Copernicus Cal/Val Solution – Cal/Val Requirements for the Constellation of Atmospheric Composition Sentinels

CCVS

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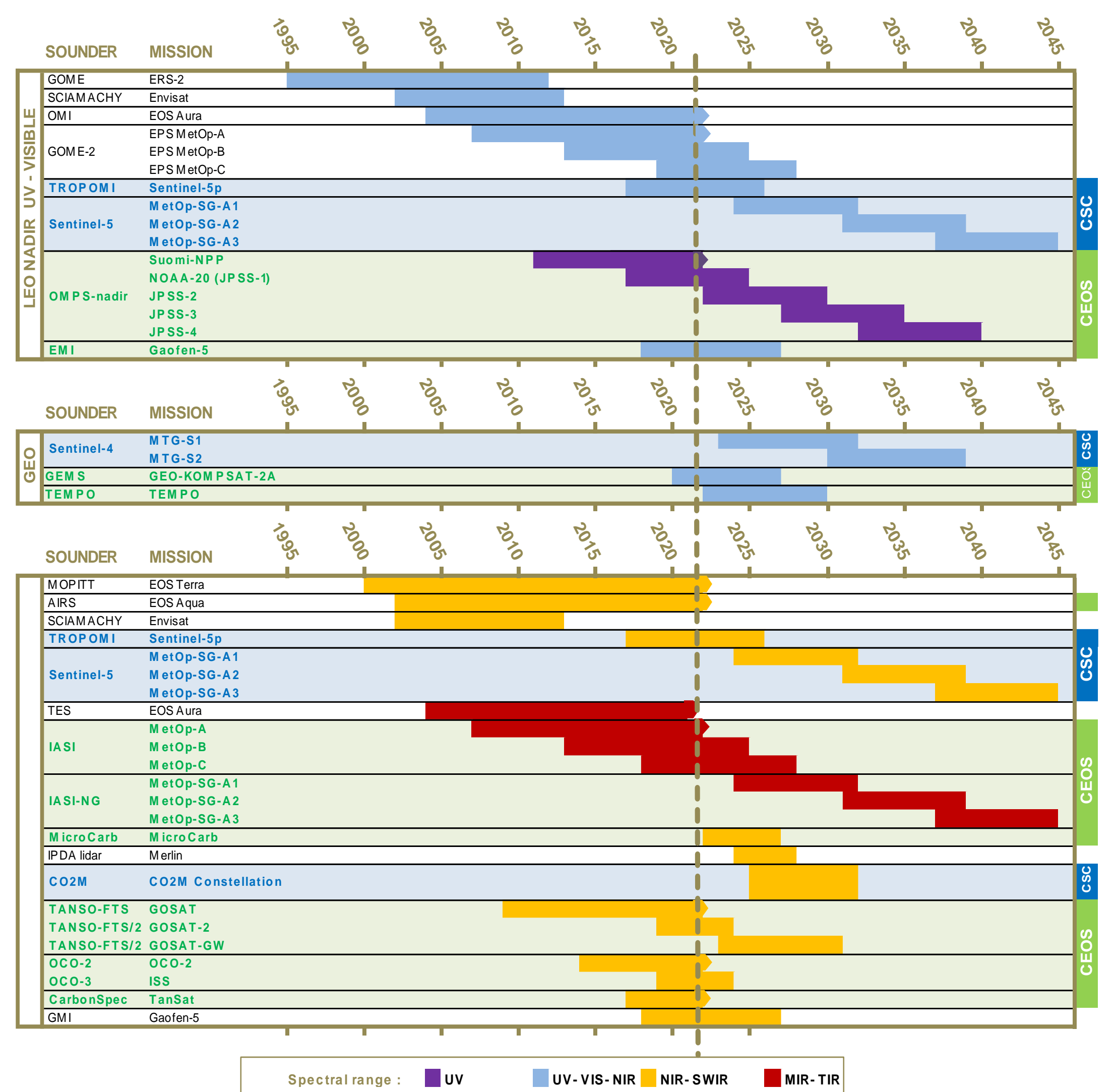
Objectives of the Copernicus Cal/Val Solution

EC H2020 project to define a holistic solution for all Copernicus Sentinel missions to overcome current limitations of Calibration and Validation (Cal/Val) activities   http://ccvs.eu

Required operational Cal/Val for Copernicus data currently limited by:

- need to revisit requirements and objectives to consider new usage of Copernicus products, interoperability requirements, and to anticipate the needs of future Copernicus missions,
- programmatic and budgetary requirements constraining current Cal/Val activities, not necessarily following scientific priorities,
- operational availability of high-quality Fiducial Reference Measurements (FRM) which are today mostly provided by external entities without strong commitment to the Copernicus programme,
- lack of systematic exploration of synergies within Copernicus and with other national and international programmes.

Atmospheric Composition Missions

Cal/Val requirements for Sentinel-4, Sentinel-5p, Sentinel-5, and CO2M

- for every Sentinel instrument
- for interoperability
  - within the constellation of atmospheric Sentinels (Copernicus Space Component, CSC)
  - with instruments co-hosted on the same platform: e.g., synergies CO2M CLIM & MAP, Sentinel-4 UVN & IRS, Sentinel-5 UVNS & IASI-NG
  - within the international satellite constellations for Air Quality, Greenhouse Gases, Ozone… and for international assessments (CLRTAP, LOTUS, TOAR, WMO O3)

Standards and Traceability

- QA4EO data quality strategy
- Traceable Quality Indicators
- Standard terminology
- Community endorsed best practices
- Traceability of Cal/Val process

Cardinal Cal/Val Targets: Validity of

- Level-1 and Level-2 data
- Auxiliary and ancillary parameters
- Calibration parameters and quality flags
- Ex-ante uncertainties

Mission and User Requirements

- Goal: fitness-for-purpose of Sentinels Requirements: mission (MRTD), Copernicus services, core users
- Interoperability with(in) CEOS and CGMS constellations

Data Content and Documentation

- Traceability of data processing chain, versions, ancillary data etc.
- Full uncertainty budget, diagnostics

Validation Approaches

- From Lebel-1 to Level-2
- Evaluation vs. FRMs, other satellites, field campaigns, alternative retrievals
- Evaluation by Copernicus services
- Specific approaches for synergistic data

Validation Data Analysis

- Generic validation chain
- Evaluation of maturity of validation:
  - Reference data representativeness
  - Reference data quality
  - Validation method
  - Validation results

Sentinel-5(p) Specificities

- Unprecedented horizontal resolution
- Small-scale spatial variability
- Effects of clouds on tropo. retrievals
- Diurnal cycle effects in inter-calibration and cross-validation vs. other satellites
- Interoperability with heritage missions

Sentinel-4 Specificities

- Full diurnal cycle
- Dependences on solar & viewing angles
- Directional (incl. obscuration) effects
- Synergies FCI/MTG-I for enhanced UVN L2 retrievals, and UVN/IRS
- LEO satellites as travelling standard

CO2M Specificities

- Polarization properties by MAP
- Small-scale to continental variability
- Validation of point sources
- CO_2/NO_2 plume detection
- Interoperability in CO2M constellation and vs. other GHG missions

Planning and Organization

- From pre-launch to Phase F
- Operational + in-depth validation
- Facilities and workforce
- Communication

Tools and Services

- Validation database
- Sustainable acquisition of FRM data
- Orbit/overpass predictor
- Satellite data extractor
- Common validation analysis tools
- Validation reporting (incl. timeliness)
- Anomaly tracking

Cal/Val requirement by category

Cal/Val requirement by category	Sections	Identifier
Standards and traceability		
EO Cal/Val activities shall adhere to the general EO data quality strategy established in the QA4EO framework.	3.1.1	CCVS-REQ-AC-001
Traceable Quality Indicators shall be produced to enable users to evaluate readily the fitness-for-purpose of the EO data.	3.1.1	CCVS-REQ-AC-002
EO Cal/Val activities shall adopt standards and best practices for terminology. The expression of terms ambiguously used across teams and communities (e.g. accuracy) shall be clarified.	1.3.1	CCVS-REQ-AC-003
EO Cal/Val activities shall base data comparisons shall adopt community endorsed processes of generic operations and specific operations.	3.3	CCVS-REQ-AC-004
Maturity of the EO Cal/Val shall be assessed against the CEOS WGISS Data Management and Stewardship Maturity Matrix for satellite data validation.	3.4	CCVS-REQ-AC-005
Traceability of the validation process, methods, tools and data shall be documented.	3.1.1	CCVS-REQ-AC-006
Validation reporting shall include traceability information on the Sentinel data product, the validation processing, and the validation teams having performed the work and issued the report.	3.1.1	CCVS-REQ-AC-007
Cardinal validation targets		
Quality indicators shall be established for Level-1b data (radiance, reflectance and irradiance) and for their radiometric calibration, spectral assignment and geolocation.	3.1.2	CCVS-REQ-AC-008
Quality indicators shall be established for Level-2 geophysical quantities (column and profile of atmospheric constituents).	3.1.1, 3.1.2	CCVS-REQ-AC-009
Validity of the auxiliary and ancillary parameters used by the Level-1-to-2 data processors shall be verified.	3.1.2	CCVS-REQ-AC-010
Theoretical ex-ante uncertainties associated with the Level-1b and Level-2 data products shall be given quantitative evidence of their validity.	3.1.1, 3.1.2	CCVS-REQ-AC-011
Quality flags and data usage recommendations associated with the data products shall be given evidence of their validity and efficiency.	3.1.1, 3.1.2	CCVS-REQ-AC-012
Compliance of actual quality of the data product shall be evaluated with respect to mission requirements and core user requirements.	3.1.2	CCVS-REQ-AC-013
Compliance of actual quality of the data product shall be evaluated with respect to product specifications.	3.1.2	CCVS-REQ-AC-014
Mission and user requirements		
Cal/Val activities shall establish quality indicators enabling to judge the fitness-for-purpose of the Sentinel data quality comply with product specifications and mission requirements.	3.1.1	CCVS-REQ-AC-015
Cal/Val activities shall establish quality indicators enabling the Copernicus services to readily evaluate the fitness of the Sentinel data for their purposes.	3.1.1, 3.1.2	CCVS-REQ-AC-016
Cal/Val activities shall establish quality indicators enabling to readily evaluate whether the Sentinel data comply with interoperability requirements within the Copernicus constellations and within the CEOS and CGMS constellations.	4.2.2, 4.7	CCVS-REQ-AC-017
Cal/Val requirements for the atmospheric composition Sentinels shall be adapted during mission lifetime and beyond to reflect the evolution of core user data quality requirements.	1.1.3, 4.2, 4.2.1.2	CCVS-REQ-AC-018
Requirements on Sentinel data content and documentation		
Each Sentinel data product shall be provided with full identification of the data processing chain: data processor versions, but also identification of the ancillary and auxiliary data used in the processing.	3.1.1	CCVS-REQ-AC-019
Each Sentinel data product shall have associated with it a full uncertainty budget described in detail in an Algorithm Theoretical Basis Document (ATBD), with identification of the intermediate parameters, influence quantities and ancillary parameters influencing data quality.	2.4, 3.1.2	CCVS-REQ-AC-020
Each Sentinel data product shall include intermediate retrieved quantities, diagnostic data (averaging kernels…) and other quality information required to perform data content and information content analysis.	2.4, 3.3, 3.1.2	CCVS-REQ-AC-021
Validation approaches		
Sentinel Level-1b radiance and reflectance data shall be compared to natural targets for validation of geolocation, of calibration, of long-term stability, and of mutual consistency with other missions.	3.1.2	CCVS-REQ-AC-022
Sentinel Level-1b radiance and reflectance data shall be inter-compared with other satellite measurements.	3.1.2, 3.2.4	CCVS-REQ-AC-023
Sentinel Level-1b data shall be compared to (ground-based) Fiducial Reference Measurements.	3.2.2	CCVS-REQ-AC-024
Sentinel-1b extra-terrestrial spectral irradiance data shall be compared to other satellite measurements.	3.1.2	CCVS-REQ-AC-025
Sentinel Level-2 data shall be compared to (ground-based) Fiducial Reference Measurements tailored to Cal/Val needs of traceability, documentation, uncertainty assignment, timeliness of delivery, and long-term continuity.	3.2.2	CCVS-REQ-AC-026
Sentinel Level-2 data shall be compared to ground-based measurements from operational monitoring networks.	3.2.3	CCVS-REQ-AC-027
Sentinel Level-2 data shall be compared to other satellite measurements.	3.2.4	CCVS-REQ-AC-028
Official Sentinel Level-2 data shall be compared to alternative Level-1b-to-2 retrievals from the same Level-1b data.	3.2.5	CCVS-REQ-AC-029
Sentinel data shall be compared to data from field validation campaigns.	3.2.6	CCVS-REQ-AC-030
Leve-1b-to-2 data processing shall be validated end-to-end through validation – where possible – of retrieved intermediate quantities, ancillary parameters, and auxiliary parameters used in the retrieval.	2.4, 3.1.2, 3.2.4	CCVS-REQ-AC-031
Sentinel data products candidate for assimilation into a Copernicus service shall be tested by this service in close collaboration with the data producers and validation teams.	3.2.7	CCVS-REQ-AC-032
Modelling support shall investigate and document internal consistency of the Sentinel data and detect errors and features not reachable – or hardly – by existing measurement systems.	3.2.7	CCVS-REQ-AC-033
Specific validation approaches shall be developed for and applied to synergistic retrievals based on concurrent observations from different spectral domains (e.g., TIR combined with UV, VIS-NIR, and/or SWIR), and especially for synergistic retrievals from UVN and IRS on-board MTG-S, and from UVNS and IASI-NG on-board EPS MetOp-SG.	2.3.3, 2.3.4	CCVS-REQ-AC-034
Data analysis		
Appropriate methods and tools shall be developed, implemented, and their efficient application to Sentinel data demonstrated for every step of the generic validation process diagram producing quality indicators (Steps 1 to 9).	3.3	CCVS-REQ-AC-035
The validation process shall include data content analysis.	3.3	CCVS-REQ-AC-036
The validation process shall include information content analysis.	3.3	CCVS-REQ-AC-037
The validation process shall include data comparison studies.	3.3	CCVS-REQ-AC-038
As far as possible error propagation shall be performed along the chain of operations in order to produce a reliable uncertainty budget of the full validation process.	3.2.8	CCVS-REQ-AC-039
The uncertainty budget of the data comparisons will be calculated, including co-location and smoothing mismatch errors when possible to assess them.	3.2.8	CCVS-REQ-AC-040
Data comparisons shall be designed and interpreted to test the agreement between the Sentinel and the correlative quantity values.	3.2.8	CCVS-REQ-AC-041

Cal/Val requirement by category	Sections	Identifier
Sentinel-5p specificities		
Cal/Val activities listed above shall be performed for the list of Sentinel-5p data products delivered to core users and the public.	4.3	CCVS-REQ-AC-042
Emphasis shall be given to the validation of clouds as a major influence quantity affecting the tropospheric data retrievals.	4.3	CCVS-REQ-AC-043
Emphasis shall be given to small-scale spatial variability in tropospheric column data.	4.3, 4.2.3.2	CCVS-REQ-AC-044
Cal/Val activities shall include validation of the geolocation and horizontal resolution of ground pixels under a variety of measurement conditions.	4.2.3.2	CCVS-REQ-AC-045
Inter-calibration and cross-validation of Sentinel-5p with other LEO satellites shall take into account diurnal cycle effects on atmospheric constituents, measurement parameters, and influence quantities.	4.4,4.3,4.7	CCVS-REQ-AC-046
Interoperability of Sentinel-5p with other missions of the AQ, GHG and ozone constellations shall be verified.	4.7, 4.3, 4.2.3.2	CCVS-REQ-AC-047
Sentinel-5 specificities		
Cal/Val activities listed above shall be performed for the list of Sentinel-5 data products delivered to core users and the public.	4.4	CCVS-REQ-AC-048
Emphasis shall be given to the validation of clouds as a major influence quantity affecting the tropospheric data retrievals.	4.4	CCVS-REQ-AC-049
Cal/Val activities shall include validation of the geolocation and horizontal resolution of ground pixels under a variety of measurement conditions.	4.2.3.2	CCVS-REQ-AC-050
Cal/Val activities shall address the synergistic retrievals based on concurrent observations from UVNS and IASI-NG on-board the EPS MetOp-SG platform.	2.3.3	CCVS-REQ-AC-051
Inter-calibration and cross-validation of Sentinel-5 with other LEO satellites shall take into account diurnal cycle effects on atmospheric constituents, measurement parameters, and influence quantities.	4.4,4.3,4.7	CCVS-REQ-AC-052
Interoperability of Sentinel-5 with other missions of the Air Quality, Greenhouse Gases and Ozone satellite constellations shall be verified.	4.7,4.2.2, 4.2.3.2, 4.2.4.2,	CCVS-REQ-AC-053
Sentinel-4 specificities		
Cal/Val activities listed above shall be performed for the list of Sentinel-4 data products delivered to core users and the public.	4.5	CCVS-REQ-AC-054
Cal/Val activities shall put emphasis on the diurnal cycle of atmospheric constituents, measurement parameters, and influence quantities.	4.5, 2.4	CCVS-REQ-AC-055
Cal/Val activities shall give special attention to the dependence of data quality on solar and viewing angles.	4.5, 2.4	CCVS-REQ-AC-056
Emphasis shall be given to the validation of clouds as a major influence quantity affecting the tropospheric data retrievals.	4.5, 4.3,4.4	CCVS-REQ-AC-057
Directional effects (related to the viewing of atmospheric and surface properties) on Sentinel data quality shall be investigated.	4.5, 2.4	CCVS-REQ-AC-058
Cal/Val activities shall include validation of the geolocation and horizontal resolution of ground pixels at representative conditions of the measured area (Europe, Northern Africa and Western Turkey).	4.5, 4.2.3.2	CCVS-REQ-AC-059
Cal/Val activities shall address the use of Flexible Combined Imager (FCI) data aboard the MTG-Imager (MTG-I) platform for enhanced Sentinel-4 UVN Level-2 retrievals.	2.3.4	CCVS-REQ-AC-060
Cal/Val activities shall address the synergistic retrievals based on concurrent observations from UVN and IRS on-board the same MTG-S platform.	2.3.4	CCVS-REQ-AC-061
Interoperability of Sentinel-4 with other geostationary platforms and within the Air Quality satellite constellation shall be verified using Sentinel-5 (and possibly other LEO missions) as transfer standard.	4.2.3.2, 4.7, 4.5	CCVS-REQ-AC-062
CO2M specificities		
Top-of-atmosphere (TOA) radiance and reflectance require dedicated (inter-)calibration validated and product validation, among others through vicarious methods and ground-based measurements extrapolated to TOA.	4.6	CCVS-REQ-AC-063
Directional effects (related to the viewing of atmospheric, cloud and surface properties) on CO2M data quality shall be investigated.	4.6, 2.4	CCVS-REQ-AC-064
Cal/Val activities shall address polarisation properties measured by Multi-Angle Polarimeter (MAP).	4.6	CCVS-REQ-AC-065
Cal/Val activities shall give special attention to the cloud and aerosol data measured by Cloud Imager (CLIM) and Multi-Angle Polarimeter (MAP) data. Special attention shall be given to the proper detection of cirrus clouds.	4.6	CCVS-REQ-AC-066
Validation shall consider the various scales of application of CO2M data, from small-scale spatial variability to continental budgets.	4.6	CCVS-REQ-AC-067
Cal/Val activities shall include validation of the geolocation and horizontal resolution of ground pixels under a variety of measurement conditions, including validation of the geolocation in case of concurrent measurements by two CO2M satellites.	4.2.3.2	CCVS-REQ-AC-068
Emphasis shall be given to the validation of the geo-fitting approach for the tropospheric trace gases.	4.6	CCVS-REQ-AC-069
Multiple dedicated validation measurements near large point sources shall be undertaken to enable validation of geographical, temporal and vertical aspects of the CO2/NO2 plume detection.	4.6	CCVS-REQ-AC-070
Interoperability of the different satellites of the CO2M system shall be verified.	4.6, 4.7, 4.2.4.2	CCVS-REQ-AC-071
Interoperability of CO2M with other missions of the Greenhouse Gas satellite constellation shall be verified.	4.2.4.2, 4.7	CCVS-REQ-AC-072
Planning, organisation and international collaboration		
Cal/Val activities shall follow the life cycle and specificities of the Sentinel missions during mission lifetime: pre-launch, Phase E1 and Phase E2.	3.5.1	CCVS-REQ-AC-073
Cal/Val activities during Phase E2 shall include a main validation phase, routine operations validation, and validation of data and algorithm evolution.	3.5.1.3, 3.5.1.4, 3.5.1.5	CCVS-REQ-AC-074
Documentation, validation databases and tools shall be maintained after the termination of the mission to allow Phase F (post-mission) data evolution, validation, and long-term data preservation.	3.5.1.6	CCVS-REQ-AC-075
Communication channels shall ensure optimal exchange of information between agencies, data producers, algorithms developers, calibration teams, validation teams, and core users.	3.5.2	CCVS-REQ-AC-076
The needs for and the definition and implementation of a coordinating body for Cal/Val activities at least at European level shall be investigated.	3.5.2	CCVS-REQ-AC-077
The need to validate data products over the useful range of measurand values, ancillary parameters and influence quantities, requires international collaboration and cooperation for establishing and operating Cal/Val facilities in a variety of locations across the globe.	3.5.3	CCVS-REQ-AC-078
Interoperability requirements and the need to adopt (and benchmark on) community endorsed Cal/Val processes and standards require international collaboration through established bodies like CEOS and CGMS.	3.5.3	CCVS-REQ-AC-079
Tools and services		
A data centre shall be implemented for format control, storage, traceability and exchange of all validation data, and made available to the validation community.	4.8.1	CCVS-REQ-AC-080
The validation data centre shall be fed with sustainable and timely FRM data streams supported by a continuous resourcing programme.	4.8.2	CCVS-REQ-AC-081
An overpass predictor for each mission shall be made available to the validation community.	4.8.3	CCVS-REQ-AC-082
Satellite data extraction tools or routines shall be provided to the validation community.	4.8.4	CCVS-REQ-AC-083
Fit-for-purpose tools openly available to the community shall be designed, developed, tested and implemented for all steps of the validation process in Table 3, and for each official data product with its own specificities.	4.8.5	CCVS-REQ-AC-084
A suite of tools, eventually part of a coordinated reporting system for reasons of efficiency and internal coherence, shall be designed, developed, tested and implemented for various purposes.	4.8.6	CCVS-REQ-AC-085
An anomaly tracking system shall be implemented to register anomalies and required actions related to the satellite data, the validation data, and the validation process.	4.8.7	CCVS-REQ-AC-086