborne/L2B_SIF_Satellite (only A)	FluoSingleSites, FluoMultiSites, FluoImageSites, FluoSatSites	31
leaf_chlorophyll_content	L2C_Bio_Campaign/L2C_Veg_RTM/L2C_Veg_Satellite	BioCampSites, BioIndirectSites, BioImageSites	31
fraction_of_absorbed_photosynthetically_active_radiation	L2C_Bio_Campaign/L2C_Bio_Network/L2C_Veg_RTM/L2C_Veg_Satellite	BioCampSites, BioDirectSites, BioIndirectSites, BioImageSites	83
fapar_chlorophyll	L2C_Veg_RTM	BioIndirectSites	31
apar_chlorophyll_photons	L2C_Veg_RTM	BioIndirectSites	31
leaf_area_index	L2C_Bio_Campaign/L2C_Bio_Network/L2C_Veg_RTM/L2C_Veg_Satellite	BioCampSites, BioDirectSites, BioIndirectSites, BioImageSites	83
leaf_carotenoid_content	L2C_Bio_Campaign/L2C_Veg_RTM	BioCampSites, BioIndirectSites	31
reversible_energy_dissipation	L2C_Photosyn_Campaign	BioCampSites	-
fluorescence_quantum_efficiency	L2C_Photosyn_Campaign/L2C_Veg_RTM	BioCampSites	31
electron_transport_rate	L2C_Photosyn_Campaign	BioCampSites, BioIndirectSites	-
fluorescence_escape_probability	L2C_Veg_RTM	FluoSingleSites	31

Table 6/2: Target variables, cal/val tools name, sites typology and preliminary number of sites available for validation of each variable

7.8. Uncertainty budget and validation metrics

To validate the FLEX products, the ground/airborne/satellite data derived from other sensors will need to have an overall uncertainty equal or lower than the expected satellite uncertainty values.

Estimating uncertainties is a process that requires information about the contributing sources and their relationship. The uncertainty on a measurement describes the expected magnitude of the error by characterising the distribution of error that would be found if the measurement was infinitely repeated.

All measurements of physical quantities are subject to uncertainties in the measurements. Both FLORIS products and ground truth measurements will have inherently associated uncertainties and variances from sources such as: i) intrinsic instrument accuracy caused by random and systematic noises and retrieval approach; ii) natural variability of target properties at different spatial scales at the time of acquisition (that is modulated by the sampling strategy); iii) environmental conditions variations (e.g. illumination, wind...) during ground truth measurements; iv) error propagation in retrieval algorithms or radiative transfer simulations. Such uncertainties should be assessed in the validation scheme. Accuracy, error, precision and uncertainty of ground spectrometers, drone spectrometers, airborne and spaceborne sensors should be quantified.

A key aspect for satellite product validation relies on the spatial representativeness of the ground data in comparison to the satellite spatial resolution. In general, field observations at representative sites are frequently used in calibration and validation activities for satellite missions (Bouvet et al., 2019), e.g. for the Sentinel-2 mission. Due to general recommendations for suitable land monitoring sites (e.g. homogeneity, size, number of cloud free days) mostly desert locations, defined as pseudo invariant calibration sites, are chosen (Lamquin et al., 2019; Marcq et al., 2018)

According to this scheme, the overall uncertainty budget is defined by different sources related to: i) field sensor instrumental uncertainties (both affecting upwelling and downwelling radiances), ii) retrieval uncertainty, iii) spatial representativeness, iv) flying sensors (e.g. aircraft and UAV) instrumental uncertainties, v) model uncertainty for atmospheric data corrections. .

Figure 7 shows a hypothetical example of a remote sensing uncertainty assessment for one single point at FLEX core site.

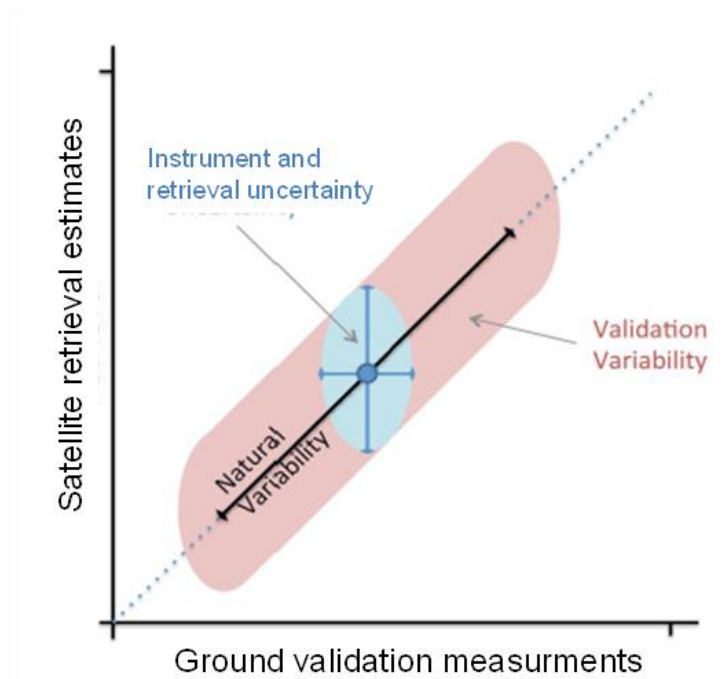


Figure 7: Sources of variance in ground and satellite data over a validation site (modified from ESA FLEX Bridge Study Final Report, 2016).

Repeated measurements and sampling are needed to quantify the associated variance of the validation target. The ground-truth measurement uncertainty is expected to be smaller than the uncertainty of a corresponding satellite estimate (blue ellipse). Uncertainty of the ground truth measurements in terms of instrument and retrieval should be performed properly. Field instruments require repeated calibration at core sites. The variance due to natural variability (spatial representativeness) can be determined by sampling over several spots at the core site. Black arrow shows the expected natural variability in a real case of the vegetation parameter within the examined kernel. Variability in environmental conditions can increase variability of ground measurements. This point is strictly linked with the temporal requirement to perform spatial measurements. The orange zone identifies the variability captured in the validation process and multiple spots are needed. The dashed line indicates the expected best fit over the one-to-one line. Variance of FLEX products at 2x2 or 3x3 pixel size, acquisition characteristics and geolocation errors. In case it is not possible to make repeated measurements, it could be useful to apply an error propagation study to determine the variance of the final product. Radiometric stability and atmospheric correction accuracy can be derived from standard Cal/Val sites (radiance by ground truth using spectral radiance measurement of stable and homogeneous targets, e.g. desert plains). A further contributor to variance in this validation process refers to the upscaling solutions and the transfer function used. These uncertainties can be injected into

the retrieval algorithm through the E2E simulator and the cal/val toolboxes to determine the resulting variance. Currently, how to define the spatial representativeness at the core sites is an ongoing topic. The knowledge of the spatial representativeness provides the overall uncertainty of the ground measurements, and it drives the definition of the numbers of points to be sampled. The determination of spatial representativeness of ground measurement should be done in at least 3x3 FLEX pixel size, to account for both nominal single pixel size and the expected geolocation accuracy. We can consider different methods to evaluate spatial uncertainty at core sites, reported below. Spatial representativeness is a property of the site. Uncertainty corresponds to the standard deviation of the variable vector within the core site. It depends on the target and its variability in space and time. After the identification of the core sites, the variance due to natural variability can be determined by sampling over several spots or by using images at higher spatial resolution.

Validation metrics

To validate satellite products, it is common practice to compare them against reference measurements, which can come from various sources (e.g. surface measurements from in-situ campaigns, automated networks collecting reference data, other satellite products, simulations, ...). There are a range of methods to validate satellite products against reference data (see e.g. Loew et al. 2017 for a review). However, it is important that a metrologically robust approach is followed wherever possible. For FLEX, we intend to follow a metrological approach and to perform the comparison between field data and each satellite product using a proper match up considering uncertainty in both data. Where uncertainties are not available in satellite products or field data, the validation will be conducted by using traditional statistical metrics.

Match-up by a metrological approach

The Quality Assurance framework for Earth Observation (QA4EO) was established and endorsed by the Committee on Earth Observation Satellites (CEOS). QA4EO provides a metrological framework, which includes comparisons such as those used in satellite validations.

The FLEX matchup should be evaluated considering three primary sources of uncertainty:

- 1- Uncertainties associated with the FLEX product (u_x), which include errors originating from different sources and they are typical for of each product;
- 2- Uncertainties in the reference data (u_y) (instrument precision, measurement protocols , retrieval approach...);
- 3- Uncertainties introduced by the match-up process itself (u_{comp}) (spectral, spatial, angular and temporal discrepancies between satellite and in situ measurements and take into account differences in sampling geometry and scene heterogeneity).

When validating satellite products, a *match-up* often refers to the comparison between satellite data and independent field measurements acquired under conditions as similar as possible in time, spatial location, and observational geometry. The match-up uncertainties arise from multiple factors and should be minimized wherever feasible. Some examples of the types of uncertainties that need to be propagated in this process include (this list is somewhat tailored to fluorescence and surface reflectance uncertainties; other products might include other types of uncertainties):

- Spectral uncertainty related to differences in the spectral characteristics of satellite sensors and in-situ instruments:
 - SRF uncertainties
 - Lack of knowledge on the shape of the spectrum at higher resolution than sampled by the product
 - Retrieval approach
- Spatial uncertainty related to different spatial resolution:
 - Point to pixel uncertainties
 - Single point, ROI (1x1, 3x3 or 5x5) small area compared to FLEX pixel
 - Spatial variability affecting representativeness (e.g. quantified from high spatial resolution data)
 - Spatial response uncertainties
- Angular uncertainty related to discrepancies in viewing geometries between satellite sensors and in-situ measurements:
 - BRDF uncertainties due to viewing geometry
 - Directional vs conical measurements (e.g. FLOX field of view is larger than satellite products)
- Temporal uncertainty related to the differences in acquisition time between satellite and in-situ measurements
 - Changes in illumination (effect through BRDF)
 - Changes in atmospheric conditions
 - Changes in surface itself (e.g. due to wind)

The list above is somewhat tailored to spectral measurements, other measurands might have other contributors as fully described in the specific documents.

The total uncertainty is therefore the combination of multiple contributors and arises from several sources of uncertainty, not from different “types” of uncertainty in a conceptual sense:

- Instrumental and retrieval errors
- sampling variability
- calibration errors
- spatial/temporal mismatch (in the satellite–ground match-up)
- noise, etc.

These contributors are combined together, typically in quadrature, if independent.

The most fundamental comparison metric is to check whether the difference between the satellite product and the reference measurement is within the combined uncertainties:

$$|x - y| < k\sqrt{u_x^2 + u_y^2 + u_{comp}^2} \quad (1)$$

Where x is the measurand (i.e. the quantity intended to be measured – see JCGM 200) derived from the satellite (here FLEX) product, and y is the measurand derived from the reference product, u_x and u_y are the standard uncertainties on those measurands, u_{comp} is the standard uncertainty associated with the comparison itself and k is the coverage factor for the appropriate confidence interval (for FLEX $k = 2$ to have a confidence interval of ~95 %).

The challenge lies in that the satellite product and the reference typically do not measure exactly the same thing. Therefore, some processing needs to be applied to go from the measured values, to a common measurand. When performing validation, it is critical to clearly describe what this measurand is for which we will compare the satellite data to the reference. In formula (1), x and y provide this measurand, and some processing has thus already been applied to the satellite data and reference data itself in order to make them as comparable as possible.

As an example, the measurand in question might be fluorescence at nadir, over a 1km-by-1km area. In that case x , will likely be an average over multiple FLEX pixels, with a BRDF correction to nadir. y might e.g. combine multiple nadir in situ measurements, or a correction to account for the spatial variability. The uncertainties u_x and u_y will not only include the FLEX product uncertainties (for u_x) and the reference data uncertainties (for u_y), but will also need to include the uncertainties associated with generating the common measurand from the satellite and reference data, respectively.

If x and y can be made to be perfectly comparable (i.e. same spatial, temporal, angular and spectral resolution), then $u_{comp} = 0$. If not, it needs to be very clearly described what x and y are (and how they differ) and u_{comp} includes any remaining mismatch uncertainties. For example, if there is no information about how the surface changes temporally, there is no way to correct for the temporal mismatch between the time of the satellite measurement and the time of the reference measurement. In that case, any uncertainty associated with temporal variability cannot be assigned to u_x or u_y , and is instead assigned to u_{comp} .

Equation (2) can also be rewritten as an Equivalence ratio and at 95% of confidence level, the FLEX product and the in-situ data are in statistical agreement if:

$$E_N = \frac{|x - y|}{k \sqrt{u_x^2 + u_y^2 + u_{comp}^2}} \quad (2)$$

This form matches Equation (6) in the QA4EO metrological guidance document¹. An equivalence ratio $E_N < 1$ (for $k = 2$) suggests that the two measured values agree within their uncertainties, while a larger E_N ratio suggests that at least one uncertainty is underestimated.

Match-up by traditional statistical metrics

In the absence of uncertainty information, there are a wealth of validation metrics that have been used in the literature (e.g. Loew et al. 2017) and that can be used to provide useful validation information:

1. RMSE:

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^N (x_i - y_i)^2}$$

2. Mean residual (bias, systematic error):

$$\mu = \frac{1}{N} \sum_{i=1}^N (x_i - y_i)$$

3. Variance or standard deviation around mean measured value (random uncertainty)

$$\sigma^2 = \frac{1}{N} \sum_{i=1}^N ((x_i - y_i) - \mu)^2$$

Throughout this document, where possible (i.e. if relevant uncertainties are available), Equation (2) will be used to validate the FLEX products. When doing this is critical that:

- The measurand used for the validation is clearly described and the same measurand is used for x and y (i.e. what is being measured, what is the spatial, temporal, angular and spectral resolution being used, ...).
- Where possible all uncertainties related to processing the satellite product to the measurand x are included in u_x .

¹ Section 3.2 in https://qa4eo.org/docs/2_Metrology_Document.pdf

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- Where possible all uncertainties related to processing the reference data to the measurand y are included in u_y .
 - Uncertainties due to any remaining differences that cannot be corrected are included in u_{comp} , and the mismatch between x and y is clearly described.
 - The results need to be interpreted in the context of a confidence interval. For a single comparison using $k = 2$, there is only a 5% chance that Equation 1 is not satisfied for products that are consistent. However, when doing many of these comparisons, it is expected that 5% will fail this criterium (if all comparisons pass, the uncertainties are likely overestimated).

Overall accuracy of the retrieved FLEX products will be measured applying the proposed error metrics and considering the intrinsic variance of the ground/satellite measurements over each site. The accuracy will be driven for those cal/val sites where the variance is lower (e.g., homogeneity of the ground target, accuracy of the retrieval, lower instrument noises). In addition, the global validation might be affected by sites suffering systematic deviations, and analysis of the longer temporal trend will help to determine the source of the deviation.

8. Validation timeline

The FLEX Cal/Val Plan includes pre-launch and post-launch activities starting in Phase C/D and continuing after launch and commissioning through the end of the mission (Phase E). The Cal/Val preparation, in fact, benefits from technical activities that will have already started or completed in phases C and D with a focus on comprehensive instrument characterisation and definition of calibration strategies.

The scope of the Cal/Val plan is to set all the activities that enable the pre-and post-launch Cal/Val objectives to be met.

Basically, the Pre-Launch objectives of the Cal/Val program are:

- To acquire and process data with to calibrate, test, and improve models and algorithms used for retrieving FLEX science data products;
- To develop and validate the infrastructure and protocols for post-launch validation; this obviously includes establishing an in-situ observation strategy for the post-launch phase.

The Post-Launch objectives of the Cal/Val program are:

- To verify and improve the performance of the science algorithms;
- To validate the accuracy of the science data products.

A timeline for validation activities is still in preparation, and it will be prepared in the next few months. However, a preliminary timeline for the different products is presented in the ESL validation documents. Prior characterisation of selected calibration/validation sites is needed to determine the most adequate sampling strategy (i.e., instrument type) in each case. Posterior re-characterisation might be needed, especially at the cal/val sites that present strong seasonal evolution or odd behaviours with respect to expected seasonal or long-term trends.

Priority shall be given to checking that appropriate data transfer procedures, including the use of central storage facilities and databases are satisfactorily working to support the Cal/Val activities during the Commissioning phase, and complete testing of all specific software tools foreseen to be used by the Cal/Val teams.

8.1. Validation preparation activities

The objective of FLEX Validation in the pre-launch phase includes a Development phase (21 months) and a Preparation phase (10 months).

Within the Development and the Preparation, the strategies for the validation of core products, the cal val/tool implementation/validation and the definition of protocols and guidelines represent the most important activities. The following tasks need to be accomplished:

-
- Review and update the draft of the Validation Plan. Update and consolidate the FLEX cal/val plan for Commissioning and Routine Operation;
 - Review of datasets, networks and sites used in the cal/val activities;
 - Consolidation of the validation approaches and procedures for validating different FLEX Products
 - Establishing Validation teams after AoO;
 - Supporting discussions and tests concerning the corrective maintenance activities of the following processors:
 - instrument simulators (SPS),
 - prototype processors (L1 GPP processors and L2 RM processors),
 - operational processors (IPFs);
 - Supporting discussions addressing potential evolutions of instruments' data processors;
 - Completing the planning of Validation activities, including:
 - the detailed definition of interfaces expected to support the Validation activities
 - the detailed plan of in-situ campaigns for the different FLEX products;
 - Specifying and having technical resources developed, such as:
 - computer infrastructures dedicated to Validation activities,
 - design and implementation of the needed SW tools,
 - validation databases for storing in-situ campaign data,
 - automated product subset extractions,
 - data screening and quality assurance protocols,
 - 3rd party RS data (i.e. S3...).
 - Performing the validation rehearsal:
 - Identification of its scope and coordination of its activities.

The Validation rehearsal shall at least cover the following tasks:

- support any activity addressing the verification of all systems and tools that will be used for the Validation activities, such as:
 - PDGS processing,
 - dissemination of data to Validation teams

- exercising the Quality Control (QC) tools
- generation of and access to all internal and external pre-launch ADFs;
- test read and write access to all Validation databases;
- verify data quality monitoring procedures for Commissioning phase;
- generate mission timeline data, instrument mode switching procedures;
- verify all Validation procedures, including the procedures expected to report between the different teams and agencies.

To assess the maturity and readiness of all Commissioning phase Cal/Val related activities a Cal/Val rehearsal shall be conducted before the launch. At about 8/4 months prior to launch, a validation rehearsal will be held. Prior to the rehearsal, industries and ESL should have all tools and resources in place and prepare an observation schedule based on a simulated scenario provided by ESA. During the rehearsal a simulation analysis will be performed according to a pre-defined scenario.

The simulated analysis results are to be exchanged within the FLEX Calibration and Validation Teams in the context of the Validation Rehearsal and Readiness Review, and any difficulties encountered will be reported to ESA. This review will be scheduled approximately one month after the end of the rehearsal. During this review also instrument and algorithm experts will be involved. It is not intended as a formal review (document deliverables and RIDs) but rather as a working session to exchange experiences from the rehearsal and benefit from each other's expertise and see whether any further action is needed to be ready for commissioning phase validation.

8.2. Validation during Commissioning

The nominal duration of the Commissioning phase will be 3 months. The objective of FLEX Validation during the Commissioning Phase (E1) is to perform a preliminary assessment of the quality of FLEX Level 1 and selected Level 2 (A, B and C) products by comparing them to independent data. It is expected that at least a preliminary quality assessment of most of L2 products shall be given at the In-Orbit Commissioning Review (IOCR).

The FLEX products will be evaluated using different tools and by employing various types of data and reference networks

1. Systematic Quality Control Tests and Quality indicators;
2. Ad-hoc quality assessment;
3. Validation by cal/val tools (using reference networks and campaigns data).

These three types of validation are described in the document "FLEX DISC cal/val activities – Preparation and Commissioning". A detailed presentation of the cal/val tools is provided in the individual Cal/Val Plans, while the section related to the QC/QI tests to be used is

described in the "Quality Control Monitoring Baseline Document (MBD)" FLEXDISC-QC-MBD-MAG-053.

During the commissioning phase the instruments will be switched on and the functional checking and performance verification of the instruments, platform and ground segment will be performed. Most likely, validation of all products (not only L2) will continue during operation. In such cases, the formal handover marks the end of phase E1 even though technically not all Level 2 requirements have been validated.

Overall, the objectives of the Cal/Val activities during the Commissioning phase will therefore be to:

- calibrate all instruments;
- tune all L1 processing parameters;
- verify all L1 processing functions (ie. geolocation, datation etc.);
- verification and preliminary validation of all L1 products;
- provide a preliminary quality assessment of all other L2 products, including synergy Products by field campaigns.

In-Orbit Commissioning Review will be released, even if not all data products will have been validated by then and hence no full compliance with the Mission Requirements can be demonstrated yet. In this period, the highest priority regarding data products is the verification and validation of the Level 1 products. As soon as the Level 1 products of an instrument appear to have achieved a reasonable stability and performance, the validation of the respective down-stream Level 2 products can start. The initial validation of Level 2 data products during the Commissioning Phase will be important to further consolidate the confidence in the Level 1 data, as well as for an initial assessment of the validity of the retrieval algorithms. The IOCR assesses the FLEX readiness to enter in the operational phase (E2). This review will (among others) take the assessments of the Level 1 (and Level 2, if available) data product quality available by the time of the IOCR into consideration in order to assess if the mission is ready to enter the mission exploitation phase. The data product verification and validation will continue during Phase E2.

The IOCR marks the end of the Space Segment commissioning phase. Its objectives, should be to:

- Ensure the satellite and its subsystems have reached the required performance stability fulfilling the success criteria specified for entering into the operational phase;
- Confirmation that all the instruments are in their operational modes and calibrated,
- Confirmation that the conditions for mission handover from the Project team to the Mission Operation team are met;
- At this stage, the PDGS is able to support data production and distribution as required for the Phase E2.

In-Orbit Commissioning Review marks the end of commissioning. At this milestone the in-orbit verification of the System Requirements and the preliminary validation of the Mission Requirements are reviewed, and the mission is declared operational (which implies a handover of responsibility from mission development to mission operations). During the In-Orbit Commissioning Phase the overall satellite, including the instrument, will be brought into a fully operational state. Relevant adjustments may be made to the instrument operational parameters or software to optimise performance. During the Commissioning Phase the end-to-end measurements of the FLEX system will be calibrated and validated such that the performances and measurement quality are known and controlled.

During the Commissioning Phase, the *Satellite In-Orbit Verification (SIOV)* and the Instrument switch-on and first health check will be performed. Some assumptions for the Satellite in-orbit Commissioning Review can be outlined.

Within the SIOV phase, the payload instrument is brought into initial operation. Any deployment remaining after the LEOP is also performed during this phase. Specific SIOV activities will include:

- satellite functional checkout, in which overall satellite basic functions and health are verified;
- verification of instrument data generation and handling;
- verification of instrument measurements;
- setting of satellite and instrument parameters;
- implementation of on-board operations.

The nominal duration of the SIOV sub-phase is 2 weeks. The duration of each phase is TBC, to be discussed and agreed with S/C.

The scope of the instrument test is to perform post-launch and orbit insertion verifications of FLORIS, checking the capability to control the instrument from ground during the visibility with the ground stations through the correct management of telecommands and telemetries and critical FLORIS/Platform interfaces.

Finally, some assumptions on Ground segment status can be outlined. In order to process all instrument data streams for Cal/Val purposes the most important objectives for the ground segment are:

- Confirm readiness of the PDGS system for initial data processing capabilities (i.e all Level 1 and partial Level 2 data product availability) required to serve Phase E1 Cal/Val activities. In addition, the following PDGS elements should be functional or completed:

- All prototype processors have been successfully cross-validated with the operational IPF system thus confirming no software related processing errors or remaining errors in product specifications.
- Cal/Val rehearsals are successfully completed
- All necessary auxiliary data sets are validated and are available to process instrument data during commissioning.
- Mission planning and management tools are operational (this includes calibration acquisitions schedules, orbit control and monitoring)
- Details of PDGS Commissioning procedures have been established including detailed planning and contingencies plans.
- Operation procedures are established by FOS and/or PDGS for specific needs expressed in the Cal/Val plan, such as calibration sequences, extract requests, routine incorporation of calibration changes/updates in the ground segment.
- Access to all instrument characterization data (SCDDB) is ensured for all instruments and any Cal/Val task.
- Coordinate with Mission management dedicated collection and processing of specific payload data products for given geographical locations and times to ensure that instruments are collecting data at the right place and right time coincident with in situ campaign activities as required.

The overall commissioning of the PDGS including the “ramp up” of operational functions and data dissemination up to and following IOCR is described in a specific “PDGS commissioning document”.

Overall, most of the efforts in Commissioning will be devoted to L1 products, while we expect a full validation of L2 products only during the Operational Phase. During Commissioning an Early Product Validation will be conducted (Figure 8).

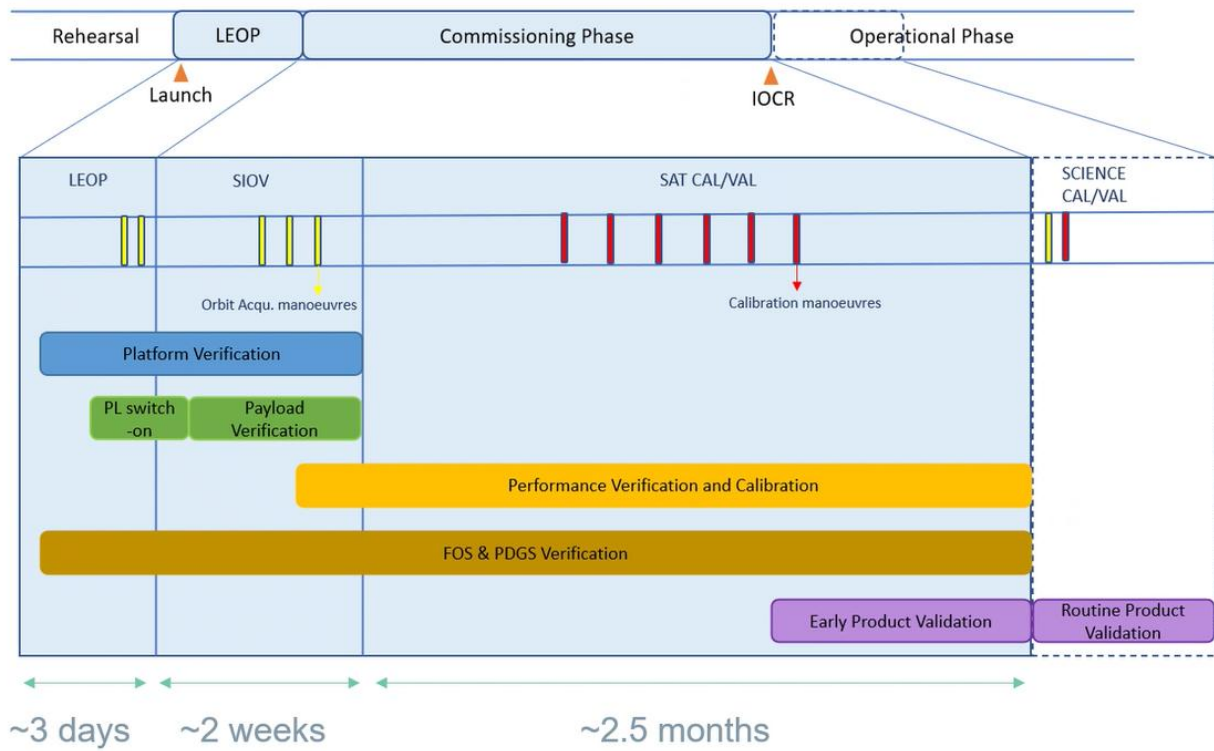


Figure 8: Validation activities during Commissioning (credit ESA)

An initial analysis about how to conduct the validation of each product in Commissioning and the frequency report is currently ongoing and a preliminary table is shown in Table 7.

FLEX DISC Cal/Val Plan Overview

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						Commissioning						
Data type	Product Level	Variable Type	FLEX L1C/L2 variable	Units	Cal/Val tool name	Direct Validation with Cal/Val Tool (Category A)	Indirect Validation with Cal/Val Tool (Category B)	Satellite intercomparison with Cal/Val Tool (Category C)	Evaluation using Quality Control (QC-MBD)	Qualitative Assessment (QA)	On event-based ticket (JIRA)	Frequency Report in Commissioning Phase (E1)
Core Science Data	LaB	La	floris_toa_reflectance (from LaB radiance)	-	VICALOPS	n	x (forward modelling)	x	n	n		15 days
	LaC	La	floris_toa_radiance	mW.m-2.sr-1.nm-1	-	n	n	n	n	n		n
	LaA	La	floris_apparent_reflectance	-	LaA_AtmCorr	xxx	n	x	n	n		15 days
	LaB	La	total_integrated_sif	mW.m-2.sr-1	LaB_SIF_SinglePoint/LaB_SIF_MultiplePoints/LaB_SIF_Airborne	x	n	n	x	xxx		15 days
	LaB	La	sif_peak_positions	nm	LaB_SIF_SinglePoint/LaB_SIF_MultiplePoints/LaB_SIF_Airborne	x	n	n	x	xx		15 days
	LaB	La	sif_peak_values	mW.m-2.sr-1.nm-1	LaB_SIF_SinglePoint/LaB_SIF_MultiplePoints/LaB_SIF_Airborne	x	n	n	x	xx		15 days
	LaB	La	sif_O2_bands_values	mW.m-2.sr-1.nm-1	LaB_SIF_SinglePoint/LaB_SIF_MultiplePoints/LaB_SIF_Airborne/LaB_SIF_Satellite (only A)	x	n	xxx	x	xxx		15 days
	LaB	La	sif_emission_spectrum	mW.m-2.sr-1.nm-1	-	n	n	n	x	n		n
Supporting Science Data	LaA	La	direct_irradiance	mW.m-2.nm-1	LaA_AtmCorr	xxx	n	n	x	xx		15 days
	LaA	La	diffuse_irradiance	mW.m-2.nm-1	LaA_AtmCorr	xxx	n	n	x	xx		15 days
	LaC	La	leaf_chlorophyll_content	µg.cm-2	LaC_Bio_Campaign/LaC_Veg_RTM/LaC_Veg_Satellite	x	x	xxx	x	xx		15 days
	LaC	La	fraction_of_absorbed_photosynthetically_active_radiation	µmol.µmol-1	LaC_Bio_Campaign/LaC_Bio_network/LaC_Veg_RTM/LaC_Veg_Satellite	x	x	xxx	x	xx		15 days
	LaC	La	apar_chlorophyll	µmol.µmol-1	LaC_Veg_RTM	n	n	n	x	n		15 days
	LaC	La	apar_chlorophyll_photons	µmol.photons.m-2.s-1	LaC_Veg_RTM	n	x	n	x	n		15 days
	LaC	La	leaf_area_index	m2.m-2	LaC_Bio_Campaign/LaC_Bio_network/LaC_Veg_RTM/LaC_Veg_Satellite	x	x	xxx	x	xx		15 days
	LaC	La	leaf_carotenoid_content	µg.cm-2	LaC_Bio_Campaign/LaC_Veg_RTM	x	x	n	x	x		15 days
	LaA	La	land_surface_temperature	K	LaA_LST	x	n	n	x	x		1 month
	LaA	La	aerosol_optical_thickness	-	LaA_AtmChar	xxx	n	n	x	x		1-2 weeks
LaA	La	columnar_water_vapor	g.cm-2	LaA_AtmChar	xxx	n	n	x	x		1-2 weeks	
Experimental Science Data	LaC	La	reversible_energy_dissipation	µmol.m-2.s-1	LaC_Photosyn_campaign	x	n	n	x	n		1 month
	LaC	La	fluorescence_quantum_efficiency	µmol.µmol-1	LaC_Photosyn_campaign/LaC_Veg_RTM	x	x	n	x	n		1 month
	LaC	La	electron_transport_rate	µmol.m-2.s-1	LaC_Photosyn_campaign	x	n	n	x	n		1 month
	LaC	La	fluorescence_escape_probability	-	LaC_Veg_RTM	n	x	n	x	n		15 days
	LaC	La	PSI_PSIII_relative_contribution	-	-	n	n	n	x	n		n
	LaA	La	angstrom_exponent	-	LaA_AtmChar	x	n	n	x	x		1 month
	LaA	La	asymmetry_parameter	-	LaA_AtmChar	x	n	n	x	x		1 month
	Ancillary Science Data	LaB	La	floris_real_reflectance	-	-	n	n	n	n	n	
LaA		La	integrated_par	µmol.photons.m-2.s-1	-	n	n	n	n	n		n
LaC		La	crosscalibration_coefficients	-	LaC_RADCAL	n	n	xxx	x	n		15 days
LaC		La	floris_spectral_channel_central_wavelengths	nm	LaC_SPECAL	n	n	n	x	n		15 days
LaC		La	floris_spectral_channel_fullhm	nm	LaC_SPECAL	n	xx	n	x	n		15 days
LaC & La		La/La	longitude	deg	LaC_GEOLOC/La_GEOLOC	x	n	x	x	n		15 days
LaC & La		La/La	latitude	deg	LaC_GEOLOC/La_GEOLOC	x	n	x	x	n		15 days
LaC		La	olci_toa_radiance	mW.m-2.sr-1.nm-1	-	n	n	n	n	n		n
LaC		La	slstr_nadir_toa_radiance	mW.m-2.sr-1.nm-1	-	n	n	n	n	n		n
LaC		La	slstr_oblique_toa_radiance	mW.m-2.sr-1.nm-2	-	n	n	n	n	n		n
LaC		La	slstr_nadir_tir_toa_radiance	mW.m-2.sr-1.nm-3	-	n	n	n	n	n		n
LaA		La	olci_apparent_reflectance	-	-	n	n	n	n	n		n
LaA		La	slstr_apparent_reflectance	-	-	n	n	n	n	n		n

Table 7: Validation activities in E1. The Frequency in Routine Phase (E2) is currently set every 4 months

8.3. Validation during Routine Operations

After the completion of the commissioning, i.e. in Exploitation/Routine Phase (E2), FLEX platform and instrument settings are expected to have stabilised, and mainly routine characterization, calibration, and monitoring is expected to be required nominally. The Phase E2 validation program will focus on the completion of the initial validation of products that could not be validated during phase E1 (typically the L2 products), and on the long-term validation where more statistical relevance is obtained. The organisation of the Phase E2 validation activities (AO/RA or additional operational or semi-operational activities) will be defined in the next few months.

For the Long-term Validation Objectives in Phase E2, the first objective is to complete the preliminary validation of all FLEX data products. As statistics build up, the second objective will be achieved, namely to obtain consolidated long-term validation results. A third objective applies after any improvement of algorithms followed by (priority) reprocessing of the collocated FLEX data, namely to perform a 'delta validation' by repeating the inter-comparison with collocated correlative observations but now with the improved subset of collocated FLEX products (reprocessed with the new algorithms) and the (consolidated) correlative data. During Phase E2, the frequency of reporting will be reduced.

In phase E2, automatic monthly reports are planned for all variables, while every four months more complete "manual" reports will be produced.

It is acknowledged that the duration of the Space Segment Commissioning phase and the available resources will not permit sufficient time to scientifically validate the L2 products. It is therefore envisaged to pursue the validation of remaining L2 products during the first phase of the Routine Operations. This should lead to declaring FLEX fully operational only a few months after the end of the Space Segment Commissioning phase (Phase E1). These validation activities will continue to exploit dedicated in-situ measurement campaigns and all Commissioning phase results. Further fine-tuning of processing parameters might also still be necessary during the Routine Operations phase. Also, for all L2 products uncertainty estimates should be made available and routinely produced during the extended validation phase.

This validation phase will be concluded with a dedicated validation workshop(s) where the readiness of data dissemination to all users for each L2 product will be finally assessed. Common practice for ESA Earth Explorer missions is to organise a yearly Science and Validation Workshop.

Following the Validation of all L2 products, the following activities shall be pursued during the Routine Operations phase for each instrument/product:

- Continuous monitoring and revision of instrument on-board calibration and characterization;
- Further science algorithms and data product improvement developments.

Periodic full mission reprocessing incorporating new instrument knowledge and algorithm advancements and improve mission operational and scientific output and continuity

Members of the ESA, ESL and Validation Teams and the ESL Algorithm Development teams will have exclusive access to preliminary data products after successful initial quality check, under nondisclosure agreements. The target dates for the release of preliminary data will be defined in the next months.

The release of preliminary data to the ESL and Validation Teams will be accompanied by data quality disclaimers identifying parameters affected by incomplete calibrations and other known sources of degraded quality. The validation team must use it with full understanding of this situation and use such products only for feedback to the Agency. The Validation Teams and ESL will subsequently analyse the well-calibrated and consolidated data products as soon as these become available.

Consolidated data products are generated with the results of complete calibration and improved processing settings after feedback from the ESL, Validation Teams, the Engineering Teams and the Algorithm Teams on the preliminary products. Consolidated products can also be accompanied by data quality disclaimers. There will be an ongoing iterative process to improve data products before and after public release. In case the algorithms and processors need to be updated before the public release, the products generated with these updated processors will again be made available first to the members of the ESA validation teams. The results of verification and validation will be assessed at staggered product reviews prior to their public release. For the public release target dates will be defined.

8.4. Reprocessing Campaigns Validation

The activities in the FLEX DISC project are expected to lead to algorithm and processor evolutions. Once new algorithms are evaluated by the ESL and have been shown correct and capable of improving FLEX products, the processors will be updated, tested, and then deployed in the ground segment. Prior to the deployment of new processors, the ESL will collaborate to analyze selected re-processed data to ensure products have improved and nothing is broken. Once the reprocessing campaign starts, the ESL will provide support in analyzing selected reprocessed data (from the operational chain as they become available) to a) quantify the achieved improvements, and b) to identify any possible issues related to the new algorithms/processors. The results of these activities together with a set of recommendations will be included in a report and released at the end of the reprocessing campaign.

Overview

The FLEX Cal/Val Plan outlines all activities required to assess, verify, and ensure the accuracy of FLEX mission data products from **pre-launch through routine operations** (Phases C/D → E1 → E2). Activities include instrument characterization, calibration strategy development, validation infrastructure setup, and continuous post-launch algorithm and product validation.

Pre-Launch (Development & Preparation Phases)

Objectives

- Prepare and improve algorithms and models using existing data.
- Establish the full post-launch Cal/Val infrastructure, including in-situ strategies and protocols.

Key Activities

- Update and finalize the Validation Plan.
- Review datasets, networks, and Cal/Val sites.
- Define validation approaches for all FLEX products.
- Establish Validation Teams.
- Support development and testing of:
 - Instrument simulators (SPS)
 - Prototype processors (L1 GPP, L2 PP)
 - Operational processors (IPFs)
- Complete detailed planning for in-situ campaigns.
- Develop required software tools, databases, screening protocols, and data extraction tools.

Validation Rehearsal

Conducted ~4 months before launch to:

- Verify all systems and tools required for validation.
 - Test PDGS processing and data dissemination.
 - Exercise QC tools and database access.
 - Test mission timelines, calibration sequences, and reporting procedures.
- A review follows to identify any remaining actions before commissioning.

Commissioning Phase (E1) — ~3 months

Objective

Preliminary assessment of Level 1 and selected Level 2 products using independent data.

Key Tasks

- Calibrate all instruments.
- Tune and verify all L1 processing functions (geolocation, timing).
- Perform preliminary validation of L1 + initial assessments of L2 products.

- Conduct field campaigns for synergy product validation.

In-Orbit Commissioning Review (IOCR)

Marks the end of commissioning and transition to operations. It verifies:

- Spacecraft and instrument performance stability.
- Operational readiness of all instruments and ground segment systems (PDGS, FOS).
- Availability of L1 and partial L2 products to support ongoing validation.

SIOV (Satellite In-Orbit Verification)

During the first ~2 weeks post-launch:

- Functional checks of satellite and payload.
- Verification of instrument data, telemetry, and operations.
- Parameter setup and implementation of onboard operations.

Routine Operations (E2)

Objectives

- Complete validation of all products, especially those not fully validated in E1 (typically L2 products).
- Perform long-term validation with statistically robust datasets.
- Continue algorithm improvements and periodic mission reprocessing.

Key Points

- Validation frequency decreases as system stabilizes.
- Uncertainty estimates for all L2 products must be routinely produced.
- Validation results feed into:
 - Data product updates
 - Reprocessing campaigns
 - Annual Science & Validation Workshops
- Preliminary data are made available under NDA, with quality disclaimers.
- Consolidated products follow after full calibration and processing refinement.

Reprocessing Validation Campaigns

Driven by algorithm/processor updates from the FLEX DISC project.

Activities include:

- ESL evaluation of new algorithms.
- Testing updated processors before deployment.
- Analysis of reprocessed data to confirm improvements.
- Reporting issues and recommendations at the end of the campaign.

A synthetic flowchart of the activities is presented below (Figure 9).

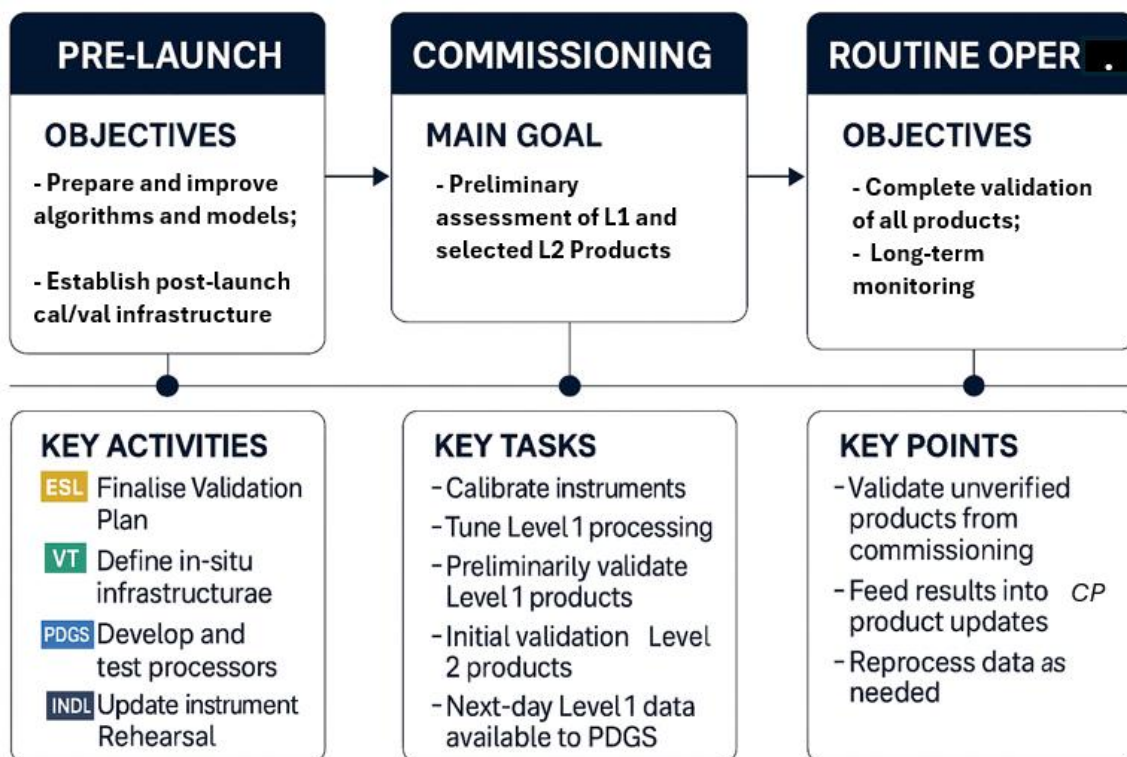


Figure 9: Summary of the validation activities in pre-launch, commissioning and operation phases

9. International collaborations, campaigns, opportunities and resources

International collaboration in FLEX Cal/Val consists of in situ observations in the Validation Site (after selection) or sparse networks, field campaigns that provide pre- and/or post-launch sensor and geophysical observations, and satellite-based observations and products. FLEX will interact with multidisciplinary cooperative initiatives such as the European Cooperation in Science & Technology (COST), which fosters synergy in fields of emerging research. FLEX preparatory activities already involve investigators in the COST actions, and mission activities are directly relevant to COST initiatives. Through such linkages, FLEX will be thoroughly integrated into international efforts.

Despite having an extensive network of validation sites available, in the best case only a few complete datasets of radiance, reflectance, fluorescence, photosynthesis, fluxes and

biophysical parameters spatially distributed over several vegetation types or biomes may be available. Dedicated field campaigns, due to their complexity and costs, will take place sporadically and be limited to a few selected sites. Such campaigns are foreseen to take place mostly during commissioning and the early operational phases of the mission. The campaign implementation plan will be depicted in the next months, considering also additional ESA initiatives.

9.1. Supporting and Opportunity

The activities of the ESA validation will be solicited by an Announcement of Opportunity, which will be emitted by the Agency approximately 1.5 years prior to launch. ESA, DISC and all the Validation Teams collaborate intensely on FLEX Validation. This involves:

- Regular Coordination meetings and teleconferences;
- Agreement on procedures to inform each other on instrument and data product characteristics changes, operations anomalies, calibration planning and any other information that is relevant for the work of the scientists in the validation teams;
- Coordination on validation campaigns;
- scientific exchanges between the ESA and validation team members themselves;

At least one joint pre-launch workshop will be organised to foster scientific interaction

The information will then be gathered and further processed in the Mission Quality Working Group which will provide synthetic results and recommendations to the mission manager for improving the data products quality and knowledge.

9.2. Resources and Services

Specific tools and resources which are considered mandatory for each Cal/Val task are described in each ESL validation document within the corresponding Cal/Val task description.

Instrument Performance Simulators

One central resource will be the different System Performance Simulators (SPS) which allow an end-to-end performance analysis for each instrument up to Level 2 products. As

one essential element, ground processor prototypes (GPP) are being developed for L1 and L2 processing.

For pre-launch the SPS/GPP tools will be used:

- to generate representative data sets and the corresponding level 0-2 test data;
- to assess the performance of ground processing (e.g. FLORIS straylight correction);
- to verify that processing has no negative impact on instrument performance (e.g., SNR, spectral calibration);
- to provide the appropriate test data sets to tune/optimize ground processing algorithms for potential design changes or in cases of inferior instrument performances;
- to provide the appropriate test data sets to tune/optimize algorithms for Level-2 products.

The prototype processors will be cross-validated with the operational Payload Data Ground Segment (PDGS) systems. The generation of appropriate test data sets is with the FLEX project responsibility.

The SPS/GPP tools will then be used during the Space Segment commissioning phase for the first part of the Validation phase. The L0 data produced by the Satellite will be injected into the GPP/SPS chain and the generated products will be compared with the corresponding operational products produced by the PDGS.

Cal/Val data storage and distribution

Several data streams have to be coordinated and made available to all relevant Cal/Val entities:

Instrument status and calibration data, SPS/GPP Test Data Sets, in-situ data from validation campaigns and vicarious calibration sources, external auxiliary data (i.e. meteo, and potential 3rd party RS data products). Basic requirements for such databases include:

- easy access with clear documentation of data sources, formats and quality
- appropriate management and scheduling of data streams (i.e. ensure availability of campaign data during Commissioning Phase)

The Mission Analysis and Algorithm Platform is envisaged to be used for ensuring data availability for both Commissioning and Operations Phases.

The interactive FLEX Collaborative Platform (CP) portal is one of the most important validation support functions. The functional architecture of the CP almost developed and is fully described in a companion document. The preliminary architecture is shown in Figure 10. The functional architecture of the FLEX CP will provide analysis tools that enable

generation and assessment of quality indicators from specified products and by accommodating special data processing needs. External ancillary data including Cal/Val data from field campaigns, in situ networks, and special target data sets provided by the validation teams are ingested into the Cal/Val Database.

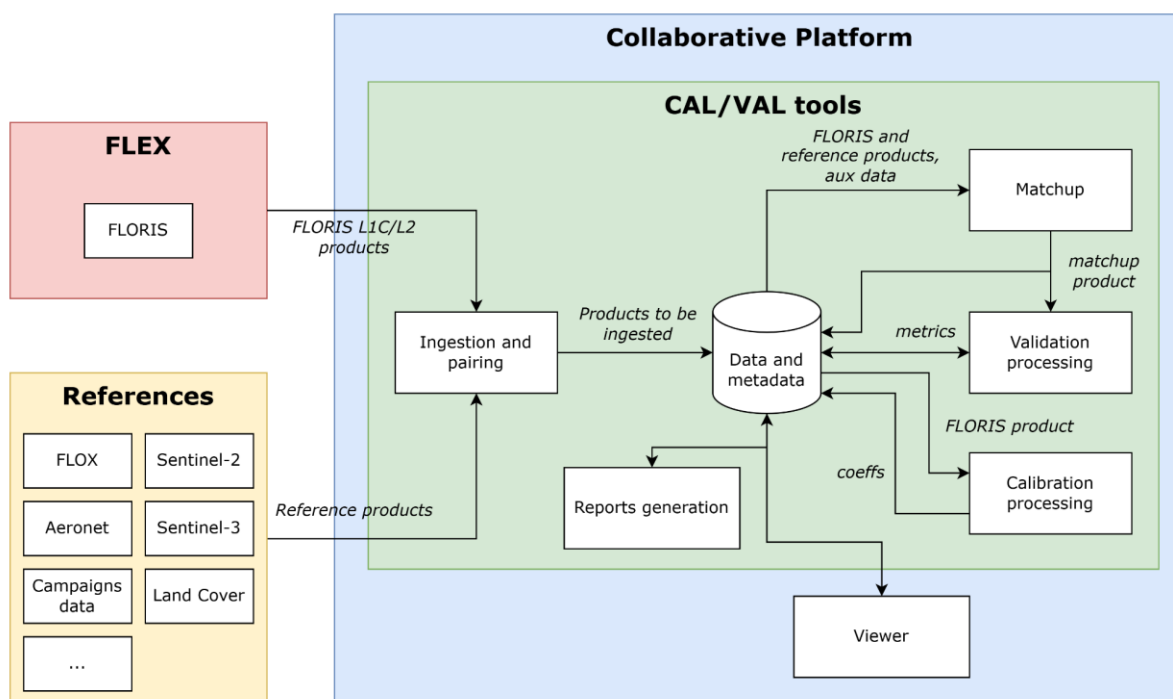


Figure 10: Preliminary architecture of the Collaborative Platform

A Technical Note describing the overall CP architecture and the FLEX Match Up Database will be made publicly available to the user community. This document will be part of the cal/val documentation. The Graphical user interface of the CP is shown in figure 11.

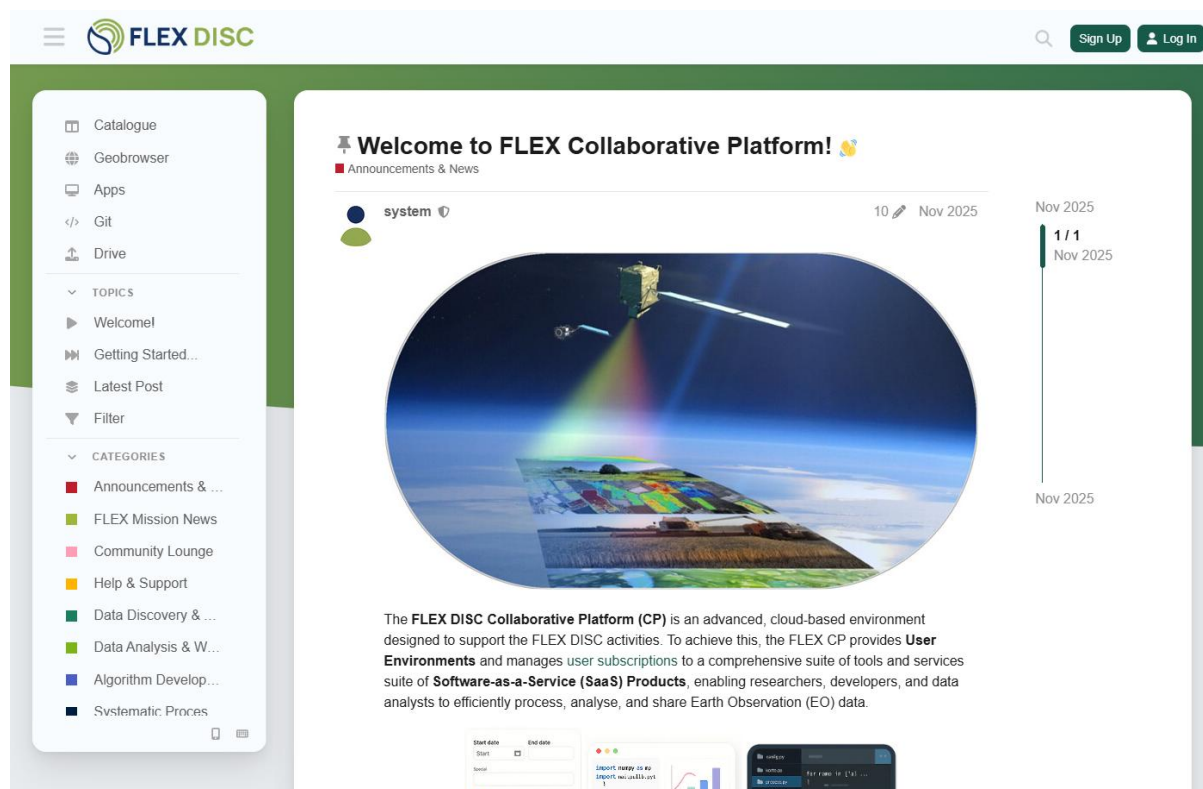


Figure 11: Example of the graphical interface used within the CP

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