Sentinel-4 and Sentinel-5 Calibration and Validation Plan

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Change Record

Version	*Date*	*DCR* No. if applicable*	*Description of Changes*
V1	05/05/2020	N/A	New document
V1A	28/05/2024	EPSG_DCR_2793	• General document maintenance • Update of reference data descriptions (section 7.3), • Update of tool descriptions (section 7.4), • Rework of test description Verification of the Goniometry of the Solar Diffuser (A5.4) • Addition of test procedure per activity (Appendix B), • Addition of Appendix C: Mapping of Cal/Val tool to toolboxes

V1B	08/03/2025	n/a	Version for EPS-SG SIVVR-A
			• IFCT-7168: Rework of Geolocation verification activities:
			  ○ Reduced A5.1.1, A5.1.2 and A5.1.3 to Sentinel-4/UVN only and updated sections 6.2.2.1.1 to 6.2.2.1.3 accordingly.
			  ○ Introduced sections 6.2.2.1.4 and 6.2.2.1.5 as well as activity descriptions A5.1.4 and A5.1.5, including detailed description of Sentinel-5/UVNS geolocation and co-registration validation using PIQMICS.
			• IFCT-7172: Requirement identifiers have been added in the activity descriptions (Appendix B), where applicable.
			• Update of activity A5.6.1 and section 6.2.2.6.1 to align it with Sentinel-5 spectral range.
			• Update of activities A5.6.2 to A5.6.5 and section 6.2.2.6.2 w.r.t. use of MICMICS tool for verification of radiometric bias and stability.

DCR = Document Change Request

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INTRODUCTION

1.1 Purpose and Scope

This document forms part of the suite of Calibration and Validation (Cal/Val hereafter) plans for the EPS-SG & MTG programs.

The focus of this document is on scientific and technical activities needed in support of Cal/Val. This document does not address management and/or programmatic issues and planning. These aspects are addressed in higher level documents. These are the MTG System Commissioning Plan [SCP], EUM/MTG/PLN/11/0203 [AD1], the MTG LEOP and Commissioning Support Plan [LCSP], EUM/MTG/PLN/19/1075627 [RD5], and the ESA Sentinel-4 System Commissioning Plan, S4-ESA-SY-PL-0790 , [RD57] for Sentinel-4/UVN, and the EPS-SG LEOP and Commissioning Management Plan (LCMP), EUM/LEO-EPSSG/PLN/18/1031948 [RD6] and the ESA Sentinel-5 Commissioning and Calibration/Validation Plan, S5-PL-ESA-SYS-0466 [RD58] for Sentinel-5/UVNS.

For MTG, the MTG System Commissioning Plan [AD1] defines how the system is verified and validated after the launch, including the in-orbit verification (confirmation that the satellite, including instruments, meets the space segment requirements), the system verification (confirmation that the MTG system meets the system level requirements), the operational validation (confirmation that the system is able to support the operational services according to the operational concept and using the operational processes), and the scientific validation (confirmation that the scientific data and products generated by the System meet the intended scientific performance objectives). The Sentinel-4 Commissioning Plan [RD56] outlines the commissioning phase activities that will be conducted under the responsibility of ESA. It describes the relationship between Launch and Early Orbit Phase (LEOP) activities, Satellite In-Orbit Verification (SIOV) of the Sentinel-4/UVN instrument, Ground Segment commissioning, and Cal/Val, referring to the present document for Cal/Val planning. In this overall context, the Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val Plan addresses aspects related to scientific validation.

For EPS-SG there is one Instrument Cal/Val Plan for each of Sentinel-5/UVNS, METimage, IASI-NG, 3MI, SCAT and RO, and they complement the more general information contained in the EPS-SG Programme Overall Calibration and Validation Plan, EUM/LEO-EPSSG/PLN/14/758341[AD2]. This overall plan also contains relevant definitions and the EPS-SG philosophy for Cal/Val planning and generic descriptions for activities applicable to all instrument Cal/Val activities. The Instrument Plans drive the activities described in the Overall Plan and form a part of the overall set of plans describing the pre- and post-launch activities to be conducted to verify and validate the EPS-SG system. In several sections, the CVPs will refer to related activities and resources that are more completely described in other documents. In particular,

- The EPS-SG Reference Operations Plan [RD2] contains the detailed rules and constraints for system control procedures and the EPS-SG Systems Operations File (SOF) [RD3] will contain procedures to operate the space and ground segments, as well as the system control procedures themselves. These procedures will include the operational procedures required to execute the activities described in the individual instrument Cal/Val Plans.
- The EPS-SG OGS and System Integration, Verification, and Validation Plan [RD4], will contain tests that verify that the EPS-SG System infrastructure is sufficient to calibrate and validate EPS-SG data products using the activities detailed in the CVPs.
- The EPS-SG LEOP and Commissioning Management Plan [RD5] contains the overall planning of activities during Commissioning. The Commissioning Phase is divided in two parts. First, the

Satellite In-Orbit Verification (SIOV) takes place, where the instruments are switched on, basic checks are performed on them, and the instrument modes are characterised. Following the SIOV, the EPS-SG In-Orbit System V&V follows during the rest of the commissioning, which includes all product Cal/Val activities. The SIOV is formally concluded by the SIOV Review; however, because of the parallelism between the instrument chains, Cal/Val activities may start for given instrument chain(s) before the SIOV is completed for other chain(s).

- The Sentinel-5 Commissioning and Calibration/Validation Plan [RD57] outlines the Sentinel-5 related commissioning phase activities that will be conducted. It describes the relationship between Launch and Early Orbit Phase (LEOP) activities, Satellite In-Orbit Verification (SIOV) of the Sentinel-5/UVNS instrument, Ground Segment commissioning, and Cal/Val, referring to the present document for Cal/Val planning.

These Cal/Val Plans are not meant to supersede or replace these documents. However, they will identify related activities that are a critical prerequisite for successful calibration and validation activities.

The present document specifies the objectives, requirements and approach for the Cal/Val of the Sentinel-4/UVN and Sentinel-5/UVNS products. A variety of activities are needed to address these goals, comprising long-term operational monitoring, routine calibration and validation activities, and campaigns with a short run time. An Announcement of Opportunity (AO) Call will be released to trigger and coordinate campaign activities, with a focus on elements that are not expected to be covered by routine calibration and validation activities or long-term operational monitoring. The AO call mechanism is outlined in Section 1.4.

The Cal/Val Plans should be viewed as evolving documents, with successive iterations containing more detail as activities become better defined. They will identify the **inputs**, **activities**, and **outputs** for successful Copernicus Sentinel-4/UVN and Sentinel-5/UVNS product calibration and validation, including the identification of the **linkages** and timing & **resource requirements** for these activities.

In this document, the specific objectives of Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val are outlined in Section 2, as well as major high-level constraints in Section 3. The Phasing is described in Section 4. An overview of the Sentinel-4/UVN and Sentinel-5/UVNS instruments and their processing chains, and the Cal/Val approach are given in Section 5. The detailed methods and activities required to meet the Cal/Val objectives are then described in Section 6. Required resources are identified in Section 7 and necessary expertise and training requirements in Section 8. Finally, planning details are provided in Section 9.

Issues To Be Confirmed (TBC) or To Be Decided (TBD) are listed in Section 1.5, and will be updated with subsequent evolution of the document.

Abbreviations and acronyms are defined in Appendix A. Detailed activity descriptions are provided in Appendix B, clearly identifying the activities that still require resource allocation and/or detailed planning. Finally, Appendix C provides a mapping of which tool functionality is implemented in which toolbox.

1.2 Document structure

This plan is intended for use by all entities involved in the MTG Sentinel-4/UVN and EPS-SG Sentinel-5/UVNS Cal/Val activities. This will include but is not limited to the following:

- EUMETSAT and its partner NOAA,
- ESA

- the Satellite Application Facilities (SAF's) and in particular the SAF on Atmospheric Composition Monitoring who will generate a subset of the operational Level 2 products from Sentinel-4/UVN and Sentinel-5/UVNS,
- other external partners involved in Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val activities,
- Sentinel-4/UVN and Sentinel-5/UVNS data product users.

Within EUMETSAT, the intended use is to:

- develop the Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val sub-system (involved facilities, required interfaces, involved teams, responsibilities, schedule etc.),
- procure and develop the Sentinel-4/UVN and Sentinel-5/UVNS related functionality of the EUMETSAT offline operational environment,
- plan and execute the instrument monitoring (both short and long-term) and product verification and validation activities,
- plan and execute cross-characterisation and cross-validation activities during the operation of more than one EPS-SG and/or MTG satellite and Sentinel-4/UVN and/or Sentinel-5/UVNS instrument.

For a discussion of the intended use within ESA see Section 1.4.

This Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val plan is applicable to the pre-launch, commissioning and routine operations phases.

1.3 Assumptions

The role of the product Cal/Val activities within the general verification & validation strategy is to carry out all actions required to thoroughly characterise, calibrate and validate the Sentinel-4/UVN and Sentinel-5/UVNS products end-to-end. Those activities that are considered to be within the scope of the plan are discussed in Sections 5.3.1.1 and 5.3.2.1 and further elaborated in later sections. Those that are outside the scope of the plan are summarised in Sections 5.3.1.2 and 5.3.2.2.

In addition, the following assumptions have been made in the preparation of this plan:

- Long-term monitoring activities and trend assessment will be an integral part of Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val activities therefore many of the activities described in this plan will be applicable for the lifetime of the mission including all MTG and EPS-SG satellites and Sentinel-4/UVN and Sentinel-5/UVNS instruments.
- Dedicated Cal/Val activities are required to address the cross-calibration and cross-validation of Sentinel-4/UVN and Sentinel-5/UVNS instruments on MTG and EPS-SG satellites flying at the same time as well as Sentinel-4/UVN and Sentinel-5 UVNS instruments flying on recurrent satellites in tandem. These activities are considered an addition to the basic set of Cal/Val activities that are required to characterise, calibrate and validate the Sentinel-4/UVN and Sentinel-5/UVNS products from a single independent satellite/instrument and are also applicable, at least in part, to cross-calibration and cross-validation of instruments that form part of the CEOS Atmospheric Composition Virtual Constellation. These activities will provide an additional mechanism for product improvement. They are described further in Section 6.2.4 and 6.2.5.
- The Satellite Application Facility on Atmospheric Composition Monitoring (AC SAF) will produce additional Level 2 products from Sentinel-4/UVN and Sentinel-5/UVNS and are fully responsible for the validation of these products. See Section 5.3.2.2 for further details.

- The activities described in this plan may be supplemented by Cal/Val activities carried out by the scientific community. See Section 5.3.2.2 for further details.
- It is expected that Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val activities will lead to recommendations for upgrades or improvements to the product processing software. The procedures by which operational software are to be upgraded are not described in this plan however it is assumed that dedicated Cal/Val activities will be required to confirm the correct implementation of product processing software changes.

1.4 The Announcement of Opportunity

As noted in Section 1.1, an Announcement of Opportunity (AO) Call will be released to trigger proposals for campaign activities, with a focus on elements that are not expected to be covered by routine calibration and validation activities or long-term operational monitoring. The Cal/Val objectives and the requirements specified in the present document provide the basis for the preparation of this Call. One single AO Call will be issued covering both Sentinel-4 and Sentinel-5, unless the respective launch dates are temporally too far apart (by more than the typical planning horizon for Cal/Val activities, which is about 1.5 years).

The AO is jointly prepared by ESA and EUMETSAT. Cal/Val activities conducted in response to this AO Call will be coordinated by ESA and EUMETSAT. ESA will be involved in Cal/Val activities until a certain point in time. EUMETSAT intends to continue the coordination of AO activities that may be performed after the end of this ESA involvement. The outcome of all Cal/Val activities will be used to establish and maintain the data quality of the Sentinel-4/UVN and Sentinel-5/UVNS products and are thus input to the commissioning of the respective instruments and ground segments.

This version of the Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val plan is expected to evolve, in particular in response to the outcome of the AO Call. At this point an analysis will be performed to determine which requirements and goals are either fully or partially met by funded activities, proposed through the AO call. In case additional complementary Cal/Val activities are deemed necessary, this may be captured in a specific implementation plan.

1.5 Open Issues

Open issues related to management and/or programmatic aspects are not addressed here. For these aspects please see the MTG System Commissioning Plan [SCP], EUM/MTG/PLN/11/0203 [AD1], the MTG LEOP and Commissioning Support Plan [LCSP], EUM/MTG/PLN/19/1075627 [RD5], and the ESA Sentinel-4 System Commissioning Plan, S4-ESA-SY-PL-0790 [RD57] for Sentinel-4/UVN, and the EPS-SG LEOP and Commissioning Management Plan (LCMP), EUM/LEO-EPSSG/PLN/18/1031948 [RD6] and the ESA Sentinel-5 Commissioning and Calibration/Validation Plan, S5-PL-ESA-SYS-0466 [RD58] for Sentinel-5/UVNS.

There are a number of technical issues that are to be specified or further elaborated in future issues of this document. These are listed below:

- Definition of specific parameters required for instrument monitoring will be updated and confirmed as instrument source packet and housekeeping data definition is further consolidated.
- Specific details regarding the monitoring of the Instrument Spectral Response Function are to be written.
- Specific details of the verification of straylight correction performance are to be consolidated when the straylight performance of the instrument has been characterised in detail.

In general, details of calibration and validation analysis will be further elaborated in future updates of this document however the overall scope and structure of activities is not expected to change.

1.6 Applicable Documents

[AD1] MTG System Commissioning Plan [SCP], EUM/MTG/PLN/11/0203

[AD2] EPS-SG Programme Overall Calibration and Validation Plan, EUM/LEO-EPSSG/PLN/14/758341

[AD3] Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017

[AD4] Sentinel-4 Level-2 Processor Requirements Specification, S4.ESA.UVN.RS.0093, Issue 2, Revision 1, 27/11/2018

[AD5] Sentinel-5 Level-2 Prototype Processor Development Requirements Specification, S5-RS-ESA-GR-0131, Issue 1, Revision 8, 15 July 2019

[AD6] Sentinel-4/UVN - Instrument Requirements Specification, GS4.ASG.UVN.RS.00001

[AD7] Sentinel-5/UVNS - Instrument Requirements Specification, GS5.RS.ASG.UVNS.00012

[AD8] Copernicus Sentinel-4 Product Distribution Baseline at EUM [S4HQ], EUM/MTG/SPE/12/0767 and S4-ESA-SY-LI-0142

[AD9] Copernicus Sentinel-5 Data Distribution Baseline, S5-LI-ESA-SY-0085

1.7 Reference Documents

1.7.1 System Reference Documents

[RD1] MTG Reference Operations Plan [ROP], EUM/OPS-MTG/PLN/14/779920

[RD2] EPS-SG Reference Operations Plan (ROP) EUM/OPS-EPSSG/PLN/15/765678

[RD3] EPS-SG System Operations File (SOF), EUM/OPS-EPSSG/DOC/16/856475

[RD4] EPS-SG OGS and System Integration, Verification and Validation (OSIVV) Plan, EUM/LEO-EPSSG/PLN/17/960848

[RD5] MTG LEOP and Commissioning Support Plan [LCSP], EUM/MTG/PLN/19/1075627

[RD6] EPS-SG LEOP and Commissioning Management Plan (LCMP), EUM/LEO-EPSSG/PLN/18/1031948

[RD7] MTG – Spacecraft System Requirements Document, MTG.ESA.SA.RS.0062

[RD8] MetOp Second Generation (MetOp-SG) Space Segment Requirements Document (SSRD), MOS-RS-ESA-SYS-0001

[RD9] S4/UVN - Commissioning Plan, GS4-ADSO-UVN-PL-1000148199

[RD10] S5/UVNS - Instrument In-Orbit Verification Plan, GS5.PL.ASG.UVNS.00058

[RD11] Sentinel-4/UVN Flight Operations Manual, GS4.ASG.UVN.MA.00002

[RD12] Sentinel-5/UVNS Instrument Flight Operation Manual, GS5-SP-ADSO-UVNS-1000108068

[RD13] MTG UVN Level 0 & 1 Processing Specification, EUM/MTG/SPE/10/0438

[RD14] EPS-SG Sentinel-5 Level 1b Product Generation Specification, EUM/LEO-EPSSG/SPE/14/772047

[RD15] Sentinel-4 L2 Input Output Data Specification (IODS), S4-L2-DLR-IODS-4004

[RD16] Sentinel-4 L2 Processor Component Development Interface Requirements Document (IRD), S4-L2-DLR-IRD-4002

[RD17] Sentinel-4 L2 Processor Component Development Project Management Plan, S4-L2-DLR-PMP-1004

[RD18] Sentinel-4 Level 2 Product User Manual (PUM) O3 Total Column, S4-L2-DLR-PUM-4102

[RD19] Sentinel-4 Level 2 Product User Manual (PUM) Tropospheric O3, S4-L2-DLR-PUM-4103

[RD20] Sentinel-4 Level 2 Product User Manual (PUM) Nitrogen dioxide NO2, S4-L2-DLR-PUM-4104

[RD21] Sentinel-4 Level 2 Product User Manual (PUM) Sulfur Dioxide SO2, S4-L2-DLR-PUM-4105

[RD22] Sentinel-4 Level 2 Product User Manual (PUM) Formaldehyde HCHO, S4-L2-DLR-PUM-4106

[RD23] Sentinel-4 Level 2 Product User Manual (PUM) Tropospheric Glyoxal CHOCHO, S4-L2-DLR-PUM-4107

[RD24] Sentinel-4 Level 2 Product User Manual (PUM) Aerosol Layer Height, S4-L2-DLR-PUM-4108

[RD25] Sentinel-4 Level 2 Product User Manual (PUM) Cloud Properties, S4-L2-DLR-PUM-4109

[RD26] Sentinel-4 Level 2 Product User Manual (PUM) Surface Reflectance, S4-L2-DLR-PUM-4110

[RD27] Sentinel-4 Level 2 Product User Manual (PUM) FCI Cloud Support, S4-L2-DLR-PUM-4111

[RD28] Sentinel-4 Level 2 Product User Manual (PUM) UV Aerosol Index, S4-L2-DLR-PUM-4117

[RD29] Sentinel-5/UVNS L1bPP Algorithm Theoretical Basis Document (ATBD), GS5.RP.ASG.UVNS.00044

[RD30] EPS-SG Sentinel-5 Level 1b Products Format Specification, EUM/LEO-EPSSG/SPE/14/772065

[RD31] EPS-SG Sentinel-5 Level 2 Products Format Specification, EUM/LEO/EPSSG/SPE/16/887629

[RD32] EPS-SG Sentinel-5 Level 1b Auxiliary Data Specification, EUM/LEO-EPSSG/SPE/14/772051

[RD33] EPS-SG Sentinel-5 Level 2 Auxiliary Data Specification, EUM/LEO-EPSSG/SPE/16/887628

[RD34] EPS-SG Sentinel-5 Level 2 Aerosol Optical Depth Product Generation Specification, EUM/LEO- EPSSG/SPE/17/927444

[RD35] EPS-SG Sentinel-5 Level 2 Aerosol UV Index Product Generation Specification, EUM/LEO-EPSSG/SPE/17/927445

[RD36] EPS-SG Sentinel-5 Level 2 Methane Product Generation Specification, EUM/LEO-, EPSSG/SPE/17/927446

[RD37] EPS-SG Sentinel-5 Level 2 Cloud Product Generation Specification, EUM/LEO-EPSSG/SPE/17/927448

[RD38] EPS-SG Sentinel-5 Level 2 Carbon Monoxide Product Generation Specification, EUM/LEO-EPSSG/SPE/17/927449

[RD39] EPS-SG Sentinel-5 Level 2 Formaldehyde Product Generation Specification, EUM/LEO-EPSSG/SPE/17/927450

[RD40] EPS-SG Sentinel-5 Level 2 Glyoxal Product Generation Specification, EUM/LEO-EPSSG/SPE/17/927451

[RD41] EPS-SG Sentinel-5 Level 2 Auxiliary VII Product Generation Specification, EUM/LEO-EPSSG/SPE/17/927452

[RD42] EPS-SG Sentinel-5 Level 2 Nitrogen Dioxide Product Generation Specification, EUM/LEO-EPSSG/SPE/17/927453

[RD43] EPS-SG Sentinel-5 Level 2 Ozone Total Column Product Generation Specification, EUM/LEO- EPSSG/SPE/17/927454

[RD44] EPS-SG Sentinel-5 Level 2 Ozone Profile Product Generation Specification, EUM/LEO-EPSSG/SPE/17/927455

[RD45] EPS-SG Sentinel-5 Level 2 Effective Reflectance Product Generation Specification, EUM/LEO- EPSSG/SPE/17/927456

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2 OBJECTIVES

The overall objective of the Sentinel-4/UVN and Sentinel-5/UVNS characterisation, calibration and validation activities is to ensure that, after the commissioning phase and thereafter during the mission lifetime, the Sentinel-4/UVN and Sentinel-5/UVNS instruments achieve their expected performance with respect to the Sentinel-4/UVN and Sentinel-5/UVNS requirements specifications [AD6] and [AD7] and that the products satisfy the End User Requirements specified [AD3], [AD4] and [AD5]. A further objective is that the Sentinel-4/UVN and Sentinel-5/UVNS product accuracy will continuously improve as far as possible to satisfy the evolving state of the art user requirements.

The following specific objectives determine the product Cal/Val activities for Sentinel-4/UVN and Sentinel-5/UVNS, in the framework of the overall product Cal/Val objectives as expressed in [AD1] and [AD2].

- verification of instrument performance, as relevant for generation of Level 1b products, through monitoring of the Sentinel-4/UVN and Sentinel-5/UVNS instruments and Level 1b products;
- calibration and characterisation of the Sentinel-4/UVN and Sentinel-5/UVNS instruments taking into account long term changes in instrument performance in-flight;
- provision of confidence checked and verified Sentinel-4/UVN and Sentinel-5/UVNS Level 1b and Level 2 products;
- provision of validated Sentinel-4/UVN and Sentinel-5/UVNS Level 1b and Level 2 products taking account of the feed-back between Level 1b and Level 2 product validation and additional information available from cross-comparison of Sentinel-4/UVN and Sentinel-5/UVNS data products and when applicable, tandem operation of the Sentinel-4/UVN and/or Sentinel-5/UVNS instruments;
- identifying the need for revision of product generation processing algorithms and auxiliary data to ensure that the products first meet, and then exceed, user expectations.

These objectives will be achieved by the following:

- extensive checks of internal data consistency and consistency with a priori knowledge;
- continuous monitoring of the Sentinel-4/UVN and Sentinel-5/UVNS instrument performance and data product quality;
- the collection of suitable validation data e.g. measurements from ground-based, airborne and satellite platforms as appropriate;
- the development of an easily accessible validation database and a data ingestion facility for validation;
- the development of appropriate tools (e.g. coincidence predictors, software for data ingestion, cataloguing, database tools, data display and manipulation tools etc.);
- the provision of auxiliary data (atmospheric parameters etc.) not measured by the satellite instrument but needed for validation studies;
- the analysis of validation data sets;
- the assessment of the uncertainties of the instrument data products;
- and iterative validation and reprocessing, converging to high quality data products.

3 CONSTRAINTS

The activities described within this plan will be carried out within the constraints imposed by the overall MTG and EPS-SG satellite operations and the operational requirements of the payloads as a whole, [RD1], [RD2], [RD4] and [RD5].

In addition the Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val activities will be constrained by the in-orbit instrument activities and observation mode planning described in the S4/UVN - Commissioning Plan, GS4-ADSO-UVN-PL-1000148199 [RD9] and the S5/UVNS - Instrument In-Orbit Verification Plan, GS5.PL.ASG.UVNS.00058 [RD10]. These documents describe the baseline set of in-orbit instrument activities required to provide all in-flight calibration measurements needed to achieve well calibrated Level 1b data products.

Detailed Sentinel-4/UVN and Sentinel-5/UVNS operations will be planned in conjunction with ESA and industry taking into account the baseline activities described in [RD49] and [RD50], the Sentinel-4/UVN and Sentinel-5/UVNS In-Orbit Verification activities described in [RD9] and [RD10], and the constraints imposed by this Cal/Val plan and known science requirements listed above.

In particular, the Verification of the Goniometry of the Solar Diffuser (A5.4) requires dedicated platform operations to be carried out during the commissioning period. Similarly, should a lunar viewing opportunity arise during the EPS-SG Commissioning period, Verification of Radiometric Performance using Moon Observations (A5.6.5), would require a dedicated platform manoeuvre to enable lunar viewing.

Note that when applicable, the determination of the optimal mode of operation for tandem operations of more than one Sentinel-4/UVN and/or Sentinel-5/UVNS instrument will require information from both Level 1 and Level 2 cross-calibration and cross-validation activities and specific decision points will be required to assess this information when necessary.

4 PHASING

Calibration and Validation activities for Sentinel-4/UVN and Sentinel-5/UVNS will be organised in three main phases: pre-launch activities, commissioning phase activities and routine operational activities.

4.1 Pre-launch activities

Pre-launch activities comprise all activities required to be completed prior to launch. Those relevant to Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val activities include on-ground instrument calibration and characterisation, definition of Cal/Val activities and procedures, procurement of all supporting data sets and tools, and activities related to co-ordination, planning and management.

4.2 Commissioning phase activities

Commissioning phase activities will begin with Satellite In-Orbit Verification (SIOV), which is under the responsibility of the European Space Agency (ESA) and industrial partners. SIOV will be carried out in the time period, launch to launch plus 6 months for Sentine-4/MTG-S [RD57] and 3 months for Sentinel-5/EPS-SG [RD58]. The SIOV activities will be concluded by an SIOV review marking verification of nominal satellite and instrument performance. In-orbit satellite verification activities test the in-orbit satellite performance against the satellite system requirements [RD7] and [RD8] and will be detailed in the MTG Reference Operations Plan [ROP], EUM/OPS-MTG/PLN/14/779920 [RD1] and the EPS-SG Reference Operations Plan (ROP) EUM/OPS-EPSSG/PLN/15/765678 [RD2]. These activities will be further detailed in the MTG LEOP and Commissioning Support Plan [LCSP], EUM/MTG/PLN/19/1075627 [RD5] and the EPS-SG LEOP and Commissioning Management Plan (LCMP), EUM/LEO-EPSSG/PLN/18/1031948 [RD6] and references therein and are a necessary prerequisite to the in-orbit verification of the individual instruments, including Sentinel-4/UVN and Sentinel-5/UVNS. The Sentinel-4 Commissioning Plan [RD57] and the Sentinel-5 Commissioning and Calibration/Validation Plan [RD58] establish an overall planning for the early post-launch functional check-out, characterisation and calibration activities for the Sentinel-4/UVN and Sentinel-5/UVNS instruments. The activities in [RD57] and [RD58] take into consideration the IOV of the instrument and the commissioning of its associated ground segment elements. The Sentinel-4/UVN and Sentinel-5/UVNS IOV will start with instrument switch-on and end formally at the SIOV review. The primary objective of Sentinel-4/UVN and Sentinel-5/UVNS IOV is to verify that the instruments meet their functional and performance requirements. This will be achieved by exercising specific instrument operations, first via manual commanding and then using dedicated test timelines. For further details, see [RD9] and [RD10]. The detailed plans for in-orbit operation of the Sentinel-4/UVN and Sentinel-5/UVNS instrument will be described in the Sentinel-4/UVN Flight Operations Manual, GS4.ASG.UVN.MA.00002 [RD11] and Sentinel-5/UVNS Instrument Flight Operation Manual, GS5-SP-ADSO-UVNS-1000108068 [RD12].

Successful conclusion of the SIOV review is a prerequisite for the start of product verification and validation activities. Instrument monitoring activities will begin during SIOV and will continue throughout the lifetime of the mission. Confidence checking and verification of the operational Level 1b products begins after the SIOV and will be followed by validation of both Level 1b and Level 2 products against independent measurements. The initial validation of Level 2 products to identify potential issues, anomalies, and shortcomings is started once the Level 1b product quality is consolidated. Completion of this initial validation and resolution of any main reported issues is needed for Level 2 product release. Ideally, validation of Level 2 product performance would be carried out for at least half a seasonal cycle including summer, equinox, and winter conditions. Comparisons with other satellite data and with fiducial

reference measurements are long-term activities and the results from such comparisons are key for the initial validation.

It should also be noted that, as a result of the complex interactions and feedback between these activities, they will not be carried out in strict sequence and many activities may be carried out in parallel. Short-term reprocessing may also be required during the commissioning phase following correction of calibration key data, processing algorithms or other related issues. At the conclusion of the commissioning phase, it is expected that correct instrument functioning has been verified and nominal product quality achieved. The conclusion is marked by a Commissioning phase hand-over review following which the system is handed over for routine operations.

As different instruments will take a different length of time to reach verified instrument functioning and nominal product quality, it is possible that a partly commissioned system will be passed for routine operations.

4.3 Routine operational activities

Following a successful Commissioning phase hand-over review, routine operations begin.

In case more than one MTG-S and EPS-SG satellite and Sentinel-4/UVN and Sentinel-5/UVNS instrument are being flown in tandem operation, the initial phase of routine operations will be dedicated to cross-calibration and cross-validation activities. These activities will first assess the relative product quality of both instruments and subsequently use this information to determine the optimal instrument configuration for tandem operation. As the assessment of the optimal configuration for tandem operation will ultimately rely on the assessment of the quality of the operational Level 2 data products. Close interaction with the algorithm developers is required including involvement in the decision process for the final configuration for tandem operations.

Routine operations will continue once the configuration for nominal operations or when applicable tandem operations are established. During routine operations the Sentinel-4/UVN and Sentinel-5/UVNS instrument monitoring activities will continue, paying particular attention to in-flight instrument degradation and the calculation of correction factors to account for this if necessary. A complete reprocessing of the Sentinel-4/UVN and Sentinel-5/UVNS data for the entire mission may need to be accommodated during routine operations to correct successfully for degradation effects. Furthermore, continued verification and validation activities are required in order to assess the product quality for all seasons, latitudinal ranges and atmospheric conditions (which may not be possible during the time constraints of the commissioning phase). Improvements to product processing algorithms and product quality beyond that achieved during the commissioning phase are expected during this period and will be supported by the on-going verification and validation activities, including cross-calibration and cross-validation activities.

Long-term monitoring and continuous validation should include automated data quality monitoring, trend monitoring, and monitoring of expected range exceedances. Automated report generation is also expected in this phase.

5 OVERVIEW

5.1 Overview of the Sentinel-4 Instrument and Processing

The Copernicus Sentinel-4/UVN mission consists of an Ultraviolet-Visible-Near-infrared (UVN) imaging spectrometer instrument embarked on the Meteosat Third Generation Sounding (MTG-S) satellite. The main objective of the Sentinel-4/UVN mission is to monitor key air quality trace gases and aerosols over Europe in support of the Copernicus Atmosphere Monitoring Service (CAMS) at high spatial resolution and with a frequent revisit time.

5.1.1 Sentinel-4/UVN Instrument

The Sentinel-4/UVN instrument consists of an Optical Instrument Module (OIM) and a sunshield, placed on the nadir panel of the MTG-S platform, as well as two pieces of electronic hardware, the Instrument Control Unit (ICU) and the Scanner Drive Electronics (SDE), which are placed inside the satellite and are connected to the instrument by a dedicated harness (see Figure 5.1).

The OIM, whose cross-section is shown in Figure 5.2 (left), has two view ports that can be selected with a scan mirror: an Earth observation view (nadir port) that can also observe stars and the moon, and the Calibration Assembly (CAA) view port. The CAA view port is used for sun viewing and viewing of the on-board White-Light-Source (WLS).

The two-axis scan mirror is used for various purposes:

- to switch between CAA port (solar port, WLS) and Earth view (nadir port);
- to scan the Earth in east-west direction in the Earth observation mode;
- to set the scan mirror to the correct angle in the north-south direction;
- to scan over stars;
- to measure the moon.

In reality the Earth view consists of two ports since the bi-annual yaw-flip manoeuvre of the MTG-S satellite necessitates an opposite orientation of the scanner north-south angle in summer and winter to enable pointing towards the target Earth coverage area around Europe. For this reason, the Earth port aperture cover mechanism has two flaps that are adjacent in the north-south direction: a summer and a winter opening flap.

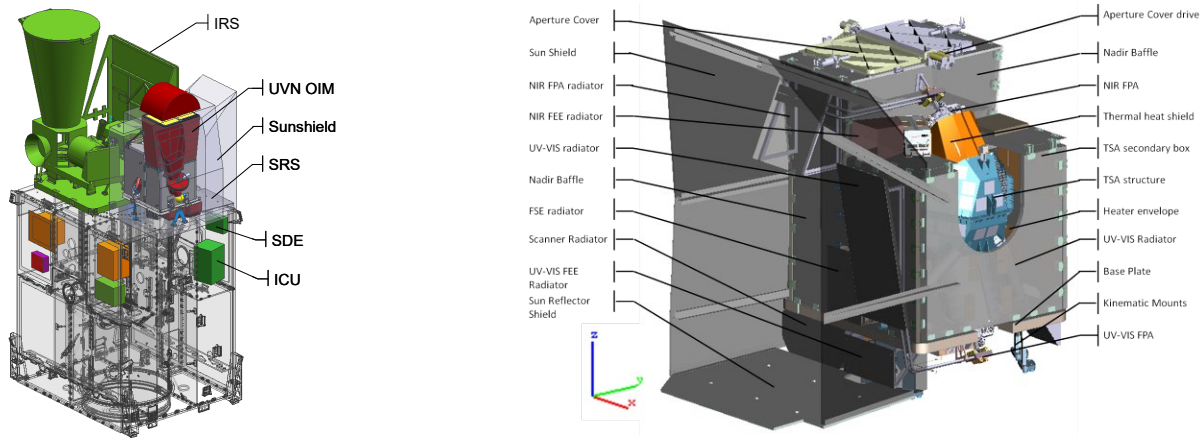


Figure 5.1: Left: Sentinel-4/UVN configuration together with the IRS instrument on the MTG-S satellite. Right: Sentinel-4/UVN OIM from a radiator-side and IRS-side perspective.

The CAA port also has two principal sub-viewing options that can be selected by the setting of the diffuser wheel mechanism of the CAA. In the first setting the sun is observed through one of two selectable and identical transmission diffusers (nominal and reference). In the other setting the on-board WLS is observed for instrument transmission and pixel response diagnostic (and calibration) purposes. Deep space, and in particular star viewing is enabled by extensions of the nadir baffle clear Field of View (FOV) towards the east. This allows the instrument instantaneous entrance slit to be pointed sufficiently far to the east such that the entire slit points beyond Earth into deep space. In summary, the instrument has several external views: Earth (radiance) observation, star viewing, moon (all through the same nadir port) and sun (irradiance) observation.

Next in the light path after the scan mirror comes the Telescope-Spectrograph-Assembly (TSA), which features a common telescope for all spectral bands, followed by a dichroic beam splitter combined with the entrance slit assembly, which separates the NIR from the UVVIS band(s). The UVVIS bands (305-500 nm) are covered by a single spectrometer all the way down to the detector, otherwise known as the Focal Plane Assembly (FPA). The NIR spectral band (750-775 nm) is also covered by a single spectrometer and detector or FPA.

The light of the UVVIS band is dispersed by a transmissive grism (a combination of a transmissive grating and a prism) in the UVVIS spectrometer and by a reflective grating in the NIR spectrometer. The NIR grating assembly includes a thermally activated co-registration compensation mechanism, which allows fine-tuning of the NIR detector image position in spatial (north-south) direction, thereby achieving optimum north-south co-alignment between UVVIS and NIR. The two FPAs feature CCD detectors acquiring the spectral channels in one direction and the spatial sampling in the orthogonal direction. In addition, each FPA includes a dedicated LED light source, which is optimized for homogeneous in-band illumination of the respective detector. The illumination of the LED towards the CCDs is not via the spectrometer optics, so the colour of the LED is not spectrally resolved on the detectors.

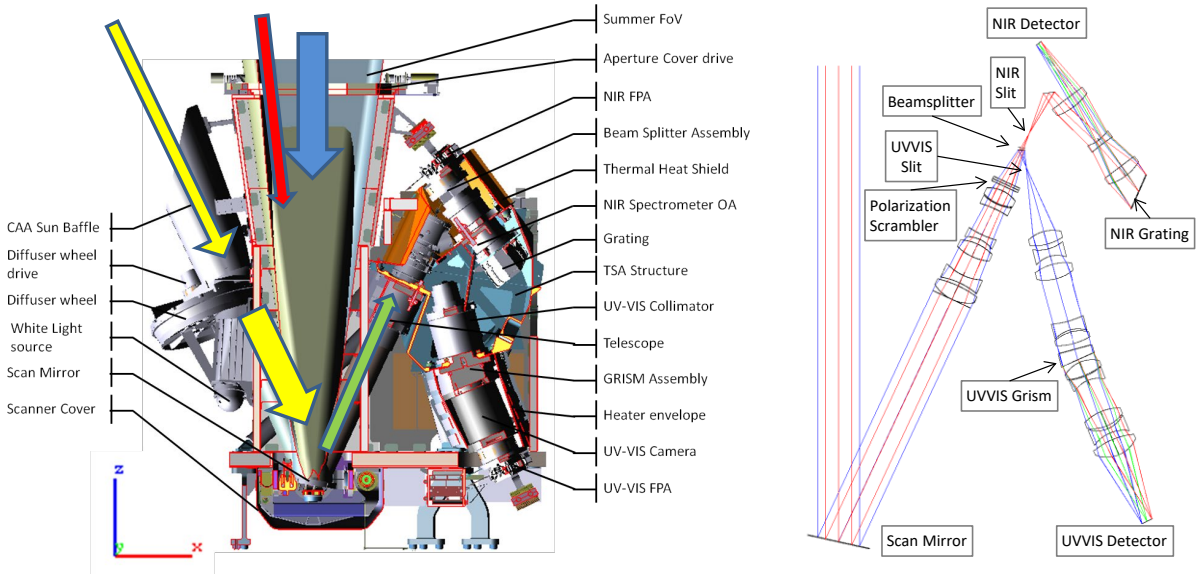


Figure 5.2: Left: Sentinel-4/UVN OIM in a cross-section parallel to the main optical plane. The blue arrow indicates the Earth radiance and Moon path, the yellow arrows the sun irradiance path, the red arrow the star viewing path. The green arrow indicates the observation path from scanner towards the telescope, which is common to all external viewings (Earth, sun, moon, stars, WLS) and to all spectral bands (UV, VIS and NIR). Right: Core optics layout in the same view. The UVVIS path is in blue, the NIR path in red.

The LED light sources integrated in the FPAs are used for calibration purposes. The detector is the core element of the FPA where the detected light is converted into an analogue electrical signal and subsequently processed by the Front End Electronics (FEE) where the analogue signal is converted into digital data and sent via a ChannelLink interface to the ICU. The ICU adds dedicated ancillary telemetry to the image data such that they are self-contained, avoiding the need to re-assemble the observation and telemetry data on ground. In addition, the ICU is responsible for operating and controlling the instrument in its various operational modes.

The instrument thermal design utilises a concept based upon a combination of passive cooling and active (closed-loop) heater control for temperature stabilisation. While the core optics will be maintained and controlled at 293 K, the CCDs temperature will be maintained at 215 K via additional passive cooling. In-orbit temperature stability, both short- and long-term, on the order of 0.1 to 0.2 K of the key optical elements and the detectors are necessary, in order to achieve the radiometric, geometric and spectral accuracy specifications.

Spectral			
Parameter	**UVVIS values**	**NIR values**	**Comments**
Wavelength range	305-500 nm	750-775 nm	
Spectral Resolution / Spectral Oversampling	0.5 nm / > 3	0.12 nm / >3	Oversampling is Resolution divided by spectral pixel sampling
Spectral Calibration Accuracy	0.0017 nm	0.0020 nm	
Geometric and Temporal Coverage			
Parameter	**Value(s)**		**Comments**
Spatial Sampling Distance (SSD)	8 km (EW) x 8 km (NS)		On-ground-projected SSD at reference point in Europe (45°N latitude; sub-satellite-point longitude)
Integrated Energy	70% over 1.47 SSD EW*1.13 SSD NS 90% over 1.72 SSD EW*1.72 SSD NS		Integrated energy is a measure for the spatial resolution of the instrument
N/S slit field-of-view (swath)	4.0°		
East-west coverage & repeat cycle	See Figure 5.3 and Figure 5.4		See Figure 5.3 and Figure 5.4
Daily Earth observation time [2000-01-01 (UTC)]	Summer max: 01:40 – 21:40 Winter min: 03:40 – 19:40		Adjusted to seasonally varying solar Earth illumination on monthly basis
Spatial co-registration	Intra-detector: 10% of SSD Inter-detector: 20% of SSD		2-dimensional (E/W & N/S) absolute co-registration
Radiometric			
Parameter	**UVVIS values**	**NIR values**	**Comments**
Optical Throughput	~50% (in UV)	~60%	End-to-end scanner-to-detector
Radiometric Aperture	70 mm	44 mm	Circular diameter
Earth Signal-to-Noise-Ratio (SNR)	UV: >160 VIS: >1600	759-770nm: >90	For specified Earth radiance Reference scene

		Rest NIR: >600	
Earth Absolute Radiometric Accuracy (RA)	< 3% (2% goal)	< 3% (2% goal)	For Earth radiance & reflectance
Sun Absolute Radiometric Accuracy (RA)	< 3% (2% goal)	< 3% (2% goal)	For sun irradiance
Polarization Sensitivity	< 1%	< 1%	
Polarization spectral features	< 0.015%	< 0.1%	Caused by speckle effect
Sun diffuser spectral features	< 0.042%	< 0.076%	

Table 5.1: Main design and performance parameters of Sentinel-4/UVN.

5.1.1.1 Observational Scenarios

The Earth will be measured by repetition of one-hour scans from east to west. Each scan is followed by a rapid 20 second backscan to the starting position in the east. Note that the UVN instrument does not observe the full illuminated Earth disc. The instrument only observes the area over Europe and the north Atlantic, as indicated in Figure 5.3 and Figure 5.4. The UVN measurement concept is based on the observation of backscattered solar light. The observed Earth radiance is strongly dependent on the observation geometry defined between the incident solar irradiance and the radiance backscattered from the Earth and the atmosphere and received by the UVN instrument. The observation geometry strongly varies with the diurnal cycle of sun position (Solar Zenith Angle, SZA). Therefore, for useful data the required observation starts in the morning after the eclipse when the scene is illuminated with a SZA larger than 92 degrees.

The instrument scans the scene continuously with a constant scan speed that is defined for a full coverage of the required Earth area at noon within 60 min. The baseline is to operate always with one hour's east-west scans. However, the starting point in the east is changed twice during the day, i.e. moving it from the very east in the morning towards the west in the evening, as shown in Figure 5.5. The number of one-hour east-west scans is a function of season, as the illumination conditions over the geographical coverage zone change with season. Typically, the Earth measurements are performed between 3:00 and 21:00, but more Earth radiance measurements are performed in the summer than in the winter. During the times when the UVN is not measuring Earth radiance, i.e. during the night, several calibration measurements are performed: sun, dark, background, star, sometimes moon, WLS and LED. The non-Earth-radiance calibration and characterisation measurements have different observation frequencies: daily, weekly, monthly, incidental. The measurement configurations are organised in measurement sequences.

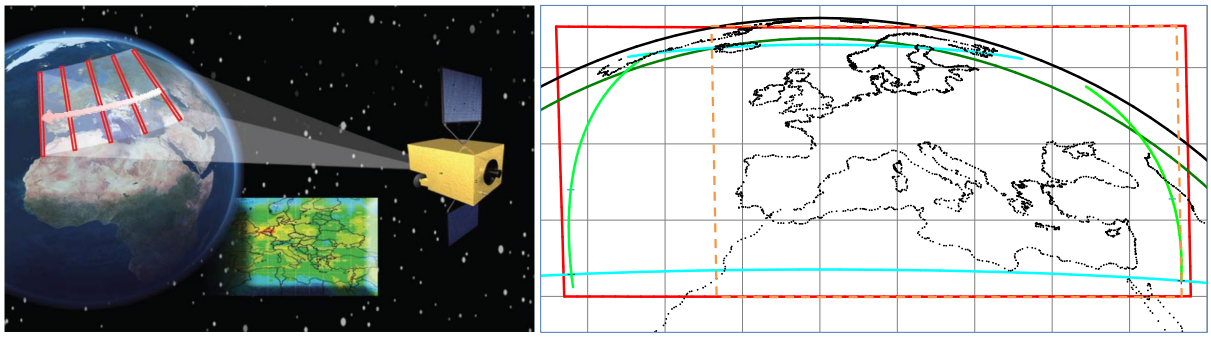


Figure 5.3: Earth observation and scan concept of Sentinel-4/UVN. The right hand picture shows Earth coverage from the geostationary Sentinel-44/UVN perspective. Green/turquoise lines indicate the borders of the specified Geo-Coverage area, which is the total area to be covered every day. The red rectangle represents the actual daily observation area covered by multiple E/W scans of the N/S-oriented slit FOV. The overall daily Earth observation pattern consists of a series of 1h-long east-to-west scans ("repeat cycles") with a fast west-to-east retrace in-between. The orange dashed rectangle indicates the size of a 1h repeat cycle (Reference Coverage). Depending on the seasonally varying duration of Earth illumination by the sun, the daily Earth observation scan series consist of 16 (winter) to 20 (summer) 1h-scans. The first scan of a day starts at the eastern edge of the Geo-Coverage area. The 1h repeat cycle coverage is shifted westward in two steps during each day in order to follow the sun illumination and to achieve full Geo-Coverage.

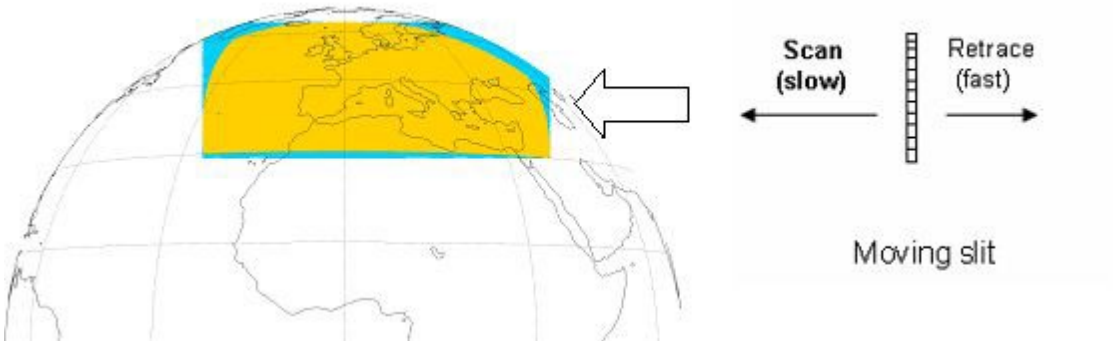


Figure 5.4: Sentinel-4/UVN geographical coverage area comprising Europe and North Africa. The instantaneous acquisition is a stripe (roughly) in the north-south direction on the ground, corresponding to the entrance slit of the instrument. This slit is moved by a scan mirror from east to west across the scene.

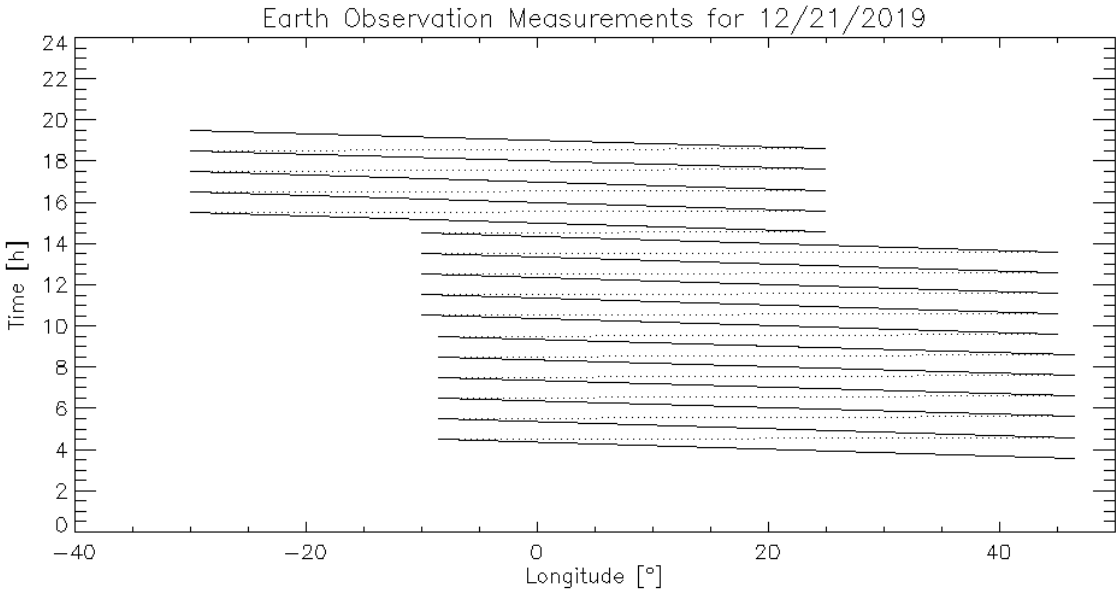


Figure 5.5: East-west geographical scans as a function of the daytime. The scan repeat cycle is 60 minutes. In this example 16 1-hour east-west scans are performed during the day.

5.1.2 Sentinel-4/UVN Product Generation Chain

5.1.2.1 Level 0 to Level 1b Product Generation

The Sentinel-4/UVN Level 0 to Level 1b data processing software performs the following tasks:

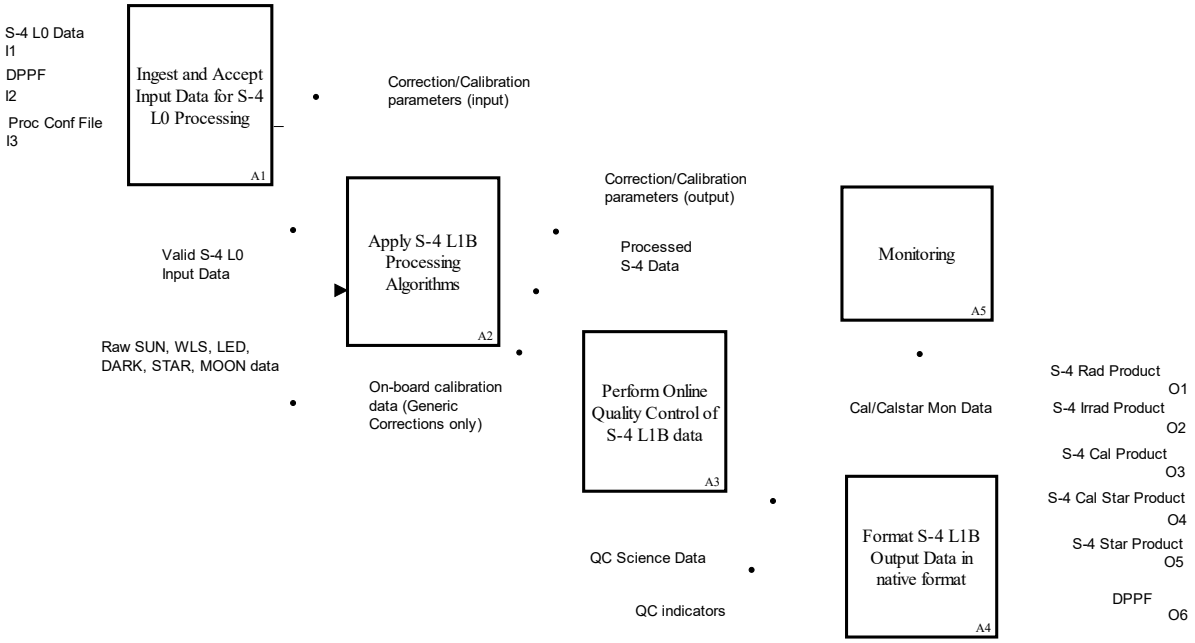
- process Level 0 data into Level 1b datasets;
- provide, in the Level 1b datasets, quality information on individual pixel level, spectrum level (per north-south viewing direction) and measurement level;
- provide Level 1b dataset metadata that allows fast and efficient searching of the data;
- enable the calculation of new calibration key parameters (key data) from in-orbit measurement data for accurate Level 0 to Level 1b data processing of subsequent measurement data;
- analyse and process all required measurement data in order to provide the necessary information to allow the performance and calibration of the instrument and its datasets to be monitored.

Level 1b data is defined as fully geophysical, calibrated measurement data. For the Sentinel-4/UVN, this means calibrating digital counts into radiances or irradiances, pixels into wavelengths and pixels into geophysical coordinates and viewing angles on the surface of the Earth. The latter is also referred to as Image Navigation and Registration (INR).

The external data flow of the Sentinel-4/UVN L0 to L1 processor is defined as follows:

- L0 instrument data (reconstructed from the input data packets)
- L1b datasets including:
  Level 1b Earth spectral radiance dataset.
  Level 1b sun spectral irradiance dataset.
  Level 1b calibration datasets (several).
  Level 1b calibration star dataset, one of the Level 1b calibration datasets for star measurement data.
  Level 1b star dataset.
- L1b Data Processing Parameters File (DPPF) Data
  Level 1b data processing parameters file (DPPF) dataset.

An overview of the Sentinel-4/UVN Level 0 to 1 processing flow is shown in Figure 5.6.


S-4 L0 Data
I1
DPPF
I2
Proc Conf File
I3
Ingest and Accept Input Data for S-4 L0 Processing
A1
Correction/Calibration parameters (input)
Valid S-4 L0 Input Data
Apply S-4 L1B Processing Algorithms
A2
Correction/Calibration parameters (output)
Processed S-4 Data
Monitoring
A5
Raw SUN, WLS, LED, DARK, STAR, MOON data
On-board calibration data (Generic Corrections only)
Perform Online Quality Control of S-4 L1B data
A3
Cal/Calstar Mon Data
S-4 Rad Product
O1
S-4 Irrad Product
O2
S-4 Cal Product
O3
S-4 Cal Star Product
O4
S-4 Star Product
O5
DPPF
O6
QC Science Data
QC indicators
Format S-4 L1B Output Data in native format
A4

5.1.2.2 Level 1b to Level 2 Product Generation

The Sentinel-4/UVN Level 2 Operational Processor (S4 L2OP) is under development by ESA and will be integrated into the MTG Level 2 Processing Facility (L2PF). The overall processing flow of the S4 L2OP, including dependencies is shown in Figure 5.7. For further information, see [RD16].

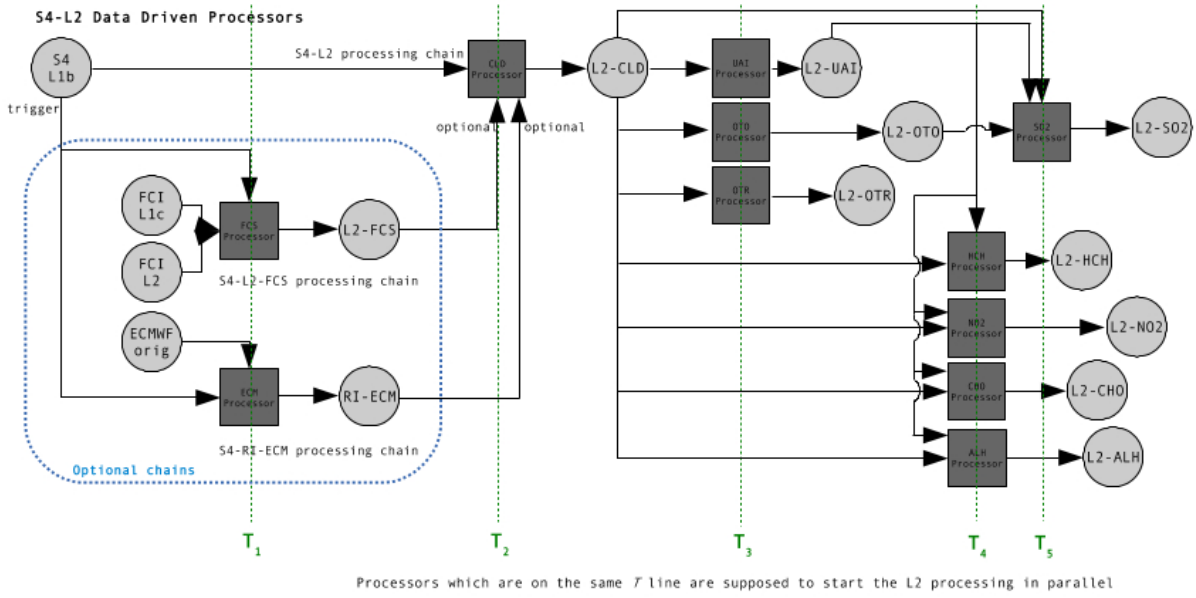


Figure 5.7: Sentinel-4/UVN Level 2 Processor Dependencies

The resulting Sentinel-4/UVN Level 2 products to be produced and the role of the responsible institutes within the S4 L2OP project are provided in Table 5.3. For more information see [RD17].

Table 5.3: Sentinel-4/UVN Level-2 Products

Processor ID	S4 L2 Product	Algorithm Bread-boarding (RAL)	Independent Verification (MPIC)	Processor Suite (DLR)	Type	Conditions
S4-L2-OTO	Total O_3 Processor	DLR/BIRA	KNMI	DLR	Product	All-sky
S4-L2-OTR	Tropospheric O_3	RAL	KNMI	RAL	Product	All-sky
S4-L2-NO2	Tropospheric NO_2	IUP-UB/KNMI	MPIC/DLR	DLR	Product	All-sky

S4-L2-SO2	SO_2	BIRA	MPIC/DLR	DLR	Product	All-sky
S4-L2-HCH	HCHO	BIRA	IUP-UB	DLR	Product	All-sky
S4-L2-CHO	CHOCHO	IUP-UB	BIRA	DLR	Product	All-sky
S4-L2-UAI	Aerosol Index	KNMI	RAL; MPIC	KNMI/S&T	Product	All-sky
S4-L2-ALH	Aerosol layer height	KNMI	RAL; MPIC	KNMI/S&T	Product	Clear-sky
S4-L2-CLD	Cloud properties (fraction, optical thickness, height)	DLR	IUP-UB	DLR	Product	All-sky
S4-L2-SUR	Surface reflectance (LER albedo, BRF, and aerosol optical depth). Daily product with hourly time resolution	LOA/ Catalyst	Rayference/ Catalysts	Catalysts	Product	Clear-sky
S4-L2-GSR	Gapless surface reflectance (LER albedo, BRF, and aerosol optical depth). Daily product with hourly time resolution.	LOA/ Catalyst	Rayference/ Catalysts	Catalysts	Product	All-sky
S4-L2-FCS	FCI-L2 Cloud re-gridded to Sentinel-4/UVN (cloud fraction, snow/ice flag, scene inhomogeneity)	RAL		RAL	Auxiliary Product	All-sky

5.1.2.3 Product quality information

A large range of product quality information and flags are included in both the Level 1 and Level 2 products from Sentinel-4/UVN. For more information on product quality and flagging within the Sentinel-4/UVN Level 1 products see [RD13].

Each of the Sentinel-4/UVN Level 2 products also includes a range of product quality information and flags. These are described in the Product User Manuals (PUMs) for each specific product. For further information see [RD18], [RD19], [RD20], [RD21], [RD22], [RD24], [RD25], [RD26], [RD27], and [RD28].

5.1.2.4 Auxiliary Data Sets (ADS)

The auxiliary data sets used in the Sentinel-4/UVN Level 0 to Level 1 processing are captured in the Data Processing Parameters File (DPPF). For more information, see [RD51].

The Sentinel-4/UVN Level 2 operational processors also require a range of auxiliary data sets. These are described in the Sentinel-4 L2 Input Output Data Specification (IODS), S4-L2-DLR-IODS-4004, [RD15].

5.1.2.5 Product Requirements

The target and goal performances of the Sentinel-4/UVN product processor development are given in Table 5.4. The uncertainty of the products will be mainly limited by the signal-to-noise ratio of the Sentinel-4/UVN measurements and the knowledge of the *a priori* parameters. For more information, including on the applicability of the product requirements stratified into application are see [AD3].

Table 5.4: Sentinel 4 Level 2 Products with Target/Goal Performances

Product	Threshold	Goal	Scenario
O_3 total column	4%	3%	SZA < 60° VZA < 60° all clouds
Tropospheric O_3	40%	25%	SZA < 60° VZA < 60° CF < 20%
Tropospheric NO_2	troposphere $1.5*10^{15}$ molec/cm² or 50 %	troposphere $1.5*10^{15}$ molec/cm² or 30%	SZA < 60° VZA < 60° CF < 20%
SO_2	total column $5.0*10^{16}$ molec/cm^2 or 100%	total column $3.0*10^{16}$ molec/cm² or 60 %	SZA < 60° VZA < 60° CF < 20%

HCHO	total column $1.5*10^{16}$ molec/cm² or 100%	total column $1.5*10^{16}$ molec/cm² or 50%	SZA < 60° VZA < 60° CF < 20%
CHOCHO	n/a	total column random $1.5*10^{15}$ molec/cm², systematic $2.5*10^{14}$ molec/cm^2 or 50%	SZA < 60° VZA < 60° CF < 20%
Aerosol layer height	1 km	n/a	SZA < 60° VZA < 60° AOD @760 nm > 0.3 ALH > 1.5 km
Aerosol Index	0.5	0.3	SZA < 60° VZA < 60° All-cloud
AOD total column	0.05 or 15%	n/a	SZA < 60° VZA < 60° cloud-free homogeneous
Cloud properties	cloud fraction 20% cloud top height 1km cloud optical thickness (albedo) 30%	cloud fraction 10% cloud top height 0.5km cloud optical thickness (albedo) 20%	SZA < 60° VZA < 60° COT > 5 CF > 10%
Surface	first BRF parameter k: 0.02 ($k \leq 0.03$), 0.01 or 5% ($k > 0.03$)	n/a	SZA < 60° VZA < 60° cloud-free homogeneous

5.2 Overview of the Sentinel-5 Instrument and Processing

The Copernicus Sentinel-5 mission consists of an Ultraviolet-Visible-Near-infrared-Shortwave-infrared (UVNS) imaging spectrometer instrument embarked on the European Polar System - Second Generation (EPS-SG) A satellite. The Sentinel-5/UVNS mission focuses on the monitoring of trace gas concentrations and aerosols in the atmosphere to support operational services covering air-quality near-real time applications, air-quality protocol monitoring and climate protocol monitoring.

5.2.1 Sentinel-5/UVNS Instrument

Sentinel-5/UVNS is a nadir viewing push broom mode spectrometer flying in sun synchronous low earth orbit. The instrument has wide swath of approximately 2670 km, across track, and provides near daily coverage of the Earth's surface, as illustrated in Figure 5.8. Sentinel-5/UVNS builds on heritage from the Global Ozone Monitoring Experiment (GOME), the SCanning Imaging Absorption SpectroMeter for Atmospheric CHartographY (SCIAMACHY), the Ozone Monitoring Instrument (OMI) and the Global Ozone Monitoring Experiment-2 (GOME-2).

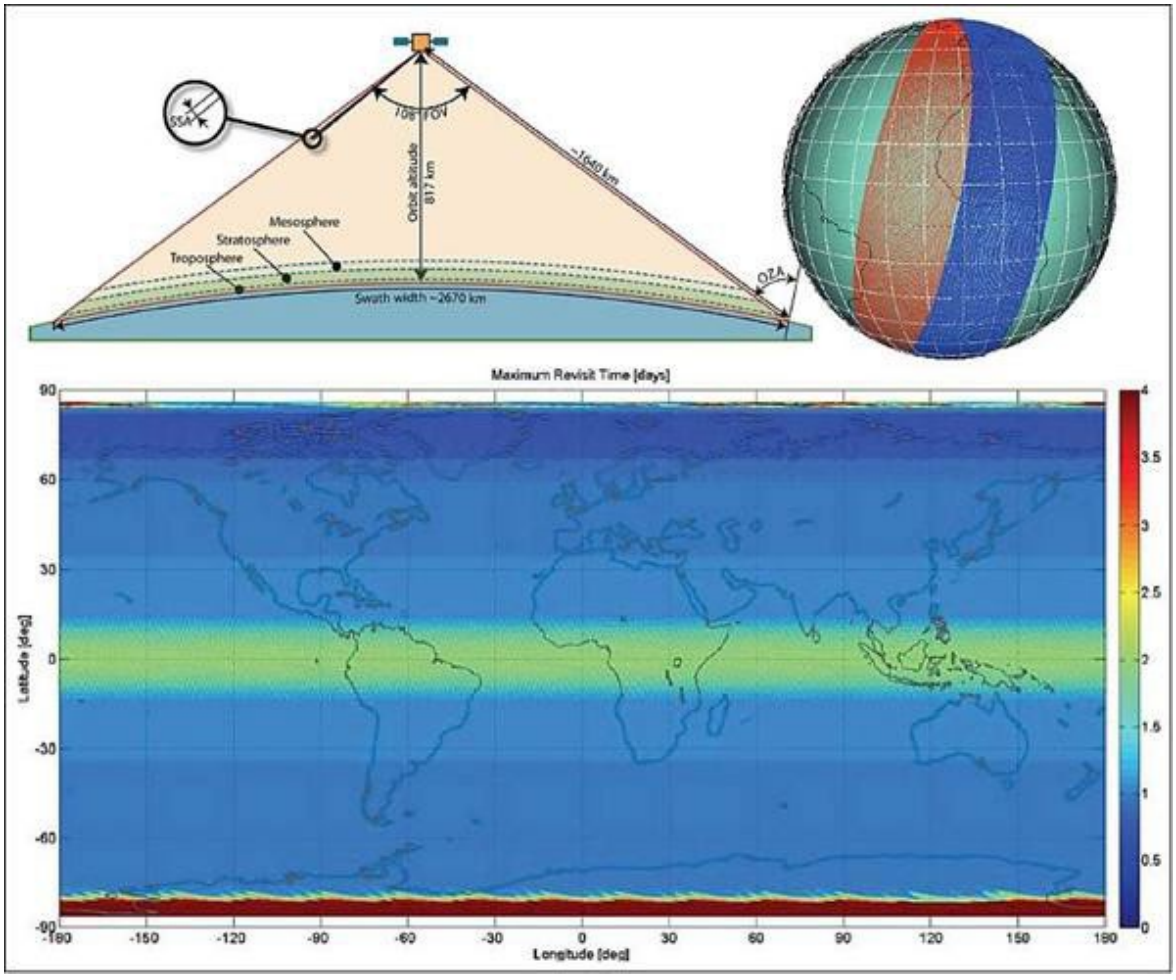


Figure 5.8: Sentinel-5/UVNS observation geometry and coverage requirements (credit: ESA).

The Sentinel-5/UVNS instrument comprises two co-aligned telescopes beyond which the optical chain is divided into five spectral bands, namely telescope 1 for UV1 (265 nm – 325 nm), SWIR1 (1590 nm – 1675 nm) and SWIR3 (2305 nm – 2385 nm) and telescope 2 for UV2VIS (300 nm – 500 nm) and NIR (685 - 773 nm). The instrument provides measurements with a spatial sampling distance of < 7.5 km at nadir in both along-track (ALT) and across-track (ACT) directions for all bands, with the exception of:

- the UV1a band ($\lambda < 300$ nm) where the data are downlinked at a 6 times coarser spatial sampling in the ALT direction (45km). The ACT sampling of the downlinked data is similar to that of the other bands.
- the NIR2 band ($755\text{nm} < \lambda < 773$ nm) where the downlinked ACT sampling distance is 6 times lower (1.3km) in order to allow for optimal co-registration with the other spectral bands by re- gridding the higher-sampling NIR2 to the other spectral bands' ground sampling grid. The higher ACT sampling will be sustained throughout L1b processing and included in the L1b products.

Due to constant spatial sampling angle increments between spatial pixels, the ACT spatial sampling distance on the Earth's surfaces increases towards the swath edges.

Sentinel-5/UVNS employs two types of detectors. For the Ultraviolet, Visible, Near Infrared (UVN) chains, the detectors are split frame transfer Charge Coupled Device (CCD), whereas the SWIR chains make use of Mercury-Cadmium-Telluride active pixel devices. The UV1 and NIR CCD detectors are subdivided into separate spectral bands. A summary of the characteristics of the Sentinel-5/UVNS detectors and bands in terms of spectral range and resolution and spatial sampling is given in Table 5.5.

A schematic of the instrument is shown in Figure 5.9. In nominal observation mode the injection mechanisms provide free access to the Earth field-of-view, which is received by the telescopes. A polarisation scrambler is included in the optical path of each telescope to reduce the instruments sensitivity to the polarisation state of the scene. After each of the telescopes, the collimated light is split into spectral bands by means of dichroic mirrors and is imaged on three slits for the spectral channels, one for the UV1, one common slit for the UV2VIS and NIR, and one common slit for the SWIR1&3.

Detector	**UV1**		**UV2VIS**	**NIR**			**SWIR1**	**SWIR3**
Detector Type	CCD						MCT-CMOS	
Detector wavelength range	265 – 325		300 – 500	685 – 773			1590 – 1675	2305 – 2385
Band name	UV1a (UV1)	UV1b (UV2a)	UV2VIS	NIR1	NIR2a	NIR2	SWIR1	SWIR3
Band numbering	1a	1b	2	3a	3b	3c	4	5
Band wavelength range (nm)	265 – 300	300 – 325	300 – 500	685 – 710	745 – 755	755 – 773	1590 – 1675	2305 – 2385
Band spectral resolution (nm)	1	1	0.5	0.4	0.4	0.4	0.25	0.25
Band spectral oversampling (≥)	3	3	3	3	2.5	2.5	2.5	2.5
Number of spectral samples (TBC)	105	90	1288	215	87	155	951	899
SSD at nadir (L0) (ACT km × ALT km)	7.3 × 42.7	7.3 × 7.1	7.3 × 7.1	7.3 × 7.1	7.3 × 7.1	1.2 × 7.1	7.3 × 7.1	7.3 × 7.1
SSD at nadir (L1b) (ACT km × ALT km)	7.3 × 42.7	7.3 × 7.1	7.3 × 7.1	7.3 × 7.1	7.3 × 7.1	1.2 × 7.1	7.3 × 7.1	7.3 × 7.1
Number of ACT samples (L1b, TBC)	219	219	220	219	219	1314	218	217
Radiance product	UVR			NIR			SWR	
Irradiance product	IRR							

Table 5.5: Sentinel-5/UVNS detectors, bands and Level 1b radiance and irradiance products.

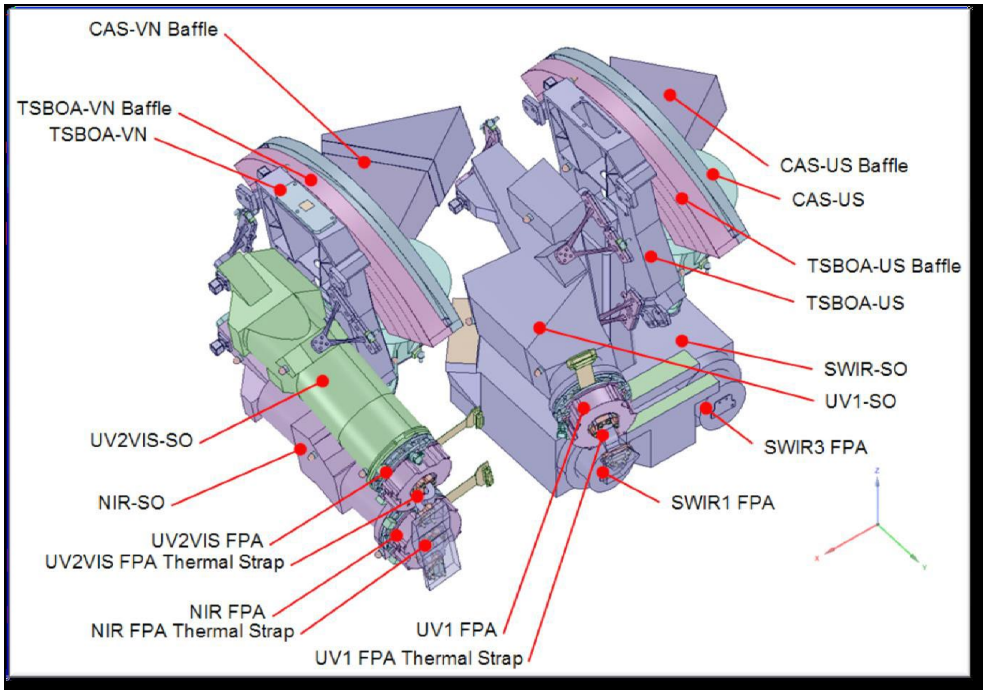


Figure 5.9: Schematic of the Sentinel-5/UVNS instrument showing the location of the spectrometer optics, the telescopes and the calibration assemblies (image credit: Airbus).

The Sentinel-5/UVNS features a special type of slit, called a slit homogeniser, which is a reflective tunnel elongated along the direction of the light path. Multiple reflections during the passage of this device scramble the across-slit (along-track) spatial information, which makes the instrument insensitive to a varying illumination in this direction, thus avoiding spectral errors by deformation of the Instrument Spectral Response Function (ISRF).

For in-orbit calibration purposes, the Sentinel-5/UVNS instrument features a Calibration Subsystem (CAS), which injects different calibration signals via an actuated injection mirror. Located right before the first optical element of the telescopes this allows a calibration of the instruments full optical path. For absolute radiometric calibration, the CAS allows observation of the sun via a diffuser. A reference diffuser allows the nominal diffuser to be monitored for potential degradation. Signals from the internal broadband White Light Source (WLS), and on-board Light Emitting Diodes (LEDs) in each of the spectrometers are used for diagnostic flat field illumination of the detectors. The CAS is implemented in two independent units, one for each telescope.

5.2.1.1 Observational Scenarios

The Sentinel-5/UVNS instrument will generate a number of different measurement types, depending on whether an Earth scene is observed, the Sun irradiance is measured, or an internal calibration source is used to illuminate the detectors. In addition, dark current and background measurements are taken without any detector illumination. The different measurement types and their main usage are summarized in Table 5.6.

Measurement type	Background measurement	Data output
Earth radiance	Dark side Earth port measurement	Level 1b radiance products Earth calibration file
Sun irradiance	Dark side Sun measurement	Level 1b irradiance product SUN calibration file Wavelength map
WLS	WLS switched off, following orbit	WLS calibration file WLS dead pixel/sample map (OPF update) Photo-Response Non-Uniformity (PRNU) map (OPF update)
SLS	SLS switched off, following orbit	SLS calibration file ISRF NIR / SWIR (Monitoring / OPF update)
LED	LED switched off, following orbit	LED calibration file LED dead pixel/sample map (OPF update) Linearity data (OPF update) Charge Transfer Inefficiency (CTI) monitoring
Dark current	-	Dark & Background calibration files Background CKD (OPF update) Dark current for the image and read-out section and the register (Monitoring / OPF update) Dead pixel / sample map with respect to dark current (OPF update)
Deep space view	-	Deep Space calibration file Offset monitoring

Table 5.6: Sentinel-5/UVNS measurement types and usage

Figure 5.10 shows a schematic overview of the sequence of measurement types during one orbit. Generally, Earth radiance measurements are taken on the complete sunlit part of the orbit. Once per day, these are followed by solar calibration measurements taken during the crossing of the orbital South Pole. The remaining part of the orbit is used for internal calibration measurements with each kind of calibration measurement being deployed at individual time scales and frequencies.

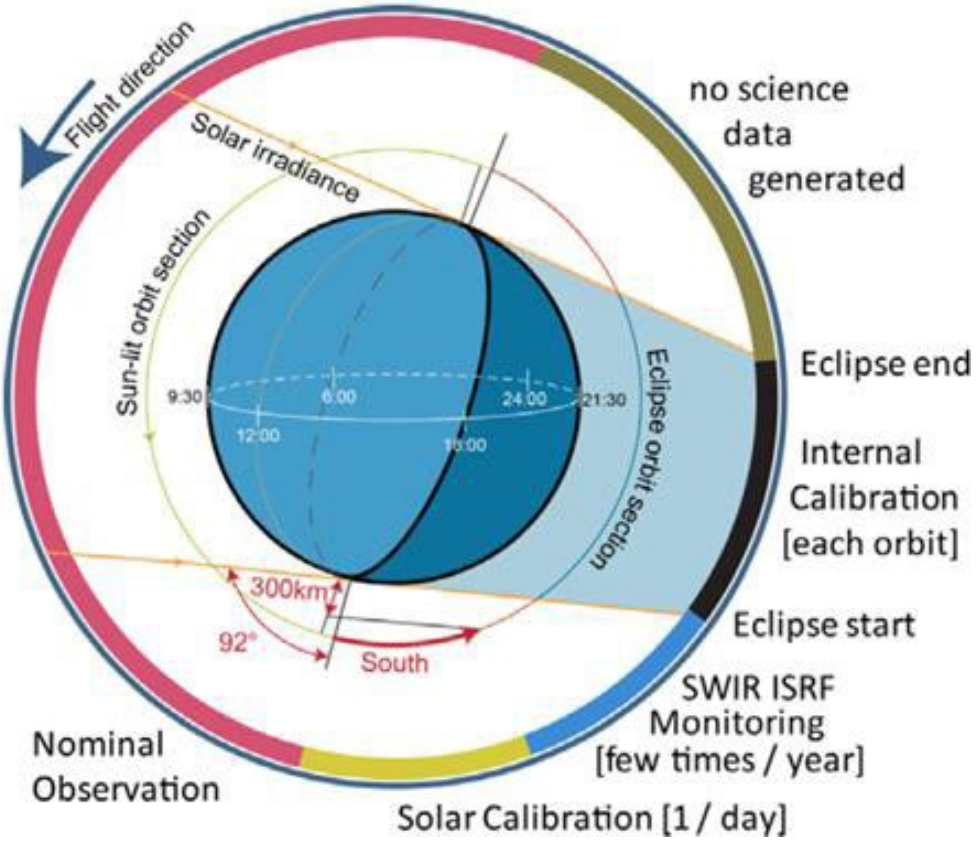


Figure 5.10: Instrument modes with respect to orbit position (figure taken from [RD29]).

One complete orbit takes about 6000s. Out of these, Earth radiance measurements take up to 3420s. The daily solar observation covers 239s. The instrument will be in full eclipse for about 1700s. During this time, internal calibration measurements are foreseen, not necessarily covering the whole eclipse period. Dark and Deep Space measurements will always be part of these, optionally complemented by measurements of additional calibration stimuli (WLS, SLS, LED). These measurements are used to characterise the instrument ISRF, PRNU, linearity and response by making use of the on-board WLS for radiometric calibration, LEDs for a uniform illumination of the detector and laser diodes (SLS) to support the monitoring of the ISRF of the Near Infrared (NIR) and SWIR bands. The remaining time in eclipse or semi-eclipse remains unused, no science data is generated. Sun measurements are planned on a daily basis and will be performed over the South Pole, which allows the implementation of the calibration view in anti-flight direction. This is preferred to minimise degradation effects on the exposed calibration optics.

5.2.2 Sentinel-5/UVNS Product generation chain

5.2.2.1 Level 0 to Level 1b product generation

The overall context of the Sentinel-5/UVNS Level 0 to 1 processor is shown in Figure 5.11.

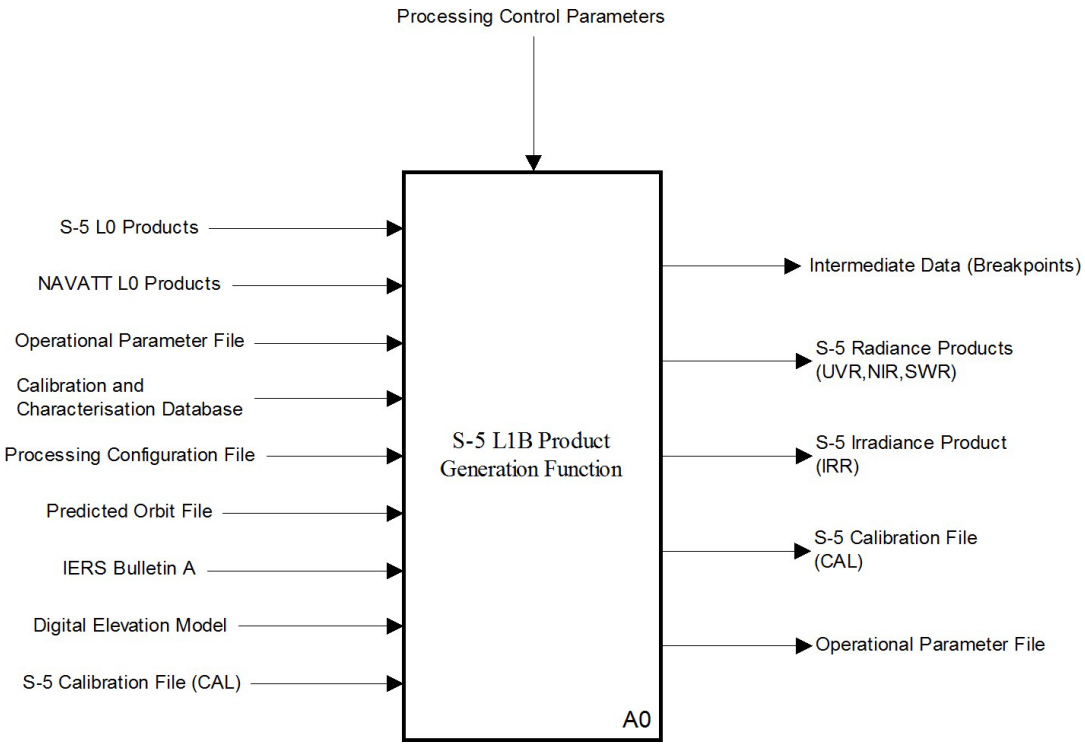


Figure 5.11: Context Diagram for Sentinel-5/UVN Level 1b PGF.

The Sentinel-5/UVNS Level 1b products comprise three Earth radiance products (Ultraviolet and Visible Radiances (UVR), Near Infrared Radiances (NIR), Shortwave Infrared Radiances (SWR)) for the Ultraviolet and Visible (UV1, UV2VIS), NIR1/NIR2, and SWIR1/SWIR3 spectral ranges, respectively, and a Solar Irradiance (IRR) product. The Level 1b products temporal coverage depends on the Level 0 data temporal coverage in input, covering the corresponding time period. The Sentinel-5/UVNS Level 1b products are formatted according to [RD30].

Level 1b Earth radiance products

The Level 1b Earth radiance product is the main input for the Level-2 processors. Its main parameter for Level 1b users is the measured spectral radiance for each spectral pixel and ground sample. Please see [RD30] for a complete outline of the structure and contents of the product.

Level 1b Solar irradiance product

The Level 1b irradiance product contains one averaged solar irradiance spectrum for each sampled swath viewing angle, including annotation data. The product includes all spectral bands. The Level 2 processors will use the irradiance products to calculate reflectance from the Earth radiance data. The spectral smile effect causes each spatial across track pixel to have an individual wavelength annotation vector, necessitating the irradiance product to contain an individual irradiance spectrum for each across track swath angle.

The Sentinel-5/UVNS instrument generates solar measurements on a daily basis, during two of the fifteen orbits, separately for the two telescopes. The measurements consist of a sequence of irradiance spectra,

recorded during a time span of several minutes. Correspondingly, the Level 1b solar irradiance product is generated once per day by temporally averaging the solar spectra recorded for each spectral band. The Level 0 data needed to generate a nominal solar irradiance product is therefore the complete sequence of solar measurements of the two particular orbits.

If no solar measurements are available in the input Level 0 product, no irradiance product will be generated by the Sentinel-5/UVNS Level 0 to 1b product processor. If the number of individual solar measurements in the input Level 0 product is not sufficient, the Sentinel-5/UVNS Level 0 to 1b product processor will generate a degraded product.

Please see [RD30] for a complete outline of the structure and contents of the product.

Sentinel-5/UVNS Calibration File

The Sentinel-5/UVNS CAL Files contain raw and calibrated measurements of all measurement classes, where each type of measurement (LED, WLS, etc.) is written to a dedicated calibration file, see [RD32].

The content and the generation frequency of these files depend on the measurement class: For each EARTH radiance granule, i.e. for each set of UVR, NIR and SWR products, one associated EARTH calibration file is generated, containing raw (i.e. unprocessed) data as well as averaged radiances and quality statistics for all spectral bands. For each SUN observation sequence, the raw as well as the calibrated individual irradiance spectra are written to the SUN calibration file, differentiating nominal and reference diffuser measurements. For each type of on-board calibration measurement, i.e., LED, WLS or SLS data, as well as dark or deep space data, the complete measurement sequence (raw and calibrated) is written to a dedicated calibration file.

For dark measurements, there is an additional output calibration file, designed for containing back- ground data. Background data is generated from raw dark measurements (except for temporal co-addition correction) that are taken with the exact same settings as those for which they are used to correct. This means that for each sequence of measurements of any type, an associated dark measurement sequence is executed. These dark measurements are used to generate a Background Calibration file as well as a Dark Calibration file, where the latter has more calibration steps applied. Once per orbit, new CKD as well as other monitoring parameters are calculated from the individual CAL files. The new CKD is used to update the OPF and all monitoring parameters are written to a dedicated CAL file type ("Derived"). The Sentinel-5/UVNS Level 1b calibration files are therefore the main input for the Sentinel-5/UVNS Level 0 to 1b product processor, when run to generate a new OPF (once per orbit), and the offline calibration facilities that will use this data for generating trending and monitoring products.

Operational Parameter File

The Operational Parameter File, as described in [RD32] serves both as mandatory input to the Level 1b PGF whilst also being updated by the PGF, nominally once per orbit, after the processing of all orbit data. Since some types of on-board calibration measurements, such as Earth background measurements, are performed during each crossing of the night side of the Earth, specific parts of the OPF, such as the background correction CKD, are updated after each orbit. Other OPF elements will have lower update frequencies.

The OPF is valid for a specific date time range, nominally one orbit. The data processor performs compliance checks for OPF validity vs. Level 0 input file date time range and decides which kind of processing is to be done or which flags to be raised, e.g. nominal product, degraded product.

An overview of the Sentinel-5/UVNS Level 0 to 1 processing flow is shown in Figure 5.6.

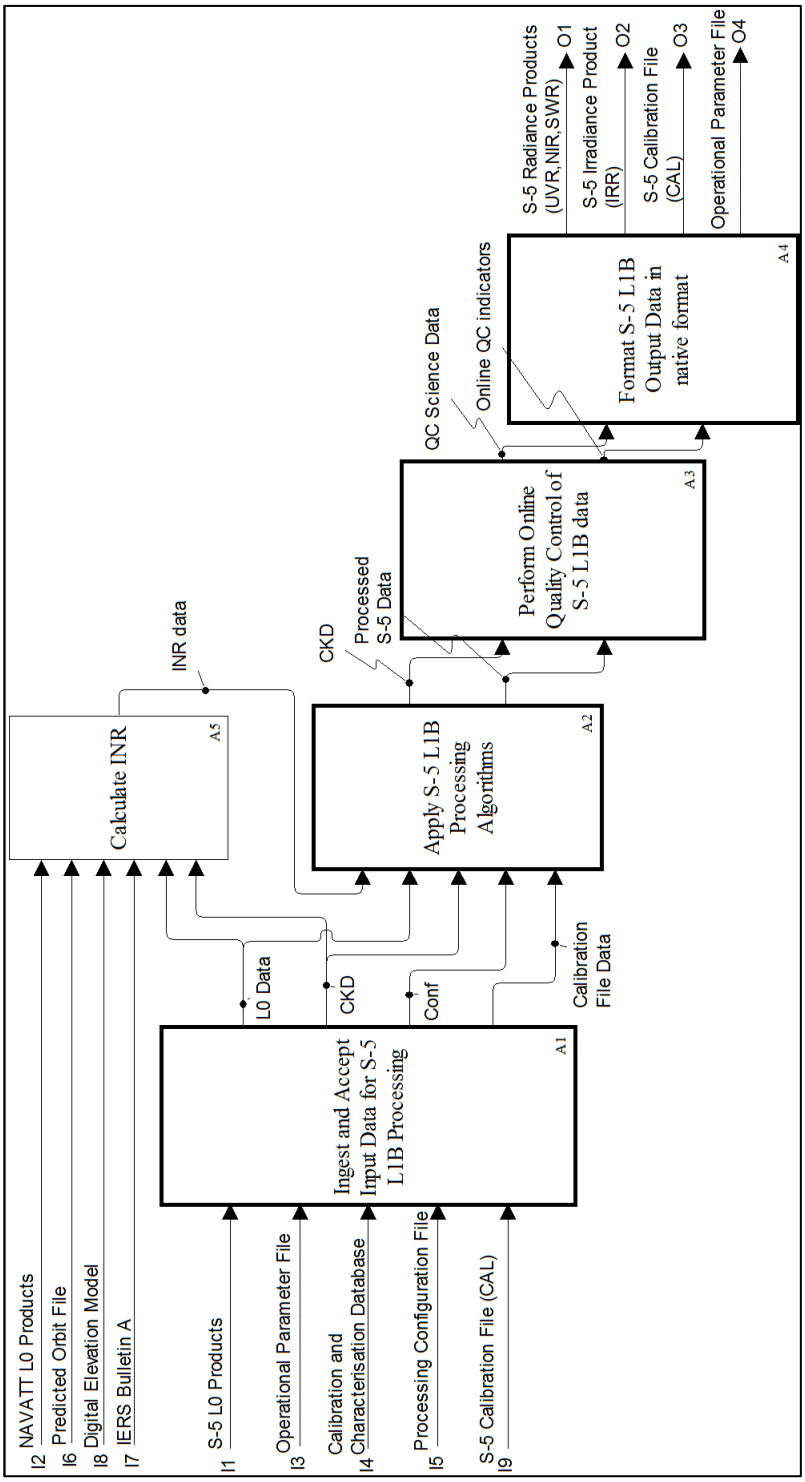


Figure 5.12: Functional decomposition of Sentinel-5/UVNS L0 to L1b processor.

For more information see [RD14].

The Sentinel-5/UVNS Level 1b products are listed below in Table 5.7 and Table 5.8.

Table 5.7: Sentinel-5/UVNS L1b End-user Products

Data	Contents	Use
UV1 and UV2-VIS Radiance	Sentinel-5/UVNS UV1 and UV2-VIS radiance measurements for each spectral pixel and ground sample	Input to L2 processing
NIR1 and NIR2 Radiance	Sentinel-5/UVNS NIR1 and NIR2 radiance measurements for each spectral pixel and ground sample	Input to L2 processing
SWIR1 and SWIR3 Radiance	Sentinel-5/UVNS SWIR1 and SWIR3 radiance measurements for each spectral pixel and ground sample	Input to L2 processing
Irradiance	Sentinel-5/UVNS solar irradiance measurements	Input to L2 processing

Table 5.8: Sentinel-5/UVNS L1 Specialist Products

Data	Contents	Use
Calibration	Calibration data	Input to off-line Sentinel-5/UVNS trending and monitoring functions
OPFs	Current calibration key data parameters	Input to L1b processing
Sentinel-5/UVNS L1 Processor Logs	Logs and any intermediate results (e.g. breakpoints) used to track the functioning of the Sentinel-5/UVNS L1b processor	Input to operations monitoring and software maintenance activities

5.2.2.2 Level 1b to Level 2 product generation

The Sentinel-5/UVNS Level 2 Prototype Processor (S5 L2PP) is under development by ESA and will be used by EUMETSAT as the basis for the development of the Sentinel-5/UVNS Level 2 Operational Processor (S5 L2OP). The S5 L2OP will be integrated into the EPS-SG Payload Data Acquisition and Processing Facility (PDAP). The overall processing flow of the S5 L2OP, including dependencies is shown in Figure 5.13. The output products are formatted according to [RD31].

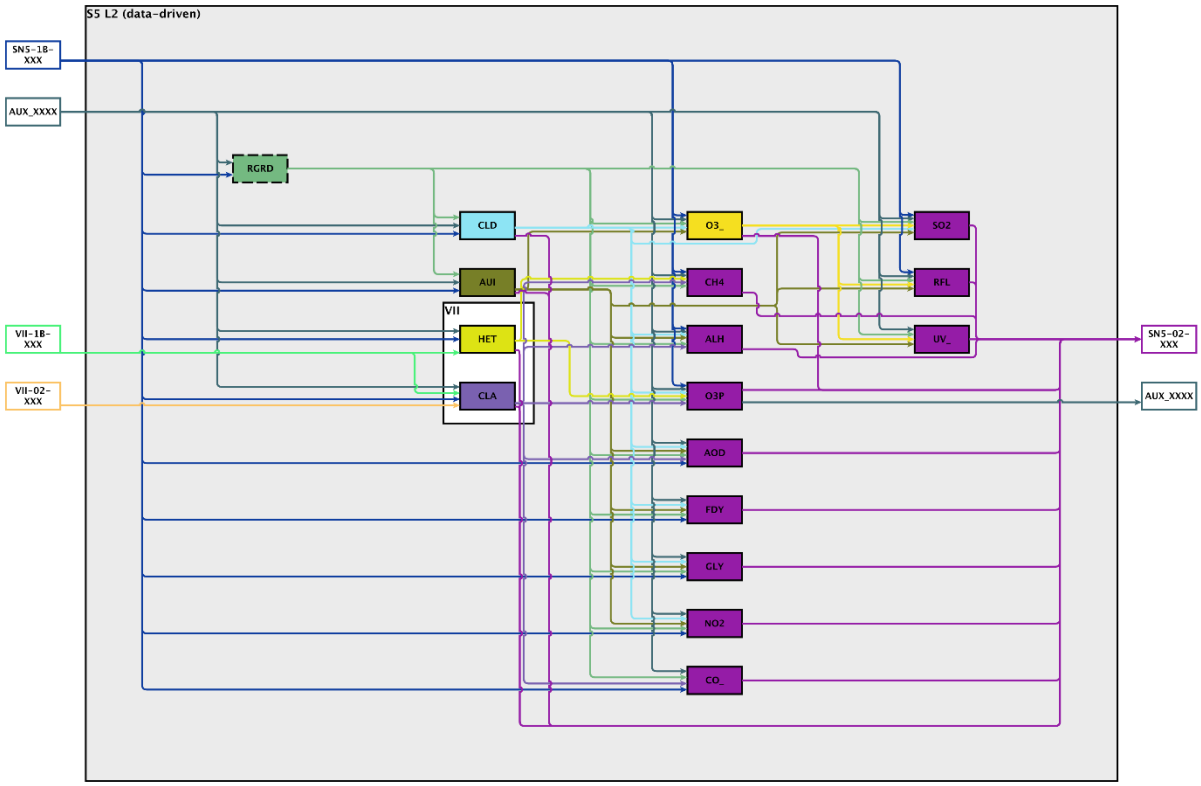


Figure 5.13: Sentinel-5/UVNS Level 2 Operational Processor internal inter-dependencies for the data-driven processors. Solid lines indicate flow of data used directly by subsequent processors, dotted lines indicate flow of data after co-registration/re-gridding has been applied.

The resulting Sentinel-5/UVNS Level 2 products to be produced and their classification are shown in Table 5.9.

Table 5.9: Sentinel-5/UVNS Level-2 Products and Type Classification

Output dataset	Type
NWP forecast/analysis data (re-gridded)	Auxiliary product
CAMS forecast data (re-gridded)	Auxiliary product
CMEMS Global Analysis (re-gridded)	Auxiliary product
NISE snow/ice map (re-gridded)	Auxiliary product
LER Data (re-gridded)	Auxiliary product
Bi-Directional Reflectivity Distribution Function Database (re-gridded)	Auxiliary product
Digital Elevation Model (re-gridded)	Auxiliary product
Land-sea mask / land cover type (re-gridded)	Auxiliary product
Chlorophyll Concentration Database (re-gridded)	Auxiliary product
S5 L1b NIR co-registered, co-registered L1b NIR data	Product
S5 L1b SWIR co-registered, co-registered L1b SWIR data	Product
S5 L2 CLD co-registered, co-registered VII cloud data	Product
S5 L2 AUI co-registered, co-registered absorbing aerosol index data	Product
S5 L2 O3_ , total column ozone	Product
S5 L2 SO2, total column SO2	Product
S5 L2 FDY, total column formaldehyde	Product
S5 L2 GLY, glyoxal	Product
S5 L2 NO2, total and tropospheric column nitrogen dioxide	Product
S5 L2 CH4, methane	Product
S5 L2 CO_ , carbon monoxide	Product
S5 L2 O3P, ozone profile	Product
S5 L2 AUI, absorbing aerosol index	Product
S5 L2 ALH, aerosol layer height	Product
S5 L2 AOD, aerosol optical depth	Product
S5 L2 UV_ , surface UV	Product
S5 L2 CLD, cloud	Product
S5 L2 RFL, surface reflectance	Product

S5 L2 HET, heterogeneity	Product
S5 L2 CLA, cloud analysis	Product
SO2 (Sulphur dioxide) Background Database	Background
Reference Radiance Database	Background
FDY (Formaldehyde) Background Database	Background
GLY (Glyoxal) Background Database	Background
NO2 (Nitrogen Dioxide) Background Database	Background

5.2.2.3 Product quality information

A large range of product quality information and flags are included in both the Level 1 and Level 2 products from Sentinel-5/UVNS. For more information on product quality and flagging within the Sentinel-5/UVNS Level 1 products see [RD14].

Each of the Sentinel-5/UVNS Level 2 products also include a range of product quality information and flags. These are described in the Product Generation Specifications (PGSs) for each specific product. For further information see [RD34], [RD35], [RD36], [RD37], [RD38], [RD39], [RD40], [RD41], [RD42], [RD43], [RD44], [RD45], [RD46], [RD47], and [RD48].

5.2.2.4 Auxiliary Data Sets (ADS)

The auxiliary data sets used in the Sentinel-5/UVNS Level 0 to Level 1 processing are captured in EPS-SG Sentinel-5 Level 1b Auxiliary Data Specification, EUM/LEO-EPSSG/SPE/14/772051, [RD32].

The Sentinel-5/UVNS Level 2 operational processors also require a range of auxiliary data sets. These are described in the EPS-SG Sentinel-5 Level 2 Auxiliary Data Specification, EUM/LEO-EPSSG/SPE/16/887628, [RD33].

5.2.2.5 Product requirements

The uncertainty and stability performances of the Sentinel-5/UVNS product processor development are given in Table 5.4. The uncertainty of the products will be mainly limited by the signal-to-noise ratio of the Sentinel-5/UVNS measurements and the knowledge of the *a priori* parameters. For more information, including on the applicability of the product requirements stratified into applications see [AD3].

Table 5.10: Sentinel-5/UVNS Level 2 Products with Target/Goal Performances

Product	Uncertainty[1]	Stability per Decade[1]	Scenario
O_3 total column	3%	<1%	SZA < 80° VZA < 66°
Tropospheric O_3	< 25 ppb or 8% (breakthrough) to < 50 ppb or 16% (threshold) horizontal resolution < 10 km (breakthrough) to < 20 km (threshold)	3% or 10 ppb	SZA < 80° VZA < 66° Effective cloud fractions < 0.1
Stratospheric O_3 Profile	O_3 lower stratospheric column density (300 hPa to 50 hPa) < 8% (breakthrough) to <16% (threshold) horizontal resolution < 25 km (breakthrough) to < 50 km (threshold) O_3 higher stratospheric and mesospheric column density (50 hPa to 0.1 hPa) < 4% (breakthrough) to < 8% (threshold) horizontal resolution <50 km (breakthrough) to < 100 km (threshold)	O_3 lower stratospheric column density (300 hPa to 50 hPa) < 3% or 10 ppb O_3 higher stratospheric and mesospheric column density (50 hPa to 0.1 hPa) < 2%	SZA < 65° VZA < 66°
Total column NO_2	< $1.3*10^{15}$ molecules.cm^{-2} or 20%	< $2.6*10^{14}$ molecules.cm^{-2} or 4%	SZA < 77° VZA < 66° cloud radiance fractions < 0.5
Tropospheric NO_2	<$1.3*10^{15}$ molecules.cm^{-2} or 20%	<$2.6*10^{14}$ molecules.cm^{-2} or 4%	SZA < 77° VZA < 66° cloud radiance fractions < 0.5
SO_2	<$3.0*10^{16}$ (goal) to $6.0*10^{16}$ (threshold) molecules.cm^{-2} or 50%	< $2.6*10^{14}$ molecules.cm^{-2} or 6%	SZA < 70° VZA < 66°

			Effective cloud fractions < 0.3
SO_2 Layer Height	<1 km (breakthrough) to < 2 km (threshold) for SO_2 total column densities larger than 25 DU	N/A	SZA < 80° VZA < 66°
HCHO	random error < $1.2*10^{16}$ molecules.cm^{-2} systematic error < maximum of $5*10^{15}$ molecules.cm^{-2} or 50%.	< $2.6*10^{14}$ molecules.cm^{-2} or 6%	SZA < 70° VZA < 70° Effective cloud fractions < 0.3
CHOCHO	random error < $1.5*10^{15}$ molecules.cm^{-2} systematic error < maximum of $2.5*10^{14}$ molecules.cm^{-2} or 50%	<$2.6*10^{14}$ molecules.cm^{-2} or 6%.	SZA < 70° VZA < 70° Effective cloud fractions < 0.3
CO	uncertainty < $4*10^{17}$ molecules.cm-2 bias < 5% for total CO column densities larger than $1.6*10^{18}$ molecules.cm^{-2}	< $8*10^{16}$ molecules.cm^{-2}	SZA < 80° VZA < 66° excluding high and optically thick cloud
CH_4	bias < 10 ppbv or 0.5% (goal) to < 18 ppbv or 1% (threshold) precision < 10 ppbv or 0.5% (goal) to < 18 ppbv or 1% (threshold).	< 4 ppb or 0.25%	SZA < 70° VZA < 60° Clear sky
Aerosol Layer Height	< 0.5 km (breakthrough) to < 1 km (threshold), in cloud-free conditions and for aerosol optical depths larger than 0.1	< 0.2 km	SZA < 60° VZA < 60° Cloud-free
Aerosol Absorbing Index	< 0.25	< 0.05	SZA < 80° VZA < 66° All sky
AOD total column	**spectral region between 340 nm and 390 nm**	**spectral region between 340 nm and 390 nm**	SZA < 80° VZA < 66°

	< 0.05 or 10% (target) to < 0.10 or 25% (threshold) **spectral region between 390 nm and 500 nm** < 0.02 or 10% (target) < 0.10 or 25% (threshold) **at 760 nm** < 0.01 or 10% (target) to < 0.10 or 25% (threshold)	< 0.016 or 2% **spectral region between 390 nm and 500 nm** < 0.01 or 2% **at 760 nm** < 0.01 or 2%	Cloud-free
UV Index	< 0.5 or 10%	n/a	SZA < 80° VZA < 66° Cloud-free

1. Depending on the scenario the least stringent of the absolute and the relative requirements applies

5.3 Overview of the Cal/Val approach

5.3.1 Pre-launch activities

A number of Cal/Val activities are required to be carried out pre-launch and are necessarily a prerequisite for the start of commissioning phase Cal/Val activities. The activities listed below are separated into those, which are within the scope of this plan, and those which are outside. For those activities, which are considered to be outside the scope of this plan, appropriate references to further documentation are provided.

5.3.1.1 Activities within the Scope of this Plan

Pre-launch activities that are addressed within the scope of this plan, may be separated into three broad areas.

5.3.1.1.1 Definition of Cal/Val Activities and Procedures

Completion of this activity is equivalent to completion of this plan.

5.3.1.1.2 Definition and Acquisition of Cal/Val Data Sets and Tools

All activities related to development and configuration of product Cal/Val tools, and procurement of necessary input data sets to perform product Cal/Val activities, based on details provided in this plan and other associated documentation referenced herein, will be carried out in this phase. Full lists of Cal/Val data sets and tools necessary to support Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val activities are given in Section 7.3 and Section 7.4.

5.3.1.1.3 Co-ordination and Planning of Cal/Val Activities

All activities related to technical co-ordination with external validation partners, preparation of campaigns, and rehearsal of Cal/Val activities are also required pre-launch. Note that many of these activities will continue throughout the mission lifetime. Campaign data will be solicited via preparation of an AO call to be coordinated by ESA with the support of EUMETSAT in the first instance.

5.3.1.2 Activities outside the Scope of this Plan

5.3.1.2.1 Sentinel-4/UVN and Sentinel-5/UVNS instrument build and on-ground Calibration and Characterisation

The Sentinel-4/UVN instrument is built by an industrial consortium led by Airbus Defence and Space where Airbus are also responsible for the characterisation of the instrument. The requirements against which the instrument is built are detailed in [AD6]. The Sentinel-5/UVNS instrument is built by an industrial consortium also led by Airbus Defence and Space and within which TNO are responsible for the on-ground calibration and characterisation. The requirements against which the instrument is built are detailed in [AD7].

Characterisation measurements are taken during an extensive on-ground calibration and characterisation campaign. The characterisation activities for Sentinel-4/UVN and Sentinel-5/UVNS are documented in [RD49] and [RD50]. Characterisation measurements are post-processed to provide Calibration Key Data (CKD) files that are documented, both in terms of content and format, in [RD51] and [RD52]. The CKD are a required input to the Sentinel-4/UVN and Sentinel-5/UVNS Level 0 to 1 processors. For a full list of those CKD used by the Sentinel-4/UVN and Sentinel-5/UVNS Level 0 to 1b processing chains see [RD13] and [RD14]. Other CKD describe aspects of the on-ground behaviour of the instrument, which will also be measured in-orbit using on-board calibration targets. For these aspects, the CKD form the starting point for instrument monitoring activities that are further described in Section 6.2.1.

5.3.1.2.2 Verification and Validation of the Overall Ground Segment

A necessary pre-requisite for the start of Cal/Val activities is the verification and validation of the Overall Ground Segment. Related activities are described in the MTG System Commissioning Plan [SCP], EUM/MTG/PLN/11/0203 [AD1] and the EPS-SG OGS and System Integration, Verification and Validation (OSIVV) Plan, EUM/LEO-EPSSG/PLN/17/960848 [RD4]. In the case of MTG, those facilities of the Overall Ground Segment that are of particular importance to Sentinel-4/UVN are the Mission Operations Facility (MOF), the Instrument Data Processing Facility – Sounding (IDPF-S), the Level 2 Processing Facility (L2PF), and the System Monitoring & Control Facility (System M&C). Also of importance is the availability of the offline operational environment EUMETSAT offline operational environment.

In the case of EPS-SG, those facilities of the Overall Ground Segment that are of particular importance to the Sentinel-5/UVNS are the Mission Control and Operations Facility (MCO), and the Product Data Acquisition and Processing Facility (PDAP). Also of importance is the availability of the offline operational environment of the EUMETSAT TCE.

In the case the verification and validation of the OGS includes use of in-orbit data, Sentinel-4/UVN or Sentinel-5/UVNS Cal/Val activities may be initiated in parallel.

Interface verification activities also fall within the scope of the MTG System Commissioning Plan [SCP], EUM/MTG/PLN/11/0203 [AD1] and the EPS-SG OGS and System Integration, Verification and Validation (OSIVV) Plan, EUM/LEO-EPSSG/PLN/17/960848 [RD4]. In the case of Sentinel-4/UVN activities, the relevant interfaces are those between the IDPF-S and the L2PF and the EUMETSAT Date Lake, the offline operational environment of the EUMETSAT TCE, the EUMETSAT Data Centre, and external data providers. In the case of Sentinel-5/UVNS activities, the relevant interfaces are those between the PDAP and the EUMETSAT Data Lake, the offline operational environment of the EUMETSAT TCE, the EUMETSAT Data Centre, and external data providers.

5.3.2 Commissioning Phase and Routine Operations Activities

5.3.2.1 Activities within the Scope of this Plan

The following activities are relevant to both the commissioning phase and to routine operations. In general, the frequency of implementation and the priority given to different tasks will differ between the two phases, but the basic activities will remain the same. Further information on the frequency of implementation and overall planning see Section 6 and Section 9.

5.3.2.1.1 Instrument Monitoring

The starting point for instrument monitoring activities is the on-ground instrument performance as described by the CKD. Continuous monitoring of Sentinel-4/UVN and Sentinel-5/UVNS instrument performance in-orbit will start during the In-Orbit Verification (IOV) phase and continue during the remainder of the commissioning phase and routine operations. Demonstration of nominal instrument performance is a prerequisite for successful Sentinel-4/UVN and Sentinel-5/UVNS IOV and Commissioning Phase Hand-over Reviews.

Although Sentinel-4/UVN and Sentinel-5/UVNS IOV activities are outside the scope of this plan (see below), the first instrument monitoring data will be available in this phase and co-ordination of activities is necessary to ensure that IOV operations planning meets all data needs anticipated for this period. Furthermore, the Sentinel-4/UVN and Sentinel-5/UVNS IOV activities will provide significant input for planning of further commissioning phase and routine operations

Performance shall be monitored both from an engineering point of view, using selected housekeeping data, and from a scientific point of view using spectral data, in particular in-flight calibration data. Monitoring parameters will be retrieved and further analysed for a given time frame, which may extend from a few scans/orbits to several years of data. The monitoring information is evaluated and condensed by statistical analysis. Analysis of the housekeeping data is used to diagnose the instrument health covering thermal, electrical, and mechanical aspects, and maintaining usage statistics for life-limited items. Spectral data are analysed in order to monitor the optical properties of the instrument, and ultimately to derive correction factors to compensate for instrument degradation in the Level 0 to 1 processing is needed. A detailed description of these activities can be found in Section 6.

5.3.2.1.2 Level 1 Verification, Confidence Checking and Validation

It is not possible to fully verify and validate all Sentinel-4/UVN and Sentinel-5/UVNS Level 1 products without feedback from the validation of geophysical parameter retrievals. For further details on the validation of geophysical parameter retrievals, in support of Level 1 validation, see below. The spectral solar irradiance data may be fully validated, but spectral radiance data can only be partially validated. There are however a number of other parameters in the Level 1 product that can be verified or used for confidence checking. The planned activities address the following main areas:

- Verification and Validation of Geolocation Information (A5.1)
- Validation of Geolocation Information for Earth Measurements (Sentinel-5/UVNS) (A5.1.4)
- Monitoring of In-Flight Calibration Parameters (A4.3)
- Monitor Instrument Spectral Response Function (A4.3.4)
- Validation of the Average Solar Irradiance Spectrum (A5.5)
- Preliminary Validation of Earthshine Radiance Spectra and Albedo (A5.6)

Furthermore, taking into account that the Commissioning Phase is planned to last for six months only and that data will have a limited seasonal coverage by the time of the Commissioning Hand-over Review, products from Sentinel-4/UVN and Sentinel-5/UVNS can at best be confidence checked and partially validated at this time.

5.3.2.1.3 Geophysical Parameter Verification and Validation

The operational Level 2 geophysical parameters products to be produced centrally at EUMETSAT are described in Sections 5.1.2.2 and 5.2.2.2. See Table 5.4 and Table 5.10 for further details on expected accuracy and product quality. Level 2 product validation activities are expected to provide relevant feedback for Level 1 product validation. In particular diagnostic output from the Level 2 retrieval algorithms will contain useful information for analysis of Level 1 product quality. Similarly, information on instrument performance and Level 1 product quality, obtained during the Level 1 verification and validation activities, will provide valuable input to the Level 2 validation activities.

Validation of retrieved geophysical parameters will be based on comparison of the retrieved parameters with independently validated collocated measurements, taking into account differences in spatial resolution and instrument characteristics. Possible sources of independent validation measurements include ground-based measurements, aircraft and balloon measurements and independently validated satellite measurements. How meaningful a given source of validation data is depends on its similarity to the system to be validated. The more similar the validation data is in terms of instrument, measurement principle, wavelength range, analysis methods and associated assumptions therein, data sets used etc., the less independent the information will be. This must be borne in mind when comparing validation results from different data sources. Data assimilation systems, which assimilate data from many independent data sources in a self-consistent way, provide a useful mechanism for examination of spatial and temporal variations including biases between different data sets as they typically provide full global and temporal coverage. They do not however provide an absolute validation reference. For further details on validation of Level 2 products see Section 6.2.3.

5.3.2.1.4 Cross-Comparison of Sentinel-4/UVN and Sentinel-5/UVNS with other AC-VC Missions

The Sentinel-4/UVN and Sentinel-5/UVNS missions are part of the CEOS Atmospheric Composition Virtual Constellation (AC-VC). Within AC-VC, the geostationary missions GEMS, Sentinel-4/UVN, and TEMPO are considered as the Geostationary Air Quality (Geo-AQ) Constellation. The relevant polar orbiting missions include Sentinel-5/UVNS, Sentinel-5 Precursor/TROPOMI, GOME-2, EMI, and OMPS. The CEOS AC-VC specifies inter-mission consistency targets for common products labelled as ‘Constellation Products’. This set includes the Level 1b Earth radiance and Average Solar Irradiance products and a set of Level 2 products. For further details, see Section 6.2.4. The activities specified in this section aim at verifying the inter-mission consistency of these products and will be carried out only during the routine operations phase and after the dedicated validation of Sentinel-4/UVN and Sentinel-5/UVNS products. These activities should also be understood to be a community activity carried out within the scope of, and building on, the activities of other bodies such as GSICS and AC-VC.

5.3.2.1.5 Cross-Calibration and Characterisation Activities During Tandem Operations

During tandem operations of two Sentinel-4/UVN and/or Sentinel-5/UVNS instruments, cross-calibration and cross-validation of the data products in this operational mode will be required to establish the relative data quality from both Sentinel-4/UVN and/or Sentinel-5/UVNS instruments. The cross-calibration and cross-validation activities required to inform this analysis comprise cross-validation of instrument monitoring data, Level 1 and Level 2 data products. For further details, see Section 6.2.5.

5.3.2.2 Activities outside the Scope of this Plan

5.3.2.2.1 Sentinel-4/UVN and Sentinel-5/UVNS In-Orbit Instrument Verification

Sentinel-4/UVN and Sentinel-5/UVNS Instrument Verification will be carried out as part of the Satellite In-Orbit Verification (SIOV) activities (see Section 4 for further details) and is under the overall responsibility of ESA and industrial partners. The objective of the Sentinel-4/UVN and Sentinel-5/UVNS IOV is to verify that the instruments meet their functional and performance requirements. Activities during this phase are expected to include specific instrument operations using dedicated test timelines, and analysis of raw data from, both telemetry and science data, using dedicated test tools. A full description of the planned activities may be found in the S4/UVN - Commissioning Plan, GS4-ADSO-UVN-PL-1000148199 [RD9] and the S5/UVNS - Instrument In-Orbit Verification Plan, GS5.PL.ASG.UVNS.00058, [RD10].

5.3.2.2.2 Validation of AC SAF Products

In the event that the AC SAF produces additional products from Sentinel-4/UVN and Sentienl-5/UVNS, the validation of these products will be outside the scope of this plan and will be under the responsibility of the AC SAF itself. Validation results from these activities and also the diagnostic quantities produced will provide additional valuable feedback to the Level 1 validation activities. Conversely, Level 1 verification and validation activities will provide necessary input to the AC SAF validation activities.

5.3.2.2.3 Scientific Activities

It is anticipated that scientific support to Sentinel-4/UVN and Sentinel-5/UVNS calibration and validation activities may be provided via activities carried out in the wider scientific community, outside of the frame of an Announcement of Opportunity call. Feedback from such activities is welcomed, however the description of, and detailed planning for, such additional scientific investigations which may be carried out in support of Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val activities is outside the scope of this plan.

6 METHODS AND ACTIVITIES

This chapter identifies the tasks that are to be carried out during Sentinel-4/UVN and Sentinel-5 UVNS Cal/Val. Note that all of these tasks are expected to appear in the AO Call with the exception of:

- A1 as the preparation of the Cal/Val plan is the responsibility of ESA and EUMETSAT
- A4 as instrument monitoring is performed as part of the EUMETSAT ground segment functionality. Note that the AO call will cover activities that complement the long-term automated data quality monitoring, trend monitoring, monitoring of expected range exceedances performed operationally by EUMETSAT.
- activities in A5 where there is overlap between with the activities that will be performed as part of satellite or instrument SIOV related to performance requirements that are verified in-orbit by ESA and its industrial partners or with routine calibration and validation activities that are performed as part of the EUMETSAT ground segment functionality.
- activities in A6 where there is overlap with routine calibration and validation activities that are performed as part of the EUMETSAT ground segment functionality.

6.1 Pre-launch Activities

6.1.1 Definition of Cal/Val Activities and Procedures (A1)

This activity comprises the completion of this Plan in co-operation with internal and external partners through appropriate review cycles.

6.1.2 Definition and Acquisition of Cal/Val Data Sets and Tools (A2)

Sentinel-4/UVN & Sentinel-5/UVNS Cal/Val activities will require the definition, and acquisition, of additional data sets prior to launch. These data sets are in addition to those auxiliary data sets required by the Level 0 to 1 and Level 1 to 2 processing product processing facilities and include the independent Level 1 and 2 validation data sets to be supplied by external partners. The list of data sets that are required to support the Cal/Val activities described in this plan are further detailed in Section 7.3 on page 90.

In addition, in order to support the Cal/Val activities and procedures described in this plan, a set of necessary tools is defined. The list of tools required to support the Cal/Val activities described in this plan is further detailed in Section 7.4 on page 105.

6.1.2.1 Definition and Acquisition of Cal/Val Data Sets (A2.1)

A number of Cal/Val data sets have been identified for the Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val activities. Static data sets will be procured and integrated into the EUMETSAT offline operational environment prior to launch. In the case of dynamic validation data sets (e.g. Data from Ground-based Sensors, Data from Satellite-based Sensors, Data from Dedicated Measurement Campaigns, and European Centre for Medium Range Weather Forecasting (ECMWF) and Copernicus Atmosphere Monitoring Service (CAMS) Analysis & Forecast Fields that will be used in real time in support of Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val activities, activities must be initiated to:

- Put in place cooperation agreements to allow data access
- Determine the validation data product format
- Develop product readers and data subset selection tools
- Define data transfer mechanisms and protocols

The first and last of these activities will be addressed within the MTG System Commissioning Plan [SCP], EUM/MTG/PLN/11/0203 [AD1] and the EPS-SG Programme Overall Calibration and Validation Plan, EUM/LEO-EPSSG/PLN/14/758341 [AD2]. Documents and specifications, which describe the data format, can be obtained from the data providers as listed in Section 7.3.

In the specific case of Campaign data, all related activities are expected to be initiated through the release of an announcement of opportunity call by ESA, with the support of EUMETSAT.

6.1.2.2 Definition and Acquisition of Cal/Val Tools (A2.2)

Activities required for the definition and acquisition of Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val tools may be separated into two categories related to the possible source of the tools in question. These are:

- Complex tools to be procured from third party developers e.g. Radiative Transfer Models
- Tools to be available via in-house prototyping, potentially with the provision of software support via a frame contract

The sources of the tools required in support of Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val activities are given in Section 7.4.

6.1.3 Coordination and Planning of Cal/Val Activities (A3)

6.1.3.1 Coordination with External Partners (A3.1)

External partners to be involved in the Calibration/Validation process must be identified and the framework for interaction and participation in Cal/Val activities defined. The list of potential partners will include at a minimum SSST, CAMS, ECMWF, the AC SAF consortium, and selected scientific groups and institutes. In each case, specific tasks and roles must be defined and in particular communication and reporting mechanisms appropriate to each group established. The framework for interaction and participation and the definition of communications and reporting mechanisms will be addressed in the MTG System Commissioning Plan [SCP], EUM/MTG/PLN/11/0203 [AD1] and the EPS-SG Programme Overall Calibration and Validation Plan, EUM/LEO-EPSSG/PLN/14/758341 [AD2]. The definition of tasks and roles for each group relevant to Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val activities must be identified within this plan.

This activity is currently on going in conjunction with completion of this plan (see Section 6.1.1).

6.1.3.2 Planning and Coordination of Campaigns (A3.2)

A validation campaign involving coordinated balloon launches and aircraft flights, timed to coincide with satellite overpass times and other dedicated ground-based observations requires the involvement and coordination of many scientists and institutions.

In case that there are observations essential to Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val activities, that are not available either routinely or through the proposals received as part of the AO call a targeted procurement will be considered.

In the case that campaign data are available from other related scientific campaigns they will also be considered for use.

6.1.3.3 Rehearsal Period (A3.3)

A full rehearsal must be carried out prior to launch to test interfaces, data transfer links, and tools required for Cal/Val activities. All activities related to planning, coordination and execution of a full rehearsal prior to launch are addressed within MTG System Commissioning Plan [SCP], EUM/MTG/PLN/11/0203 [AD1] and the EPS-SG Programme Overall Calibration and Validation Plan, EUM/LEO-EPSSG/PLN/14/758341 [AD2].

6.2 Commissioning Phase and Routine Operational Activities

The in-orbit instrument verification activities that are conducted under the responsibility of the instrument prime are described in [RD9] and [RD10]. This section identifies activities that are complementary to these activities and includes instrument monitoring activities, and Level 1 and Level 2 product verification, confidence checking, validation and long-term monitoring activities.

6.2.1 Instrument Monitoring (A4)

Verification of Level 1 products from the Sentinel-4/UVN and Sentinel-5/UVNS instruments is dependent on correct functioning of the Sentinel-4/UVN and Sentinel-5/UVNS instruments themselves. To ensure the production of high-quality Level 1 products, continuous instrument monitoring activities are required. These activities will start during the commissioning phase, specifically during in-orbit verification of the instrument function and performance and continue during the remainder of commissioning phase and during routine operations. Furthermore, instrument characteristics such as radiance and irradiance sensitivity may change during the Sentinel-4/UVN and Sentinel-5/UVNS instruments lifetime due to in-orbit degradation of instrument performance. A subset of Level 0, 1 and calibration data necessary for instrument performance monitoring and for the calculation of correction factors to account for changes in the sensitivity of the instrument will be stored in a database in the EUMETSAT offline operational environment, see [RD13] and [RD14] and Sections 5.1.2.1 and 5.2.2.1 for further details. These monitoring data will be made available for further analysis and for the derivation of degradation correction factors where appropriate. This will be done asynchronously from the product processing and will require an external operator. These data will also form the basis for automated reporting and data quality monitoring including but not limited to, trend monitoring, monitoring of expected range exceedances, generations of maps, correlation scatterplots, and histograms.

6.2.1.1 Monitoring of Housekeeping Data (A4.1)

Analysis of the housekeeping data is performed in order to diagnose the instrument health from an engineering point of view, covering thermal, electrical, and mechanical aspects, and maintaining usage statistics for life-limited items. Unless otherwise specified analysis of time-series data shall include calculation of the mean, standard deviation, maximum and minimum values, and modelling of the time series by fitting a linear function, a periodic function or an exponential function as appropriate to the behaviour of the data. The following monitoring activities will be carried out on a routine basis:

6.2.1.1.1 Derive Usage Statistics for Life-Limited Items and Mode Statistics (A4.1.1)

The life-limited items to be monitored are the White light Source (WLS), Spectral Line Source (SLS), LEDs, scanner, aperture covers and calibration assembly mechanisms. Information on the expected lifetime and characteristics of these items can be found in [RD11] and [RD12].

The total duration for which each of the life-limited items were switched on and the number of times they have been switched on is to be calculated. For the Sentinel-4/UVN scanner the total number of scans in

any of the earth scanning modes is to be calculated. For the aperture covers the total number of actuations and the total duration during which the covers were open are calculated. For calibration assembly mechanisms, the total number of actuations is to be calculated.

Furthermore, the total number of scans (in the case of Sentinel-4/UVN) per instrument mode, the total duration per mode and its percentage of the total measurement time are to be calculated.

6.2.1.1.2 Monitor Thermal Performance (A4.1.2)

In order to monitor the thermal performance of the instrument, time series of radiator, and optical bench temperatures, plus any other relevant thermistor temperatures (exact list see Table C2 and C3 in [RD14]) will be analysed to determine the amplitudes and phases of orbital and seasonal variations for these temperatures. Furthermore, the time-series of detector temperatures, for the measurements where the respective cooler is switched on shall be analysed.

6.2.1.1.3 Monitor Electrical Performance (A4.1.3)

The time-series of SLS and WLS voltages and currents (additional items see Table C.5 in [RD14]) shall be analysed both per switch-on period and as a long-term time-series. Furthermore time-series of the lamp stabilisation time, shall be analysed.

6.2.1.1.4 Monitor Scanner Performance (A4.1.4)

This activity is specific to Sentinel-4/UVN.

For static modes, the time-series of the scanner position with respect to the set value shall be analysed and for earth scanning mode, the scanner positions across the scan shall be compared with the expected values, the deviations calculated, and the resulting time-series analysed.

6.2.1.2 Monitoring using Internal Calibration Sources (A4.2)

The starting point for monitoring activities using internal calibration sources are on-ground reference measurements contained within the set of Calibration Key Data files described in [RD51] and [RD52]. Any changes between on-ground measurements and the initial in-orbit performance will be analysed during the Sentinel-4/UVN and Sentinel-5/UVNS IOV (see [RD9] and [RD10]). Following IOV, monitoring activities will continue with the analysis of longer time-series of in-orbit measurements.

6.2.1.2.1 Monitor Signals from Internal Light Sources (A4.2.1)

For monitoring of the internal light sources (SLS, WLS and LEDs) the following Calibration Key Data files (see [RD13] and [RD32]) are relevant:

- Sentinel-4: UVN-1-DPP-STATIC and UVN-1-DPP-RADDAY
- Sentinel-5: DET_PRNU, RA_FFWLS, RA_FFLED, DET_FCCD, DET_FCMOS, DET_BAD and DET_LIN in both Calibration and Characterisation Database (CCDB) and Operational Parameter File (OPF)

Time series of in-orbit measurements from internal light sources (SLS, WLS, LED) will be analysed. Within a time series, the integration time, time after stabilisation, and (for the WLS) lamp current have to be identical for a meaningful analysis to be carried out.

6.2.1.2.2 Monitor Diffuser Transmission (A4.2.2)

The transmission of the on-board diffusers will be characterised during the on-ground calibration and characterisation campaign. The relevant Calibration Key Data file (see [RD13] and [RD32]) is:

- Sentinel-4: UVN-1-DPP-STATIC and UVN-1-DPP-RADDAY
- Sentienel-5: RA_DIRR in CCDB

This data forms the starting point for the monitoring of diffuser reflectivity in-orbit, the time series of which shall be analysed and compared to observations taken with the reference solar diffuser to derive degradation coefficients. The specific method is described in section 3.2 of [RD60] and section 4.6.33 of [RD13].

6.2.1.3 Monitoring of In-Flight Calibration Parameters (A4.3)

The starting point for the monitoring of in-flight calibration parameters is the set of on-ground calibration parameters contained within the Calibration Key Data files described in [RD51] and [RD52]. Again, any changes between on-ground measurements and the initial in-orbit performance will be analysed during the Sentinel-4/UVN and Sentinel-5/UVNS IOV (see [RD9] and [RD10]). Following IOV, monitoring activities will continue with the analysis of longer time-series of in-orbit measurements.

6.2.1.3.1 Monitor Dark Signals (A4.3.1)

During the on-ground calibration and characterisation activities, combinations of dark signal measurements at different integration times and different detector temperatures provide all necessary information about the dark current and noise characteristics of the instrument. The relevant Calibration Key Data files (see [RD13] and [RD32]) describing on-ground dark current and noise performance are:

- Sentinel-4: UVN-1-DPP-STATIC and UVN-1-DPP-RADDAY
- Sentinel-5: DET_DRK in CCDB and OPF

These data will be used as the starting point for the analysis of time series of electronic off-sets, leakage current, dark signal and dark signal noise (per detector pixel).

6.2.1.3.2 Monitor Photo Response Non-Uniformity (A4.3.2)

On-ground measurements using the WLS to illuminate the detectors are performed repeatedly during the on-ground calibration period for all instruments, both in ambient and thermal vacuum. These measurements are used to generate PNRU correction factors as described in [RD49], [RD50], [RD52] and [RD54]. In addition, the PNRU is calculated using measurements from the internal LEDs. The relevant Calibration Key Data files (see [RD13] and [RD32]) describing the on-ground PNRU characterisation are:

- Sentinel-4: UVN-1-DPP-STATIC and UVN-1-DPP-RADWLS
- Sentinel-5: DET_PRNU in CCDB and OPF

These data will be used as the starting point for the analysis of time series of PNRU correction factors (per detector pixel) in orbit.

6.2.1.3.3 Monitor Spectral Stability (A4.3.3)

Spectral Calibration Parameters are determined on-ground. The stimulus and algorithm used for the calculation of spectral calibration parameters during the on-ground calibration and characterisation

activities are described in [RD49], [RD50], [RD52] and [RD54]. The relevant Calibration Key Data files describing the on-ground spectral calibration of the instrument are:

- Sentinel-4: UVN-1-DPP-STATIC and UVN-1-DPP-NONLIN
- Sentinel-5: SPEC_DISP in CCDB and OPF

These data will be used as a basis to assess the spectral stability in-orbit. First, calculate wavelengths for selected detector pixels using the in-orbit spectral calibration parameters as described in [RD13] and [RD14]. The time-series of the wavelengths associated with these selected detector pixels are then analysed.

6.2.1.3.4 Monitor Instrument Spectral Response Function (A4.3.4)

Instrument spectral response function (ISRF) parameters are determined on-ground. The stimulus and algorithm used for the calculation of ISRF parameters during the on-ground calibration and characterisation activities are described in [RD49], [RD50], [RD52] and [RD54]. The relevant Calibration Key Data files (see [RD13] and [RD32]) describing the on-ground spectral calibration of the instrument are:

- Sentinel-4: UVN-1-DPP-STATIC and UVN-1-DPP-SUPPORT
- Sentinel-5: SPEC_ISRF in CCDB

These data will be used as a basis to assess the spectral response stability in-orbit. The ISRF variation map will be generated by calculating he ratio of the mean ISRF and the reference ISRF. The reference ISRF will be chosen at the beginning of the mission (which may be a daily or weekly average at the beginning of the mission).

6.2.1.3.5 Monitor Instrument Throughput using Solar Measurements (A4.3.5)

Solar variability when measurements are normalised to an Earth-Sun distance of 1AU, is expected to be no more than a few percent between 210nm and 300nm and less than one percent above 300nm [SCD4]. Therefore, by analysing time-series of solar measurements relative to a reference solar spectrum, changes in the throughput of the Sentinel-4/UVN and Sentinel-5/UVNS instruments may be monitored. First, the reference solar spectrum must be normalised to a solar distance of 1AU. Then, it must be spectrally interpolated to the fixed wavelength grid used for the solar measurements in the monitoring database. Next, ratios of solar spectra with a reference solar spectrum are calculated. Broadband and narrowband effects are separated in the ratios by subtracting a low-order polynomial in the spectral domain. Time-series of both components are to be analysed paying particular attention to periodicities (e.g., annual). See also the related activity Validation of the Average Solar Irradiance Spectrum (A5.5).

6.2.1.4 Monitoring of Radiance Measurements (A4.4)

Spectral data are analysed in order to monitor the optical properties of the instrument, and ultimately to derive correction factors to compensate for instrument degradation in the Level 0 to 1 processing. The following activities will be carried out on a routine basis.

6.2.1.4.1 Monitor Instrument Throughput using Earthshine Measurements (A4.4.1)

Specific locations such as Greenland and the Antarctic ice sheets, which have high surface albedo, a stable ground scene and typically low aerosol amount have been used successfully for monitoring changes in instrument throughput of SBUV/2 and GOME-2 at 340nm where ozone absorption is low [SCD3]. Other possibilities include the South Pacific Ocean and the Libyan Desert. For specific scenes and viewing angles,

calculate the ratio of Earthshine spectra with a reference Earthshine spectrum for the same scene and viewing angle (at a different time). The time series are to be analysed as a function of viewing angle with the aim of diagnosing any changes in instrument throughput. The analysis is to be repeated for Earthshine albedos. The field of regard of Sentinel-4/UVN does not however cover the typical geographical areas used for this monitoring activity and it is therefore necessary to consider the use of polar orbiting satellites as a travelling standard. For further discussion, see Section 6.2.4.4.

In addition, in the summer hemisphere, for polar orbiting satellites, high latitudes are observed on both the ascending and descending nodes of the orbit, at two different SZAs. A calibrated radiance at a specific wavelength can be selected for each SZA such that the associated contribution functions are similar. Time-series of both wavelengths, including monthly averages, shall be analysed and the results compared to detect spectrally dependent changes in calibration. This method has been successfully used for SBUV/2 [SCD1].

Finally, using "Quick-Look" ozone line ratios corresponding to the D-pair and A-pair [DAT1] and [DAT17], select those data which lie in equatorial regions and for which the SZA<60^{o}. Compare the two ozone line ratios and analyse their residuals to detect spectrally dependent changes in calibration. This method has also been successfully used for SBUV/2 [SCD1].

6.2.1.5 Reporting Instrument Monitoring Activities (A4.5)

The results of all Instrument Monitoring (A4) activities are to be presented in summary form at a frequency compatible with the monitoring activities (daily, weekly, monthly and yearly as appropriate - note that this does not preclude providing summaries of instrument operations and house-keeping data at a higher frequency if appropriate).

Where appropriate results shall be presented in the following categories:

- Monitoring of Housekeeping Data
- Monitoring using Internal Calibration Sources
- Monitoring of In-Flight Calibration Parameters
- Monitoring of Radiance Measurements

and summarised as a function of:

- Observation mode
- Solar Zenith Angle
- Viewing angle
- Latitude and longitude
- Season

Reporting templates are to be defined however, results shall at a minimum be presented in the form of:

- Time series plots and analysis
- Spectral plots
- 2-dimensional maps
- Scatter plots

Recommendations for update of degradation correction factors shall be made where appropriate including a description of the analysis that justifies the update.

6.2.2 Level 1 Product Verification, Confidence Checking and Validation (A5)

Level 1b product verification, confidence checking, and validation first requires the verification of the completeness of all fields, confirming that expected ranges have not been exceeded and that all quality flags have been set. More detailed verification activities will follow, including verification of the validity of the CKD obtained on ground, and potentially, depending on need, the generation of specific CKD that have not been generated by industry. The outcome of these activities will ultimately be confirmed by independent verification of the Level 1b performance by users of the data.

The in-orbit instrument verification activities that are conducted under the responsibility of the instrument prime are described in [RD9] and [RD10]. Specific activities to be addressed in this Cal/Val plan are detailed in the following sections.

6.2.2.1 Verification and Validation of Geolocation Information (A5.1)

Geolocation information is verified and validated as follows.

6.2.2.1.1 Verification of Sub-Satellite Point for Earth Measurements (Sentinel-4/UVN) (A5.1.1)

Select the central pixel in a scanline (TBC), for a fixed number of scanlines per hour. Compare this with the equivalent information calculated using restituted orbit information, from an independent orbit propagation tool available within the offline operational environment or provided by the Flight Dynamics Function (FDF). Confirm that the across-track difference between the geolocated and the calculated point is less than a pre-specified tolerance based on expected orbit prediction and pointing accuracy.

6.2.2.1.2 Verification of Scanline Width and Ground Pixel Size for Earth Measurements (Sentinel-4/UVN) (A5.1.2)

Calculate the scanline width from the geodetic latitude and geocentric longitude of the outside corner points of the first and last ground pixels in a scan line for a fixed number of scans per hour and compare to the expected scanline width. Confirm that the two are within a pre-specified tolerance taking into account the expected pointing accuracy.

Furthermore, the ground pixel sizes, calculated on the basis of geolocation information for the actual integration times, as indicated by the geodetic latitude and geocentric longitude at ground in the Level 1b product, shall be compared for consistency with ground pixel size expected on the basis of the commanded integration times specified in the current instrument operating timeline and position of the pixel in the scan line. Acceptable tolerances shall be defined based on known pointing accuracy.

6.2.2.1.3 Validation of Geolocation Information for Earth Measurements (Sentinel-4/UVN) (A5.1.3)

First, overlay a validated coastline map on Quick Look False Colour images [DAT17] and visually inspect. Confirm that there are no deviations, within the limits of the spatial resolution of the measurements, between the coastline observed in the False Colour image and that from the coastline map.

Subsequent to this initial check, geolocation performance of Earth measurements will be verified by image matching with co-registered imager data from MTG-I FCI.

Sentinel-4/UVN Image Navigation and Registration (INR) is performed separately for the UV-Vis and NIR bands based on images constructed by averaging Sentinel-4/UVN Earth radiance signals in the continuum across a reference spectral window in the visible and near-infrared. For Sentinel-4/UVN, the current baseline spectral windows are 475.0 - 495.6 nm for the VIS and 770.9 - 774.0 nm for the NIR, respectively.

The Sentinel-4/UVN validation is performed by matching FCI images in the 'VIS 0.4' channel (centred at 444 nm) with Sentinel-4/UVN images from the reference spectral window in the visible, and by matching FCI images in the 'VIS 0.8' channel (centred at 865 nm) with Sentinel-4/UVN images from the reference spectral window in the near infrared.

Possible offsets between the spectrometer and the imager geolocation are determined by image matching. The higher spatial resolution imager data are sampled on the coarser spectrometer spatial grid, repeatedly, with varying spatial offset. The best estimate of offsets is obtained by optimizing the matching of images. Preferred target scenes contain coastlines and other temporally persistent spatial patterns. If significant biases are observed, either persistent or with a repetitive diurnal dependence, the INR related Calibration Key Data (CKD) must be analysed and potentially updated.

An assessment of the accuracy of the inter-band co-registration knowledge from the Level 1b geolocation information can also be made using image matching techniques. The verification is performed by matching FCI images in one single channel (e.g. the 'VIS 0.5' channel (centred at 510 nm) once with Sentinel-4/UVN images in the visible, and a second time with Sentinel-4/UVN images in the NIR. The preferred targets scenes contain cloud structures that are expected to be spectrally invariant across the VIS-NIR spectral domain. Again, if significant biases are observed, either persistent or with a repetitive diurnal dependence, the co-registration related Calibration Key Data (CKD) must be analysed and potentially updated (see Sentinel-4/5 MAG Recommendation 17.02, [RD55]. Observations of the moon can also contribute to assessment of spatial co-registration (intra-band and inter-band) performance using from edge detection methods on the moon observations.

6.2.2.1.4 Validation of Geolocation Information for Earth Measurements (Sentinel-5/UVNS) (A5.1.4)

The Sentinel-5/UVNS geolocation will be validated using a feature matching against a land-sea mask (LSM) in the PGSP (**P**rinciple component analysis (PCA), **G**aussian Mixture Model (GMM) thresholding, **S**hi-Tomasi Feature tracking (STF), and **P**hase Cross Correlation (PCC)) algorithm.

The single steps are the following:

- Through a PCA, the full hyperspectral dataset of each pixel is utilized and translated into a low number of parameters (components). One component, in which the difference between land and sea is most discernible, is selected by configuration per band.

- The image represented in this component is separated into two components, representing land and sea, via GMM thresholding.

- An LSM is read from reference data and a Gaussian smoothing is applied to it.

- With STF tracking, peaks are found in the LSM.

- The peaks are matched between the smoothed LSM and the processed PCA component. From the correlation maps of all matched peaks that show a good enough peak-to-noise ratio, a global correlation map is calculated.

- From the global correlation map, a global ALT and ACT shift is estimated through phase cross correlation. This is the main result of the PGSP algorithm.

• The peaks undergo further selection, yielding a set of high quality so-called surviving peaks, which are stored for reference, along with their individual shifts.

The requirement is understood to be fulfilled for products where the total ALT-ACT-shift returned based on the global correlation map is within the given limit.

6.2.2.1.5 Validation of inter- and intra-band Co-registration (Sentinel-5/UVNS) (A5.1.5)

The Sentinel-5/UVNS inter- and intra-band co-registration will be validated using a similar approach as described in section 6.2.2.1.4, however replacing the LSM with a reference spectral band image in order to compare two images from two different spectral bands and test the co-registration requirement.

6.2.2.2 Validation of Wavelength Calibration Parameters (A5.2)

For both Sentinel-4/UVN and Sentinel-5/UVNS, spectral calibration is a two-step process consisting of an initial spectral assignment parametrised in terms of temperature, orbital phase, and in the case of Sentinel-4, scene inhomogeneity. This initial assignment is further refined in a spectral calibration step for selected spatial pixels, using Fraunhofer lines in the Sun or Earth spectrum. The solar spectrum contains well-documented Fraunhofer absorption lines in the spectral range of Sentinel-4/UVN and Sentinel-5/UVNS [SCD4]. By cross-correlating the Fraunhofer lines in a wavelength calibrated high resolution reference solar spectrum, with those in either the Sentinel-4/UVN or Sentinel-5/UVNS solar spectrum, or in calibrated Sentinel-4/UVN or Sentinel-5/UVNS Earth measurements, a refined estimate of the spectral calibration may be obtained. It should be noted that satellite-based reference solar spectra are generally not of sufficiently high spectral resolution to be used for this purpose. In addition, reference spectra measured on ground, provide sufficiently high spectral resolution but may suffer from residual atmospheric contamination. Activities required to verify the spectral calibration are listed below:

- First, verify that the on-ground CKD relevant for spectral processing are still valid in flight i.e. that may be successfully used to produce a first spectral assignment.
- To evaluate the stability of the spectral axis of Earth radiance and solar irradiance measurements the results from selected spectral calibrations will be evaluated to assess the correlation of perturbations with thermal variability and in the case of the Earth radiance, orbital phase, see also Section 6.2.1.3.3.
- The spectral knowledge obtained by spectral assignment is verified by comparison with the results obtained from dedicated spectral calibration activities. The deviations shall be confirmed to be within the limits expected from the monitoring of spectral stability with respect to thermal environment and orbital phase.
- The validity of the Doppler shift correction shall be verified in a similar fashion.
- The validation of the spectral knowledge shall be verified for Earth radiance and solar irradiance by analysing the spectral position of the Fraunhofer lines and by assessing the fit residuals from the Level 2 retrievals.
- The nominal (homogeneous) Instrument Spectral Response Function (ISRF) is described, following on-ground calibration and characterisation activities, in the Calibration Key Data (CKD). The ISRF knowledge is verified by comparing measured solar irradiance spectra, with high spectral resolution reference solar spectra, convolved with the nominal ISRF described in the CKD. In order to address the ISRF of Earth radiance measurements, this verification will be complemented by analysis of Level 2 fit residuals for a selected of homogeneous scenes. Homogeneous scenes shall be identified

based on analysis of High Spatial Sampling (HSS) and data either from the MTG-I Flexible Combined Imager (FCI) or in the case of Sentinel-5, METimage.

- In the case of Sentinel-4/UVN, (the Sentinel-5/UVNS instrument includes a slit homogeniser so this activity is not relevant) the predicted ISRF of Earth radiance measurements for heterogeneous scenes is verified using the following series of tests. Note that for this predicted ISRF, which comprises the telescope PSF, the slit width, the spectrometer and detector PSF, and the dispersion relation, the verification implicitly covers the CKD. First, compare the predicted ISRF with the nominal ISRF for the homogeneous case and ensure deviations are within the expected range. Measured Earth radiance spectra are then compared with synthetic spectra generated using the predicted ISRF for homogeneous cases and heterogeneous cases. Scene heterogeneity is characterised based on High Spatial Sampling (HSS) data and imager data from MTG-I FCI.

6.2.2.3 Verification of Straylight Performance (A5.3)

Straylight is a performance driver for all key radiometric performances. The straylight kernels are provided within the CKD and generated from on-ground calibration and characterisation measurements. They need to be verified in-flight, for in-flight conditions using solar irradiance and Earth radiance measurements with real spectral and spatial content. The verification of the straylight kernels and the assessment of the instrument straylight behaviour is complex and is expected to require a large effort. The detailed approach to this verification and assessment is partly anomaly driven and will be informed by the activities described in following sections. The strategy for straylight CKD verification might rely on two different methods ([RD59]):

- employ redundancy and assess the consistency between measurements that are performed to derive straylight CKD
- utilize the L1b processor to rectify measurements (those either unintended or insufficiently refine for generating straylight CKD) for straylight and look for residuals after straylight correction.

6.2.2.4 Verification of the Goniometry of the Solar Diffuser (A5.4)

The goniometry of the solar diffusers of Sentinel-4/UVN and Sentinel-5/UVNS can be characterised in orbit using a time series of measurements such that the complete range of anticipated incident elevation and azimuth angles on the solar diffuser are exercised. Under normal operations scenarios the elevation varies significantly during one solar observation period but the azimuth angles only vary slowly with season over the year. I.e., in the absence of dedicated platform manoeuvres used to sample the angular space during a shorter period, the verification of the goniometry can only take place after a sufficient number of solar measurements has been recorded during the first year in orbit.

The degradations of the instrument and the diffuser itself, which happen in parallel, complicate and disturb the analysis of the diffuser goniometry. For Sentinel-5/UVNS, it is therefore foreseen to perform solar observations under the nominal observation angle at regular intervals (such as once per month during the commissioning phase), which is achieved by performing dedicated S/C manoeuvres around the time of the solar calibration at sunset (at the South pole). Using these reference measurements, the instrument and diffuser degradations can be isolated from the goniometry itself. For Sentinel-4/UVN, this separation can rely on the analysis of the performance of the nominal diffuser as compared to the monitoring diffuser.

Using the degradation-corrected, in-orbit time series of solar measurements, on-ground characterisation measurements of the diffuser goniometry can be verified and supplemented with higher angular sampling.

6.2.2.5 Validation of the Average Solar Irradiance Spectrum (A5.5)

The solar irradiance measurements made by Sentinel-4/UVN and Sentinel-5/UVNS, typically obtained once per day, are combined into an Average Solar Irradiance spectrum which represents an average of a number of solar spectra, subject to quality control criteria, measured during the course of a solar viewing timeline, (see [RD13] and [RD14] for more details). The Average Solar Irradiance spectrum shall be validated by comparison to reference solar spectra, obtained from one or more satellite or ground-based instruments measuring in the same spectral region.

Although it is advantageous to obtain coincident measurements in space and time, solar variability when measurements are normalised to an Earth-Sun distance of 1 AU, is expected to be no more than a few percent between 210 and 300 nm and less than one percent above 300 nm [SCD4] as noted above. Therefore, close space time coincidence is not a strong requirement.

If the spectral resolution of the reference measurements differs significantly from that of Sentinel-4/UVN or Sentinel-5/UVNS it is necessary to convert both spectra to a common wavelength grid and resolution to take account of differences in spectral sampling and spectral resolution. The procedure used by Woods *et al.* (1996) [SCD11] may be taken as a baseline. In this procedure, both spectra are interpolated to a common high-resolution wavelength scale and then convolved with a triangular convolution kernel of 1 nm FWHM. It is assumed that the wavelength calibration accuracy of both spectra (see above for validation of Sentinel-4/UVN and Sentinel-5/UVNS wavelength calibration) is equivalent to or better than the FWHM of the convolution kernel. This procedure should minimise, but not completely eliminate, the differences related to spectral resolution and sampling.

The resulting spectra shall be differenced to confirm that the difference is less than the root sum square of the relative error on the Average Solar Irradiance spectrum and the reference spectrum.

6.2.2.6 Preliminary Validation of Earthshine Radiance Spectra and Albedo (A5.6)

Sentinel-4/UVN and Sentinel-5/UVNS have a number of Earth observation modes in which measurements of backscattered radiance spectra are made (see [RD11], [RD12], [RD13] and [RD14]). The validation of Earthshine radiance measurements from Sentinel-4/UVN and Sentinel-5/UVNS is a difficult task due to the inherent variability of the observed atmosphere, clouds, and ground scenes, and the dependence of the measured spectrum on the viewing geometry. These data cannot be completely validated without feedback from Level 2 product validation. Diagnostic information produced will provide useful feedback on the quality of the Sentinel-4/UVN and Sentinel-5/UVNS Level 1b data products. In addition, a number of possibilities exist for the preliminary checking and validation of Sentinel-4/UVN and Sentinel-5/UVNS radiance spectra and these are detailed below. Implicit in these activities is the verification that CKD measured during the on-ground calibration and characterisation campaign remain valid in-flight.

6.2.2.6.1 Confidence Check Using UV Albedo (Sentinel-5/UVNS) (A5.6.1)

The UV albedo as measured by Sentinel-5/UVNS is calculated as a ratio of the calibrated radiance spectrum to the Average Irradiance spectrum. This should be calculated for the wavelength range ~265 – 290 nm where surface contributions to the back-scattered radiance are expected to be low. First, interpolate the radiance spectrum to the wavelength grid of the Average Irradiance spectrum using Spline or Akima interpolation. Compare the calculated UV albedo to coarse limits that define a physically reasonable range. This provides a preliminary confidence check on the pre-flight characterisation of the radiance and irradiance response of the instrument and on the in-flight calibration of the radiance and irradiance spectra themselves.

The spectral and temporal continuity of the UV albedo, which is expected to be smooth, shall be analysed to provide an independent estimate of the accuracy of the noise and dark current corrections.

6.2.2.6.2 Verification of Radiometric Bias and Stability

6.2.2.6.2.1 Verification of Radiometric Accuracy using Satellite Intercomparisons

The objective of this task is to validate the Sentinel-4/UVN and Sentinel-5/UVNS backscattered L1 radiances against the absolute radiometric bias accuracy requirements (<3% for UV,VIS and NIR with 2% goal). Additionally, the temporal stability of these radiances will be monitored by comparing them with data from other missions (both imager and hyperspectral) to assess the long-term stability of the L1 radiances.

Intercomparisons can be performed using either imager or hyperspectral instruments. Imager instruments provide a robust baseline for validating the radiometric bias of UVN and UVNS, benefiting from well-calibrated reference instruments such as Sentinel-3 OLCI. Meanwhile, hyperspectral instruments enable validation of L1 radiometric accuracy at finer spectral resolutions.
Ideally, these comparisons should be conducted during simultaneous nadir overpasses to minimize scene variability and differences in viewing geometry. While this is feasible for instruments onboard the same satellite (e.g., METimage), comparisons with other instruments require defining an appropriate time window to ensure sufficient collocations. Only cloud-free scenes, pre-filtered based on spatial, angular, and temporal criteria, will be used in the analysis.

Tools for radiometric validation via intercomparisons should be developed based on principles and methodologies established within GSICS. Frameworks that meet Sentinel-4/UVN and Sentinel-5/UVNS requirements have already been described (e.g., the Sentinel-3A Cal/Val environment [RD-61] and MICMICS [RD-62]). While differences exist due to the distinct nature of UVN and UVNS instruments, the core components of such tools should include:

- Instrument Information Database (IID): Contains all relevant instrument details for intercomparison, including spectral response functions (where applicable), scan and sampling geometry, etc.
- Data Acceptance Module (DAM): Automatically acquires L1 products from operational, buffered, or internet data streams.
- Collocation Tool: maps measurements from different instruments spatially and temporally according to predefined thresholds.
- Calibration Processing Module (CPM): Performs radiance intercomparisons based on instrument spatial/spectral properties and viewing geometry. This may require radiative transfer modelling to compensate for scene, atmospheric, and spectral differences.
- Auxiliary Data Access: Provides access to additional information such as surface BRDF parameters and atmospheric data (e.g., ECMWF fields, external datasets, short-term forecast models).
- Analytical Capabilities: Conducts trending analysis of error statistics, including bias error, stability, and inter-channel homogeneity.
- Data Analysis and Reporting (DAR): generates reports for the Cal/Val team, summarizing intercalibration statistics for bias, stability, and inter-channel homogeneity.

Radiometric validation will be conducted offline during commissioning and at predefined intervals (e.g., monthly) using match-up data. Due to the spectral, spatial, and temporal characteristics of Sentinel-4/UVN and Sentinel-5/UVNS, existing inter-calibration systems may have limitations, requiring adaptations to ensure optimal validation strategies.

6.2.2.6.2.1.1 Verification of Radiometric Accuracy using Imager Satellite Inter-Comparisons (A5.6.2)

Intercomparisons with other imager instruments onboard the same satellite (e.g., METimage and 3MI) and with measurements from instruments on other satellites (e.g., Sentinel-3 OLCI, MTG-I1 FCI, and VIIRS) during simultaneous nadir overpasses (SNOs) will be used to validate the Sentinel-4/UVN and Sentinel-5/UVNS L1 radiances.
Although other instruments onboard EPS-SG will also undergo validation during commissioning, past experience has shown that radiance mismatches serve as a useful starting point for identifying potential calibration issues. These mismatches can then be fine-tuned to improve radiometric alignment. The good temporal overlap of certain instruments allows for extensive radiance comparisons, enhancing the robustness of the validation process. However, when temporal overlap is limited (e.g., with OLCI and VIIRS, if available), indirect cross-comparisons can be conducted using a third reference source, such as validated geostationary satellites.
Using an imager as a reference requires spectral binning to match the spectral resolution of the reference instrument, which can vary from a few nanometers to several hundred nanometers. This approach enables an overall assessment of the instrument's radiometric performance across broader spectral bands, helping to identify wavelength-dependent inconsistencies.
The intercomparisons can be conducted over PICTs with homogeneous surfaces to minimize scene variability, and over large regions, where natural variability is included in the analysis to assess its impact on radiometric consistency.

6.2.2.6.2.1.2 Verification of Radiometric Accuracy using Hyperspectral Satellite Inter-Comparisons (A5.6.3)

Sensors with similar characteristics to Sentinel-4/UVN and Sentinel-5/UVNS, that are expected to be in operation when MTG-S and EPS-SG A are launched, include GOME-2 on Metop-B and Metop-C, the Sentinel-5 Precursor/TROPOMI, the geostationary instruments GEMS and TEMPO and OMPS on S-NPP, JPSS-1 and JPSS-2 (see Section D4 for further details). Despite differences in orbital characteristics, collocated spectra from simultaneous nadir overpasses (SNOs) can potentially be selected if their effective viewing geometries are equivalent within a user-defined tolerance, considering both spatial and temporal collocation constraints. Differences in spectral resolution must also be accounted for. Since TROPOMI and OMPS operate in afternoon orbits, the time difference between their measurements and those of Sentinel-5/UVNS will be significantly larger, leading to increased variability. This method is likely most reliable in the ultraviolet region, where sensitivity to clouds and surface albedo is reduced. However, accurate aerosol characterization will still be necessary for meaningful comparisons.

6.2.2.6.2.2 Verification of Radiometric Accuracy using Pseudo-Invariant Calibration Targets (PICTs) (A5.6.4)

The objective of this task is to validate the Sentinel-4/UVN and Sentinel-5/UVNS L1 radiances against absolute radiometric bias accuracy requirements and assess their temporal stability. Additionally, spectral homogeneity and certain aspects of inter-spatial bias can be validated, depending on the spatial distribution of suitable calibration sites.

This validation is conducted through vicarious calibration using pseudo-invariant Earth calibration targets (PICTs). These stable and homogeneous natural targets require a reference model (e.g., a radiative transfer model) to simulate top-of-atmosphere (TOA) radiances based on atmospheric conditions and surface properties at the time and location of observation. A complete description of all relevant atmospheric and surface variables is essential, particularly for clear-sky conditions, to ensure accurate radiative transfer modelling in the spectral regions corresponding to UVN and UVNS observations.

Vicarious calibration techniques for operational missions have been developed in MICMICS for other instruments. While there are intrinsic differences between UVN/UVNS and currently operational instruments (primarily imagers), the same principles apply with necessary modifications and algorithm refinements. Several natural stable targets are suitable for vicarious calibration, including: Desert sites; Rayleigh scattering; Sun-glint over the ocean; and Deep convective clouds (DCC). Among these, Desert sites and DCC calibration methods are already implemented in MICMICS and will be utilized when applicable, depending on their presence within the instrument's spatial coverage. Since DCC locations are dynamic, observations are gathered from frequently occurring regions in the tropics. For very fine spectral resolution instruments, spectral binning may be necessary to align with the spectral resolution of reference models.

Vicarious calibration methods typically have an intrinsic accuracy of ±2-3%, which may be close to the required bias accuracy threshold. As a result, a statistically significant number of observations is needed for meaningful bias error determination. For instance, DCC observations are accumulated over a one-month period to derive reliable results.

Combining vicarious calibration and inter-satellite comparisons can provide further validation insights. The test is particularly valuable for assessing radiometric stability using time series of vicarious calibrations.

Inter-spatial homogeneity can be evaluated using large or frequently sampled sites under varying viewing geometries, helping to identify and correct scan-angle-dependent artifacts. Spectral homogeneity can be effectively validated, as some errors inherent to vicarious calibration partially cancel out when comparing results from different spectral regions.

The applicability of vicarious methods depends on the spectral and spatial characteristics of the instrument. Some techniques may only be relevant for specific spectral domains or portions of the instrument’s dynamic range.

The procedure and tools required for vicarious calibration are similar to those used for inter-satellite comparisons (see previous sections), except that matchups are performed with ground targets rather than satellite datasets. This requires dedicated databases of calibration sites rather than instrument-based databases.

The following datasets are required: (i)Time series of UVN/UVNS L1 products; (ii) ECMWF forecasts/analyses for atmospheric characterization and surface bidirectional reflectance distribution function (BRDF) parameters (if applicable)

A specialized tool is needed to identify and subset data for predefined vicarious calibration sites under specific illumination conditions and perform vicarious calibration using surface,

atmospheric, and illumination parameters. Although MICMICS already provides some of these functionalities, additional development is required depending on the instrument and calibration method.

6.2.2.6.2.3 Verification of Radiometric Performance using Moon Observations (A5.6.5)

Sentinel-4/UVN will occasionally have the opportunity to observe the moon through the nadir port during night, in the North-East corner of the space view. The moon measurements will be performed by positioning the moon approximately in the middle of the north-south viewing angle range and position the instantaneous field-of-view about 0.5 degrees to the east of the moon. The scan mirror will remain fixed in the same position. The movement of the spacecraft will move the instantaneous field-of-view over the moon from east to west. The measurement will be continued until the instantaneous field-of-view is about 0.5 degrees west of the moon. In total, the instantaneous field-of-view will thus cover about 1.5 degrees. This will take about 6 minutes in total.
Sentinel-5/UVNS does not, by default, allow observation of the moon. In order to do this, should a lunar observation opportunity, that satisfies defined lunar phase, fraction and lunar observation angle requirements, arise during commissioning, a dedicated platform manoeuvre would be required. This would provide extremely valuable data for providing a verification and reference point for the radiometric calibration of the Earth observation optical path by comparison to the GSICS Implementation of the ROLO model (GIRO) and the EUMETSAT LESSR model (inferred from SCIAMACHY and RELAB lunar measurements), both models implemented in the EUMETSAT MICMICS infrastructure. For more information, see http://gsics.atmos.umd.edu/bin/view/Development/LunarWorkArea.
Moon measurements can be used for:

- Absolute radiometric calibration with an expected accuracy between5% and 10% (1σ) for the GIRO and about 2% for LESSR.
- Relative radiometric calibration (degradation monitoring) with an expected accuracy of about 1%.
- Spatial co-registration (intra-band and inter-band) from edge detection on the moon. See also Validation of inter- and intra-band Co-registration (Sentinel-5/UVNS) (A5.1.5).

6.2.2.7 Reporting Level 1 Verification, Confidence Checking and Validation Activities (A5.7)

All results of Level 1 Product Verification, Confidence Checking and Validation (A5) are to be reported in summary format. The results shall be summarised in the following categories:

- Verification and Validation of Geolocation Information
- Validation of Wavelength Calibration Parameters
- Verification of Straylight Performance
- Verification of the Goniometry of the Solar Diffuser
- Validation of the Average Irradiance Spectrum

- Preliminary Validation of Earthshine Radiance Spectra and Albedo

Where appropriate results shall be presented as a function of:

- Solar Zenith Angle
- Viewing angle
- Cloud fraction
- Atmospheric aerosol loading
- Latitude and longitude
- Land/sea
- Season

Reporting templates are to be defined however results shall at a minimum be presented in the form of:

- Time series plots and analysis
- Spectral plots
- 2-dimensional maps
- 2-dimensional surfaces of latitude band vs time
- Scatter plot

Recommendations for upgrades to Level 0 to 1 processing algorithms and software shall be made where appropriate including a summary of the analysis which justifies the upgrade.

Recommendations for update of degradation correction factors shall be made where appropriate including a description of the analysis used to generate the degradation corrections.

6.2.3 Geophysical Parameter Verification and Validation (A6)

The geophysical products to be validated are the following:

- Ozone profile (Sentinel-5/UVNS),
- Total tropospheric, and stratospheric column ozone,
- NO_2 total, tropospheric and stratospheric columns,
- SO_2 total column,
- HCHO total column,
- CHOCHO total column,
- CH4 dry-air mole fraction,
- CO total column,
- Aerosol Absorbing Index (AAI),
- Aerosol Optical Depth (AOD),
- Aerosol Layer Height (ALH), and,
- Cloud products.

Validation of these products is primarily based on comparison with other independently validated spatially and temporally collocated measurements, where the collocation criteria will be user configurable and depends on the characteristics of each validation dataset. Sources of independent validation data sets include ground-based data, satellite-based data, and aircraft- and balloon-based data.

A prerequisite for the validation of Level 2 data products is the verification of completeness of all fields considering any exceedances of expected ranges and that all quality flags have been set.

Fiducial Reference Measurements

Fiducial Reference Measurements (FRM) are fully characterized, and traceable ground measurements available from a number of networks providing products relevant to Sentinel-4/UVN and Sentinel-5/UVNS. FRMs will form the basis of an absolute validation of Sentinel-4/UVN and Sentinel-5/UVNS data. Specific collocation possibilities depend on the Sentinel-4/UVN and Sentinel-5/UVNS observation or overpass time for each ground-based station location as compared to the nominal observation time at the ground station. If the available collocated ground-based measurements are not sufficient, additional measurements, timed to coincide with the Sentinel-4/UVN and/or Sentinel-5/UVNS observation or overpass time, may be requested as part of a coordinated calibration campaign. Alternatively, use of a chemical transport model or data assimilation model may be required to interpret measurements taken at a different time of day or Solar Zenith Angle (SZA). Relevant measurement techniques used in ground-based observations include the following:

- The Dobson spectrophotometer measures the total ozone column amount to an accuracy of 2-3% (station dependent) for solar elevations greater than 15°. It is a double monochromator which measures in the spectral region of the Ozone Huggins bands. The total column ozone is determined using the differential absorption technique applied typically to the wavelength pair 305.5 nm–325.4 nm and 317.6 nm–339.8 nm referred to as the AD pair [DAT1] & [DAT2]
- The Brewer grating spectrophotometer is similar in principle to the Dobson spectrophotometer however it is fully automated. The total column abundance of ozone is derived from five wavelengths measured in the region 306 nm – 320 nm [DAT3].
- Ultra-Violet/Visible zenith sky spectrometer observations performed at twilight allow the determination of column amounts of various trace gases using the Differential Optical Absorption Spectroscopy (DOAS) technique. The gases measured include O_3 with a reported accuracy of 3% and NO_2 with a reported accuracy of 10%. It is also possible to operate UV-visible DOAS spectrophotometers in solar occultation mode to obtain vertical distributions of O_3 and NO_2 from the upper troposphere to the mid stratosphere [DAT9].
- Fourier Transform Infrared (FTIR) spectrometers can provide, in addition to other minor trace gases, measurements of total column O_3 with a reported accuracy of 3% and NO_2 with an accuracy of 10% derived from high resolution measurements of the solar spectrum [DAT11] & [DAT12].
- Ozonesondes make in situ measurements of the vertical distribution of ozone up to an altitude of 35 km – 45 km. The principle of operation is based on recording the number of electrons generated in an electro-chemical reaction based on the titration of ozone in a potassium iodide (KI) sensing solution. An exception is the Japanese KC79/96-ozone sensor which uses potassium bromide (KBr) instead of potassium iodide (KI). The sonde is attached to a balloon. Pressure, temperature and humidity information are also measured by an attached radiosonde. The vertical resolution of the measurements is approximately 100 m, with a precision of approximately 2% and an accuracy of 5% [DAT4], [DAT5], [DAT6] & [DAT7].
- To monitor atmospheric ozone with the Differential Absorption Lidar (DIAL) technique, the choice of the laser wavelengths depends on the altitude range of the measurement required [DAT13]. The selected wavelengths differ according to whether the measurement to be made is in the troposphere or in the stratosphere. The stratospheric DIAL technique allows measurement of stratospheric ozone in the

vertical range 15 km to 45 km under clear sky conditions. The vertical resolution varies from 0.5 km to 8 km, increasing with altitude, and with a precision over the entire range of 3% or less and an accuracy varying from 0.5% to 10% depending on vertical resolution [DAT8] & [DAT13].

- Microwave radiometers provide profiles of atmospheric trace gas species, particularly ozone, in the 20 km to 70 km range with no sensitivity to weather conditions or the aerosol loading of the atmosphere. Measurements are available with an accuracy of 10% to 15% and with a vertical resolution of 8 km to 12 km [DAT14] & [DAT15].
- Sun photometer measurements of the direct (collimated) solar radiation provide information to calculate the columnar aerosol optical depth (AOD). AOD can be used to compute columnar water vapour (Precipitable Water) and estimate the aerosol size using the Angstrom parameter relationship.
- Light detection and ranging (lidar) sensors work in the optical spectral range. The lidar technique has proved to be effective for evaluating the stratification of aerosols, i.e., the vertical structure of the aerosol layers (base, top and thickness) and in particular of the Planetary Boundary Layer (PBL). Elastic (emission and reception are at the same wavelength) and Raman (the reception wavelength is shifted relative to that emitted by the Raman effect) lidar systems allow the measurement of optical properties such as the backscatter and extinction coefficients. Advanced lidar systems (at least three elastic channels and two Raman channels) also provide information on the aerosol microphysical properties (effective radius, single scattering albedo, modal volume concentration, complex refractive index) [DAT16].

The observing networks which coordinate and collect routine measurements include The World Meteorological Global Atmosphere Watch Program (GAW) (http://www.wmo.int/pages/prog/arep/gaw/gaw_home_en.html), The Network for the Detection of Atmospheric Composition Change (NDACC) (http://www.ndacc.org), The AERONET (AErosol RObotic NETwork) program (https://aeronet.gsfc.nasa.gov/), the Pandonia Global Network (PGN) (https://www.pandonia-global-network.org/) the Tropospheric Ozone Lidar Network (TOLNet) (https://www-air.larc.nasa.gov/missions/TOLNet/), The European Aerosol Research Lidar Network (EARLINET) (https://www.earlinet.org/index.php?id=earlinet_homepage), the NASA Micro-Pulse Lidar Network (MPLNET) (https://mplnet.gsfc.nasa.gov), the Asian Dust and aerosol lidar observation Network (AD-Net) (http://www-lidar.nies.go.jp/AD-Net/), Atmospheric Radiation Measurement (ARM) user facility (https://www.arm.gov/data), the Total Carbon Column Observing Network (TCCON) (http://www.tccon.caltech.edu/), NOVAC, https://novac-community.org/ and the European Research Infrastructure for the observation of Aerosol, Clouds and Trace Gases (ACTRIS).

Satellite Measurements

Satellite-based measurements have the advantage of global coverage which facilitates cross-comparison and validation for all seasons and latitudes. Specific collocation possibilities depend on the detailed orbit characteristics of each satellite. In the case that the data are not closely collocated in time, access to additional analysis tools (e.g. Chemical Transport Models, Data Assimilation Systems etc.) will be required for optimal interpretation of the data comparison. Satellite-based measurements do not provide a direct validation reference measurement as they are themselves validated with respect to FRMs and ground-based measurement systems. However, on the assumption that this validation has been successfully carried out they provide an important validation data set, particularly for the examination of seasonal and temporal variability on a global scale. Several satellites, carrying instruments which measure products of relevance to Sentinel-4/UVN and Sentinel-5/UVNS, and from which validation data may be available, are expected to be flying concurrently with MTG and/or EPS-SG. These include but are not limited to GOME-2 and

IASI on Metop-B/C, the Sentinel-5/UVNS Precursor carrying the TROPOMI instrument, launched in 2017, Ozone Mapping and Profiler Suite (OMPS) the Suomi National Polar-orbiting Partnership (Suomi NPP) launched in 2011 and on NOAA-20 launched in 2017, the Geostationary Environment Monitoring Spectrometer (GEMS) launched in February 2020, and the Tropospheric Emissions: Monitoring of Pollution (TEMPO) launched in April 2023. See Section D3.7 on page 94 for more details on these instruments.

Campaign Data, Aircraft and Balloon Measurements

A validation campaign may involve coordinated balloon launches and aircraft flights, timed to coincide with satellite overpass times and other dedicated ground-based observations, and requires the involvement and coordination of many scientists and institutions. In addition to the meteorological balloons, referred to above as ozonesondes and classed here as ground-based measurements, larger balloons which require experienced personnel and dedicated launching sites can be used to carry multi-instrument payloads. Intensive balloon campaigns have been used in the past in the context of dedicated campaigns for the validation of satellite-based data or in the framework of specific scientific programmes initiated by the European Commission. Aircraft are also used to carry multi-instrument payloads which are capable of making detailed measurements of ozone, other trace gases, and aerosol in the upper troposphere and lower stratosphere. They have also been used in dedicated campaigns. Less complex campaigns are also possible and may be limited to the acquisition of observations at selected overpass times.

Specific needs for campaign data have been identified for Sentinel-4/UVN and Sentinel-5/UVNS. In particular, the capability of Sentinel-4/UVN to observe the diurnal cycle requires dedicated validation activities and data. The sampling of the diurnal cycle of atmospheric constituents is a key feature of Sentinel-4/UVN and is new with respect to heritage polar orbiting missions. Temporally varying biases caused by instrument errors (e.g. spectral or radiometric errors) or by shortcomings in the retrieval (e.g. regarding the treatment of the vertical trace gas profiles, scattering by aerosols and clouds, the surface reflectance and its directionality) may interfere with true diurnal variations. The capability to observe the diurnal cycle therefore needs to be validated and the validation of this capability is challenging. A combination of airborne, ground-based and in-situ reference measurements is needed to characterise the true diurnal variation accurately and to handle mismatches in representativeness between satellite observations and reference measurements. A comprehensive set of auxiliary data is also needed to characterise the scene, including the impact of atmospheric scattering and surface reflectance on the radiation field and its directionality, horizontal heterogeneity, the vertical trace gas profile, etc. Therefore, dedicated and intensive validation activities are required at several supersites with a suite of correlative reference measurements, within the Sentinel-4/UVN Geographic Coverage Area (GCA), and where auxiliary data from a variety of sources will be exploited. Dedicated efforts are also needed to validate the total column trace gas products from Sentinel-4/UVN and Sentinel-5/UVNS (O_3, NO_2, SO_2, HCHO, CHOCHO) based on comprehensive reference and auxiliary data sets, also including data that cannot be acquired on a long-term systematic basis (e.g. airborne measurements).

The validation of the SO_2, HCHO, and CHOCHO products is particularly challenging since the signature in satellite data tends to be weak and dominated by radiometric errors. In background and anthropogenic pollution conditions, the trace gas burden is usually low, and the bulk of the load is located in the boundary layer where the retrieval sensitivity is weak (especially for SO_2). Aggregated validation data need to be evaluated in order to obtain meaningful results.

It is expected that a number of campaigns are needed to collect such comprehensive validation data sets and to cover the relevant ranges of conditions. The validation shall address the full range of sun-satellite geometries (including all slant illumination and viewing angles) for all products. For ozone, very large and

very low total ozone columns that may occur (up to 600 DU and down to 100 DU) especially during springtime should be included. For HCHO and CHOCHO the validation data should cover a broad variety of cases with various precursor types (volatile organic compounds) from various sources (biogenic, biomass burning or anthropogenic) and with different lifetimes.

Biases related to instrument effects need to be assessed using total column data that are re-evaluated using the reference trace gas profile data. The timely availability of correlative and auxiliary data is important for a fast identification of possible anomalies in the satellite data.

For further discussion of campaign validation data needs see Section D5.

Numerical Weather Prediction and Chemical Data Assimilation Analysis Fields

Numerical Weather Prediction (NWP) and Chemical Data Assimilation systems provide an estimate of the atmospheric state based on an optimal combination of measured data, obtained from many different sources, and model forecast fields. This is typically achieved by the minimisation of an objective cost function with respect to the atmospheric state which comprises both background and observation terms. Under the assumption that the data set to be validated is not assimilated within the data assimilation system, model analysis and forecast fields provide a self-consistent independent reference which takes into account constraints both from the model and from all other assimilated observations. Therefore, although analysed model fields produced from a data assimilation system do not provide an absolute validation source, they can be used for monitoring the data to be validated. This allows biases and variability between different measurement types to be easily monitored on a global scale.

The Copernicus Atmosphere Monitoring Service (CAMS) provides online monitoring of satellite data using the global and delayed mode forecasting system. Data from the regional multi-model ensemble are also of particular interest for the evaluation of Sentinel-4/UVN data products.

Validation Method

Validation of Sentinel-4/UVN and Sentinel-5/UVNS geophysical parameters can be achieved using any of the independent validation data sources listed above. First the collocated data are selected on the basis of user configured coincidence criteria which will vary depending on the characteristics of the individual data sets. The collocated data must be sorted per instrument and in the case of ground-based data per instrument class and/or station. Collocated profiles must be sampled at the same vertical resolution, appropriate only to the ozone profile information. Typically, this will require that the profile with higher vertical resolution is convolved with the averaging kernel of the lower vertical resolution profile. The difference between the collocated profile pairs should be calculated and compared to their expected accuracy. The results for all collocated profiles are to be sorted on the basis of:

- Solar Zenith Angle (of the Sentinel-4/UVN and Sentinel-5/UVNS measurements)
- Viewing angle
- Cloud fraction
- Atmospheric aerosol loading
- Total column ozone amount *or*
- Total column amount of NO_2, SO_2, HCHO or CHOCHO as appropriate
- Latitude and longitude
- Land/sea (in the case of comparison to other satellite data)
- Surface type in the case of aerosol products
- Season

and a statistical analysis carried out. Particular attention is to be paid to correlations between any of the above quantities and the differences in the collocated data pairs. For the purposes of long-term validation and trend assessment, time series of collocated data at selected locations and in the zonal mean shall also be analysed. In the event that differences in spatial or temporal collocation are greater than the user defined tolerances access to the output of Chemical Data Assimilation Models will be required to aid interpretation. Analyses with dedicated tools are also needed to understand the apparent differences between satellite and ground-based reference measurements and to quantify the contributing measurement errors and representativeness errors. The impact of co-location mismatches and differences in the respective sensitivities can be estimated based on atmospheric composition models and on forward operators for both satellite and ground-based reference measurements [SCD12]. A dedicated effort is needed to establish the forward operators and the computation of representativeness errors. Eventually, it might be possible to generate such error and consistency diagnostics systematically in data assimilation systems where both the satellite and the reference data are assimilated. For a further discussion of tools required in support of Calibration and Validation activities see Section 7.4.

6.2.3.1 Validation of Ozone Profile Measurements (A6.1)

Retrieved ozone profile information from the Sentinel-4/UVN and Sentinel-5/UVNS class of instruments is particularly sensitive to the quality of absolute calibration of the radiance and irradiance measurements contained within the Level 1b product. As such the final quality of the Level 2 products provides a good indicator of the final quality of the Level 1b product.

6.2.3.1.1 Validation of Ozone Profiles using Ground-Based Measurements (A6.1.1)

Ozone profile information is measured on a routine basis from a range of ground-based observing systems across the globe. Measurements are made using a number of measurement techniques listed above including: ozonesondes, lidar measurements, and ground-based microwave measurements. Brewer and Dobson Umkehr measurements and MAXDOAS measurements also provide ozone profile information, although at limited vertical resolution and sensitivity.

Ozonesondes offer high vertical resolution, typically 100 m. The agreement with the satellite profiles needs to be evaluated statistically, both directly after mass conservative re-gridding and indirectly after applying the vertical averaging kernels of the satellite retrieval to the ozonesonde data. Ground-based ozone lidar instruments provide reference profiles in the troposphere or the stratosphere, depending on their settings. Comparisons to state-of-the-art atmospheric composition models are needed to complement the ozonesonde-based validation, since ozonesonde measurements are usually made only once a week or even less frequently. Additionally, ozonesondes are usually coupled to a meteorological PTU sonde and thus launched at the time recommended for WMO's Upper-Air Global Observing System. Model data can help to confirm the performance of the ozone profile products over the diurnal cycle. Also, data obtained during field campaigns can be especially useful because ozonesondes can be launched multiple times within a single day to obtain validation data over the diurnal cycle.

In all cases, averaging kernels of both observation systems need to be accounted for in order to reduce comparison errors due to significant differences in vertical smoothing. With higher vertical resolution instruments such as ozone lidar, comparison errors associated with vertical smoothing issues are caused mainly by the satellite data.

As discussed in the previous section, dedicated analyses are needed to understand the apparent differences between satellite and ground-based reference measurements and to quantify the contributing measurement errors, co-location mismatch errors and representativeness errors.

Collocated measurements shall first be obtained from the existing ground-based observing networks. In the event that insufficient collocated observations are expected to be available it may be necessary to acquire additional observations as part of a coordinated validation campaign.

The collocated data shall be analysed as described above and the results made available for reporting.

6.2.3.1.2 Validation of Ozone Profiles using Validated Satellite Measurements (A6.1.2)

The following ozone profile information is expected to be available from instruments flying on satellites concurrently with Sentinel-4/UVN and Sentinel-5.

- GOME-2, flying on the Metop series of satellites, provides ozone profile information as partial ozone columns in Dobson Units (DU) in 40 layers from the surface up to 0.001 hPa. The ground pixel size is 40 km (ALT) x 80 km (ACT) with a target accuracy of 30% in the troposphere and 15% in the stratosphere. For more information see https://acsaf.org/product_list.html.
- Sentinel-5 Precursor/TROPOMI aims to provide ozone profile information with an accuracy of better than 10-30% for a vertical resolution of < 6 km and a ground pixel size of size of 7 km x 7 km [DAT19].
- OMPS-Limb will measure ozone profile information in the height range 0 km to 60 km with a vertical resolution of 3 km and a horizontal resolution of 250 km. The accuracy is expected to be 10% for heights >15 km and 20% for heights <15 km. The precision is expected to be 3% in the height range 15 km to 50 km and 10% for heights <15 km and >50 km. The long term stability is expected to be 2% [DAT21] and [DAT25].
- The Geostationary Environment Monitoring Spectrometer (GEMS) is scheduled for launch in early 2020 and will monitor air quality from a geostationary orbit with a spatial resolution over South Korea of 7 km x 8 km for trace gases and 3.5 km x 8 km for aerosol products every hour. GEMS will provide tropospheric and stratospheric O_3 products with an accuracy of 20% and 5% respectively [DAT22] and [DAT23].
- TEMPO will measure ozone profile information as a standard data product with a precision of 10 ppbv in the PBL from 0-2 km and also in the free troposphere, and with a precision of 5% in the stratospheric column. These precision requirements will be met up to a SZA of 70°. Operational retrievals will be performed hourly at the required spatial resolution of ~ 8.4×4.4 km^2 (four co-added pixels for increased signal and reduction of computational resources) [DAT24].

Note that the Sentinel-4/UVN O_3 profile algorithm, which relies only on the UV spectral range, is sensitive to the lower tropospheric (0-6 km) sub-column but less so to near surface ozone. GEMS and TEMPO yield more stratospheric profile information as compared to Sentinel-4, as they provide measurements below 305 nm. All missions provide profile information with several degrees of freedom of signal, sufficient to separate stratospheric and tropospheric sub-columns.

Collocated data shall be analysed as described above and the results made available for reporting.

6.2.3.1.3 Validation of Ozone Profiles using Campaign, Aircraft and Balloon Measurements (A6.1.3)

Notwithstanding ozone profile data which may become available from aircraft and balloon measurements from dedicated campaigns, tropospheric profile information can be verified using reference data from instrumentation on commercial aircrafts through the IAGOS programme. The IAGOS-CORE and IAGOS-CARIBIC instrument packages provide regular profile measurements of ozone, water vapour and other trace gases during take-off and landing at several airports in Europe and on other continents (https://www.iagos.org/).

6.2.3.1.4 Validation of Ozone Profiles using Chemical Data Assimilation Analysis Fields (A6.1.4)

The Copernicus Atmosphere Monitoring Service (CAMS) coordinated by ECMWF, monitors the composition of the atmosphere in near-real-time by assimilating observations of various meteorological variables as well as reactive gases (including ozone) and aerosols into its data assimilation system.

The ozone data currently assimilated include SBUV/2 and MLS ozone profiles and OMI, GOME-2 on Metop-A and Metop-B, and TROPOMI total column ozone amounts. CAMS analysis and forecast fields of ozone can be retrieved and compared to Sentinel-4/UVN and Sentinel-5/UVNS ozone profiles. The data shall be analysed as described above and made available for reporting.

Alternatively, ozone profile information can be sent directly to CAMS where it is ingested into the assimilation system as a passive observation (i.e. not actively assimilated) and monitored on an operational basis. This is routinely done for other satellite data within the global assimilation and forecast system. This second option is only appropriate for the operational Level 2 products as operational production is a necessary prerequisite. In this case, validation statistics would be provided by CAMS.

6.2.3.2 Validation of Total Column Ozone Measurements (A6.2)

Total column ozone information has been produced on a routine basis and over a significant time period both by ground-based instruments as listed above, and by satellite-based sensors. The data record is typically well understood and well validated although determination of long-term trends in ozone amount remains a challenging task.

6.2.3.2.1 Validation of Total Column Ozone using Ground-Based Measurements (A6.2.1)

Total column ozone is measured on a routine basis from an extensive ground-based network of instruments including the Dobson spectrophotometers, Brewer spectrophotometers, UV-visible zenith-sky spectrometers deployed via the Système d'Analyse par Observation Zénithale (SAOZ) network as part of the Network for Detection of Atmospheric Composition Change (NDACC), other DOAS instruments, and FTIR spectrometers.

Specific collocation possibilities depend on the Sentinel-4/UVN and Sentinel5 observation/overpass time for each ground-based station location as compared to the nominal observation time at the ground station. If the available collocated ground-based total column ozone measurements are not sufficient it may be necessary to acquire additional measurements timed to coincide with the Sentinel-4/UVN and/or Sentinel-5/UVNS observation time as part of a coordinated calibration campaign.

The collocated data shall be analysed as described above and the results made available for reporting.

6.2.3.2.2 Validation of Total Column Ozone using Validated Satellite Measurements (A6.2.2)

The total column ozone data expected to be available from other satellite sensors have the following basic characteristics:

- GOME-2, flying on the Metop series of satellites, provides total and tropospheric column ozone. The ground pixel size is 40 km (ALT) x 80 km (ACT) with a target total column ozone accuracy of 4% for SZA< 80º and 6% for SZA >80º. The target accuracy for the tropospheric ozone product is 20%. For more information see https://acsaf.org/product_list.html.
- TROPOMI aims to provide total column ozone information with an accuracy of 3.5-5%, a precision of 1.6-2.5% and a ground pixel size of ~3.5 km ACT x 5.6 km ALT [DAT19].

- OMPS will measure total column ozone amount with an accuracy of 3% or better, a precision of 0.5% or better, and a horizontal resolution of 50 km. The long term stability is expected to be 2% [DAT20] and [DAT25].
- The Geostationary Environment Monitoring Spectrometer (GEMS) is scheduled for launch in early 2020 and will monitor air quality from a geostationary orbit with a spatial resolution over South Korea of 7 km x 8 km for trace gases and 3.5 km x 8 km for aerosol products every hour. GEMS will provide total column O_3 products with an accuracy of 3% [DAT22] and [DAT23].
- TEMPO will measure total column ozone information as a standard data product with a precision of 3%. This precision requirements will be met up to a SZA of 70°. Operational retrievals will be provided hourly at native spatial resolution (~2.1×4.4 km^2) during the day-light period. The precision quoted is for four co-added pixels, as that is the form of the NASA precision requirements for the mission [DAT24].

Collocated data shall be analysed as described above and the results made available for reporting.

6.2.3.2.3 Validation of Total Column Ozone using Campaign, Aircraft and Balloon Measurements (A6.2.3)

There are no specific activities planned with the exception of collection of campaign data that may become available through an AO call. In that case, the data will be analysed as described above.

6.2.3.2.4 Validation of Total Column Ozone using Chemical Data Assimilation Analysis Fields (A6.2.4)

The discussion provided above for Validation of Ozone Profiles using Chemical Data Assimilation Analysis Fields (A6.1.4) applies equally to total column ozone amounts. The same procedures may be followed.

6.2.3.3 Validation of Trace Gas Column Measurements (A6.3)

The trace gas parameters targeted to be produced from Sentinel-4/UVN and Sentinel-5/UVNS are NO_2 total, tropospheric and stratospheric columns, SO_2 total column, HCHO total column, and CHOCHO total column and in the case of Sentinel-5/UVNS also CO and CH_4 total columns. Nadir satellite measurements are sensitive to the total NO_2 column amount and provide only limited information regarding the vertical distribution. None-the-less tropospheric and stratospheric sub-columns are reported separately in the products. The separation is usually based on forecast data that is obtained by data assimilation and spatial filtering techniques. The stratospheric NO_2 information should be validated as a stand-alone product and not only as a corrective term for deriving tropospheric columns from total columns. Correlative data of importance for this activity include ground-based DOAS UV-visible spectrometers, ground-based twilight measurements acquired by zenith-scattered-light DOAS UV-Visible spectrometers in pristine areas, with support from a 1D stacked-box photochemical model to account for diurnal variation effects, stratospheric NO_2 profile measurements from limb/occultation and stratospheric modelling data. With respect to SO_2, volcanoes can emit large amounts of SO_2 that can be transported over large distances in elevated plumes. The signatures of elevated volcanic SO_2 in satellite observations can be very strong especially for eruptive events. Owing to their improved spatial resolution, new sensors are also able to monitor plumes from degassing volcanoes that release SO_2 into the lower troposphere. In addition to total column algorithms, new schemes are becoming mature that provide SO_2 plume altitude estimates. The validation of SO_2 total column products should cover both eruptive events and degassing cases as well as the layer height, which is most relevant for eruptive cases. Specific activities targeting volcanic eruptions fall under the umbrella

of campaign data. In particular, ground-based spectrometers (MAXDOAS or sun photometers) could be placed near volcanoes that are typically active over a longer period and for which the chance of capturing the plume is reasonably high. Dedicated and expensive activities would only be feasible if the event is large and long lasting. For volcanic degassing long-term observations from ground-based scanning DOAS systems (NOVAC, https://novac-community.org/), which provide hourly SO_2 flux values at a large number of active volcanoes. In addition, correlative data such as SO_2 total column from ground based spectrometers (Pandora, MAXDOAS), SO_2 vertical profile information, from ground-based multi-axis DOAS, and SO_2 flux measurements from the NOVAC network will be required. Similarly auxiliary surface reflectance, cloud, and aerosol data, and wind information for flux estimates are also needed.

6.2.3.3.1 Validation of Trace Gas Column using Ground-Based Measurements (A6.3.1)

Ground based measurements of NO_2 are available from UV/Visible spectrometers and FTIR spectrometers deployed as part of the ground-based networks. Both measurement techniques report an accuracy of 10% for NO_2 [DAT9] & [DAT10]. The available ground-based measuring stations will primarily be those of the ACTRIS, NDACC, NOVAC and the PNG.

Ground-based measurements of CO and CH_4 are available from FTIR spectrometers as part of the TCCON network, which is affiliated with NDACC. The TCCON measurement precision is < 0.25% under clear or partly cloudy skies (up to 5% fractional variation in solar intensity), and solar zenith angles < 82 degrees (see Section D3.11 for further details).

Collocated data shall be analysed as described above and the results made available for reporting.

6.2.3.3.2 Validation of Trace Gas Column using Validated Satellite Measurements (A6.3.2)

The trace gas total column data expected to be available from other satellite sensors have the following basic characteristics:

- GOME-2, flying on the Metop series of satellites, provides total and tropospheric column NO_2 with a target accuracy of 8-15% of the annual mean and 30% respectively, total column HCHO with a target accuracy of 50% under polluted conditions, total column SO_2 with a target accuracy of 50% for SZA< 70°, total column BrO with a target accuracy of 30% and total column OClO with a target accuracy of 50%. The ground pixel size is 40 km (ALT) x 80 km (ACT). For more information see https://acsaf.org/product_list.html.
- TROPOMI provides NO_2 tropospheric and stratospheric column amounts with an accuracy of 25-50% and < 10% respectively, SO_2 with an accuracy of 30 – 50%, HCHO with an accuracy of 40 – 80%, CO with an accuracy of 15% and CH_4 with an accuracy of 1%. The ground pixel size is currently 3.5 x 5.6 km^2 for NO_2, SO_2, and HCHO whilst the ground pixel size for CO and CH_4 is ~7 x 7 km [DAT19].
- The Geostationary Environment Monitoring Spectrometer (GEMS) was launched in 2020 and monitors air quality from a geostationary orbit with a spatial resolution over South Korea of 7 km x 8 km for trace gases and 3.5 km x 8 km for aerosol products every hour. GEMS provides NO_2, SO_2, HCHO, CHOCHO products with an accuracy of $1x10^{15}$ molec. cm^{-2}, $1x10^{16}$ molec. cm^{-2}, $1x10^{16}$ molec. cm^{-2} and $1x10^{15}$ molec. cm^{-2} respectively [DAT22] and [DAT23].
- TEMPO will measure total column NO_2 and HCHO as standard data products with a precision of $1x10^{15}$ molec. cm^{-2} and $10x10^{15}$ molec. cm^{-2} respectively. For CHOCHO the precision requirement is TBC. This precision requirements will be met up to a SZA of 70° for NO^2 and 50° for HCHO. Operational retrievals will be done hourly at native spatial resolution (~2.1 × 4.4 km^2) during the day-lit period for

NO_2 and three times per day for HCHO and CHOCHO. The precision quoted is for four co-added pixels, as that is the form of the NASA precision requirements for the mission [DAT24].

- IASI measures in the infrared part of the electromagnetic spectrum with a spatial resolution of 12 km over a swath width of about 2,200 km and provides global observations twice a day. IASI provides information on a number of trace gases including CO and CH_4. IASI NRT CO products are produced centrally at EUMETSAT on behalf of the AC SAF with an accuracy on the total column product of 5 – 25% for pixels with less than 25% cloud cover [SAF1] and [SAF2]. A number of IASI CH_4 products are also available in the community although they typically represent partial columns.
- GOSAT/GOSAT-2 TANSO-FTS can provide CO_2, CH_4, O_3, and H_2O and be a potential source of CH_4 data for cross- validation. For more information see GOSAT Data Products | Greenhouse gases Observing SATellite (nies.go.jp).

Collocated data shall be analysed as described above and the results made available for reporting.

6.2.3.3.3 Validation of Trace Gas Column using Campaign, Aircraft and Balloon Measurements (A6.3.3)

There are no specific activities planned with the exception of collection of campaign data that may become available through an AO call. In that case, the data will be analysed as described above.

6.2.3.3.4 Validation of Trace Gas Column using Chemical Data Assimilation Analysis Fields (A6.3.4)

The discussion provided above for Validation of Ozone Profiles using Chemical Data Assimilation Analysis Fields (A6.1.4) applies equally to total column ozone amounts. The same procedures may be followed.

6.2.3.4 Validation of Aerosol Parameters (A6.4)

The aerosol parameters to be provided by Sentinel-4/UVN and Sentinel-5/UVNS are the aerosol Absorbing Index (AAI), Aerosol Optical Depth (AOD) and the Aerosol Layer Height (ALH).

6.2.3.4.1 Validation of Aerosol Absorbing Index (AAI) (A6.4.1)

The AAI can be inferred directly from the Level 1b Sentinel-4/UVN and Sentinel-5/UVNS spectra [SCD2]. As the index is based on a ratio of the reflectance at 340nm to that at 380nm it is sensitive to wavelength dependent instrument degradation [SAF3].

The primary sources of AAI to be used for validation are GOME-2, the Sentinel-5/UVNS Precursor TROPOMI and OMPS. Collocated data shall be analysed as described above and the results made available for reporting.

6.2.3.4.2 Validation of Aerosol Optical Depth (A6.4.2)

The Sentinel-4/UVN and Sentinel-5/UVNS aerosol optical depth product and microphysical parameters that are by-products or for which assumptions are made in the retrieval need to be compared with reference data, e.g. from ground-based sun-photometer measurements (AERONET or Pandora). Also, high resolution (preferably 1 km or smaller) cloud information is important for identifying possible sub-pixel cloud contamination which can strongly impact satellite AOD retrievals. The Sentinel-4/UVN and Sentinel-5/UVNS aerosol data collocated with AERONET data shall be analysed as described above and the results made available for reporting.

6.2.3.4.3 Validation of Aerosol Layer Height (A6.4.3)

Sentinel-4/UVN and Sentinel-5/UVNS provide an Aerosol Layer Height (ALH) product that is retrieved from measurements in the O_2-A band. The product is new and less mature as compared to the other products. A validation of this product requires dedicated effort. Vertical profile data from ground based lidars (EARLINET, AD-NET) and from spaceborne lidar instruments such as EarthCare (Atlid), Aeolus, or CALIOP provide a good reference. The aerosol amount and microphysical parameters that are by-products or for which assumptions are made in the retrieval need to be compared with reference data, e.g. from ground based sun-photometer measurements (AERONET or Pandora).

6.2.3.5 Validation of Cloud Parameters (A6.5)

6.2.3.5.1 Validation of Cloud Parameters using Imager Data (A6.5.1)

The Flexible Combined Imager (FCI), flying on the MTG-I satellite, produces full disc cloud information at a resolution of approximately 2 x 2 km at sub-satellite point every 10 minutes [DAT26] and [DAT27]. The METimage instrument flying on the EPS-SG A satellite will produce cloud information at a resolution of approximately 500 x 500 m at sub-satellite point [DAT28] and [DAT29]. The swath width of METimage is ~2670 km, corresponding to a scan angle of ±53deg, with a constant spatial sampling angle across the swath and providing complete coverage of the Sentinel-5/UVNS swath. This provides a potential data set with which to validate the FRESCO cloud products produced using Sentinel-5/UVNS data. However, it should be taken into account that because Sentinel-4UVN/Sentinel-5/UVNS and FCI/METimage measure in different spectral regions they will show different sensitivity to clouds. This must be considered in the analysis of any unexplained differences in the two estimates of effective cloud fraction and cloud top height. The METimage cloud parameters that are relevant to Sentinel-5/UVNS are the cloud flag and cloud top pressure, in particular that derived from the O_2 A-band. These parameters are available on the Sentinel-5/UVNS spatial grid as output of the internal Sentinel-5/UVNS METimage cloud co-registration function. Note that the cloud data products generated by FRESCO should not be used over snow- or ice-covered surfaces or for solar zenith angles greater than 85°. Any dependence of the differences on viewing angle or solar zenith angle shall be investigated. Similarly, MTG-I FCI cloud information is co-registered to the Sentinel-4/UVN grid internally to the Sentinel-4/UVN Level 2 operational processor and may be used for validation of Sentinel-4/UVN cloud products.

6.2.3.6 Emission Source Estimation (A6.6)

The estimation of emissions of primary pollutants is an important application area of the Geostationary Air Quality missions. It is expected that emissions of NO_2 and SO_2 are estimated using inverse modelling techniques. Also emissions of Volatile Organic Compounds (methane and non-methane VOC) are expected to be constrained using the observations of HCHO and CHOCHO which are indicators for VOC oxidation. Such estimates will be compared and possibly be used to update existing emission inventories.

An attempt should be made to validate this capability. Satellite observations of known isolated sources should be analysed. Satellite based emission estimates can be compared to the prior knowledge of the source and to estimates made using other methods. Ground based observations of the column density together with wind information on the boundary around the source can be used to estimate the flux across the boundary and the source strength within this boundary. Aircraft imaging spectrometers can provide reference data for the spatial gradients measured by the satellite. Also, reference emission estimates can be made based on such aircraft data.

6.2.3.7 Reporting Geophysical Parameter Verification and Validation Activities (A6.7)

All results of Geophysical Parameter Verification and Validation (A6) activities shall be reported in summary format including a summary of diagnostic quantities produced during retrieval of geophysical parameters.

The results shall be summarised in the following categories:

• Validation of Ozone Profile Measurements
• Validation of Total Column Ozone Measurements
• Validation of Trace Gas Total Column Measurements
• Validation of Aerosol Parameters

Results shall be presented as a function of:

- Solar Zenith Angle (of the Sentinel-4/UVN and Sentinel-5/UVNS measurements)
- Viewing angle
- Cloud fraction
- Atmospheric aerosol loading
- Total column ozone amount *or*
- Total column amount of NO_2, SO_2, HCHO and CHOCHO where appropriate
- Latitude and longitude
- Land/sea
- Surface type as appropriate
- Season

Results shall at a minimum be presented in the form of:

- Profile plots
- 2-dimensional maps
- 2-dimensional cross-sections
- 2-dimensional surfaces of latitude band vs time
- Scatter plots
- Time series analysis

Recommendations for upgrades to Level 0 to 1 and Level 1 to 2 processing algorithms and software shall be made where appropriate including a summary of the analysis which justifies the upgrade.

6.2.4 Cross-Comparison with other CEOS AC-VC Missions (A7)

The Sentinel-4/UVN and Sentinel-5/UVNS missions are part of the CEOS Atmospheric Composition Virtual Constellation (AC-VC). Within AC-VC, the geostationary missions GEMS, Sentinel-4/UVN, and TEMPO are considered as the Geostationary Air Quality (Geo-AQ) Constellation. The relevant polar orbiting missions include Sentinel-5/UVNS, Sentinel-5P, GOME-2, EMI, and OMPS. The CEOS AC-VC [RD56] specifies inter-mission consistency targets for common products labelled as ‘Constellation Products’. This set includes the L1b Earth radiance and Average Solar Irradiance products, and Level 2 products for O_3, NO_2, SO_2, HCHO, CHOCHO, and aerosol optical depth. The activities specified in this section aim at verifying the inter-mission consistency of these products.

6.2.4.1 CEOS AC-VC Level 1b Average Solar Irradiance (A7.1)

Direct inter-comparisons of Average Solar Irradiance spectra from Sentinel-4/UVN, Sentinel-5/UVNS and other AC-VC missions shall be performed. Comparison of Average Solar Irradiance spectra with reference solar spectra is also required. See Section 6.2.2.5 for more details. Methods developed within the frame of the WMO GSICS initiative should be applied and radiometric inter-calibration factors derived as appropriate (http://gsics.atmos.umd.edu/bin/view/Development/20161201).

6.2.4.2 CEOS AC-VC Level 1b Earth Radiance (A7.2)

Various approaches are needed to address the imperfect matching of sun-satellite geometries between any of the pairs of satellite sensors, and the non-overlapping fields of view of the Geo-AQ missions.

Comparison of data acquired over known targets such as very bright clouds and dark ocean scenes shall be performed as described in Section 6.2.2.6. Statistical analyses of a large collection of measurements with a variety of sun-satellite geometries and conditions are needed to isolate instrument effects from geophysical effects. This approach has the potential to verify the radiometric consistency between the missions at minimum and maximum signal levels. For collocated geostationary and polar orbiting measurements these comparisons can be applied to a wider range of target scenes. Precise and approximate ray matching techniques as explored by Doelling et al. (2013) [SCD13], can be applied to the sub-set of data with comparable sun-satellite geometries. Collocated measurements acquired with different viewing geometries are also valuable for this purpose, as long as the scene directionality can be modelled sufficiently accurately. This could be the case for bright clouds and dark ocean scenes or at radiometric calibration sites used for vicarious calibration of spaceborne imagers, relying on accurate knowledge of surface reflectance and its directionality. The intermission consistency of the geostationary missions should be assessed indirectly by using polar orbiting mission data as a travelling standard. Methods developed within the frame of the WMO GSICS initiative should be applied and radiometric inter-calibration factors derived (http://gsics.atmos.umd.edu/bin/view/Development/WebHome).

6.2.4.3 CEOS AC-VC Level 2 Product Comparison with FRMs (A7.3)

It is expected that validation by comparison with FRMs are performed for all AC-VC missions using inter-calibrated reference data from global networks of ground based instruments, such as the NDACC network with Brewer, DOAS, Dobson and lidar instruments and the Pandonia Global Network (PGN) with Pandora instruments as described in Section 6.2.3. Inter-mission consistency is assessed indirectly by a global analysis of these comparisons and should be performed to infer the inter-mission consistency of Level 2 products.

6.2.4.4 CEOS AC-VC Level 2 Product Comparison using Polar Orbiting Missions as a Travelling Standard (A7.4)

The inter-mission consistency between the Geo-AQ missions is verified indirectly by using polar orbiting missions as a travelling standard. Most Level 2 products of the Geo-AQ missions are also provided by the polar orbiting missions Sentinel-5/UVNS, Sentinel-5P, OMPS and OMI. Amongst these polar orbiting missions, Sentinel-5/UVNS and Sentinel-5P are considered very valuable in view of their high spatial resolution that is similar to that of the resolution of the geostationary missions. Additionally, for ozone columns and profiles, data from GOME-2 and from thermal infrared sounders (IASI, IASI-NG, CRiS, or AIRS) should be considered. For aerosol products, data from multi-view imaging polarimeters (3MI or DPC) are likely the best candidate for providing polar orbiting reference data. When inter-comparing

satellite measurements, special care has to be taken with differences in spatial resolutions, resulting in possible offsets between satellite observations [SCD14]. For an accurate interpretation of polar orbiting versus geostationary comparisons of Level 2 products, scene knowledge is crucial. Therefore, these comparisons should be made systematically at all Level 2 validation sites for which comprehensive auxiliary information on horizontal and vertical distributions of trace gases, aerosol amount and vertical distribution, surface reflectance and cloud conditions is collected.

6.2.4.5 CEOS AC-VC Level 2 Algorithm Cross-validation (A7.5)

Level 2 algorithms are cross-validated by applying them to a common set of Level 1b data. A number of issues need to be addressed to make the Level 2 processors developed for one mission fit for ingesting Level 1b products from another mission, e.g. the handling of the different Level 1b product formats, the treatment of flags, and approaches to background correction or the use of reference radiance or irradiance spectra might have to be adapted. If such issues can be addressed, the analysis of Level 2 data thus obtained is valuable for identifying Level 2 algorithm issues and discrepancies.

In the particular case of stratospheric ozone, the inter-mission consistency is assessed by comparing monthly zonal mean values of the stratospheric sub-column from the ozone profile [SCD15], with a consistent definition of the tropopause height. Sampling difference effects need to be taken into account [SCD16].

6.2.4.6 CEOS AC-VC Level 2 Constellation Products (A7.6)

A common set of Level 2 algorithms should be agreed for the Level 2 constellation products (O_3 total column, NO_2 total column, NO_2 tropospheric column, SO_2 total column, HCHO total column, CHOCHO total column). A number of issues need to be addressed to make the Level 2 processors developed for one mission fit for ingesting Level 1b products from another mission (see previous section).

This set of common Level 2 algorithms should be used to process Level 1b data from the various missions, ideally also from one or more of the polar orbiting missions. The systematic generation of Level 2 constellation products generated using the agreed common set of algorithms should be considered.

The analysis of the Level 2 data thus obtained is expected to be valuable to identify possible Level 1b issues related to instrument, calibration and processing. Direct comparisons of Level 2 data from co-located LEO and GEO observations are expected to be meaningful, even when the viewing geometries differ, since Level 2 processing ideally removes viewing angle dependencies.

6.2.4.7 CEOS AC-VC Joint Validation Campaigns (A7.8)

Validation campaigns as outlined is Section 6.1.3.2 are conducted with exchange of reference airborne and ground-based instruments between the mission teams including TEMPO and GEMS.

6.2.5 Tandem Operations of Recurrent Instruments (A8)

During tandem operations of two Sentinel-4/UVN and/or Sentinel-5/UVNS instruments, cross-calibration and cross-validation of the data products in this operational mode will be required to establish the relative data quality from both Sentinel-4/UVN and/or Sentinel-5/UVNS instruments. The cross-calibration and cross-validation activities required to inform this analysis are detailed below.

6.2.5.1 Cross-Comparison of Instrument Monitoring Data (A8.1)

All instrument monitoring activities described in Section 6.2.1 including Monitoring of Housekeeping Data (A4.1), Monitoring using Internal Calibration Sources (A4.2), Monitoring of In-Flight Calibration Parameters (A4.3), and Monitoring of Radiance Measurements (A4.4) will be carried out for both Sentinel-4/UVN and Sentinel-5/UVNS instruments. Activities start following a successful IOV review and will continue for the lifetime of the instrument. Comparison of the output from Monitoring of Housekeeping Data (A4.1) and Monitoring using Internal Calibration Sources (A4.2) will primarily provide information regarding the health and basic characteristics of each instrument, whilst Monitoring of In-Flight Calibration Parameters (A4.3) and Monitoring of Radiance Measurements (A4.4) will provide information on the relative quality of the Level 1 data products. Specifically, Monitor Instrument Throughput using Solar Measurements (A4.3.5) and Monitoring of Radiance Measurements (A4.4) will provide information on the relative degradation characteristics of the two instruments including their time-dependent behaviour. Continuous cross-comparison of monitoring information from two instruments operated in tandem shall be carried out to identify any differences in instrument performance and their evolution with time.

6.2.5.2 Cross-Validation of Level 1 Data (A8.2)

Although the data from Sentinel-4/UVN and Sentinel-5/UVNS instruments in tandem operation may not be precisely collocated in time and space there will nonetheless, under certain conditions, be opportunities for cross-calibration and cross-validation of degradation corrected Sentinel-4/UVN and Sentinel-5/UVNS Level 1 data products. Parameters for which reasonable cross-validation opportunities exist are the geolocation information and the Average Irradiance spectrum. A comparison of the quality of the geolocation parameters for Sentinel-4/UVN and Sentinel-5/UVNS shall be made using the output of Verification and Validation of Geolocation Information (A5.1). Cross-validation of the Average Irradiance spectra can be carried out on a daily basis by evaluation of the differences between the Sentinel-4/UVN and Sentinel-5/UVNS Average Irradiance spectra. In addition, on a longer time scale, the seasonal variation of differences between the Average Irradiance spectra will provide information on the azimuth dependence of differences in the Average Irradiance spectra and therefore differences in the performance of the solar diffuser. Other parameters for which cross-validation would be of interest are the Level 1 radiance product however because of the dependence of these products on solar and viewing geometry, direct comparison of calibrated backscattered radiance products may not be meaningful under most circumstances. An alternative approach is to use radiative transfer models as an intermediary, which takes account of differences in viewing geometry. Measured spectra can be compared to simulated spectra using the same auxiliary and input data for collocated measurements. The differences between the simulated and measured spectra for each collocated ground pixel can be compared and analysed as a function of viewing and solar geometry and scan position. This will provide information regarding the relative performance of the two instruments.

6.2.5.3 Cross-Validation of Geophysical Parameter Data (A8.3)

In order to validate the end-to-end performance of Sentinel-4/UVN and Sentinel-5/UVNS instruments in tandem operations it is necessary to cross-validate Level 2 products for spatially collocated ground-pixels. Independent validation of Level 2 products from each instrument is a prerequisite for this activity. Differences in Level 2 products for collocated ground pixels should be analysed in terms of mean and standard deviation as a function of latitude, solar zenith angle, view angle (or scan position), scattering angle and time. Whilst the initial analysis will be carried out using the EUMETSAT offline operational environment, involvement of the relevant algorithm providers is essential for evaluation of the operational Level 2 products. Ultimately, the final decision on the optimal way to operate more than one Sentinel-

4/UVN and Sentinel-5/UVNS instrument in tandem operations will rest on the relative quality of the operational Level 2 data products.

7 RESOURCES

7.1 Available Expertise

The following provides a summary of the known list of available expertise:

- EUMETSAT staff members and contractors
- ESA and industrial partners
- NOAA and NASA
- The AC SAF who will provide feedback from any Level 1 to 2 validation activities
- Developers of complex tools to be implemented in the EUMETSAT offline operational environment, procured by external contract
- Support from external data providers
- Support from the scientific community

7.2 Environments/Functions/Facilities

EUMETSAT facilities directly required for the Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val activities are:

- the EUMETSAT Core Ground Segment(s)
- the EUMETSAT offline operational environment
- the EUMETSAT Technical Computing Environment (TCE)
- the EUMETSAT Data Centre

Facilities contributing to the Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val activities:

- ESA and industrial in-orbit verification and Cal/Val facilities
- AC SAF product processing facilities, as applicable
- NOAA product processing facilities (for processing Sentinel-4/UVN and Sentinel-5/UVNS Level 1b data using the NOAA algorithms)
- CAMS satellite monitoring functionalities as part of the data assimilation and forecast system
- Facilities available at scientific institutes

7.3 Data Sets

D1 Static Data Sets

Note that this list is not exhaustive. It excludes static data sets that may be provided with tools procured from third party developers. See Section 7.4 on page 105 for further details.

D1.1 Validated Coastline Map

A validated coastline map, with spatial resolution better than that of the Sentinel-4/UVN and Sentinel-5/UVNS measurements is required. One appropriate data set is the NOAA World Vector Shoreline [SCD5]. For more information, see https://shoreline.noaa.gov/data/datasheets/wvs.html.

An alternative shoreline map, which is publicly available, is the Global Self-consistent, Hierachical, High-resolution Shoreline Database (GSHHS). The processing and assembly of the GSHHS is described in

[SCD6]. The data set may be retrieved electronically both from https://www.ngdc.noaa.gov/mgg/shorelines/shorelines.html and http://www.soest.hawaii.edu/wessel/gshhs/gshhs.html. Access software is also provided.

D1.2 High Resolution Reference Solar Irradiance Spectrum

A high-resolution spectral solar irradiance spectrum is required for the generation of an independent estimate of the Sentinel-4/UVN and Sentinel-5/UVNS wavelength calibration parameters in the UV-Vis-NIR. This is not relevant for the SWIR bands due to the absence of sufficiently strong Fraunhofer lines in that spectral domain. Spectral solar irradiance measurements available from satellite do not have sufficiently high spectral resolution for this purpose. Instead, the use of a high-resolution ground-based reference spectral solar irradiance spectrum, commonly used in UVNS spectrometer data processing activities, is proposed. The spectral solar irradiance data was obtained with the Fourier Transform Spectrometer at the McMath/Pierce Solar Telescope situated on Kitt Peak, Arizona, and operated by the National Solar Observatory, a Division of the National Optical Astronomy Observatories. NOAO is administered by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

The data are available from 296 nm to 1300 nm at a resolution of approximately 0.01 nm. Further details are given in [SCD7]. Note that this data set is known to suffer from residual atmospheric absorption features in some spectral regions. The only restriction on the use of the data is as follows. If the data are used in a published paper, it is requested that the following acknowledgement is given “NSO/Kitt Peak FTS data used here were produced by NSF/NOAO”.

D1.3 Trace Gas Climatology Data

In order to perform coarse checks on the Sentinel-4/UVN and Sentinel-5/UVNS Level 1b radiance data, trace gas climatology data are required for all gases, which absorb in the Sentinel-4/UVN and Sentinel-5/UVNS spectral range, to be used as input for Radiative Transfer Model calculations in the absence of independent collocated measurements. At a minimum, the trace gases required are NO_2, BrO, SO_2, HCHO, CHOCHO, and aerosol information. Ozone climatology data may also be included in climatological data sets however, it is assumed that independent collocated ozone measurements will be available. Detailed selection of trace gas climatology data can be found in Sentinel-4 Level 2 PUMs and Sentinel-5 Level 2 PGSs e.g. [RD20], [RD21], [RD22], [RD23], [RD39], [RD40], [RD42] and [RD46].

D2 Configuration and Initialisation Data Sets

It is essential to have access to all configuration and initialisation data used in both the Level 0 to 1 processing and for Level 2 geophysical parameter retrieval.

D3 Data from Ground-based Sensors

A number of ground-based networks exist which routinely collect data in support of atmospheric trace gas and climate monitoring activities.

D3.1 The World Meteorological Global Atmosphere Watch Program (GAW)

The Global Atmosphere Watch (GAW) Programme provides globally harmonized, quality-assured data on variables of importance to atmospheric composition. A network of observational stations constitutes the core of the Programme. The Global Atmosphere Watch includes a comprehensive quality assurance and data archiving system, supported through a set of Member-hosted Central Facilities for the various

categories of variables. Scientific Advisory Groups and Expert Teams, consisting of leading scientists in their fields, provide guidance to the programme when it comes to data quality, utilization of data for environmental assessments and development of products based on Global Atmosphere Watch data.

The Global Atmosphere Watch Programme monitors and studies the variability and trends in the composition of the global atmosphere and the related physical parameters and assesses their consequences. The foremost challenges for the Global Atmosphere Watch include gaining understanding of stratospheric ozone depletion and the increase of ultraviolet (UV) radiation, the changes in the weather and climate due to the impact of human activities on atmospheric composition, especially on greenhouse gas, ozone and aerosol levels, and the risks of air pollution on human health and other issues related to atmospheric deposition and the long-range transport of air pollution, and how to reduce these.

The Programme increasingly focuses on service delivery in application areas where Global Atmosphere Watch data can provide added value. For further information, see https://public.wmo.int/en/programmes/global-atmosphere-watch-programme.

GAW Station Information System (GAWSIS) is an initiative by QA/SAC Switzerland in collaboration with the WMO Secretariat, the GAW World Data Centres and other GAW representatives to improve the management of information about the GAW network of ground-based stations. GAWSIS was adopted by WMO as the official information system of GAW. GAWSIS provides information on sites, measurement programs and data, and contacts.

Currently, there are six GAW World Data Centres each responsible for archiving one or more GAW measurement parameters or measurement types. They are operated and maintained by their individual host institutions. They collect, document and archive atmospheric measurements and the associated metadata from measurement stations worldwide and make these data freely available to the scientific community. In some cases, WDCs also provide additional products including data analyses, maps of data distributions, and data summaries. For more information on available data and data access, see https://gawsis.meteoswiss.ch/.

D3.2 The World Ozone and Ultraviolet Radiation Centre (WOUDC)

The World Ozone and Ultraviolet Radiation Data Centre (WOUDC) is one of six World Data Centres which are part of the Global Atmosphere Watch programme of the World Meteorological Organization. The WOUDC data centre is operated by the Meteorological Service of Canada, a branch of Environment and Climate Change Canada. Ozone data set categories include total column ozone and vertical profile data from lidar measurements, ozonesonde flights, and the Umkehr technique. Ultraviolet (UV) radiation data set categories include broadband, multiband, and high resolution spectral data types.

There are over 500 registered stations in the archive from over 150 contributors. Metadata such as station lists with locations, are available from the WOUDC Website. Value added data products include total ozone time series graphs and near real-time ozone maps. All WOUDC data are made available by using the data search / download, or web accessible folder (WAF) access. In addition, the Open Geospatial Consortium web services provide enhanced access to the archive, which provides standards-based-on-demand access to the archive. For more information, please refer to the data access page. For further information, see https://woudc.org/data/products/.

D3.3 The Network for the Detection of Atmospheric Composition Change (NDACC)

The international Network for the Detection of Atmospheric Composition Change (NDACC) is composed of more than 60 globally distributed, ground-based, remote-sensing research stations with more than 160 currently active instruments. The network provides high quality, consistent, standardized, long-term

measurements of atmospheric temperatures and trace gases, particles, spectral UV radiation reaching the Earth's surface, and other physical parameters. These data are used for the detection of trends in overall atmospheric composition, understanding their impacts on the stratosphere, troposphere, and mesosphere, establishing links between climate change and atmospheric composition, testing and validating atmospheric measurements from satellites, supporting process-focused scientific field campaigns, and testing and improving theoretical models of the atmosphere.

The NDACC began network operations as The Network for Detection of Stratospheric Change (NDSC) in January 1991. The NDACC has been endorsed by national and international scientific agencies, including the United Nations Environment Program (UNEP) and the International Ozone Commission of the International Association of Meteorology and Atmospheric Sciences. NDACC is a major contributor to the Global Atmosphere Watch (GAW) Program of the World Meteorological Organization (WMO) and a key component of the Integrated Global Atmospheric Chemistry Observation (IGACO) initiative.

The primary instruments are Brewer, Dobson, FTIR Spectrometer, lidar, microwave radiometer, sonde, UV Spectroradiometer, and UV/Visible Spectrometer.

Available measurements include:

- Ozone lidar (vertical profiles of ozone from the tropopause to at least 40 km altitude; in some cases tropospheric ozone will also be measured)
- Temperature lidar (vertical profiles of temperature from approximately 30 km to 80 km)
- Aerosol lidar (vertical profiles of aerosol optical depth in the lower stratosphere)
- Water vapour lidar (vertical profiles of water vapour in the lower stratosphere)
- Ozone microwave (vertical profiles of stratospheric ozone from 20 km to 70 km)
- H_2O microwave (vertical profiles of water vapour from approximately 20 km to 80 km)
- ClO microwave (vertical profiles of ClO from about 25 km to 45 km, depending on latitude)
- Ultraviolet/Visible spectrometer (column abundance of ozone, NO_2, and, at some latitudes, OClO and BrO)
- DOAS/Max-DOAS, full-sky and/or zenith viewing (column abundance of ozone and NO_2)
- Fourier Transform Infrared spectrometer (column abundances of a broad range of species including ozone, HCl, NO, NO_2, $ClONO_2$, and HNO_3)
- UV irradiance from UV spectroradiometer

For a full list of data, see https://www-air.larc.nasa.gov/missions/ndacc/data.html#. For a full list of measurement stations, see https://ndacc.larc.nasa.gov/stations. Note that measurements are normally publically available one year after acquisition. Rapid delivery data and available with a maximum delay of one month. If these rapid delivery data are of lesser quality than traditional NDACC certified data, if the data have not yet been quality controlled, or if the data are less complete (e.g. missing uncertainty estimates) then these data must be identified as Rapid Delivery (RD).

These are available separately on the NDACC public website at ftp://ftp.cpc.ncep.noaa.gov/ndacc/RD. As soon as the standard verified version is available, the RD data will be removed and the fully verified version will be archived in the NDACC archive. Some RD datasets are from instruments that are not yet NDACC affiliated instruments.

D3.4 The Aerosol Robotic Network (AERONET)

The AERONET (AErosol RObotic NETwork) project is a federation of ground-based remote sensing aerosol networks established by NASA and PHOTONS (PHOtométrie pour le Traitement Opérationnel de

Normalisation Satellitaire) and is greatly expanded by additional networks collaborators from national agencies, institutes, universities, individual scientists, and partners. For more than 25 years, the project has provided long-term, continuous and readily accessible public domain database of aerosol optical, microphysical and radiative properties for aerosol research and characterization, validation of satellite retrievals, and synergism with other databases. The network imposes standardization of instruments, calibration, processing and distribution (https://aeronet.gsfc.nasa.gov/).

Three data versions (versions 1, 2 and 3) and three quality levels (Levels 1.0, 1.5, 2.0) exist for each product. While Levels 1.0 and 1.5 are provided in near real-time, the 12-month or longer delay (due to final calibration and manual inspection) ensures that the highest quality data can be found in version 2, Level 2.0 data products. The Level 1.0 (unscreened) measurement series are formed from Level 1.0 points. The cloud and pointing error screening is applied to Level 1.0 data to produce a Level 1.5 data set. The Level 1.5 data series are raised to Level 2.0 (quality-assured) series after final calibration values are applied and manual data inspection is completed. Version 2 AOD processing now includes fine and coarse mode AOD as well as fine mode fraction.

The AERONET web site provides data analysis and dissemination tools. Data may be viewed in charts using the data display interface, acquired using the data download tool, analysed and downloaded with related data sets using the BAMGOMAS data display interface, or analysed off-line using a number of analysis tools provided by AERONET/PHOTONS. More information can be found at https://aeronet.gsfc.nasa.gov/new_web/data.html.

D3.5 The Pandonia Global network (PGN)

The Pandonia Global Network aims to provide real time, standardised, calibrated and verified quality assured, quality controlled atmospheric composition data. The PGN also seeks to coordinate and implement network standards regarding common algorithms and data processing, instrument operating routines, QA/QC, real time data processing and data archiving. PGN participants are primarily government and academic researchers. There are almost 100 stations currently producing timely data within the network. Species retrieved are O_3, NO_2, SO_2, and HCHO, though not all stations retrieve all four species.

Data are available from http://data.pandonia-global-network.org/.

D3.6 The Tropospheric Ozone Lidar Network (TOLNet)

The Tropospheric Ozone Lidar Network (TOLNet), currently comprising five lidars, is an interagency initiative started by NASA Research &Analysis, NOAA/ESRL, and the Environmental Protection Agency (EPA) in 2011. TOLNet provides high-resolution spatio-temporal measurements of tropospheric (surface to tropopause) ozone and aerosol vertical profiles to address fundamental air-quality science questions in cooperation with national, state, and local organizations and to support the DISCOVER-AQ, GEO-CAPE, and TEMPO missions. TOLNet also develops recommendations for lower-cost, more-robust lidar systems to better enable their more widespread use.

As the TOLNet measurement sites are currently located in North America, the data cannot be directly used for Sentinel-4/UVN validation but can be used for Sentinel-5/UVNS.

For more information, see https://www-air.larc.nasa.gov/missions/TOLNet/data.html.

D3.7 The European Aerosol Research Lidar Network (EARLINET)

The European Aerosol Research Lidar Network, EARLINET, was established in 2000 as a research project with the goal of creating a quantitative, comprehensive, and statistically significant database for the

horizontal, vertical, and temporal distribution of aerosols on a continental scale. Since then, EARLINET has continued to provide the most extensive collection of ground-based data for the aerosol vertical distribution over Europe. The goal is to provide aerosol data with unbiased sampling, for important selected processes, and air-mass history, together with comprehensive analyses of these data. The objectives will be reached by operating a network distributed over most of Europe, using advanced quantitative laser remote sensing to directly measure the vertical distribution of aerosols, supported by a suite of more conventional observations. EARLINET measurements must meet stringent stability and absolute accuracy standards. For the full harmonization of data analysis and data traceability, the EARLINET Single Calculus Chain (SCC), a tool for the automatic analysis of lidar measurements has been developed. At present, 30 active stations distributed over Europe are part of the network. Data are stored in NetCDF format. For more information, see https://www.earlinet.org.

D3.8 The NASA Micro-Pulse Lidar Network (MPLNET)

The NASA Micro-Pulse Lidar Network (MPLNET) is a federated network of Micro-Pulse Lidar (MPL) systems designed to measure aerosol and cloud vertical structure, and boundary layer heights. The data are collected continuously, day and night, over long time periods from sites around the world. Most MPLNET sites are co-located with sites in the NASA Aerosol Robotic Network (AERONET). MPLNET is also a contributing network to the World Meteorological Organization (WMO) Global Atmospheric Watch (GAW) Aerosol Lidar Observation Network, GALION.

MPLNET is composed of NASA sites and others run by, or with help from, partners from around the world. Principal investigators for individual network sites may be from NASA, other US government agencies, universities, or foreign institutions.

MPLNET V3 products are NetCDF 4, CF compliant files. Subsets for each product may be selected to reduce file sizes. For more information, see https://mplnet.gsfc.nasa.gov/.

D3.9 The Asian Dust and aerosol lidar observation NETwork (AD-Net)

AD-Net is a lidar network for continuous observation of vertical distributions of Asian dust and other aerosols in East Asia. AD-Net is a contributing network to the WMO GAW Program, and it forms an East Asian component of the GAW Aerosol Lidar Observation Network (GALION). The primary objective of AD-Net is to observe vertical distributions of Asian dust and other aerosols (including industrial, forest fire, volcanic) continuously, for studying the effects of aerosols on the environment in East Asia. This is achieved by continuous observation with automatic lidars. The standard lidar system in AD-Net is a two-wavelength (1064 nm, 532 nm) polarization sensitive (532 nm) Mie-scattering lidar (Sugimoto et al., 2008). The measured data are transferred to the National Institute for Environmental Studies, Japan (NIES) in real time and processed automatically. Basic parameters derived are the attenuated backscattering coefficients at 1064 nm and 532 nm, and the volume depolarization ratio at 532 nm. Extinction coefficient estimates for non-spherical and spherical aerosols are also derived with the method using the backscattering and depolarization ratio. For quantitative analysis of aerosol optical characteristics, receivers for nitrogen Raman scattering at 607 nm were added to the lidars at primary stations. Also, some stations are collocated with SKYNET sky radiometers. Data are provided in NetCDF format.

As the AD-Net measurement sites are located in Asia the data cannot be directly used for Sentinel-4/UVN validation but can be used for Sentinel-5/UVNS. For more information, see https://www-lidar.nies.go.jp/AD-Net/.

D3.10 The Atmospheric Radiation Measurements User Facility (ARM)

The Atmospheric Radiation Measurement (ARM) user facility is a multi-laboratory, U.S. Department of Energy (DOE) scientific user facility, and a key contributor to national and international climate research efforts. ARM data are currently collected from three atmospheric observatories—Southern Great Plains, North Slope of Alaska, and Eastern North Atlantic which represent the broad range of climate conditions around the world, as well as from the three ARM mobile facilities and ARM aerial facilities. Data from these atmospheric observatories, as well as from past research campaigns and the former Tropical Western Pacific observatory, are available at no charge through the ARM Data Centre via Data Discovery. ARM focuses on obtaining continuous measurements, supplemented by field campaigns, and providing data products that promote the advancement of climate models. The ARM Data Centre collects and archives approximately 20 terabytes of data per month. Data streams are generally available for download within 48 hours. The most relevant observations are those related to measurements of aerosol, carbon monoxide, ozone and greenhouse gases, with a focus on remotely sensed data such as lidar. For more information, see https://www.arm.gov/data.

D3.11 The Total Carbon Column Observing Network (TCCON)

The Total Carbon Column Observing Network (TCCON) is a network of ground-based Fourier Transform Spectrometers recording direct solar spectra in the near-infrared spectral region. From these spectra, accurate and precise column-averaged abundance of CO_2, CH_4, N_2O, HF, CO, H_2O, and HDO are retrieved. The standard spectral resolution for a ~90 s scan is 0.02 cm^{-1}. TCCON provides an essential validation resource for the Orbiting Carbon Observatory (OCO), GOSAT, Sentinel-5/UVNS Precursor, Sentinel-5/UVNS, and future carbon missions. The network is not an operational system – the instruments are maintained by local research funding and data analysed by individual PI's/research groups. An effort to improve the timeliness of the data delivery (currently only required within a year) is being considered within the Cal/Val plans of other upcoming carbon-oriented missions (CO2M and MicroCarb).

For more information, see https://tccon-wiki.caltech.edu/.

D3.12 The COllaborative Carbon Column Observing Network (COCCON)

The COllaborative Carbon Column Observing Newtork (COCCON) builds on the success of the TCCON network, using newer, EM27/SUN FTIR spectrometers. COCCON currently has more than 40 devices installed around the globe, along with a small number of 'roving' instruments that can be used in temporary locations or as travelling standards to calibrate COCCON and TCCON stations. The network produces column-averaged abundances of CO_2, CH_4, water vapour, and CO. The spectral resolution of the COCCON spectrometers is lower than the TCCON instruments, at 0.5 cm^{-1}. The spectra from the instruments are uploaded to a central server, hosted at KIT (Karlsruhe Institute of Technology), and all processing are performed there. This reduces the analysis burden on the institutions hosting the instruments, and ensures the analysis is consistent across all instruments.

As with TCCON, the network will be critical for validation of several upcoming missions but is not operational. There is some federalised funding for the network (from ESA) but this is not currently guaranteed long term.

For more information, see https://www.imk-asf.kit.edu/english/COCCON.php.

D3.13 The Network for Observation of Volcanic and Atmospheric Change (NOVAC)

The Network for Observation of Volcanic and Atmospheric Change (NOVAC) is a community of volcano observatories and research institutions that together develop and apply ultraviolet differential optical

absorption spectroscopy (DOAS) instruments to measure volcanic gas emission rates. The collected data are used for assessment of volcanic activity, eruption forecasting, research on volcanic processes, and studying the atmospheric impact of volcanic degassing. Together, the institutions participating in NOVAC run the largest instrument network for monitoring gas emissions from volcanoes around the world. Data are available for more than forty volcanoes. The usefulness for validation purposes will be opportunistic depending on volcanic activity in the time frame of the Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val activities. For more information see http://novac-community.org/.

D3.14 The Aerosol, Clouds and Trace Gases Research Infrastructure (ACTRIS)

Aerosol, Clouds and Trace Gases Research Infrastructure (ACTRIS) is a pan-European initiative consolidating actions amongst European partners producing high-quality observations of aerosols, clouds and trace gases. ACTRIS aims to provide a platform for researchers to combine their efforts more effectively, by providing observational data of aerosols, clouds and trace gases openly to anyone who might want to use them. Currently the coordination of ACTRIS is supported by two different EC-projects; ACTRIS-2 and ACTRIS Preparatory Phase Project (PPP). The former revolves around the on-going research, coordinating efforts of partner organisations and producing observations and data, while the latter is a project aiming to establish a research infrastructure with its own legal entity and operational structure that will carry on the work done by ACTRIS-2.

The ACTRIS Data portal allows you to search, analyse, and download atmospheric composition data from a multitude of data archives. The data results from the activities of the ACTRIS infrastructure network complemented with data from other relevant networks and gives free access to atmospheric observational data to analyse atmospheric composition. Almost 135 different atmospheric variables are included in ACTRIS and about 65 sites are active. The measurements are made with 25 different methodologies with time resolution ranging from seconds to 1 week. The ACTRIS data management plan describes the data sets ACTRIS generates, how the data are made available, and the data repositories. The document also includes a list with all ACTRIS atmospheric variables together with recommended methodology. For more information see https://www.actris.eu/DataServices/Data/DataCentre.aspx.

D4 Data from Satellite-based Sensors

D4.1 Total and Solar Spectral Irradiance Sensor (TSIS): Spectral Solar Irradiance Data

The Total and Solar Spectral Irradiance Sensor (TSIS) provided measurements of incoming ultraviolet, visible, near-infrared, and total solar radiation. TSIS follows the Solar Radiation and Climate Experiment (SORCE) mission, with improved instrumentation, to continue the solar irradiance record, one of the longest and most important climate records derived from satellite remote sensing.

TSIS-1 was launched on December 15, 2017, and was installed Station as one of the science mission payloads on the International Space two weeks later. The ISS has a drifting orbit at an altitude of 407 km and an inclination of 51.6°. It was built and is operated by the Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado (CU) in Boulder, Colorado, USA. The package comprises of two instruments – the Total Irradiance Monitor (TIM) and the Spectral Irradiance Monitor (SIM).

The TIM measures the Total Solar Irradiance (TSI), the total amount of light emitted by the sun. It has an absolute accuracy of 100 ppm (0.01%) and a relative accuracy of 10 ppm/year (0.001%/y).

The SIM measures how solar energy is distributed across the spectrum, from UV to IR. It has a spectral range of 200 – 2400 nm with a spectral resolution of 0.25 – 0.33 nm. The absolute accuracy is 0.2% (2000 ppm), relative accuracy of 0.01% (100 ppm), and a variable long-term relative stability of 0.05%/y for λ<400nm, and 0.01%/y for λ>400nm.

Measurements of TSI are produced 4 times per day, and SSI are produced twice per day.

TSIS provides measurements of the solar spectral irradiance at in the Sentinel-4/UVN and Sentinel-5/UVNS spectral range with the SIM instrument.

A follow-up mission, TSIS-2, will be a free-flying platform, also carrying the TIM and SIM instruments. At the time of writing, the platform is due for launch in Q2 2025, and the TSIS-1 instrument lifetime has been extended to cover the difference.

Data are available from https://lasp.colorado.edu/tsis/data/, https://lasp.colorado.edu/lisird/data/tsis_tsi_6hr, and http://lasp.colorado.edu/lisird/data/tsts_ssi_12hr.

D4.2 The Global Ozone Monitoring Experiment (GOME-2) on MetOp

GOME-2 is a medium-resolution UV-VIS spectrometer, fed by a scan mirror that enables across-track scanning in nadir, as well as sideways viewing for polar coverage and instrument characterisation measurements using the moon. This scan mirror can also be directed towards internal calibration sources or towards a diffuser plate for calibration measurements using the sun. GOME-2 comprises four main optical channels which focus the spectrum on linear detector arrays of 1024 pixels each, and two Polarisation Measurement Devices (PMDs) containing the same type of arrays for measurement of linearly polarised intensity in two perpendicular directions. The four main channels provide continuous spectral coverage of the wavelengths between 240 and 790 nm with a spectral resolution (FWHM) between 0.25 nm and 0.5 nm. Compared to the main channels, the PMD measurements are performed at lower spectral resolution, but at higher spatial resolution. The PMDs are required because GOME-2 is a polarisation sensitive instrument. Therefore, the intensity calibration of GOME-2 has to take account of the polarisation state of the incoming light using information from the PMDs. The two PMD channels are designed such that maximum similarity in their optical properties is ensured. The wavelength dependent dispersion of the prisms causes a much higher spectral resolution in the ultraviolet than in the red part of the spectrum.

The GOME-2 instrument has been in orbit on Metop-A since October 2006, Metop-B since September 2012 and on Metop-C since November 2018. From July 2013 until Nov 2021 (when MetOp-A was decommissioned), the two instruments on Metop-A and Metop-B operated in tandem with a wide swath of 1920 km at 40 x 80 km ground pixel resolution for Metop-B and a narrow swath of 960 km at 40 x 40 km resolution for Metop-A. Since Nov 2021, GOME-2 on MetOp-B has operated alone. GOME-2 on Metop-C operates with a wide swath of 1920km and a ground pixel size of 80 x 40 km.

The MetOp platforms follow a sun-synchronous orbit with a Local Equatorial Overpass time of 09:30 (descending node) and 21:30, with approximately 14 orbits per day. Since GOME-2 requires daylight conditions, this produces global coverage once per day.

GOME-2 Level 1b products comprise sun-normalised nadir radiance, absolute nadir radiance, absolute sun radiance, spectral calibration parameters, sun mean reference spectrum, effective cloud fraction, and cloud top pressure. For more information, see [DAT17] and [DAT18].

The operational Level 2 GOME-2 products are produced by the AC SAF and include total column ozone, high resolution ozone profiles, total column and tropospheric column O_3, total column and tropospheric NO_2, total column SO_2, HCHO, BrO and OClO, Absorbing Aerosol Index, and surface UV products. For more information, see http://acsaf.org.

D4.3 The Infrared Atmospheric Sounding Interferometer (IASI) on MetOp

The primary goal of the IASI instrument is to support Numerical Weather prediction. IASI measures in the infrared part of the electromagnetic spectrum at a horizontal resolution of 12 km over a swath width of

about 2,200 km. As with GOME-2, IASI has flown on all three MetOp platforms, with MetOp-B and –C still operational at the time of writing. Since IASI observes in the IR, global observations can be provided twice a day. The temperature of the troposphere and lower stratosphere is measured under cloud-free conditions with a vertical resolution of 1 km in the lower troposphere, a horizontal resolution of 25 km, and an accuracy of 1 K. The humidity of the troposphere is measured under cloud-free conditions, with a vertical resolution of 1–2 km in the lower troposphere and a horizontal resolution of 25 km, with an accuracy of 10%. IASI also measures the fractional cloud cover and cloud top temperature and pressure. IASI is also able to measure a range of trace gases including O_3 profile and column amounts of CH_4, CO, HNO_3, volcanic SO_2, volcanic ash and dust. For more information, see https://acsaf.org and https://www.eumetsat.int/website/home/Satellites/CurrentSatellites/Metop/MetopDesign/IASI/index.html .

D4.4 The Sentinel-5/UVNS Precursor TROPOspheric Monitoring Instrument (TROPOMI)

The TROPOspheric Monitoring Instrument (TROPOMI) is the satellite instrument on board of the Copernicus Sentinel-5/UVNS Precursor satellite. The Sentinel-5/UVNS Precursor (S5P) is the first of the atmospheric composition Sentinels, launched on 13 October 2017 with a planned mission lifetime of seven years. TROPOMI is a spaceborne nadir viewing spectrometer with bands in the ultraviolet and visible (270 to 495 nm), the near infrared (675 to 775 nm) and the shortwave infrared (2305 to 2385 nm). TROPOMI combines daily global coverage with a high spatial resolution of 3.5 km (ACT) x 5.6 km (ALT) in order to focus on the troposphere where concentrations of trace gas and aerosol species rapidly change. For more information on the TROPOMI instrument, see http://www.tropomi.eu/.

TROPOMI products include O_3 profile information, total and tropospheric ozone columns, total and tropospheric NO_2 columns, SO_2, HCHO, CO, CH_4, UV aerosol index, aerosol layer height, cloud fraction, albedo and cloud top pressure and UV information. For more information and related documentation, please see http://www.tropomi.eu/data-products/level-2-products.

D4.5 The Ozone Mapping and Profiler Suite (OMPS)

The Ozone Mapping and Profiler Suite (OMPS) flies on the Suomi National Polar-orbiting Partnership (Suomi NPP) and the Joint Polar Satellite System (JPSS), the new generation polar-orbiting operational environmental satellite system. JPSS is a collaborative program between the National Oceanic and Atmospheric Administration (NOAA) and its acquisition agent, National Aeronautics and Space Administration (NASA). Suomi-NPP launched on 28 October 2011. The first JPSS satellite, JPSS-1 (now named NOAA-20) launched on 18 November 2017 and JPSS-2 (NOAA-21) launched on 10 November 2022.

OMPS continues the daily global data produced by the current ozone monitoring systems, the Solar Backscatter Ultraviolet radiometer (SBUV)/2 and Total Ozone Mapping Spectrometer (TOMS), but with improved characteristics. All three instruments fly in a sun-synchronous afternoon (~13:25-13:30 ascending node) orbit. Primary products include total column ozone amount, nadir vertical ozone profile, limb vertical ozone profile, and calibrated radiances. Secondary products include an SO_2 index, aerosol information (both an index and a profile), UV-B radiance at the earth's surface, total column NO_2, surface albedo, and cloud top height.

The OMPS comprises two sensors: a nadir sensor and a limb sensor. The nadir total column spectrometer measures the scene radiance between 300 nm to 380 nm with a resolution of 1 nm sampled at 0.42 nm and a 24-hour ground revisit time. Measurements from the nadir sensor will provide total column ozone data with better than 50 km x 50 km resolution at nadir, with a 2800 km swath. The nadir profile spectrometer

measures between 250 nm and 310 nm with the same spectral sampling, in a single ground pixel of 250 km x 250 km. The limb sensor measures the along-track limb scattered solar radiance with 1 km vertical sampling in the spectral range of 290 nm to 1000 nm. Three vertical slits sample the limb at 250 km cross-track intervals to provide ~4-day ground revisit times. The three slits are imaged onto a single CCD (Charge-Couple Device). Solar irradiance measurements are made periodically. See also [DAT25].

The Earth Data Record (EDR) total column ozone data product is expected to be produced with a horizontal resolution of 50 km at nadir, with an accuracy of 15 DU or better in the range 50 DU to 650 DU. The precision is expected to be 3 DU (+0.5%) or better with a long-term stability over seven years of 1%.

The EDR ozone profile product is expected to be produced over a vertical range from the tropopause to 60 km, with a horizontal resolution of 250 km at nadir, and an accuracy of 10% in the height range 15 km – 60 km and 20% in the height range from the tropopause to 15 km. The precision is expected to be 3% in the height range 15 km – 50 km and 10% in the height range from the tropopause to 15 km and from 50 km to 60 km. The long-term stability is expected to be 2% over seven years.

More information on the OMPS data products can be found at https://www.star.nesdis.noaa.gov/portfolio/detail_OMPS.php and on the current status of operational data products, including ATBDs, at https://www.star.nesdis.noaa.gov/jpss/JPSS_products.php and links. Specifically, information on the nadir total column ozone and limb profile ozone algorithms may be found in [DAT20] and [DAT21].

D4.6 Geostationary Environment Monitoring Spectrometer (GEMS)

The Geostationary Environment Monitoring Spectrometer (GEMS) launched on 19 February 2020 and is monitoring air quality from a geostationary orbit with a spatial resolution over South Korea of 7 km x 8 km for trace gases and 3.5 km x 8 km for aerosol products every hour. The region of interest for GEMS covers East Asia, corresponding to longitudes 75° E – 145° E and latitudes of 5° S – 45° N. Its sampling spatial resolution is 3.5 × 8 km (north–south and east–west, respectively) per pixel at Seoul, with spatial and temporal co-adding depending on product category. Since GEMS is in geostationary orbit, direct comparisons with S4 will not be possible. However, S5 will have 4-5 temporally coincident orbits per day. GEMS provides a total of 16 Level 2 products, including aerosol optical depth (AOD), ozone (O_3), and trace gases in the atmosphere such as sulfur dioxide (SO_2), nitrogen dioxide (NO_2), glyoxal (CHOCHO), and formaldehyde (HCHO). The data availability and timeliness are TBC at the time of writing. For more information, see [DAT22] and [DAT23].

D4.7 Tropospheric Emissions: Monitoring of POllution (TEMPO)

The Tropospheric Emissions: Monitoring of POllution (TEMPO) instrument is a UV-visible spectrometer and is the first ever space-based instrument to monitor air pollutants hourly across the North American continent during daytime. TEMPO launched on 7 April 2023 and will collect high-resolution measurements of ozone, nitrogen dioxide and other pollutants. TEMPO is the first funded project of NASA's Earth Venture Instrument programme. As with GEMS, the orbital geometry of TEMPO mean it cannot be used for direct comparisons for S4, however, multiple orbits per day for S5 will coincide, with very close temporal alignment. The satellite is currently still in commissioning but data will be made available through the EPA's Remote Sensing Information Gateway (RSIG) https://www.epa.gov/hesc/remote-sensing-information-gateway. TEMPO Beta Level 1 (L1) data and preliminary, unvalidated Level 2 and Level 3 products are available from the ASDC via NASA Earthdata Search (Earthdata Search | Earthdata Search (nasa.gov)). For more information, see http://tempo.si.edu/index.html.

D4.8 Greenhouse Gases Observing Satellite (GOSAT)

The Greenhouse Gases Observing Satellite "IBUKI" (GOSAT) series measure the concentrations of carbon dioxide and methane, the two major greenhouse gases, from space. GOSAT launched in January 2009 and GOSAT-2 in October 2018; both instruments remain in operation at the time of writing. The third instrument in the series, GOSAT-GW, is due for launch in 2024, and will add a microwave radiometer to better constrain water vapour distribution.

GOSAT payload comprises of two instruments, a Fourier Transform Spectrometer (FTS) and a Cloud and Aerosol Imager (CAI). The two missions orbit at different altitudes (GOSAT: 666 km; GOSAT-2: 615 km), giving a smaller footprint size of 9.7 km for GOSAT-2, compared to 10.5 km on GOSAT.

The primary purpose of the GOSAT project is to estimate emissions and absorptions of the greenhouse gases on a subcontinental scale (several thousand kilometres square) more accurately and to assist environmental administration in evaluating the carbon balance of the land ecosystem and making assessments of regional emissions and absorptions. Analysis of GOSAT data is improving scientists understanding of the global distribution & temporal variation of greenhouse gases, as well as the global carbon cycle and its influence on climate. These are combined to improve predictions of future climate change and its impact.

GOSAT-2 added an additional channel to the FTS instrument, allowing it to retrieve column abundance of NO_2 and CO, in addition to the species retrieved by GOSAT (CO_2, CH_4, O_3, and H_2O). The CAI instrument retrieves cloud and aerosol properties on both platforms, though the resolution and imaging is improved on the GOSAT-2 platform.

For more information, see https://earth.esa.int/eogateway/missions/gosat and https://earth.esa.int/eogateway/missions/gosat-2.

D4.9 Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO)

The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) was launched on April 28, 2006 to study the roles of clouds and aerosols of climate and weather. It flew in the international "A-Train" constellation for coincident Earth observations until September 13, 2018 when CALIPSO began lowering its orbit from 705 km to 688 km (428 miles) above the Earth to resume formation flying with CloudSat as part of the “C-Train”. The CALIPSO satellite comprises three instruments, the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP Lidar), the Imaging Infrared Radiometer (IIR), and the Wide Field Camera (WFC). CALIPSO is a partnership between NASA and the French Space Agency, CNES. Relevant CALIPSO data products include, among others, aerosol profiles and later, cloud profiles and layers, merged aerosol and cloud layers and a vertical feature mask. For more information see https://eosweb.larc.nasa.gov/project/calipso/calipso_table.

D4.10 Earth Clouds, Aerosols and Radiation Explorer (EarthCARE)

EarthCARE in intended to advance our understanding of the role that clouds and aerosols play in reflecting incident solar radiation back into space and trapping infrared radiation emitted from the Earth's surface. The mission will employ high-performance lidar and radar technology to allow the relationship of clouds, aerosols and radiation at to be studied at accuracy levels that will significantly improve our understanding of these highly variable parameters. The payload comprises:

- The Atmospheric Lidar (ATLID) provides vertical profiles of aerosols and thin clouds. It operates at a wavelength of 355 nm and has a high-spectral resolution receiver and depolarisation channel.

- The Cloud Profiling Radar (CPR) provides vertical profiles measurements of clouds and has the capability to observe vertical velocities of cloud particles through Doppler measurements. It operates at 94 GHz.
- The Multi-Spectral Imager (MSI) provides across-track information on clouds and aerosols with channels in the visible, near infrared, shortwave- and thermal infrared.
- The Broad-Band Radiometer (BBR) provides measurements of top-of-the-atmosphere radiances and fluxes. It has one short-wave and one long-wave channel with three fixed viewing directions pointing in nadir and aft-directions.

The launch date for EarthCARE took place on 28 May 2024.

For more information see https://earth.esa.int/web/guest/missions/esa-future-missions/earthcare.

D4.11 Stratospheric Aerosol and Gas Experiment (SAGE)-III (ISS)

This instrument is on board the International Space Station in one of the science instrument slots. SAGE-III is an occulation instrument, using the sun and moon as illumination sources, and producing stratospheric profiles of aerosol, NO_2, O_3, and water vapour, up to 30 times per day. Given the lower orbit of the ISS, the overpasses are not fixed relative to the polar orbiting instruments, but does give the opportunity to sample profiles at different times of day (very useful for constraining the NO_2 diurnal cycle expected to be seen by S4). The profiles have very high vertical resolution (0.5 km) but poor horizontal resolution. The ISS orbital extent limits the geographical coverage of SAGE-III to 70°N to 70°S. Data are released approximately 3 weeks from the end of the previous month. Data and more information are available from https://asdc.larc.nasa.gov/project/SAGE%20III-ISS.

D4.12 Data from Other Sensors on MTG and EPS-SG

Data from all other sensors on MTG and EPS-SG will be available in NRT to be used in support of Cal/Val activities where required. Data of relevance to Sentinel-4/UVN and Sentinel-5/UVNS are listed below.

D4.13 MTG-I FCI and EPS-SG METimage Cloud Information

MTG-I FCI and EPS-SG METimage cloud information are used directly in Sentinel-4/UVN and Sentinel-5/UVNS Level 2 data processing, co-registered to the relevant spatial grid. In order to verify this co-registration process access to the original MTG-I FCI and EPS-SG METimage cloud information is required.

The MTG-I FCI instrument will provide information on cloud cover including scene identification (cloudy, cloud free, dust, volcanic ash, fire), cloud top height and temperature, cloud top phase, cloud top effective particle size, cloud optical depth and cloud sub-pixel fraction every 10 minutes with a 2 km spatial sampling distance at sub-satellite point. Product and format details are described in [DAT26] and [DAT27].

The EPS-SG METimage provides a cloud mask product including clear/cloudy flag, clear-sky probability, and surface type information (land/sea, snow/ice), cloud top height, cloud microphysics and cloud top pressure from METimage O_2 A-band observations. In addition, a volcanic ash flag is provided. Product and format details are described in [DAT28], [DAT29] and [DAT30].

D4.14 MTG-S IRS and EPS-SG IASI-NG Trace Gas, Temperature & Pressure Information

Collocated temperature and pressure profile information may be needed in the context of a number of validation activities. Sources of collocated temperature and pressure profile information are the MTG-S IRS and EPS-SG IASI-NG Level 2 products, Product and format details are described in [DAT31],

[DAT32], [DAT33], and [DAT34]. In the absence of validated temperature information from other sensors on MTG-S and EPS-SG, temperature analyses from ECMWF may be used. See D6 Section on page 105.

D4.15 EPS-SG 3MI Aerosol Data

The 3MI instrument on EPS-SG A will be the primary source of aerosol information for the EPS-SG mission. 3MI will produce aerosol information such as aerosol optical depth and single scattering albedo, the effective radius of particles, the aerosol layer height, the aerosol type, and the refractive index. These data will provide an important reference set for verification and validation of the Sentinel-4/UVN and Sentinel-5/UVNS aerosol products. Product and format information are described in [DAT35] and [DAT36].

D5 Data from Dedicated Measurement Campaigns

Dedicated campaigns will typically include data from many sources including balloon and aircraft-based observations. Supporting ancillary data (meteorological parameters etc.) are also required for data analysis purposes during campaign periods. Dedicated coordinated campaign activities may be planned as part of a co-ordinated activity in support of validation of satellite data. This is particularly relevant for the validation of minor trace gases where routine ground-based observations are not readily available.

In the case of Sentinel-4/UVN and Sentinel-5/UVNS, a number of campaign data needs have been identified. It is anticipated that these needs will in the first instance be met through a dedicated Announcement of Opportunity (AO) Call to be coordinated by ESA, with the support of EUMETSAT.

The anticipated needs are as follows. For Sentinel-4/UVN, several campaigns at a number of well instrumented sites within the Sentinel-4/UVN Geographical Coverage Area (GCA) spanning polluted and background conditions, overhead and slant illumination conditions, and ideally dark and bright surfaces, are required. The full latitudinal range of Sentinel-4/UVN and all seasons need to be addressed.

In each campaign, at least ~30 diurnal cycles need to be sampled by a valid set of satellite observations, reference measurements, and auxiliary data. This is necessary to capture the day-to-day variability of local emission characteristics, meteorology, photochemical regimes, aerosol load, etc. in a statistically meaningful way. Additionally, this will allow the mitigation of possibly large random errors in satellite and reference measurements of HCHO, CHOCHO, and SO_2 by data aggregation.

Airborne measurements characterizing the horizontal and vertical distribution of target species and potential directional biases are expensive and require significant coordination. Such measurements will likely need to be limited to a part of a campaign but need to sample multiple days with a complete diurnal cycle, ideally covering various conditions with different local emission characteristics, meteorology, and photochemical conditions. Such measurements are particularly important for NO_2 since it is a key air quality species with a pronounced diurnal cycle and the NO_2 satellite product is expected to be susceptible to diurnal retrieval biases, in particular for polluted conditions when mixing ratios peak near the surface.

In general, the validation data set should include cases that are as simple as possible. The radiation field and its directionality can be best characterised in cases with clear sky conditions, a very low aerosol load, and a Lambertian surface. The diurnal evolution of the pollutants (sources, sinks, photochemical processes, transport) can be best understood in cases with limited transport into the domain.

The correlative measurements required include:

- Total columns of O_3, NO_2, SO_2, and HCHO from ground-based spectrometer measurements with high frequency (1-5 minutes) sampling at selected locations (e.g. near the well-characterised sources and at reference background locations).

- Surface concentrations of O_3, NO_2, HCHO from in situ sensors measured with high frequency (1- 5-minutes) at selected locations (e.g. near the well-characterised sources and at reference background locations).
- Vertical profiles of O_3 and NO_2 from lidar or balloon borne in situ measurements, with hourly or better temporal sampling at selected locations (e.g. near the sources and at reference background locations). Profile measurements for O_3 need to resolve the free troposphere, in line with the Sentinel-4/UVN and/or Sentinel-5/UVNS retrieval sensitivity profile.
- Vertical profile information for O_3 and NO_2 from all-sky mode ground-based spectrometer measurements (e.g. Pandora). Such measurement can provide up to 2-3 pieces of information for tropospheric NO_2 and a tropospheric sub-column for O_3.
- Vertical mixing depth or planetary boundary layer depth with hourly or better temporal sampling, preferably obtained from instruments (e.g., ceilometer, SODAR) co-located with the correlative measurements.
- Local-region tropospheric column data with hourly or better temporal sampling and with high spatial resolution (~1 km) from airborne near-nadir imager spectrometers.
- Multi-directional NO_2 tropospheric column data with a variety of illumination and viewing geometries from airborne spectrometers.
- Aerosol amount, absorption, and particle size information, e.g. from ground-based sun-photometer measurements.
- Aerosol vertical distribution data from ground based lidar measurements.

Additional auxiliary data that will be required include:

- Atmospheric chemistry-transport model data that describe the diurnal evolution of sources, sinks, photochemical processes, and spatial distribution (especially the tropospheric profiles) of NO_2 and related species (including NOx, OH, and O_3).
- 1D photochemical box model data describing accurately the diurnal evolution of the NO_2 profile and related species in the stratosphere, ideally initiated with atmospheric fields from a 3D/4D chemistry-transport model.
- Estimates of the emission strength of NO and NO_2, resolving its diurnal variation
- Surface reflectance directionality (e.g., BRDF) measurements or climatology (monthly resolved map)
- Cloud fraction, optical depth, and height data from meteorological imagers, ground-based ceilometers, and ground based lidar instruments.

Stratospheric NO_2 and O_3 data from forecast or (re-)analysis of data assimilation systems. Direct observations from ground-based passive (e.g. Pandora/FTIR) or active (lidar) are also taken, when available.

Dedicated efforts are needed to validate the total column trace gas products (O_3, NO_2, SO_2, HCHO, CHOCHO) based on comprehensive reference and auxiliary data sets, including data that cannot be acquired on a long-term systematic basis (e.g. airborne measurements). For the validation of total column products using reference data from ground based remote sensing instrumentation, the following auxiliary data are needed:

- Trace gas profiles: The retrieval sensitivity decreases toward the ground due to light scattering in the atmosphere for the total column trace gas products, but especially for products with fit windows at short wavelengths (O_3 and SO_2). The handling of the sensitivity profile is an essential part of the retrieval scheme and is implemented based on the Air Mass Factor (AMF) concept. For the AMF computation, assumptions are made regarding trace gas profile shapes, and a-priori information on surface reflectance and clouds is used. For ozone, ozonesonde and lidar measurements are the preferred source of profile data. For NO_2, in-situ measurements from aircraft and balloon sondes are the preferred source of profile data. If such in-situ profile data are unavailable, profile information from atmospheric composition models or from reference ground based remote sensing instrumentation might be considered.
- Aerosol characteristics: In many operational algorithms the impact of aerosol on the AMF is accounted for implicitly, relying on cloud parameters from Level 2 products. In this case, a dedicated analysis is needed to verify the approach of treating aerosol as cloud. For this purpose, reference aerosol data from ground-based sun-photometers or from dedicated aerosol satellite instrumentation should be used.
- Surface characteristics: recent estimates for the surface reflectance and its spectrally resolved bidirectionality should be considered if available and if considered more accurate than the (typically climatological Lambertian equivalent) albedo data used in the retrievals. Effects on cloud retrievals might be particularly important.
- Cloud parameters: cloud characteristics from meteorological imagers and possibly from ground-based ceilometers should be used for cloud screening. Cloud characteristics from meteorological imagers are a good reference as input to cloud correction if not already exploited by the retrieval schemes.

Planning and coordination of campaign data will not be addressed further in this document except in so far as to identify the Cal/Val activities to which they may contribute. In case any essential campaign data are not proposed via the planned AO Call needs for a dedicated procurement will be considered. This is however pending the outcome of the AO Call.

D6 European Centre for Medium Range Weather Forecasting (ECMWF) and Copernicus Atmosphere Monitoring Service (CAMS) Analysis & Forecast Fields

The European Centre for Medium Range Weather (ECMWF) forecasting routinely provides analysis and forecast analysis and forecast fields of meteorological parameters which be retrieved from ECMWF. For further information see http://www.ecmwf.int/.

Additionally, the Copernicus Atmosphere Monitoring Service (CAMS), coordinated by the European Centre for Medium Range Weather (ECMWF) provides data records on atmospheric composition for recent years, data for monitoring present conditions and forecasts of the distribution of key constituents for a few days ahead. CAMS combines state-of-the-art atmospheric modelling with Earth observation data to provide information services covering European Air Quality, Global Atmospheric Composition, Climate, and UV and Solar Energy. For further information see http://atmosphere.copernicus.eu/

7.4 Tools

The essential baseline functionality required to support the Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val activities is a Cal/Val database infrastructure, with associated ingestion and reporting capabilities, to be developed as an evolution of capabilities existing in-house as part of the baseline EUMETSAT offline

operational environment. Additional tools and capabilities needed for the Cal/Val analysis which are also largely an evolution of existing capabilities are described below.

The tools described below provide the components of an overall framework for Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val analysis. Tools can be provided in two ways: as stand-alone tools or as software libraries intended for integration into other software e.g. the Basic Envisat Atmospheric Toolbox (BEAT), see below. Software libraries are preferred where appropriate. The mapping between these tools and actual toolbox developed/underdeveloped in-house or by external partners or existing libraries are provided in Appendix C. The linkages between these components that provide the overall framework are defined by the detailed activity descriptions provided in Appendix B. The framework is required at a minimum to provide to the user via a graphical user interface, the possibility to interactively select and subset data sources, to provide to the user a number of analysis possibilities appropriate to the data set under consideration, to provide appropriate options for image display available for each analysis method, and to allow intermediate and final results to be saved both in graphical and numerical format.

T1 Product Readers and Subset Selection

The product readers required to be implemented in the EUMETSAT offline operational environment or the EUMETSAT TCE, in support of Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val activities are listed below. It is assumed that all product readers will make data available for further analysis and display. The required subset selection capability is also described.

T1.1 Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection

Sentinel-4/UVN and Sentinel-5/UVNS Level 0, 1b and Level 2 product readers must be available within the EUMETSAT offline operational environment, and/or on the EUMETSAT TCE. The user shall be able to select any parameter (or sub-set of parameters) for extraction, within user configured limits. The limits shall be defined in terms of geographic location, measurement time, measurement mode, parameter type, or parameter value. The selected data are then made available for further analysis or visualisation.

Tool Implementation:

Tool functionality is implemented both in a SatPy Python 3 reader, which has been developed in-house (see acTeam / uvn_reader · GitLab (eumetsat.int)) and the AnaLiza toolbox, utilizing serval python packages. AnaLiza is a generic tool to inspect, analise, manipulate and plot data from a wide range of satellite missions, ground stations as well as climate records, among others. The AnaLiza tool can handle multi-format, multi-level, multi-mission data. The status and further details can be found in Appendix C.

T1.2 Calibration Key Data Readers and Display

Readers are required for the Sentinel-4/UVN and Sentinel-5/UVNS Calibration Key Data files described in [RD51] and [RD52]. Default graphical displays are to be associated with each Calibration Key Data file.

Tool Implementation:

Tool functionality is implemented in the AnaLiza toolbox, utilizing several Python 3 packages including Pandas and xarray. The status and further details can be found in Appendix C.

T1.3 Static Data Set Readers and Subset Selection

It is assumed that data set readers will be provided for all static data sets listed in Section D1 on page 90. In the absence of tools being made available by the data providers they shall be implemented on the basis of data set format specifications and included as part of the baseline functionality of the EUMETSAT offline operational environment. The user shall be able to select a subset of the static data set defined by

latitude/longitude, height or pressure, spectral region for spectral data, and in the case of trace gas climatology, the specific trace gas itself via a graphical user interface. The static data sets for which readers are required are:

- Validated Coastline Map
- High Resolution Reference Solar Irradiance Spectrum
- Trace Gas Climatology Data

Tool Implementation:

Tool functionality is implemented in the AnaLiza toolbox, utilizing several Python 3 packages like eccodes provided by ECMWF. These data are provided in GRIB1 format, so will utilize the reader detailed in T1.7. The status and further details can be found in Appendix C.

T1.4 Product Readers for Other Sensors on MTG and EPS-SG and Subset Selection

Product readers for data from all other sensors on MTG and EPS-SG must be available within the EUMETSAT offline operational environment, and/or on the EUMETSAT TCE. The user shall be able to select any parameter (or sub-set of parameters) for extraction, within user-configured limits. The limits shall be defined in terms of geographic location, measurement time, measurement mode, parameter type, or parameter value via a graphical user interface. In particular, the following Metop product readers are required.

- MTG-I FCI and EPS-SG METimage Cloud Information
- MTG-S IRS and EPS-SG IASI-NG Trace Gas, Temperature & Pressure Information
- EPS-SG 3MI Aerosol Data

Tool Implementation:

Tool functionality is implemented in the AnaLiza toolbox, utilizing several Python 3 packages including Pandas and xarray. The readers provide the ability to select a subset of the data from the input file.

T1.5 Product Readers for Operational and Experimental Level 2 Products from the AC SAF

Product readers for any operational and experimental products to be produced by the AC SAF (if applicable) must be available within the EUMETSAT offline operational environment, and/or on the EUMETSAT TCE. The user shall be able to select any parameter (or sub-set of parameters) for extraction, within user configured limits. The limits shall be defined in terms of geographic location, measurement time, measurement mode, parameter type, or parameter value via a graphical user interface.

Tool Implementation:

Tool functionality is implemented in the AnaLiza toolbox, utilizing several Python 3 packages including Pandas and xarray. An additional wrapper for reading these products in particular will be obtained directly from the AC SAF if required.

T1.6 Validation Data Product Readers and Subset Selection

It is assumed that product readers will be available for all validation data sets listed in D3 on page 91, D4 on page 97, and D6 on page 105. In the absence of tools being made available by the data providers they shall be developed on the basis of product format specifications and included as part of the baseline functionality of the EUMETSAT offline operational environment, and/or on the EUMETSAT TCE. For all validation and reference data the user shall be able to select collocated validation data, defined in terms of

one or more of latitude/longitude, time of observation, measurement mode, viewing geometry or Solar Zenith Angle. The user shall further be able to select any parameter (or sub-set of parameters) from the validation data set for extraction, within a specified range defined by user configured limits via a graphical user interface. The selected data are then made available for further analysis or visualisation. Product readers for the following data sets are to be provided:

- Data from Ground-based Sensors from the following ground-based networks
  - The World Meteorological Global Atmosphere Watch Program (GAW)
  - The Network for the Detection of Atmospheric Composition Change (NDACC)
  - The Aerosol Robotic Network (AERONET)
  - The Pandonia Global network (PGN)
  - The Tropospheric Ozone Lidar Network (TOLNet)
  - The European Aerosol Research Lidar Network (EARLINET)
  - The NASA Micro-Pulse Lidar Network (MPLNET)
  - The Asian Dust and aerosol lidar observation NETwork (AD-Net)
  - The Network for Observation of Volcanic and Atmospheric Change (NOVAC)
  - The Aerosol, Clouds and Trace Gases Research Infrastructure (ACTRIS)
  - D3.11
- Data from Satellite-based Sensors
  - Total and Solar Spectral Irradiance Sensor (TSIS): Spectral Solar Irradiance Data
  - The Global Ozone Monitoring Experiment (GOME-2) on MetOp
  - The Infrared Atmospheric Sounding Interferometer (IASI) on MetOp
  - The Sentinel-5/UVNS Precursor TROPOspheric Monitoring Instrument (TROPOMI)
  - The Ozone Mapping and Profiler Suite (OMPS)
  - Geostationary Environment Monitoring Spectrometer (GEMS)
  - Tropospheric Emissions: Monitoring of POllution (TEMPO)
  - Greenhouse Gases Observing Satellite (GOSAT)
  - Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO)
  - Earth Clouds, Aerosols and Radiation Explorer (EarthCARE)
  - Stratospheric Aerosol and Gas Experiment (SAGE)-III (ISS)
  - Data from Other Sensors on MTG and EPS-SG
- Data from Dedicated Measurement Campaigns
  - Currently anticipated in the context of a dedicated AO Call in support of Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val activities. Product readers and data subset selection capability will be

required as for other validation data and are expected to be available through the campaign activities themselves.

Tool Implementation:

Tool functionality is implemented in the AnaLiza toolbox, utilizing several Python 3 packages including Pandas and xarray. Meantime, the Basic Envisat Toolbox (BEAT) which supports both GOME-2 and Sentinel-5P, is available to the user community (http://www.science-and-technology.nl/beat/).

Dataset readers are available separately (from the data provider or from T1.7) and are integrated within the MONitoring of Atmospheric L2 SAtellite products (MONALiSA) tool.

T1.7 Grib and BUFR Readers

Readers are required for analysis and forecast fields produced by the ECMWF Integrated Forecast System (IFS) and CAMS Chemical Data Assimilation system, stored in GRIB format. BUFR readers are also required to read observation data files used within the ECMWF IFS.

Tool Implementation:

Tool functionality is implemented in both the AnaLiza toolbox, utilizing the eccodes python package and the Metview Meteorological data manipulation and visualisation package available from ECMWF (for further details see Section T13).

T2 Orbit Prediction Tool

Orbit prediction tools are expected to be available via the MTG and EPS-SG Flight Dynamics Function. Also, an orbit propagation tool is required within the EUMETSAT offline operational environment, and/or on the EUMETSAT TCE, for the prediction of observation/overpass times to allow the timing of additional collocated validation measurements to be accurately planned. The tool can also be used to calculate actual orbits on the basis of restituted orbit parameters, rather than the predicted orbit parameters used in the operational 0 to 1 processing.

An obvious choice for EPS-SG and MTG is the Earth Observation Mission CFI software available from ESA. For further information see https://eop-cfi.esa.int/index.php/mission-cfi-software/eocfi-software.

Tool Implementation:

Tool functionality is implemented in the EO-CFI (Earth Observation Mission CFI) Software, which is available from ESA.

T3 Collocation Tool

An automatic tool for selecting collocated validation data via a graphical user interface from a user selected validation data set shall be available within the EUMETSAT offline operational environment, and/or on the EUMETSAT TCE. At a minimum the User shall be able to specify the validation data set from which the collocated data are to be selected, and the collocation criteria expressed at a minimum in terms of latitude/longitude and observation time, with the additional options of specifying measurement mode, viewing angle and Solar Zenith Angle where appropriate. For spectral data selection of an appropriate spectral range shall is also required. The spatial collocation criteria shall be expressed either in geodetic latitude and geocentric longitude, or in km. It shall be possible to retrieve the distance between two data points in km on the basis of geodetic latitude and geocentric longitude coordinates.

Tool Implementation:

Tool functionality is implemented in both the MONALiSA tool and AnaLiza toolbox. It is evolved to cover all needed ground-based data.

T4 Normalisation of Solar Spectra

A generic tool is required to allow normalisation of solar spectra to a solar distance of 1AU as specified as specified in [RD13] and [RD14].

Tool Implementation:

Tool functionality is implemented in SpecFUN (Spectral Calibration Framework Utilising Numerics) toolbox as specified in [RD13] and [RD14]. The status and details can be found in the Appendix C.

T5 Simple Mathematical Functions

All simple mathematical functions are assumed to be available within the EUMETSAT offline operational environment, and/or on the EUMETSAT TCE. These include but are not restricted to addition, subtraction, multiplication, division, array manipulation capabilities, trigonometric functions etc. Furthermore, they are expected to be available both via standard software compilers and via a graphical user interface which provides a link to the data to be manipulated.

Tool Implementation:
Tool functionality is implemented in AnaLiza toolbox, utilizing the NumPy python package.

T6 Statistical Analysis Tools

T6.1 Perform statistical analysis on time series

The elements for the statistical analysis which have to be available for the analysis of monitoring data are described here.

Frequently, the parameter to be analysed is not a scalar (e.g., temperature), but a one-dimensional or two-dimensional array (e.g., signal values, leakage currents, pixel-to-pixel gain values), i.e., there is a time series for each element of the array. The analysis tool shall be able to handle these cases by performing the analysis described below per element of the input array, giving an array of the same shape (number of elements and dimensions) on output[1].

BASIC STATISTICS

Given a series of non-binary parameters p_n (anything except flags and counters from the storage location, e.g. temperatures, voltages, signal values, leakage currents) with associated time stamps t_n ($n = 0,\ldots, N–1$), the analysis tool shall be able to calculate its

- mean value

$$\bar{p} = \frac{1}{N}\sum_n p_n$$

- standard deviation

[1]This concept is called “elemental function reference” in Fortran-90.

$$\text{stddev}(p) = \sqrt{\frac{1}{N-1}\sum_n (p_n - \bar{p})^2}$$

- minimum value min(p),
- maximum value max(p)
- out-lying points greater than a user configurable number of standard deviation from the mean.

MODELLING THE TIME SERIES

Least-squares fitting routines shall be provided for the analysis of the time series, as a minimum:

- Linear fit of a polynomial function of order M with M+1 coefficients c_m (this includes as a special case $M = 1$, the determination of a linear trend):

$$\sum_{n=0}^{N-1}\left(\sum_{m=0}^{M} c_m (t_n - t_0)^m - p_n\right)^2 \stackrel{!}{=} \min$$

- Linear fit of periodic function with linear fit parameters C_0 and C_1:

$$\sum_{n=0}^{N-1} (C_0 \sin(2\pi(t_n - t_0)/T) + C_1 \cos(2\pi(t_n - t_0)/T) - p_n)^2 \stackrel{!}{=} \min$$

  where the amplitude c_0 and the phase c_1 can be reconstructed as:

$$c_0 = \sqrt{C_0^2 + C_0^2}$$

  and

$$c_1 = \text{atan}(C_1/C_0)$$

  The periodicity T shall not be a fit parameter but selectable by the user, e.g., one orbit, one year (see below).

- Non-linear fit of exponential function (value at t=t_0: c_0, 1/e decay time: c_1):

$$\sum_{n=0}^{N-1} (c_0 e^{-(t_n - t_0)/c_1} - p_n)^2 \stackrel{!}{=} \min$$

For the linear fits, functions similar to the singular value decomposition and back substitution functions from [NUM2] should be employed. For the non-linear fits, functions similar to the Levenberg-Marquardt routines from [NUM2] should be employed. When the particular function to be fitted is not indicated, the understanding is that the operator of the analysis tool chooses and optimises this function according to the observed temporal behaviour of a given parameter. Therefore, the function to be fitted shall not be hard coded per parameter, but selectable by the operator.

Tool Implementation:

Tool functionality is implemented in AnaLiza toolbox, utilizing the NumPy python package.

T7 Interpolation Tools (Linear, Spline and Akima)

Interpolation tools, including linear, spline and Akima shall be available within the EUMETSAT offline operational environment, and/or on the EUMETSAT TCE. Detailed specifications are provided in [NUM1] and [NUM2].

Tool Implementation:
Tool functionality is implemented in AnaLiza toolbox, utilizing the SciPy python package.

T8 Convolution Tool

A tool for calculating the convolution of a spectrum with a known spectral response function is required. Similarly, a tool for calculating the convolution of a vertical profile with a response function describing vertical resolution is also required. An implementation such as that described in [NUM2] shall be included in the EUMETSAT offline operational environment, and/or the EUMETSAT TCE.

Tool Implementation:
Tool functionality is implemented in AnaLiza toolbox, utilizing the NumPy python package.

T9 Correlation Tool

A general tool for calculating the correlation coefficient between a number of pairs of quantities shall be available within the EUMETSAT offline operational environment, and/or on the EUMETSAT TCE. The tool shall include at a minimum linear correlation, and non-parametric correlation and shall be implemented as described in [NUM2] shall be included in the EUMETSAT offline operational environment, and/or the EUMETSAT TCE.

Tool Implementation:
Tool functionality is implemented in AnaLiza toolbox, utilizing the NumPy python package.

T10 Spectral Calibration Tool

A spectral calibration algorithm based on cross-correlation of Fraunhofer lines in the measured solar spectra, or backscattered earthshine spectra, with Fraunhofer lines in a high-resolution reference solar spectrum is to be implemented in the EUMETSAT offline operational environment, and/or on the EUMETSAT TCE. The tool is required to perform spectral calibration of science data, thereby converting detector pixel numbers into the corresponding wavelengths & assigning a wavelength to each detector pixel. The algorithm is specified in [RD13] and [RD14].

Tool Implementation:

Tool functionality is implemented in SpecFun toolbox as specified in [RD13] and [RD14].

T11 Image Display Tools

A number of generic image display tools are expected to be available within the EUMETSAT offline operational environment, and/or on the EUMETSAT TCE. In all cases the following basic functionality is expected: overlay of plots, point colour and style selection, line colour and style selection, zoom capability, annotation capability, option to dump the data to an ASCII file, interactive examination of values via a moving cursor. In particular the following are required, spectral plots, scatter plots, profile plots, time series

display, mapping facilities and three-dimensional fields including selected cross-sections. Default associations are expected to be available for each data type or file. Interactive selection is required rather than hard coded plots.

Tool Implementation:

Tool functionality is implemented in AnaLiza toolbox, utilizing the MatPlotLib and CartoPy python package and Metview package.

T12 Image Matching Tool

An image matching tool that is capable of matching features such as coast line and other temporally persistent spatial patterns, in high spatial resolution imager data such as MTG-I FCI and EPS-SG METimage, with equivalent features in Sentinel-4/UVN and Sentinel-5/UVNS. The higher spatial resolution imager data are sampled on the coarser spatial resolution spectrometer grid, repeatedly, with varying spatial offset to provide an estimate of geolocation information accuracy. The best estimate of offsets is obtained by optimizing the matching of images.

Tool Implementation:

Tool functionality is implemented in Sentinel-4 and Sentinel-5 PIQMICS toolbox, developed in-house at EUMETSAT by the INRC Competence Area.

For EPS-SG, the following PIQMICS modules are required:

• IDEAL (IndepenDEnt AbsoLute) module: measurement of the absolute geometric accuracy (i.e. the difference between geolocation in the product and true geolocation)
  • IDEAL-PGSP: Applying Principle Component Analysis (PCA), Gaussian Mixture Model (GMM) thresholding, Shi-Tomasi Feature tracking (STF), and Phase Cross Correlation (PCC). Comparison is done vs. a land-sea-mask.

• IRAT (Image Registration Analysis) module:
  • IRAT-PGSP: Co-registration using the PGSP approach, where one band or fraction of the spectrum is used as “reference image” and a second one as “target image”.

• CHART

• REP Jupyter notebooks for analysis and visualization
  • jupyter notebooks that are designed to visualize results of PIQMICS tools. They allow for evaluating the processing performance and provide the basis of the Test Report.

The EPS-SG PIQMICS prototype is a framework that will run the steps needed to process the data as needed to assess the geolocation, store results in a database and make results available through visualization and reporting.

T13 Metview

The interactive package “Metview”, which allows access, manipulation, and visualisation of meteorological data is integrated within the EUMETSAT offline operational environment and on the EUMETSAT TCE. Metview is a cooperative project between ECMWF and INPE/CPTEC, Brazil. In additional to being used on a number of other Unix platforms, Metview has recently been ported to Linux.

Metview is also installed within the Operations Department at ECMWF. All ECMWF archive data are available through the Metview interface. For further information, see https://metview.readthedocs.io/en/latest/.

Tool Implementation:

Tool functionality is implemented as 'Metview' Python package (see https://github.com/ecmwf/metview-python), which is used by T1.7 and T11.

T14 Radiative Transfer Models

T14.1 Scalar Radiative Transfer Model

A multiple scattering pseudo-spherical (or spherical) Radiative Transfer Model is needed within the EUMETSAT offline operational environment, and/or on the EUMETSAT TCE, to support Sentinel-4/UVN and Sentinel-5/UVNS Level 1 product verification and validation activities. One choice is the LInearized Discrete Ordinate Radiative Transfer model (LIDORT) developed by Dr. R. Spurr of the Harvard Smithsonian Observatory. This model has been used extensively within the AC SAF Level 2 processing development chains. Furthermore, significant development work has been carried out to improve the applicability of LIDORT to these applications under the Atmospheric Composition Monitoring SAF (AC SAF) Visiting Scientist Program.

One point worthy of note is that LIDORT is called as a subroutine within an environment specified by the user. There are no internal data sets and no atmospheric climatologies. For any given application, the user must construct an atmospheric preparation module to set up the necessary inputs required by the model, the most important being the vertical optical depths and layer single-scatter albedos, along with their sensitivities to the atmospheric parameters for which weighting functions are to be calculated. For more information on LIDORT, see [SCD8] & [SCD9].

Tool Implementation:

Tool functionality is implemented in MICMICS for Sentinel-4 and Sentinel-5, developed in-house at EUMETSAT by the INRC Competence Area.

T14.2 Vector Radiative Transfer Model

Scalar radiative transfer models are normally used for radiation transfer calculations in the UV and visible due to the complexity and intensive computational demands of a fully vector model. However, it may be necessary for some activities to use a vector RTM. An appropriate choice is V-LIDORT - the vector version of the LIDORT radiative transfer model described above [SCD10]

Tool Implementation:

Tool functionality is implemented in MICMICS for Sentinel-4 and Sentinel-5, developed in-house at EUMETSAT by the INRC Competence Area.

T15 MICMICS Vicarious calibration and Inter-Calibration

Several vicarious calibration and inter-calibration systems deployed within MICMICS will be used to estimate the radiometric calibration of Sentinel-4 and Sentinel-5. These include Desert Absolute Calibration (DESCS), Desert Inter-Calibration System (DESICS), Deep Convective Clouds (DCC) inter-calibration, and lunar calibration. These systems will validate the absolute and relative radiometric accuracy of UVN and UVNS instruments. However, some calibration systems may not be applicable due to the spatial or spectral coverage of these instruments.

T15.1 DESert Calibration (DESCS) and Inter-Calibration systems (DESICS)

Desert calibration systems leverage well-characterized, bright desert targets, primarily located in the Arabian Peninsula and the Sahara Desert, to simulate top-of-atmosphere (TOA) radiance and reflectance for comparison with satellite measurements. These targets are temporally and spectrally stable, making them ideal for monitoring the reflective solar bands of spaceborne instruments once their reflectance properties are well established.
The calibration model incorporates input parameters from both the surface and the atmosphere. Surface modeling is based on a modified four-parameter version of the RPV BRDF model, with spectrally resolved BRDF parameters derived from the latest BRDF study delivery (V064). For atmospheric inputs, the model employs the US Standard Atmosphere profile, scaled with H_2O and O_3 columns, as well as atmospheric parameters and an aerosol model specifically developed for the Sahara region as part of the BRDF study.
The MICMICS desert calibration and intercalibration systems are applicable across the reflective portion of the solar spectrum, ranging from 350 nm to 2500 nm, constrained by the spectral range of the surface BRDF model and RTM. These systems enable the validation of absolute calibration accuracy and facilitate long-term drift monitoring of satellite instruments. DESCS and DESICS, it is not applicable to UVN instruments due to spatial coverage limitations, as most DCCs form over the equatorial belt, which is not covered.

T15.2 Deep Convective Clouds Inter-Calibration System (DCCICS)

DCC Inter-Calibration leverages Deep Convective Clouds (DCC) to transfer calibration from a reference instrument (NOAA-20 VIIRS, as provided by NASA) to a monitored instrument. The key assumption is that, under specific geometric conditions, DCCs act as pseudo-invariant targets. In these conditions, they behave like Lambertian diffusers, ensuring that the signal above them remains stable over space and time. Consequently, contemporaneous observations between the monitored and reference instruments are unnecessary.
DCCs are identified over the equatorial belt based on their cold temperatures (below 205 K) at around 11 µm. Since Sentinel-4 and Sentinel-5 lack IR channels, alternative data sources (e.g., METimage IR channels) will be used to detect DCCs. Identified scenes undergo additional filtering based on geometric and homogeneity criteria in both the IR and reflective solar spectrum. This process removes cloud anvils and isolates geometries where DCC tops exhibit near-perfect Lambertian diffusion with a highly uniform signal.
Subsequently, data is accumulated over 30 days, centered around the reference instrument's overpass time. The resulting distribution is corrected for an equivalent overhead sun and Sun-Earth distance. The characteristic DCC top-of-atmosphere signal is then determined by extracting the mode of the distribution.
Currently, the MICMICS DCCICS is deployed exclusively for instrument drift monitoring. However, it is not applicable to UVN instruments due to spatial coverage limitations, as most DCCs form over the equatorial belt, which is not covered.

T15.3 Lunar Calibration System

The spectral range of applicability of the EUMETSAT MICMICS Lunar Calibration System (LCS) covers the reflective part of the solar spectrum, between 250nm and 2600nm, so that it can

support multi-mission vicarious calibration activities for the imaging radiometers operated by EUMETSAT. MICMICS LCS has two components:

- The GSICS Implementation of the ROLO model (GIRO) (between 350 and 2250nm)
- The Lunar Extended Simulation Reflectance Model (LESSR) (between 250 and 2600nm)

T15.3.1 GIRO

The GIRO has been implemented by EUMETSAT within the context of an international collaboration between EUMETSAT, USGS, CNES and NASA within the GSICS and IVOS community. Within that community, GIRO serves a reference model for lunar calibration. As indicated by its name, the GSICS Implementation of the ROLO model is a reference implementation of the USGS ROLO model. EUMETSAT operates GIRO within its MICMICS infrastructure.

The lunar model has been inferred from an extensive database of radiance images acquired by the ground-based RObotic Lunar Observatory (ROLO), located at the USGS Science Center in Flagstaff, Arizona. ROLO observed the Moon on clear nights between First Quarter and Last Quarter lunar phases for over 6 years. Twin telescopes on a common mount cover the Visible and Near-infrared (VNIR) range (350-950 nm) in 23 bands, and the shortwave infrared (SWIR - 950-2350 nm) in 9 bands. Substantial observing time was dedicated to imaging stars, for the purpose of determining atmospheric extinction corrections. Calibration to radiance is based on measurements of the star Vega, although efforts to tie the ROLO data to the SI radiometric scale are ongoing, involving the radiometry group at NIST. The ROLO database contains over 85,000 individual lunar images, and several hundred thousand star images. The USGS lunar irradiance model was developed from fitting ROLO observational data that have been calibrated to exo-atmospheric radiance and spatially integrated over the entire lunar disk, regardless of the illuminated fraction. The model analytic form was determined empirically through study of the fit residuals, with the goal of reducing correlations seen in the residuals.

The lunar irradiance model fits the ROLO observational data with an average residual over all bands of just under 1%. This value constitutes a measure of the model precision with which the model can predict the variations in lunar irradiance due to view geometry, including phase, libration, and the lunar photometric function, over the useful range of the geometric variables. These range in phase from 90 degrees (before and after Full Moon) to near-eclipse (~1.5 degrees), and virtually all libration angles viewable from the Earth's surface.

T15.3.2 LESSR

The EUMETSAT LESSR model employs a combination of in-flight SCIAMACHY measurements and on ground RELAB laboratory measurements. The model benefits from the most advanced calibration of the SCIAMACHY lunar dataset provided by ESA. Its formulation differs from the GIRO model as new base functions were implemented to improve the overall accuracy of the simulated lunar reflectance. The LESSSR model complements the GIRO model as a new asset in the EUMETSAT MICMICS infrastructure.

The LESSSR model describes the disk-equivalent lunar reflectance between 250nm and 2600nm with a spectral resolution of 5nm, for a lunar phase range between -80 and 20 degrees, which is the lunar observational range for SCIAMACHY. The applicability range of lunar phases is

foreseen to be further extended beyond 30 degrees by including GOME-2 lunar measurements in the mix of observations used for inferring the lunar reflectance model parameters.

The model accuracy is estimated to be about 2% in absolute. It has been used to inter-calibrate the GOME-2 series aboard the Metop satellites with SCIAMACHY as part of a collaboration between EUMETSAT and ESA, to support the ESA's FDR4ATMOS project.

Tool Implementation:
All T15 tool functionality is implemented in the MICMICS monitoring system, developed in-house at EUMETSAT by the INRC Competence Area.

T16 Report Generation Tools

Automatic report generation tools will be required within the EUMETSAT offline operational environment, and/or on the EUMETSAT TCE. Reports will be separated into the following three categories:

- Reporting Instrument Monitoring Activities (A4.5)
- Reporting Level 1 Verification, Confidence Checking and Validation Activities (A5.7)
- Reporting Geophysical Parameter Verification and Validation Activities (A6.7)

A brief summary of the expected content of the reports is given in Section 6.2.1.5 on page 63, Section 6.2.2.7 on page 72, and Section 6.2.3.7 on 85.

Tool Implementation:

Tool functionality is implemented in CHART, UVN-STAR/UVNS-STAR, AnaLiza and MONALiSA toolbox.

8 RESONSIBILITIES AND STAFFING

8.1 Responsibilities

For a description of the responsibilities during the LEOP and Commissioning phases see the MTG System Commissioning Plan [SCP], EUM/MTG/PLN/11/0203 [AD1], the MTG LEOP and Commissioning Support Plan [LCSP], EUM/MTG/PLN/19/1075627 [RD5], and the ESA Sentinel-4 System Commissioning Plan, S4-ESA-SY-PL-0790 [RD57] for Sentinel-4/UVN, and the EPS-SG LEOP and Commissioning Management Plan (LCMP), EUM/LEO-EPSSG/PLN/18/1031948 [RD6] and the ESA Sentinel-5 Commissioning and Calibration/Validation Plan, S5-PL-ESA-SYS-0466 [RD58] for Sentinel-5/UVNS.

During routine operations the EUMETSAT is fully responsible for the in-orbit calibration, verification and validation of the Sentinel-4/UVN and Sentinel-5/UVNS Level 0, Level 1b and Level 2 data products. Activities required for routine operations will also begin during the commissioning phase and will contribute to the commissioning activities.

8.2 Structure of the Teams for the Cal/Val Activities

To be addressed within the MTG System Commissioning Plan [SCP], EUM/MTG/PLN/11/0203 [AD1] and the EPS-SG Programme Overall Calibration and Validation Plan, EUM/LEO-EPSSG/PLN/14/758341[AD2].

8.3 Training

To be addressed within the MTG System Commissioning Plan [SCP], EUM/MTG/PLN/11/0203 [AD1] and the EPS-SG Programme Overall Calibration and Validation Plan, EUM/LEO-EPSSG/PLN/14/758341[AD2].

9 LOGIC AND PLANNING

9.1 Planning and Logic of Pre-Launch Activities

Further definition of Cal/Val activities and procedures, resulting from refinement of this Plan through appropriate review cycles, will be carried out in parallel to the pre-launch Cal/Val activities discussed below. Iteration will therefore be required to achieve consistency between further evolution in the definition of Cal/Val activities and procedures, and the on-going pre-launch activities.

9.1.1 Acquisition of Cal/Val Data Sets

The first task in the acquisition of Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val data sets is the negotiation of data access for all data sets listed in in support of Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val activities in Section 7.3. It is assumed that product format descriptions will be available for all validation data sets. Once data access has been agreed, the product format descriptions must be acquired to facilitate the development of validation data set product readers, discussed below and in Section 7.4. Finally, data transfer mechanisms must be determined for each data set and subsequently tested. These activities will be further addressed within the EPS-SG Programme Overall Calibration and Validation Plan, EUM/LEO-EPSSG/PLN/14/758341 [AD2].

9.1.2 Acquisition of Cal/Val Tools

The discussion provided below focuses on the component tools required in support of Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val activities, listed in Section 7.4. Related activities will be further addressed within the MTG System Commissioning Plan [AD1] and EPS-SG Programme Overall Calibration and Validation Plan, EUM/LEO-EPSSG/PLN/14/758341 [AD2].

9.1.2.1 External Procurements from Third Party Developers

Both scalar radiative transfer models and vector radiative transfer models have been developed within the scientific community for research and scientific purposes. (V-)LIDORT are available within the EUMETSAT TCE from previous procurements however some further in-house prototyping is required to provide the user environment in which the software will be run.

9.1.2.2 Tools Expected to be Available within the EUMETSAT offline operational environment or the EUMETSAT TCE.

The following tools are expected to be available as part of the baseline configuration of the EUMETSAT offline operational environment and/or on the EUMETSAT TCE.

- Product Readers and Subset Selection
  - Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection
  - Calibration Key Data Readers and Display
  - Static Data Set Readers and Subset Selection
  - Product Readers for Other Sensors on MTG and EPS-SG and Subset Selection
  - Product Readers for Operational and Experimental Level 2 Products from the AC SAF
  - Validation Data Product Readers and Subset Selection
  - Grib and BUFR Readers

- Orbit Prediction Tool
- Collocation Tool
- Normalisation of Solar Spectra
- Simple Mathematical Functions
- Statistical Analysis Tools
- Interpolation Tools (Linear, Spline and Akima)
- Convolution Tool
- Correlation Tool
- Spectral Calibration Tool
- Image Display Tools
- Metview
- User environment for the Scalar Radiative Transfer Model
- User environment for the Vector Radiative Transfer Model
- Report Generation Tools

9.2 Planning and Logic of Commissioning Phase Activities

Commissioning phase activities will begin with Sentinel-4/UVN and Sentinel-5/UVNS In-Orbit Verification (IOV) under the responsibility of ESA/ESTEC as discussed in [AD1] and [AD2]. Sentinel-4/UVN and Sentinel-5/UVNS IOV is expected to have a duration of 6 months [RD57] and 3 months [RD58] starting at launch respectively, and will be concluded by a Sentinel-4/UVN and Sentinel-5/UVNS IOV Review. It is assumed that at the conclusion of a successful IOV review, nominal Sentinel-4/UVN and Sentinel-5/UVNS instrument functioning and performance will have been achieved. This is a necessary prerequisite for the start of Cal/Val activities.

The objective of Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val activities is to achieve the following by the time of the Commissioning Phase hand-over review:

- nominal instrument functioning and performance, as demonstrated by a successful Sentinel-4/UVN and/or Sentinel-5/UVNS IOV review and subsequently monitored throughout Commissioning Phase by dedicated instrument monitoring activities
- nominal Level 1 and Level 2 product quality and performance including, geolocation parameters, wavelength calibration parameters, Average Solar Irradiance spectra, and Level 1b Earthshine spectra, and ideally all geophysical products
- nominal product quality for geophysical parameters retrieved within the EUMETSAT offline operational environment, and/or on the EUMETSAT TCE, in support of Level 1 product verification and validation

Further details on the phasing and logic of activities required to meet these objectives is given below.

9.2.1 Instrument Monitoring (A4)

Sentinel-4/UVN and Sentinel-5/UVNS instrument monitoring activities will start during IOV and continue for the lifetime of the mission. One objective of the instrument monitoring activities is to ensure that any deviations from nominal instrument function and performance, throughout the mission lifetime, are detected and reported, and appropriate action taken. In the case of non-nominal behaviour, requirements for corrective action will be analysed on a case-by-case basis. A second objective is the monitoring and diagnosis of in-orbit instrument degradation. It is expected that monitoring activities will periodically lead to the generation of degradation correction factors to be provided to the Sentinel-4/UVN and Sentinel-5/UVNS product processing facilities for use in Sentinel-4/UVN and Sentinel-5/UVNS product processing. Whilst instrument monitoring is carried out on a continuous basis, analysis of monitoring data to assess long term changes requires accumulation of data for a period of a minimum of one month and will require the intervention of a knowledgeable operator. The analysis required for the generation of degradation correction factors is expected to be significant.

9.2.2 Level 1 Product Verification, Confidence Checking and Validation (A5)

Level 1 Verification, Confidence Checking and Validation activities will start at the completion of a successful Sentinel-4/UVN or Sentinel-5/UVNS IOV review. Activities will begin with the Verification and Validation of Geolocation Information (A5.1) and the Validation of Geolocation Information for Earth Measurements (Sentinel-5/UVNS) (A5.1.4). These activities will be carried out in parallel. Successful demonstration of nominal geolocation and wavelength calibration quality is a prerequisite for the remaining Level 1 Verification, Confidence Checking and Validation activities.

Activities related to Verification of Straylight Performance (A5.3), Verification of the Goniometry of the Solar Diffuser (A5.4), Validation of the Average Solar Irradiance Spectrum (A5.5), and Preliminary Validation of Earthshine Radiance Spectra and Albedo (A5.6) will also be carried out in parallel as significant feedback between activities is expected. The aim is to achieve nominal product quality for all Level 1 parameters by the time of Commissioning Phase hand-over review. However, the following points are of note.

- As the duration of Commissioning Phase is anticipated to be less than one year, geophysical products will at best be verified and partly validated at the time of a Commissioning Phase hand-over review. A full year, after successful Sentinel-4/UVN or Sentinel-5/UVNS IOV, is required to validate data for all seasons and latitudes.
- Furthermore, due to the difficulties in directly validating the Sentinel-4/UVN or Sentinel-5/UVNS Level 1b radiance product, as previously discussed in 6.2.2, an assessment of the quality of Level 1b Earthshine radiance data will be based not only on the outcome of the Preliminary Validation of Earthshine Radiance Spectra and Albedo (A5.6), but also implicitly on the outcome of the Geophysical Parameter Verification and Validation (A6). Feedback from the verification and validation of the operational Level 2 products will also be taken into account.
- It is possible that not all Sentinel-4/UVN or Sentinel-5/UVNS Level 1 products will be verified and validated at the Commissioning Phase hand-over review. In this case, Sentinel-4/UVN or Sentinel-5/UVNS will be considered partially commissioned.

9.2.3 Geophysical Parameter Verification and Validation (A6)

Geophysical Parameter Verification and Validation (A6) activities will start at the completion of successful Verification and Validation of Geolocation Information (A5.1) and Validation of Geolocation Information

for Earth Measurements (Sentinel-5/UVNS) (A5.1.4). However, as significant feedback is expected between the Geophysical Parameter Verification and Validation (A6) activities and the Preliminary Validation of Earthshine Radiance Spectra and Albedo (A5.6) these activities will be carried out in parallel. The aim is to achieve nominal product quality, as defined by the Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017, Sentinel-4 Level-2 Processor Requirements Specification, S4.ESA.UVN.RS.0093, Issue 2, Revision 1, 27/11/2018, and Sentinel-5 Level-2 Prototype Processor Development Requirements Specification, S5-RS-ESA-GR-0131, Issue 1, Revision 8, 15 July 2019 by the time of the Commissioning Phase hand-over review, and thereby provide an implicit statement on the quality of Sentinel-4/UVN and Sentinel-5/UVNS Level 1b data products. However, it is noted again that as Commissioning Phase is anticipated to be less than one year, products will at best be verified and partly validated at this time.

9.3 Planning and Logic of Routine Operational Activities

Routine Operations for Sentinel-4/UVN or Sentinel-5/UVNS begin at the conclusion of a successful Commissioning Phase hand-over review. It is assumed that nominal product quality, for all Sentinel-4/UVN and Sentinel-5/UVNS Level 1b and Level 2 products will have been achieved by this time. However, it is acknowledged that it is possible that the Sentinel-4/UVN or Sentinel-5/UVNS products will be partially validated and that there is there may be the hand-over of a partially commissioned system. Taking this into account, routine operations will continue the validation activities started during commissioning phase, with the objective of achieving a full validation of all Sentinel-4/UVN or Sentinel-5/UVNS Level 1 and Level 2 products within a time period of one year after a successful Sentinel-4/UVN or Sentinel-5/UVNS IOV. Continued verification and validation activities after this time, are expected to lead to improvements to product processing algorithms and product quality, and to ensure the provision of a consistent long-term data record. Analysis of these continued verification and validation activities is also expected to provide supporting information for the assessment of Sentinel-4/UVN or Sentinel-5/UVNS in-orbit instrument degradation, carried out as part of the on-going instrument monitoring activities that continue throughout Routine Operations.

It can be expected that correction of Sentinel-4/UVN or Sentinel-5/UVNS in-orbit instrument degradation will periodically require a reprocessing of the complete data set during routine operations to ensure the consistency of the long-term data record.

9.4 Announcement of Opportunity

Some of the tasks to be performed in this Cal/Val Plan are expected to be implemented using an Announcement of Opportunity (AO) Call whereby ESA and EUMETSAT invite interested groups to participate in carrying out the activities in the plan. The AO's contributions to fulfilling the Cal/Val Plan will depend not only on number and quality of the responses to the AO but on the ability of the respondents to obtain funding from national and international sources. Scientists/institutes whose AO proposals are accepted would be expected to participate in some, or all, of the following activities:

- Integration of their proposed work within a wider scientific and technical framework, and the establishment of collaboration between specialists.
- Participation in detailed pre-launch validation planning, specifically as relevant to the planning and execution of AO activities.
- Participation in post launch data product and retrieval algorithm validation, and monitoring of satellite performance and data quality for the duration of the AO activities.

- Support to the planning and execution of special satellite operations as needed and agreed for specific AO activities e.g. in conjunction with ground experiments.
- Reporting on progress in dedicated meetings and workshops.

Scientists/institutes whose AO proposals have been accepted would be regarded as Expert Users (Sentinel-4/UVN) or Specialist Users (Sentinel-5/UVNS). See [AD8] and [AD9] for further details related to data access and dissemination.

Letters of support for successful proposals seeking funding from national or international agencies, can typically be provided on request.

The activities carried out under the AO will supplement the mission critical and routine calibration and validation activities to be carried out by EUMETSAT and/or ESA as agreed.

The joint AO call is expected to be released 12-18 months prior to the earlier of the launch dates between Sentinel-4/UVN and Sentinel-5/UVNS. The evaluation, negotiation and acceptance of the AO proposals is expected to be completed 6-12 months prior to the earlier of the launch dates between S4 and S5. Regular Cal/Val reviews/workshops will be organised by ESA and EUMETSAT prior to launch and during commissioning.

APPENDIX A ABBREVIATIONS AND ACRONYMS

3MI	Multi-viewing Multi-channel Multi-polarisation Imager
AAI	Absorbing Aerosol Index
AC	Atmospheric Composition
AC-VC	Atmospheric Composition Virtual Constellation
ACT	Across Track
ACTRIS	European Research Infrastructure for the Observation of Aerosol, Clouds and Trace Gases
AD-Net	Asian Dust and aerosol lidar observation Network
ADS	Auxiliary Data Set
AERONET	AErosol RObotic NETwork
AIRS	Atmospheric Infra-Red Sounder
ALH	Aerosol Layer Height
ALT	Along Track
AO	Announcement of Opportunity
AOD	Aerosol Optical Depth
ARA	Absolute Radiometric Accuracy
ARM	Atmospheric Radiation Measurement
ATBD	Algorithm Theoretical Basis Document
ATLID	Atmospheric Lidar
BAMGOMAS	Back trajectories, AERONET, MODIS, GOCART, MPLNET Aerosol Synergism
BIRA	Belgian Institute for Space Aeronomy
BU	Binary Unit
CAL	Calibration
CAMS	Copernicus Atmosphere Monitoring Service
CAA	Calibration Assembly
CALIOP	Cloud-Aerosol Lidar with Orthogonal Polarization
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CAS	Calibration Subsystem
CCD	Charge Coupled Device

CEOS	Committee on Earth Observation Satellites
CFI	Customer Furnished Item
CGS	Core Ground Segment
CHART	Component Health Assessment Reporting Tool
CKD	Calibration Key Data
CMDL	Climate Monitoring and Diagnostics Laboratory
CMOS	Complementary Metal Oxide Semiconductor
CNES	Centre Nationale d'Etudes Spatiales
CPR	Cloud Profiling Radar
CRiS	Cross-track Infrared Sounder
CU	Calibration Unit of the GOME-2 instrument
CVF	Calibration/Validation Function
CVP	Calibration and Validation Plan
DIAL	Differential Absorption Lidar
DISCOVER-AQ	Deriving Information on Surface Conditions from Column and Vertically Resolved Observations Relevant to Air Quality
DLR	Deutsches Zentrum für Luft- und Raumfahrt e.V.
DLR-MF	Institut für Methodik der Fernerkundung, DLR (Oberpfaffenhofen, D)
DOAS	Differential Optical Absorption Spectroscopy
DOE	Department of Energy
DPC	Directional Polarimetric Camera
DPPF	Data Processing Parameters File
DU	Dobson Units
EARLINET	European Aerosol Research Lidar Network
ECMWF	European Centre for Medium-Range Weather Forecasts
EMI	Environmental Trace Gases Monitoring
ENVISAT	ENVIronmental SATellite
EO	Earth Observation
EOS	Earth Observing System
EPS	Eumetsat Polar System

EPS-SG	Eumetsat Polar System – Second Generation
ESA	European Space Agency
ESRL	Earth System Research Laboratory
ESTEC	European Space Technology Centre
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FCI	Flexible Combined Imager
FDF	Flight Dynamics Function
FEE	Front End Electronics
FOV	Field of View
FPA	Focal Plane Assembly
FRM	Fiducial reference Measurements
FTIR	Fourier Transfer InfraRed
FWHM	Full Width at Half Maximum
GALION	GAW Aerosol Lidar Observation Network
GAW	Global Atmosphere Watch
GAWSIS	GAW Station Information System
GCA	Geographic Coverage Area
GEMS	Geostationary Environment Monitoring Spectrometer
GEO-CAPE	Geostationary Coastal and Air Pollution Events
GIRO	GSICS Implementation of the ROLO model
GMM	Gaussian Mixture Model
GOME	Global Ozone Monitoring Experiment
GOSAT	Greenhouse Gases Observing Satellite “IBUKI”
GPP	Ground Processing Prototype
GS	Ground Segment
GSHHS	Global Self-consistent Hierarchical High-resolution Shoreline Database
GSICS	Global Satellite Inter-Calibration System
IASI	Infrared Atmospheric Sounding Interferometer
IASI-NG	Infrared Atmospheric Sounding Interferometer – New Generation
ICU	Instrument Control Unit

IDEAL	IndepenDEnt AbsoLute (PIQMICS module)
IDPF-S	Instrument Data Processing Facility - Sounding
IGACO	Integrated Global Atmospheric Chemistry Observation
IIR	Imaging Infrared Radiometer
INR	Image Navigation and Registration
IODS	Input Output Data Specification
IOV	In Orbit Verification
IRAT	Image Registration Analysis (PIQMICS module)
IRR	Irradiance
ISRF	Instrument Spectral Response Function
IUP-UB	Institut für UmweltPhysik. Universität Bremen
JPS	Joint Polar System
JPSS	Joint Polar Satellite System
KNMI	Koninklijk Nederlands Meteorologisch Instituut
L0	Level 0
L1	Level 1
L2	Level 2
L2OP	Level 2 Operational Processor
L2PF	Level 2 Processing Facility
LCMP	LEOP and Commissioning Management Plan
LED	Light Emitting Diode
LEOP	Launch and Early Operations Phase
LESSR	Lunar Extended Simulation Reflectance Model
LIDORT	Linearized Discrete Ordinate Radiative Transfer
LOA	Laboratoire d'Optique Atmosphérique
LOS	Line of Sight
LSM	Land Sea Mask
M&C	Monitoring and Control
MAXDOAS	Multi Axis Differential Optical Absorption Spectroscopy
MCC	Mission Control Centre

METimage	Meteorological Imager (or VII Visible Infrared Imager)
Metop	Meteorological Operational Satellite
MICMICS	Mission Integrated Calibration Monitoring Inter-Calibration System
MOF	Mission Operations Facility
MPLNET	Micro-Pulse Lidar Network
MTG	Meteosat Third Generation
MTG-I	Meteosat Third Generation – Imaging
MTG-S	Meteosat Third Generation – Sounding
MME	Müller Matrix Element
MONALiSA	MONitoring of Atmospheric L2 SAtellite products
MPIC	Max-Planck-Institut für Chemie
NASA	National Aeronautics and Space Administration
NDACC	Network for the Detection of Atmospheric Composition Change
NDSC	Network for the Detection of Stratospheric Change
NetCDF	Network Common Data Form
NIES	National Institute for Environmental Studies, Japan
NIR	Near Infra-Red
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NOAO	National Optical Astronomy Observatories
NOVAC	Network for Observation of Volcanic and Atmospheric Change
S-NPP	Suomi National Polar-orbiting Partnership
NRT	Near Real Time
NSF	National Science Foundation
NWP	Numerical Weather Prediction
OGS	Overall Ground Segment
OIM	Optical Instrument Module
OMI	Ozone Monitoring Instrument
OMPS	Ozone Mapping and Profiler Suite
OPF	Operational Parameter File

OSIVV	OGS and System Integration, Verification and Validation
PBL	Planetary Boundary Layer
PCA	Principal Component Analysis
PCC	Phase Cross Correlation
PDAP	Payload Data Acquisition and Processing
PFS	Product Format Specification
PGF	Product Generation Function
PGN	Pandonia Global Network
PGS	Product Generation function Specification
PHOTONS	PHOtométrie pour le Traitement Opérationnel de Normalisation Satellitaire
PIQMICS	Performance, Image Quality, MonItoring & Characterisation System
PMD	Polarisation measurements Device
PRNU	Photo Response Non-Uniformity
PSF	Point Spread Function
PTU	Pressure, Temperature and Humidity
PUM	Product User Manual
QA	Quality Assessment/Quality Assurance
QA-SAC	GAW Quality Assurance Science Activity Centres
QC	Quality Control
RA	Radiometric Accuracy
RAL	Rutherford Appleton Laboratory
RO	Radio Occultation
ROLO	Robotic Lunar Observatory
RSRA	Relative Spectral Radiometric Accuracy
RSXA	Relative Spatial Radiometric Accuracy
RTM	Radiative Transfer Model
SAF	Satellite Application Facility
SAO	Smithsonian Astrophysical Observatory
SBUV	Solar Backscatter Ultra-Violet Experiment
SCAT	Scatterometer

SCIAMACHY	Scanning Imaging Absorption Spectrometer for Atmospheric Cartography
SDE	Scanner Drive Electronics
SIM	Spectral Irradiance Monitor
SIOV	Satellite In Orbit Verification
SLS	Spectral Light Source
SNO	Simultaneous Nadir Overpass
SNR	Signal to Noise Ratio
SOLSTICE	Stellar Solar Irradiance Comparison Experiment
SORCE	SOlar Radiation and Climate Experiment
SpecFUN	Spectral Calibration Framework Utilising Numerics
SRON	Space Research Organisation of The Netherlands
SSD	Spatial Sampling Distance
STAR	STAtistics and Reporting
STF	Shi-Tomasi Feature
SWIR	Short-Wave Infra-Red
SZA	Solar Zenith Angle
TBC	To Be Confirmed
TBD	To Be Decided
TBW	To Be Written
TCCON	Total Carbon Column Observing Network
TCE	Technical Computing Environment
TEMPO	Tropospheric Emissions: Monitoring of Pollution
TIM	Total Irradiance Monitor
TNO	Netherlands Organisation for Applied Scientific Research
TOA	Top of Atmosphere
TOLNet	Tropospheric Ozone Lidar Network
TOMS	Total Ozone Mapping Spectrometer
TOVS	TIROS Operational Vertical Sounder
TROPOMI	TROPOspheric Monitoring Instrument
TSA	Telescope Spectrograph Assembly

USGS	U.S. Geological Survey
UTC	Universal Time Coordinate
UV	Ultra-Violet
UVN	Ultra-Violet Near-infrared
UVNS	Ultra-Violet Near-infrared Short-wave infrared
UVVIS	Ultra-Violet VISible
V-LIDORT	Vector Linearized Discrete Ordinate Radiative Transfer
V&V	Verification and Validation
VAL	Validation
VIS	Visible
WAF	Web Accessible Folder
WBS	Work Breakdown Structure
WDC	World Data Centre
WFC	Wide Field Camera
WLS	White Light Source
WMO	World Meteorological Organization
WOUDC	World Ozone and Ultraviolet Data Centre
XPS	XUV Photometer System

APPENDIX B DETAILED ACTIVITY DESCRIPTIONS

The following task descriptions are preliminary. These descriptions will be updated to capture the contributions from the AO participants when known.

Definition of Cal/Val Activities and Procedures (A1)

Item	Description
Test Name	S4_S5_CALVAL_DEF
Test Title	Definition of Cal/Val Activities and Procedures (A1)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	Preparation for Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val activities including planning of activities, and data sets and tool development and procurements.
Test Sequence Description	The definition of Cal/Val activities and procedures as defined in this plan is to be updated in cooperation with internal and external partners through appropriate review cycle. Feedback from the activities carried out during Sentinel-4/UVN and Sentinel-5/UVNS IOV and during the Commissioning phase in general is also expected and will contribute to the final definition of Cal/Val activities to be carried out during routine operations. Feedback from the scientific community is also expected and will be accommodated wherever possible. The final version of this plan will be produced at the end of the Commissioning Phase and will define the activities to be carried out during routine operations
Requirements	None.
Prerequisites	Complete definition and availability of information on Sentinel-4/UVN and Sentinel-5/UVNS instrument, products and product processing algorithms.
Required Resources	None.
Required Test Tools	None.
Required Test Data	None.
Entry Conditions	None.
Exit Conditions	None.
Deliverables	Completed Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val Plan
Team Involved	EUMETSAT/RSP ACh CA and ESA.
Periodicity	As per document revision cycle.
Initial Duration	Until final definition of Cal/Val activities to be carried out during routine operations.

Recurrent Duration	Minor revisions and additions can be anticipated during routine operations.
Pass/Fail Criteria	Published Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val Plan.
Comments	None.
Test Procedure	Not required.

Definition and Acquisition of Cal/Val Data Sets and Tools (A2)

Definition and Acquisition of Cal/Val Data Sets (A2.1)

Item	Description
Test Name	S4_S5_CALVAL_DATA
Test Title	Definition and Acquisition of Cal/Val Data Sets (A2.1)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To acquire Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val data sets.
Test Sequence Description	Static data sets: Action: Initiate procurement activities and integrate data and readers, into the EUMETSAT offline operational environment, and/or on the EUMETSAT TCE. See also S4_S5_CALVAL_TOOLS. Dynamic validation data sets (e.g. Data from Ground-based Sensors, Data from Satellite-based Sensors, Data from Dedicated Measurement Campaigns, European Centre for Medium Range Weather Forecasting (ECMWF) and Copernicus Atmosphere Monitoring Service (CAMS) Analysis & Forecast Fields Put in place cooperation agreements to allow data access. Determine the validation data product format. Develop product readers and data subset selection tools. Define data transfer mechanisms and protocols. Note: the first and last of these activities will be addressed within the MTG System Commissioning Plan [SCP], EUM/MTG/PLN/11/0203 [AD1] and EPS-SG Programme Overall Calibration and Validation Plan, EUM/LEO-EPSSG/PLN/14/758341 [AD2]. Documents and specifications which describe the data format can be obtained from the data providers as listed in Section 7.3. Product readers and data subset selection tools are expected to be available in the EUMETSAT offline operational environment, and/or on the EUMETSAT TCE, as outlined in Section 7.4. See also S4_S5_CALVAL_TOOLS.
Requirements	None.
Prerequisites	Completed review cycle of the Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val plan.
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE
Required Test Tools	None.

Required Test Data	None.
Entry Conditions	None.
Exit Conditions	None.
Deliverables	Complete set of data sets required for Cal/Val activities either implemented in the EUMETSAT offline operational environment, and/or on the EUMETSAT TCE, or mechanisms for data exchange and use finalised and tested.
Team Involved	EUMETSAT/RSP ACh CA and ESA.
Periodicity	List of data sets updated as per Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val plan revision cycle.
Initial Duration	Until final definition of Cal/Val data sets to be used during routine operations.
Recurrent Duration	Further additions expected for the complete lifetime of the mission as new data sets become available.
Pass/Fail Criteria	Baseline set of data sets implemented and tested within the EUMETSAT offline operational environment, and/or on the EUMETSAT TCE, before launch or necessary links and product readers defined, implemented and tested before launch. Linked to Definition of Cal/Val Activities and Procedures (A1) and Definition and Acquisition of Cal/Val Tools (A2.2).
Comments	None.
Test Procedure	Not required.

Definition and Acquisition of Cal/Val Tools (A2.2)

Item	Description
Test Name	S4_S5_CALVAL_TOOLS
Test Title	Definition and Acquisition of Cal/Val Tools (A2.2)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To acquire and develop Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val tools.
Test Sequence Description	Tools required to be available within the baseline EUMETSAT offline operational environment or on the EUMETSAT TCE. Product Readers and Subset Selection (T1) Orbit Prediction Tool (T2) Collocation Tool (T3) Normalisation of Solar Spectra (T4) Simple Mathematical Functions (T5) Statistical Analysis Tools (T6) Interpolation Tools (Linear, Spline and Akima) (T7) Convolution Tool (T8)

	Correlation Tool (T9) Spectral Calibration Tool (T10) Image Display Tools (T11) Image Matching Tool (T12) Metview (T13) Radiative Transfer Models (T14) Report Generation Tools (T16)
Requirements	None.
Prerequisites	Completed review cycle of the Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val plan.
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE
Required Test Tools	None.
Required Test Data	None.
Entry Conditions	None.
Exit Conditions	None.
Deliverables	Complete set of tools required for Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val activities either implemented in the EUMETSAT offline operational environment, and/or on the EUMETSAT TCE, or mechanisms for data exchange and use finalised and tested.
Team Involved	EUMETSAT/RSP ACh CA and ESA.
Periodicity	List of tools updated as per Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val plan revision cycle.
Initial Duration	Until final definition of Cal/Val tools to be used during routine operations.
Recurrent Duration	Further additions expected for the complete lifetime of the mission as new tools are identified.
Pass/Fail Criteria	Baseline set of tools implemented and tested within the EUMETSAT offline operational environment, and/or on the EUMETSAT TCE, before launch or necessary links and product readers defined, implemented and tested before launch. Linked to Definition of Cal/Val Activities and Procedures (A1) and Definition and Acquisition of Cal/Val Data Sets (A2.1).
Comments	None.
Test Procedure	Not required.

Coordination and Planning of Cal/Val Activities (A3)

Coordination with External Partners (A3.1)

Item	Description

Test Name	S4_S5_CALVAL_COORD
Test Title	Coordination with External Partners (A3.1)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	Preparation for Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val activities.
Test Sequence Description	External partners to be involved in the Calibration/Validation process must be identified and the framework for interaction and participation in Cal/Val activities defined. The framework for interaction and participation and the definition of communications and reporting mechanisms will be addressed in the MTG System Commissioning Plan [SCP], EUM/MTG/PLN/11/0203 [AD1] and EPS-SG Programme Overall Calibration and Validation Plan, EUM/LEO-EPSSG/PLN/14/758341 [AD2]. The definition of tasks and roles for each group relevant to Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val activities must be identified within this plan. This activity is currently on-going in conjunction with completion of this plan (see Section 6.1.3). The list of potential partners will include at a minimum ESA, CAMS, ECMWF, the AC SAF consortium, and selected scientific groups and institutes.
Requirements	None.
Prerequisites	Completed review cycle of the Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val plan.
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE
Required Test Tools	None.
Required Test Data	None.
Entry Conditions	None.
Exit Conditions	None.
Deliverables	List of external partners required for Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val activities established and mechanisms for data exchange, communication, interaction, and reporting finalised and tested.
Team Involved	EPS-SG System Team, MTG System Team, EUMETSAT/RSP ACh CA and ESA.
Periodicity	List of external partners updated as per Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val plan revision cycle.
Initial Duration	Until final definition of Cal/Val activities for routine operations.
Recurrent Duration	Further additions expected for the complete lifetime of the mission as new external partners are identified.

Pass/Fail Criteria	List of potential partners with an associated definition of their task and roles within the Sentinel-4/UVN and Sentinel-5/UVNS Cal/Val activities completed and mechanisms for data exchange, communication, interaction, and reporting finalised and tested. Linked to Definition of Cal/Val Activities and Procedures (A1).
Comments	None.
Test Procedure	Not required.

Planning and Coordination of Campaigns (A3.2)

Planning and coordination of campaigns will not be addressed in this plan. This is expected to be done in the frame of an AO Call to be initiated by ESA, with the support of EUMETSAT. See also Section 5.3.2.2.

Rehearsal Period (A3.3)

To be planned in the frame of the MTG System Commissioning Plan [SCP], EUM/MTG/PLN/11/0203 [AD1] and EPS-SG Programme Overall Calibration and Validation Plan, EUM/LEO-EPSSG/PLN/14/758341 [AD2].

Instrument Monitoring (A4)

Monitoring of Housekeeping Data (A4.1)

Derive Usage Statistics for Life-Limited Items and Mode Statistics (A4.1.1)

Item	Description
Test Name	S4_S5_MON_USAGE
Test Title	Derive Usage Statistics for Life-Limited Items and Mode Statistics (A4.1.1)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To monitor use of life-limited items against limits to be specified in the Sentinel-4/UVN Flight Operations Manual, GS4.ASG.UVN.MA.00002 [RD11], Sentinel-5/UVNS Instrument Flight Operation Manual, GS5-SP-ADSO-UVNS-10001080681212 [RD12] and to monitor instrument operations mode statistics with respect to commanded instrument timelines.
Test Sequence Description	For SLS, WLS, and LED calculate from their on/off status flags the total duration for which they were switched on and the number of times they were switched on. The number of times they were switched on is the number of transitions from “off” to “on” status flag. Results shall be given separately for the available LED chains and WLS currents. For the Sentinel-4/UVN scanner, calculate the total number of scans in any scanning mode. For shutters, calculate the total number of actuations, both in nominal mode and in emergency mode, and the total duration when the shutter was open. Using the instrument mode identifier, calculate the total duration per mode, and its percentage of the total measurement time (sum of duration for all modes).

Requirements	None.
Prerequisites	Successfully verified instrument function.
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Simple Mathematical Functions (T5) Image Display Tools (T11) Report Generation Tools (T16)
Required Test Data	**Pre-processed instrument housekeeping data** • On/off status flags for the SLS, WLS and LED lamps • Open/closed status flags for the shutters
Entry Conditions	Successful completion of instrument functional verification.
Exit Conditions	None – monitoring function.
Deliverables	Summary report on life limited items usage and mode statistics.
Team Involved	EUMETSAT/RSP ACh CA.
Periodicity	Per scan/orbit/product, per day, per week, per month, and per year.
Initial Duration	N/A.
Recurrent Duration	N/A.
Pass/Fail Criteria	No pass/fail criteria - monitoring purposes only.
Comments	Required for complete lifetime of the missions.
Test Procedure	Based on the tools outlined above, the test performs following steps in an automated fashion: 1. Ingest pre-processed housekeeping data. 2. Read available data from a dedicated database (DB). 3. Run a statistical analysis tool. 4. Update the DB. 5. Prepare the test report.

Monitor Thermal Performance (A4.1.2)

Item	Description
Test Name	S4_S5_MON_THERM
Test Title	Monitor Thermal Performance (A4.1.2)
WBS Reference	EPS-SG 924950; MTG COM-835730

Purpose	To monitor the thermal environment of the instrument with a specific focus on those elements which may impact the quality of the Level 1 data products.
Test Sequence Description	Analyse the time-series of selected temperatures and gradients between selected points other than the detector temperatures, e.g., selected prism, radiator, and optical bench temperatures. Determine the amplitudes and phases of orbital and seasonal variations for these temperatures as described in T6.1 with *T* set to the duration of one orbit or to one year respectively. Analyse the time-series of detector array temperatures and the cooler output for the measurements where the respective cooler is switched on.
Requirements	None.
Prerequisites	Successfully verified instrument function.
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Simple Mathematical Functions (T5) Statistical Analysis Tools (T6) Image Display Tools (T11) Report Generation Tools (T16)
Required Test Data	**Pre-processed housekeeping data comprising mean, standard deviation, maximum and minimum values.** • Prism temperatures • Radiator temperature • Optical bench temperatures • Detector array temperatures • Cooler output
Entry Conditions	Successful completion of instrument functional verification.
Exit Conditions	None – monitoring function.
Deliverables	Summary report on instrument thermal performance.
Team Involved	EUMETSAT/RSP ACh CA.
Periodicity	Per day, month, and per year.
Initial Duration	N/A.
Recurrent Duration	N/A.
Pass/Fail Criteria	No pass/fail criteria - monitoring purposes only.
Comments	Required for complete lifetime of the missions.

Test Procedure	Based on the tools outlined above, the test performs following steps in an automated fashion: 1. Ingest pre-processed housekeeping data. 2. Read available data from a dedicated database (DB). 3. Run a statistical analysis on time series. 4. Update the DB. 5. Prepare the test report.

Monitor Electrical Performance (A4.1.3)

Item	Description
Test Name	S4_S5_MON_ELEC
Test Title	Monitor Electrical Performance (A4.1.3)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To monitor the electrical environment of the instrument with a specific focus on those elements which may impact the quality of the Level 1 data products.
Test Sequence Description	Analyse the time-series of SLS and WLS voltages and currents, per switch-on period and as a long term time series. Derive ignition delay and ignition voltage from voltage and current values and analyses their time-series.
Requirements	None.
Prerequisites	Successfully verified instrument function.
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Simple Mathematical Functions (T5) Statistical Analysis Tools (T6) Image Display Tools (T11) Report Generation Tools (T16)
Required Test Data	**Pre-processed housekeeping data comprising mean, standard deviation, maximum and minimum values.** • On/off status flags the SLS and WLS lamps • SLS voltage and current • WLS voltage and current
Entry Conditions	Successful completion of instrument functional verification.
Exit Conditions	None – monitoring function.
Deliverables	Summary report on instrument electrical performance.

Team Involved	EUMETSAT/RSP ACh CA.
Periodicity	Per switch on period, per month, and per year.
Initial Duration	N/A.
Recurrent Duration	N/A.
Pass/Fail Criteria	No pass/fail criteria - monitoring purposes only.
Comments	Required for complete lifetime of the missions.
Test Procedure	Based on the tools outlined above, the test performs following steps in an automated fashion: 1. Ingest pre-processed housekeeping data. 2. Read available data from a dedicated database (DB). 3. Run a statistical analysis tool. 4. Update the DB. 5. Prepare the test report.

Monitor Scanner Performance (A4.1.4)

Item	Description
Test Name	S4_MON_SCAN
Test Title	Monitor Scanner Performance (A4.1.4)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To monitor the performance of the Sentinel-4/UVN scanner.
Test Sequence Description	For static modes (TBC), analyses time series of scanner position with respect to the set value. For earth scanning mode, compare the scanner positions across the scan with the expected values, calculate the deviations, and analyse the resulting time series. For earth scanning mode, compare the torque of the scanner motor with the expected values, calculate the deviations, and analyse the resulting time series.
Requirements	None.
Prerequisites	Successfully verified instrument function.
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Simple Mathematical Functions (T5) Statistical Analysis Tools (T6) Image Display Tools (T11)

	Report Generation Tools (T16)
Required Test Data	**Level 0 and Level 1 Products** scan_mirror_position_east_west and scan_mirror_north_south
Entry Conditions	Successful completion of instrument functional verification.
Exit Conditions	None – monitoring function.
Deliverables	Summary report on scanner performance.
Team Involved	EUMETSAT/RSP ACh CA.
Periodicity	Per day, month, and per year.
Initial Duration	N/A.
Recurrent Duration	N/A.
Pass/Fail Criteria	No pass/fail criteria - monitoring purposes only.
Comments	Required for complete lifetime of the missions.
Test Procedure	Based on the tools outlined above, the test performs following steps in an automated fashion: 1. Ingest Sentinel-4 Level 0 and Level 1 products. 2. Read available data from a dedicated database (DB). 3. Run a statistical analysis tool. 4. Update the DB. 5. Prepare the test report.

Monitoring using Internal Calibration Sources (A4.2)

Item	Description
Test Name	S4_S5_MON_INT_CAL
Test Title	Monitoring using Internal Calibration Sources (A4.2)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To monitor the performance of the Internal Calibration Sources.
Test Sequence Description	Analyse time series of signals from internal light sources (SLS, WLS, LED). Within a time series, the integration time, time after lamp stabilisation, and (for the WLS) lamp current have to be identical.
Requirements	None.
Prerequisites	Successfully verified instrument function.
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.

Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Simple Mathematical Functions (T5) Statistical Analysis Tools (T6) Image Display Tools (T11) Report Generation Tools (T16)
Required Test Data	**Calibration Key Data Files, Level 0 and Level 1 Products** • Sentinel-4: UVN-1-DPP-STATIC and UVN-1-DPP-RADDAY • Sentinel-5: DET_PRNU, RA_FFWLS, RA_FFLED, DET_FCCD, DET_FCMOS, DET_BAD and DET_LIN in both Calibration and Characterisation Database (CCDB) and Operational Parameter File (OPF)
Entry Conditions	Successful completion of instrument functional verification.
Exit Conditions	None – monitoring function.
Deliverables	Summary report on internal light source performance.
Team Involved	EUMETSAT/RSP ACh CA.
Periodicity	Per month, and per year.
Initial Duration	N/A.
Recurrent Duration	N/A.
Pass/Fail Criteria	No pass/fail criteria - monitoring purposes only.
Comments	Required for complete lifetime of the missions.
Test Procedure	Based on the tools outlined above, the test performs following steps in an automated fashion: 1. Ingest the Level 0, Level 1 products and calibration data and read the relevant variables. 2. Ingest the on-ground CKD data as reference data and read the same variables as step 1. 3. Read available data from a dedicated database (DB). 4. Run a statistical analysis on the time series. 5. Update the DB. 6. Prepare the test report.

Monitor Diffuser Transmission (A4.2.2)

Item	Description
Test Name	S4_S5_MON_INT_CAL
Test Title	Monitor Diffuser Transmission (A4.2.2)
WBS Reference	EPS-SG 924950; MTG COM-835730

Purpose	To monitor the solar diffuser reflectivity.
Test Sequence Description	Analyse time series of the primary and reference diffuser reflectivity (per spectral window) using the on-ground CKD as a reference and compare. Specific method is described in section 3.2 of [RD60] and section 4.6.33 of [RD13].
Requirements	None.
Prerequisites	Successfully verified instrument function.
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Calibration Key Data Readers and Display (T1.2) Simple Mathematical Functions (T5) Statistical Analysis Tools (T6) Image Display Tools (T11) Report Generation Tools (T16)
Required Test Data	**Calibration Key Data Files and Level 0 and Level 1 Products** • Sentinel-4: UVN-1-DPP-STATIC and UVN-1-DPP-RADDAY • Sentienel-5: RA_DIRR in CCDB
Entry Conditions	Successful completion of instrument functional verification.
Exit Conditions	None – monitoring function.
Deliverables	Summary report on solar diffuser reflectivity.
Team Involved	EUMETSAT/RSP ACh CA.
Periodicity	Per day, month, and per year.
Initial Duration	N/A.
Recurrent Duration	N/A.
Pass/Fail Criteria	No pass/fail criteria - monitoring purposes only.
Comments	Required for complete lifetime of the missions.
Test Procedure	Based on the tools outlined above, the test performs following steps in an automated fashion: 1. Ingest the Level 0, Level 1 products and in-flight CKD data and read the relevant variables. 2. Ingest the on-ground CKD data as reference data and read the same variables as step 1. 3. Read available data from a dedicated database (DB).

4. Run a statistical analysis on the time series.
5. Update the DB.
6. Prepare the test report.

Monitoring of In-Flight Calibration Parameters (A4.3)

Monitor Dark Signals (A4.3.1)

Item	Description
Test Name	S4_S5_MON_IFC
Test Title	Monitor Dark Signals (A4.3.1)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To monitor the dark signals per detector pixel.
Test Sequence Description	Analyse time series of electronic offsets, dark signal and dark signal noise (all per detector pixel) using on-ground CKD measurements as a reference.
Requirements	None.
Prerequisites	Successfully verified instrument function.
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Calibration Key Data Readers and Display (T1.2) Simple Mathematical Functions (T5) Statistical Analysis Tools (T6) Image Display Tools (T11) Report Generation Tools (T16)
Required Test Data	**Calibration Key Data Files and Level 0 and Level 1 Products** • Sentinel-4: UVN-1-DPP-STATIC and UVN-1-DPP-RADDAY • Sentinel-5: DET_DRK and DET_OFF in CCDB and OPF
Entry Conditions	Successful completion of instrument functional verification.
Exit Conditions	None – monitoring function.
Deliverables	Summary report on electronic offset and dark signal performance.
Team Involved	EUMETSAT/RSP ACh CA.
Periodicity	Per day, month, and per year.
Initial Duration	N/A.
Recurrent Duration	N/A.

Pass/Fail Criteria	No pass/fail criteria - monitoring purposes only.
Comments	Required for complete lifetime of the missions.
Test Procedure	Based on the tools outlined above, the test for Sentinel-5 performs following steps in an automated fashion: 1. Ingest Sentinel-5 OPF_ files (DET_OFF and DET_DRK) from the EPS-SG rolling buffer folder and read the relevant variables. 2. Ingest Sentinel-5 CCDB files (DET_OFF and DET_DRK) from the EPS-SG rolling buffer as reference data and read the same variables as step 1. 3. Read available data from a dedicated database (DB). 4. Run a statistical analysis on the time series. 5. Update the DB. 6. Prepare the test report.

Monitor Photo Response Non-Uniformity (A4.3.2)

Item	Description
Test Name	S4_S5_MON_PRNU
Test Title	Monitor Photo Response Non-Uniformity (A4.3.2)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To monitor the Photo Response Non-Uniformity (PRNU) of the detectors.
Test Sequence Description	Analyse time series of the PRNU (per detector pixel) using the on-ground CKD as a reference.
Requirements	None.
Prerequisites	Successfully verified instrument function.
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Calibration Key Data Readers and Display (T1.2) Simple Mathematical Functions (T5) Statistical Analysis Tools (T6) Image Display Tools (T11) Report Generation Tools (T16)
Required Test Data	**Calibration Key Data Files and Level 0 and Level 1 Products** • Sentinel-4: UVN-1-DPP-STATIC and UVN-1-DPP-RADWLS • Sentinel-5: DET_PRNU in CCDB and OPF
Entry Conditions	Successful completion of instrument functional verification.

Exit Conditions	None – monitoring function.
Deliverables	Summary report on PRNU stability and performance.
Team Involved	EUMETSAT/RSP ACh CA.
Periodicity	Per day, month, and per year.
Initial Duration	N/A.
Recurrent Duration	N/A.
Pass/Fail Criteria	No pass/fail criteria - monitoring purposes only.
Comments	Required for complete lifetime of the missions.
Test Procedure	Based on the tools outlined above, the test for Sentinel-5 performs following steps in an automated fashion: 1. Ingest Sentinel-5 OPF_ files (DET_PRNU) from the EPS-SG rolling buffer folder and read the relevant variables. 2. Ingest Sentinel-5 CCDB files (DET_PRNU) from the EPS-SG rolling buffer as reference data and read the same variables as step 1. 3. Read available data from a dedicated database (DB). 4. Run a statistical analysis on the time series. 5. Update the DB. 6. Prepare the test report.

Monitor Spectral Stability (A4.3.3)

Item	Description
Test Name	S4_S5_MON_SPEC_STAB
Test Title	Monitor Spectral Stability (A4.3.3)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To monitor the spectral stability of the Sentinel-4/UVN and Sentinel-5/UVNS instruments.
Test Sequence Description	Calculate wavelengths for selected detector pixels per channel/band and analyse their time series.
Requirements	None.
Prerequisites	Successfully verified instrument function.
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Calibration Key Data Readers and Display (T1.2)

	Simple Mathematical Functions (T5) Statistical Analysis Tools (T6) Image Display Tools (T11) Report Generation Tools (T16)
Required Test Data	**Calibration Key Data Files and Level 0 and Level 1 Products** • Sentinel-4: UVN-1-DPP-STATIC and UVN-1-DPP-NONLIN • Sentinel-5: SPEC_DISP in CCDB and OPF
Entry Conditions	Successful completion of instrument functional verification.
Exit Conditions	None – monitoring function.
Deliverables	Summary report on spectral stability.
Team Involved	EUMETSAT/RSP ACh CA.
Periodicity	Per orbit/scan, day, month, and per year.
Initial Duration	N/A.
Recurrent Duration	N/A.
Pass/Fail Criteria	No pass/fail criteria - monitoring purposes only.
Comments	Required for complete lifetime of the missions.
Test Procedure	Based on the tools outlined above, the test for Sentinel-5 performs following steps in an automated fashion: 1. Ingest Sentinel-5 OPF_ files (SPEC_DISP) from the EPS-SG rolling buffer folder and read the relevant variables. 2. Ingest Sentinel-5 CCDB files (SPEC_DISP) from the EPS-SG rolling buffer as reference data and read the same variables as step 1. 3. Read available data from a dedicated database (DB). 4. Run a statistical analysis on the time series. 5. Update the DB. 6. Prepare the test report.

Monitor Instrument Spectral Response Function (A4.3.4)

Item	Description
Test Name	S4_S5_MON_SPEC_RESP
Test Title	Monitor Instrument Spectral Response Function (A4.3.4)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To monitor the spectral response function of the Sentinel-4/UVN and Sentinel-5/UVNS instruments.

Test Sequence Description	Calculate instrument spectral response function shape for selected detector pixels per channel/band and analyse their time series. Specific method see section 4.6.4 of [RD13] and section 3.4 of [RD60]
Requirements	None.
Prerequisites	Successfully verified instrument function.
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Calibration Key Data Readers and Display (T1.2) Simple Mathematical Functions (T5) Statistical Analysis Tools (T6) Image Display Tools (T11) Report Generation Tools (T16)
Required Test Data	**Calibration Key Data Files and Level 0 and Level 1 Products** • Sentinel-4: UVN-1-DPP-STATIC • Sentinel-5: SPEC_ISRF in CCDB and OPF
Entry Conditions	Successful completion of instrument functional verification.
Exit Conditions	None – monitoring function.
Deliverables	Summary report on spectral response function stability.
Team Involved	EUMETSAT/RSP ACh CA.
Periodicity	Per month, and per year.
Initial Duration	N/A.
Recurrent Duration	N/A.
Pass/Fail Criteria	No pass/fail criteria - monitoring purposes only.
Comments	Required for complete lifetime of the missions.
Test Procedure	Based on the tools outlined above, the test performs following steps in an automated fashion: 1. Ingest the Level 0, Level 1 products and in-flight CKD data and read the relevant variables. 2. Ingest the on-ground CKD data as reference data and read the same variables as step 1. 3. Read available data from a dedicated database (DB). 4. Run a statistical analysis on the time series. 5. Update the DB. 6. Prepare the test report.

Monitor Instrument Throughput using Solar Measurements (A4.3.5)

Item	Description
Test Name	S4_S5_MON_THPUT_SOL
Test Title	Monitor Instrument Throughput using Solar Measurements (A4.3.5)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To monitor the instrument throughput using measured solar spectra.
Test Sequence Description	Spectrally interpolate reference solar spectrum onto a fixed wavelength grid Normalize the reference solar spectrum to a solar distance of 1AU Calculate ratios of solar spectra with a reference solar spectrum. Separate broadband and narrowband effects in the ratios by subtracting a low-order polynomial in the spectral domain. Analyse time series of both components at selected wavelengths. Check for periodicities (e.g., annual). See also, related activity Validation of the Average Solar Irradiance Spectrum (A5.5)
Requirements	None.
Prerequisites	Successfully verified instrument function.
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Validation Data Product Readers and Subset Selection (T1.6) Normalisation of Solar Spectra (T4) Simple Mathematical Functions (T5) Statistical Analysis Tools (T6) Interpolation Tools (Linear, Spline and Akima) (T7) Image Display Tools (T11) Report Generation Tools (T16)
Required Test Data	Spectrally interpolated solar irradiance data normalized to a solar distance of 1 AU. **External data sets – for satellite data, weekly acquisition during commissioning and thereafter monthly acquisition** High Resolution Reference Solar Irradiance Spectrum (D1.2) Total and Solar Spectral Irradiance Sensor (TSIS): Spectral Solar Irradiance Data (D4.1) The Sentinel-5/UVNS Precursor TROPOspheric Monitoring Instrument (TROPOMI) (D4.4) The Ozone Mapping and Profiler Suite (OMPS) (D4.5)

Entry Conditions	Successful completion of instrument functional verification.
Exit Conditions	None – monitoring function.
Deliverables	Summary report on instrument throughput stability from solar measurements.
Team Involved	EUMETSAT/RSP ACh CA.
Periodicity	Per month, and per year.
Initial Duration	N/A.
Recurrent Duration	N/A.
Pass/Fail Criteria	No pass/fail criteria - monitoring purposes only.
Comments	Required for complete lifetime of the missions.
Test Procedure	Based on the tools outlined above, the test performs following steps in an automated fashion: 1. Ingest the Level 1 irradiance products and read the relevant variables. 2. Ingest the solar reference data and read the same variables as step 1. 3. Read available data from a dedicated database (DB). 4. Run a statistical analysis on the time series. 5. Update the DB. 6. Prepare the test report.

Monitoring of Radiance Measurements (A4.4)

Monitor Instrument Throughput using Earthshine Measurements (A4.4.1)

Item	Description
Test Name	S4_S5_MON_THPUT_EARTH
Test Title	Monitor Instrument Throughput using Earthshine Measurements (A4.4.1)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To monitor the instrument throughput using measured Earthshine spectra.
Test Sequence Description	Calculate ratios of Earthshine spectra for a given scene and viewing angle with a reference Earthshine spectrum for the same scene and viewing angle (at a different time). Scenes over Greenland and the Antarctic ice sheets, which have high surface albedo, a stable ground scene and typically low aerosol will be analysed. Other possibilities include the Libyan Desert and the South Pacific Ocean. Do the same for Earthshine albedos (earth/sun ratios). Analyse time series (per viewing angle). For a selected high latitude in the summer hemisphere, select two wavelengths such that the contribution functions are similar for the two SZAs observed at this latitude.

	Time-series of the calibrated radiance at both wavelengths, including monthly averages, shall be analysed and the results compared to detect spectrally dependent changes in calibration. Select the Ozone Line Ratios corresponding to the D-pair and A-pair (see pair [DAT1] and [DAT17] for further details) which lie in equatorial regions and for which the SZA < 60º. Compare the two ozone line ratios and analyses their residuals to detect unexpected differences in calibration.
Requirements	None.
Prerequisites	Successfully verified instrument function.
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Normalisation of Solar Spectra (T4) Simple Mathematical Functions (T5) Statistical Analysis Tools (T6) Interpolation Tools (Linear, Spline and Akima) (T7) Image Display Tools (T11) Report Generation Tools (T16)
Required Test Data	Spectrally interpolated Earthshine data for selected scenes Spectrally interpolated Average Solar Irradiance data normalized to a solar distance of 1 AU for calculation of albedo Calculated Ozone Line Ratios
Entry Conditions	Successful completion of instrument functional verification.
Exit Conditions	None – monitoring function.
Deliverables	Summary report on instrument throughput stability from Earthshine measurements.
Team Involved	EUMETSAT/RSP ACh CA.
Periodicity	Per month, and per year.
Initial Duration	N/A.
Recurrent Duration	N/A.
Pass/Fail Criteria	No pass/fail criteria - monitoring purposes only.
Comments	Required for complete lifetime of the missions.
Test Procedure	Based on the tools outlined above, the test performs following steps in an automated fashion:

	1. Ingest the Level 1 radiance products and read the relevant variables in defined scenes and locations. 2. Read available data from a dedicated database (DB). 3. Run a statistical analysis on the time series. 4. Update the DB. 5. Prepare the test report.

Reporting Instrument Monitoring Activities (A4.5)

Item	Description
Test Name	S4_S5_MON_REPORT
Test Title	Reporting Instrument Monitoring Activities (A4.5)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To report the instrument monitoring activities in a summary report.
Test Sequence Description	Report all results of Instrument Monitoring in summary format. Summarize results in the following categories: Monitoring of Housekeeping Data (A4.1) Monitoring using Internal Calibration Sources (A4.2) Monitoring of In-Flight Calibration Parameters (A4.3) Monitoring of Radiance Measurements (A4.4) Where appropriate results shall be presented as a function of: observation mode Solar Zenith Angle viewing angle latitude and longitude Results shall at a minimum be presented in the form of: Time series plots and analysis Spectral plots 2-dimensional maps Scatter plots Recommendations for update of degradation correction factors shall be made where appropriate including reference to the updated verified degradation correction factor file and a description of the analysis which justifies the update.
Requirements	None.
Prerequisites	Successfully verified instrument function.
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Report Generation Tools (T16)

Required Test Data	**Output of Instrument Monitoring activities.**
Entry Conditions	Successful completion of instrument functional verification.
Exit Conditions	None – monitoring function.
Deliverables	Summary report on Instrument Monitoring activities Recommendations for update of degradation correction factors where appropriate.
Team Involved	EUMETSAT/RSP ACh CA.
Periodicity	Per month, and per year.
Initial Duration	N/A.
Recurrent Duration	N/A.
Pass/Fail Criteria	No pass/fail criteria - monitoring purposes only.
Comments	Required for complete lifetime of the missions.
Test Procedure	Based on the tools outlined above, the test for Sentinel-5 performs following steps in an automated fashion: 1. Read all the variables (A4.1-4.4) from DB. 2. Run analysis. 3. Generate the daily/weekly/monthly reports. 4. Prepare the test report.

Level 1 Product Verification, Confidence Checking and Validation (A5)

Verification and Validation of Geolocation Information (A5.1)

Verification of Sub-Satellite Point for Earth Measurements (Sentinel-4/UVN) (A5.1.1)

Item	Description
Test Name	S4_L1_GEO_SSP
Test Title	Verification of Sub-Satellite Point for Earth Measurements (Sentinel-4/UVN) (A5.1.1)
WBS Reference	MTG COM-835730
Purpose	To verify that the geolocation information for the central pixel in a scanline in the case of Sentinel-4/UVN is correct within a pre-specified tolerance.
Test Sequence Description	Select the central pixel in a scanline, for a fixed number of scanlines per hour. Compare this with the point calculated using restituted orbit information, from an independent orbit propagation tool available within EUMETSAT offline operational environment or the EUMETSAT TCE provided by the Flight Dynamics Function (FDF).

	Confirm that the across-track difference between the geo-located and the calculated point is less than a pre-specified tolerance based on expected orbit prediction and pointing accuracy. Note that the wavelength selection for which this verification should be performed is TBC.
Requirements	Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017 [AD3] Sentinel-4/UVN - Instrument Requirements Specification, GS4.ASG.UVN.RS.00001 [AD6]
Prerequisites	Successfully verified instrument function.
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S. Output from the FDF.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Orbit Prediction Tool (T2) Simple Mathematical Functions (T5) Image Display Tools (T11) Report Generation Tools (T16)
Required Test Data	**Level 1 data** Geolocation information **Flight Dynamics Function** Restituted orbit information
Entry Conditions	Successful completion of instrument functional verification.
Exit Conditions	Partially verified geolocation information.
Deliverables	Verified scan location within the limits of the expected orbit prediction and pointing accuracy.
Team Involved	EUMETSAT/RSP ACh CA and ESA.
Periodicity	Five (TBC) scan lines per scan (Sentinel-4/UVN) for all Earthshine measurement modes during Commissioning phase.
Initial Duration	Commissioning phase.
Recurrent Duration	At the same frequency as during commissioning phase following any software upgrades either of the product processing, INR, or flight dynamics facilities for a period of 1 day.
Pass/Fail Criteria	Scan centre location is consistent with the commanded instrument operating mode within a pre-specified tolerance based on the expected orbit prediction and pointing accuracy.

Comments	
Test Procedure	Based on the tools outlined above, the test performs following steps in an automated fashion: 1. Ingest the Level 1 products and read the relevant variables. 2. Ingest the reference data from FDF and read the same variables as step 1. 3. Read available data from a dedicated database (DB). 4. Run a statistical analysis tool. 5. Update the DB. 6. Prepare the test report.

Verification of Scanline Width and Ground Pixel Size for Earth Measurements (Sentinel-4/UVN) (A5.1.2)

Item	Description
Test Name	S4_L1_GEO_SCAN
Test Title	Verification of Scanline Width and Ground Pixel Size for Earth Measurements (Sentinel-4/UVN) (A5.1.2)
WBS Reference	MTG COM-835730
Purpose	To verify that the scan width and ground pixel size, calculated from geolocation information in the product, are consistent with the expected scanline width and ground-pixel sizes within known pointing accuracy.
Test Sequence Description	The scanline width is calculated from the geodetic latitude and geocentric longitude of the outside corner points of the first and last ground pixels in a scan line for a fixed number of scans per hour (Sentinel-4/UVN). Confirm that the two are within a pre-specified tolerance taking into account expected pointing accuracy. The ground pixel sizes, calculated on the basis of geolocation information for the actual integration times and binning strategy, as indicated by the geodetic latitude and geocentric longitude at ground in the Level 1b product, shall be compared for consistency with ground pixel size expected on the basis of the commanded integration times and binning strategies specified in the current instrument operating timeline and position of the pixel in the scan line. Acceptable tolerances shall be defined on the basis of expected pointing accuracy.
Requirements	Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017 [AD3] Sentinel-4/UVN - Instrument Requirements Specification, GS4.ASG.UVN.RS.00001 [AD6]
Prerequisites	Successfully verified instrument function.

Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S. Output from the FDF.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Orbit Prediction Tool (T2) Simple Mathematical Functions (T5) Image Display Tools (T11) Report Generation Tools (T16)
Required Test Data	Level 1 data Geolocation information Flight Dynamics Function Restituted orbit information
Entry Conditions	Successful completion of instrument functional verification.
Exit Conditions	Partially verified geolocation information.
Deliverables	Verified swath width and ground pixel size.
Team Involved	EUMETSAT/RSP ACh CA and ESA.
Periodicity	Five (TBC) scan lines per scan (Sentinel-4/UVN) for all Earthshine measurement modes during Commissioning phase.
Initial Duration	Commissioning phase.
Recurrent Duration	At the same frequency as during commissioning phase following any software upgrades either of the product processing, INR, or flight dynamics facilities for a period of 1 day.
Pass/Fail Criteria	• Swath width as calculated from geolocation information for the complete scan is consistent with the expected instrument operating swath width, within a tolerance based on expected pointing accuracy. • Ground pixel sizes calculated from the geolocation information are consistent with the commanded instrument binning strategy and integration times for all channels, within a tolerance based on expected pointing accuracy.
Comments	
Test Procedure	Based on the tools outlined above, the test performs following steps in an automated fashion: 1. Ingest the Level 1 products and read the relevant variables. 2. Ingest the reference data from FDF and read the same variables as step 1. 3. Read available data from a dedicated database (DB). 4. Run a statistical analysis tool.

5. Update the DB. 6. Prepare the test report.

Validation of Geolocation Information for Earth Measurements (Sentinel-4/UVN) (A5.1.3)

Item	Description
Test Name	S4_L1_GEO_EARTH
Test Title	Validation of Geolocation Information for Earth Measurements (Sentinel-4/UVN) (A5.1.3)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To verify that the geolocation information in the Earth measurement product is correct within known pointing accuracy.
Test Sequence Description	Geolocation information shall be validated using the Quick Look False Colour images, in which coastlines are typically visible. Overlay a validated coastline map on the Quick Look False Colour images and visually inspect. Confirm that there are no deviations, within the limits of the spatial resolution of the measurements, between the coastline observed in the False Colour image and that from the coastline map. Subsequent to this initial check, geolocation performance of Earth measurements will be verified by image matching with co-registered imager data, i.e. MTG-I FCI. The Sentinel-4/UVN validation is performed by matching FCI images in the 'VIS 0.4' channel (centred at 444 nm) with Sentinel-4/UVN images from the reference spectral window in the visible, and by matching FCI images in the 'VIS 0.8' channel (centred at 865 nm) with Sentinel-4/UVN images from the reference spectral window in the near-infrared. Possible offsets between the spectrometer and the imager geolocation are determined by image matching. Preferred target scenes contain coastlines and other temporally persistent spatial patterns. If significant biases are observed, either persistent or with a repetitive diurnal dependence, the INR processing must be verified, and the INR related Calibration Key Data (CKD) must be analysed and potentially updated. A verification of the accuracy of the inter-band co-registration knowledge from the Level 1b geolocation information is performed by matching FCI images in one single channel (e.g. the 'VIS 0.5' channel (centred at 510 nm) once with Sentinel-4/UVN images in the visible, and a second time with Sentinel-4/UVN images in the NIR. The preferred targets scenes contain cloud structures that are expected to be spectrally invariant across the VIS-NIR spectral domain. Again, if significant biases are observed, either persistent or with a repetitive diurnal dependence, the co-registration related Calibration Key Data (CKD) must be analysed and potentially updated (see Sentinel-4/5 MAG Recommendation 17.02, [RD55]. In the case that moon observations are available, spatial co-registration (intra-band and inter-band) can also be assessed from edge detection on the moon.

Requirements	Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017 [AD3] Sentinel-4/UVN - Instrument Requirements Specification, GS4.ASG.UVN.RS.00001 [AD6]
Prerequisites	Successfully verified instrument function
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Product Readers for Other Sensors on MTG and EPS-SG and Subset Selection (T1.4) Simple Mathematical Functions (T5) Statistical Analysis Tools (T6) Image Display Tools (T11) Image Matching Tool (T12) Report Generation Tools (T16)
Required Test Data	Level 1 data Validated Coastline Map (D1.1) One day of MTG FCI image data
Entry Conditions	Successfully executed S4_S5_L1_GEO_SSP and S4_S5_L1_GEO_SCAN.
Exit Conditions	Verified geolocation and inter-band co-registration performance.
Deliverables	Report on geolocation performance.
Team Involved	EUMETSAT/RSP INRC and ACh CAs and ESA.
Periodicity	Five (TBC) scan lines per scan (Sentinel-4/UVN (also taking into account different integration times) for all Earthshine measurement modes during Commissioning phase.
Initial Duration	Commissioning phase.
Recurrent Duration	At the same frequency as during commissioning phase following any software upgrades either of the product processing, INR, or flight dynamics facilities for a period of 1 day.
Pass/Fail Criteria	Swath width as calculated from geolocation information for the complete scan is consistent with the expected instrument operating swath width, within a tolerance based on expected pointing accuracy. Ground pixel sizes calculated from the geolocation information are consistent with the commanded instrument binning strategy and integration times for all channels, within a tolerance based on expected pointing accuracy.

Comments	
Test Procedure	Based on the tools outlined above, the test performs following steps in an automated fashion: 1. Ingest the Level 1 products and read the relevant variables. 2. Ingest the validated coastline maps and the reference data from FCI products and read the relevant variables. 3. Read available data from a dedicated database (DB). 4. Run a statistical analysis tool. 5. Update the DB. 6. Prepare the test report.

Validation of Geolocation Information for Earth Measurements (Sentinel-5/UVNS) (A5.1.4)

Item	Description
Test Name	S5_L1_GEO_EARTH
Test Title	Validation of Geolocation Information for Earth Measurements (Sentinel-5/UVNS) (A5.1.4)
WBS Reference	EPS-SG 924950
Purpose	The aim of this task is to validate the S5 performance in geolocation.
Test Sequence Description	1. Ingest Sentinel-5 data files available on the EPS-SG rolling buffer. These are required to amount to at least N orbits (*). 2. Process ingested data through the IDEAL tools for absolute geolocation (*). 3. Store all relevant metadata and registration results in a dedicated database (DB). Statistical information is obtained from the full set of features included in the registrations and stored per product (*). 4. Ensure completeness of the ingestion and processing using the CHART frontend. 5. Evaluate the image registration accuracy with the REP module (Jupyter notebooks): • Specify the time range of ingested data as well as the tool to be evaluated and the view for which channel co-registrations will be included. Start the analysis. • The required data, namely the ACT- and ALT- shifts resulting from the image registration, are read from the DB. • Compliance with the requirement is visualized per channel and product.

	• The number of surviving peaks and the fraction within the requirement is visualized for reference. 6. Check compliance with the requirement based on the REP module output. 7. Analyse observed results and compile report. (*) Note that steps 1 through 3 are performed automatically upon start-up of an EPS-SG PIQMICS instance that is calibrated to read from the EPS-SG rolling buffer and has not processed the data therein before.
Requirements	Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017 [AD3] Sentinel-5/UVNS - Instrument Requirements Specification, GS5.RS.ASG.UVNS.00012 [AD7]: **IRS-55, IRS-62, IRS-64, IRS-66, IRS-3382, IRS-3984**
Prerequisites	• Correctly functioning instrument after SIOV with geolocation validated at instrument level. • Radiometric calibration available for products, allowing to identify ground features. • Other Cal/Val tests executed • EPS-SG PIQMICS installed
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning EPS-SG PDAP / TGPS.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Image Matching Tool (T12)
Required Test Data	• Several orbits of Sentinel-5 Level 1 data, located at the EPS-SG rolling buffer • Static tool-internal data Level 1 data
Entry Conditions	Nominal mode
Exit Conditions	Completion of test
Deliverables	Report, including visualization of geolocation performance and its compliance with the tested EURD requirements.
Team Involved	EUMETSAT/RSP INRC and ACh CAs.
Periodicity	The test for validating the geolocation requirements will be done during the commissioning phase.
Initial Duration	Approximately 1 hour per included orbit for processing. One week for analysis and report generation.
Recurrent Duration	Approximately 1 hour per included orbit, once the required data is accumulated.

Pass/Fail Criteria	Pass if the geolocation accuracy is within specification according to the tested requirements.
Comments	
Test Procedure	As per Test Sequence Description.

Validation of inter- and intra-band Co-registration (Sentinel-5/UVNS) (A5.1.5)

Item	Description
Test Name	S5_L1_INTRA_INTER_COREG
Test Title	Validation of inter- and intra-band Co-registration (Sentinel-5/UVNS) (A5.1.5)
WBS Reference	EPS-SG 924950
Purpose	The aim of this task is to validate the S5 performance in terms of inter- and intra-band co-registration.
Test Sequence Description	1. Ingest Sentinel-5 data files available on the EPS-SG rolling buffer. These are required to amount to at least N orbits (*). 2. Process ingested data through the IRAT tools for inter- and intra-channel co-registration (*). 3. Store all relevant metadata and registration results in a dedicated database (DB). Statistical information is obtained from the full set of features included in the registrations and stored per product (*). 4. Ensure completeness of the ingestion and processing using the CHART frontend. 5. Evaluate the co-registration accuracy with the REP module (Jupyter notebooks): • Specify the time range of ingested data as well as the tool to be evaluated and the view for which channel co-registrations will be included. Start the analysis. • The required data, namely the ACT- and ALT- shifts resulting from the image registration, are read from the DB. • Compliance with the requirement is visualized per co-registration and product. • The number of surviving peaks and the fraction within the requirement is visualized for reference. Check compliance with the requirement based on the REP module output. 6. Analyze observed results and compile report.

Requirements	Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017[AD3] Sentinel-5/UVNS - Instrument Requirements Specification, GS5.RS.ASG.UVNS.00012[AD7]: **IRS-109, IRS-1971, IRS-3067, IRS-3996, IRS-3997**
Prerequisites	• Correctly functioning instrument after SIOV with geolocation validated at instrument level. • Radiometric calibration available for products, allowing to identify ground features. • Other Cal/Val tests executed • EPS-SG PIQMICS installed
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning EPS-SG PDAP / TGPS.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Image Matching Tool (T12)
Required Test Data	• Several orbits of Sentinel-5 Level 1 data, located at the EPS-SG rolling buffer • Static tool-internal data Level 1 data
Entry Conditions	Nominal mode
Exit Conditions	Completion of test
Deliverables	Report, including visualization of geolocation performance and its compliance with the tested EURD requirements.
Team Involved	EUMETSAT/RSP INRC and ACh CAs.
Periodicity	The test for validating the geolocation requirements will be done during the commissioning phase.
Initial Duration	Approximately 1 hour per included orbit for processing. One week for analysis and report generation.
Recurrent Duration	Approximately 1 hour per included orbit, once the required data is accumulated.
Pass/Fail Criteria	Pass if the geolocation accuracy is within specification according to the tested requirements.
Comments	
Test Procedure	As per Test Sequence Description.

Validation of Wavelength Calibration Parameters (A5.2)

Item	Description
Test Name	S4_S5_L1_SPEC_CAL

Test Title	Validation of Wavelength Calibration Parameters (A5.2)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To verify that the wavelength calibration parameters measured on ground remain valid in-flight and to evaluate the stability of the spectral calibration and ISRF under different thermal conditions and orbital phase.
Test Sequence Description	Verify that the on-ground CKD relevant for spectral processing are still valid in flight by evaluating whether the degree of refinement required in the subsequent spectral calibration using Fraunhofer lines in the Sun or Earth spectrum is within expected limits. Evaluate the stability of the spectral axis of Earth radiance and solar irradiance measurements with respect to the thermal environment (specific choice of thermistors TBC) and in the case of the Earth radiance, orbital phase. The validity of the Doppler shift correction shall be verified in a similar fashion. Spectral knowledge shall be verified for Earth radiance and solar irradiance by analysing the spectral position of the Fraunhofer lines and by assessing the fit residuals from Level 2 retrievals. The ISRF knowledge is verified by comparing measured solar irradiance spectra, with high spectral resolution reference solar spectra, convolved with the nominal ISRF described in the CKD. For Earth radiance measurements, this verification will be complemented by analysis of Level 2 fit residuals for selected homogeneous scenes, identified on the basis of analysis of High Spatial Sampling (HSS) data and data from either the MTG-I Flexible Combined Imager (FCI) or in the case of Sentinel-5, METimage. In the case of Sentinel-4/UVN (the Sentinel-5/UVNS instrument includes a slit homogeniser, so this activity is not relevant) the predicted ISRF of Earth radiance measurements for heterogeneous scenes is verified by comparing measured Earth radiance spectra with synthetic spectra generated using the predicted ISRF for homogeneous cases and heterogeneous cases. Scene heterogeneity is characterised based on HSS data and imager data from MTG-I FCI.
Requirements	Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017[AD3] Sentinel-4/UVN - Instrument Requirements Specification, GS4.ASG.UVN.RS.00001[AD6] Sentinel-5/UVNS - Instrument Requirements Specification, GS5.RS.ASG.UVNS.00012[AD7]: **IRS-222**
Prerequisites	Successfully geolocation performance.
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Calibration Key Data Readers and Display (T1.2)

	Static Data Set Readers and Subset Selection (T1.3) Product Readers for Other Sensors on MTG and EPS-SG and Subset Selection (T1.4) Simple Mathematical Functions (T5) Interpolation Tools (Linear, Spline and Akima) (T7) Image Display Tools (T11) Report Generation Tools (T16)
Required Test Data	Sentinel-4/UVN and/or Sentinel-5/UVNS Level 1 data Sentinel-4/UVN and/or Sentinel-5/UVNS CKD One day of MTG FCI image data One day of EPS-SG METimage Level 1 data
Entry Conditions	Successful completion of instrument functional verification.
Exit Conditions	Validated wavelength calibration parameters.
Deliverables	Report on wavelength calibration performance.
Team Involved	EUMETSAT/RSP ACh CA and ESA.
Periodicity	Daily using Sun measurements and five (TBC) scan lines per scan (Sentinel-4/UVN) or five (TBC) scans per orbit (Sentinel-5/UVNS) for all Earthshine measurement modes during Commissioning phase.
Initial Duration	Commissioning phase.
Recurrent Duration	At the same frequency as during commissioning phase following any of the product processing software, for a period of 1 day.
Pass/Fail Criteria	Wavelength calibration parameters as calculated from CKD and subsequently refined using Fraunhofer lines in the Sun and Earth spectra are consistent with expectations. Stability of wavelength calibration with respect to thermal and orbital parameters is as expected. ISRF knowledge is consistent with CKD within expected limits.
Comments	
Test Procedure	Based on the tools outlined above, the test for Sentinel-5 performs following steps in an automated fashion: 1. Ingest Sentinel-5 OPF_ files (SPEC_DISP) from the EPS-SG rolling buffer folder and read the relevant variables. 2. Ingest Sentinel-5 CCDB files (SPEC_DISP) from the EPS-SG rolling buffer as reference data and read the same variables as step 1. 3. Read available data from a dedicated database (DB). 4. Run a statistical analysis on the time series. 5. Update the DB. 6. Prepare the test report.

Verification of Straylight Performance (A5.3)

Item	Description
Test Name	S4_S5_L1_STRAYLIGHT
Test Title	Verification of Straylight Performance (A5.3)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	Verification of the validity of the straylight kernels provided within the CKD and the successful functioning of the straylight correction algorithm.
Test Sequence Description	The straylight kernels provided within the CKD and generated from on-ground calibration and characterisation measurements need to be verified for in-flight conditions using solar irradiance and Earth radiance measurements with real spectral and spatial content. The verification of the straylight kernels and the assessment of the instrument straylight behaviour is complex and is expected to require a large effort. The detailed approach to this verification and assessment is partly anomaly driven. The strategy for straylight CKD verification might rely on two different methods ([RD59]: • employ redundancy and assess the consistency between measurements that are performed to derive straylight CKD • utilize the L1b processor to rectify measurements (those either unintended or insufficiently refine for generating straylight CKD) for straylight and look for residuals after straylight correction.
Requirements	Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017[AD3] Sentinel-4/UVN - Instrument Requirements Specification, GS4.ASG.UVN.RS.00001 [AD6] Sentinel-5/UVNS - Instrument Requirements Specification, GS5.RS.ASG.UVNS.00012[AD7]: **IRS-259, IRS-1707**
Prerequisites	Successfully verified instrument function and validated geolocation and wavelength calibration performance.
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Calibration Key Data Readers and Display (T1.2) Product Readers for Other Sensors on MTG and EPS-SG and Subset Selection (T1.4) Simple Mathematical Functions (T5) Statistical Analysis Tools (T6) Interpolation Tools (Linear, Spline and Akima) (T7) Image Display Tools (T11) Report Generation Tools (T16)

Required Test Data	Sentinel-4/UVN and/or Sentinel-5/UVNS Level 1 data Sentinel-4/UVN and/or Sentinel-5/UVNS CKD One day of MTG FCI image data One day of EPS-SG METimage Level 1 data
Entry Conditions	Successfully executed S4_S5_L1_GEO_EARTH and S4_S5_L1_SPEC_CAL.
Exit Conditions	Verified straylight performance.
Deliverables	Report on straylight performance.
Team Involved	EUMETSAT/RSP ACh CA and ESA.
Periodicity	Selected cases with high spatial and/or spectral contrast in the scene.
Initial Duration	Commissioning phase.
Recurrent Duration	At the same frequency as during commissioning phase following any software upgrades either of the product processing for a period of 1 day.
Pass/Fail Criteria	Straylight correction performs at a Level sufficient to allow the overall radiometric calibration error to be compliant with the requirements for all scenes.
Comments	
Test Procedure	Based on the tools outlined above, the test performs following steps in an automated fashion: 1. Ingest the Level 1 products and read the relevant variables. 2. Ingest the validated coastline maps and the reference data from FCI and METImage products and read the relevant variables. 3. Read available data from a dedicated database (DB). 4. Run a statistical analysis tool. 5. Update the DB. 6. Prepare the test report.

Verification of the Goniometry of the Solar Diffuser (A5.4)

Item	Description
Test Name	S4_S5_L1_DIFF_GON
Test Title	Verification of the Goniometry of the Solar Diffuser (A5.4)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To validate the CKD describing the goniometry of the solar diffusers of Sentinel-4/UVN and Sentinel-5/UVNS.
Test Sequence Description	The goniometry of the solar diffuser can be characterised in orbit using a time series of solar measurements, covering the complete angular space so that

	the complete range of anticipated incident elevation and azimuth angles on the solar diffuser are exercised. Calibrate measured solar spectra (with the exception of correction for solar diffuser goniometry) and sort as a function of solar elevation and azimuth angle bins. Correct the measured solar spectra for degradation of the instrument and the diffuser. Ratio to determine the goniometry of the solar diffuser as measured in orbit. Compare on-ground characterisation measurements of the diffuser goniometry with those obtained via dedicated spacecraft operations also providing higher angular sampling. This activity is linked to Validation of the Average Solar Irradiance Spectrum (A5.5)
Requirements	Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017[AD3] Sentinel-4/UVN - Instrument Requirements Specification, GS4.ASG.UVN.RS.00001 Sentinel-5/UVNS - Instrument Requirements Specification, GS5.RS.ASG.UVNS.00012: **IRS-4012**
Prerequisites	Successfully validated geolocation and wavelength calibration performance.
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Calibration Key Data Readers and Display (T1.2) Static Data Set Readers and Subset Selection (T1.3) Normalisation of Solar Spectra (T4) Simple Mathematical Functions (T5) Statistical Analysis Tools (T6) Interpolation Tools (Linear, Spline and Akima) (T7) Image Display Tools (T11) Report Generation Tools (T16)
Required Test Data	Sentinel-4/UVN and/or Sentinel-5/UVNS Level 1 Solar measurements Sentinel-4/UVN and/or Sentinel-5/UVNS CKD
Entry Conditions	Successfully executed S4_S5_L1_GEO_EARTH and S4_S5_L1_SPEC_CAL.
Exit Conditions	Verified solar diffuser goniometry performance.
Deliverables	Report on solar diffuser goniometry performance.
Team Involved	EUMETSAT/RSP ACh CA and ESA.

Periodicity	None.
Initial Duration	Commissioning phase.
Recurrent Duration	TBC depending on changes in instrument performance in-orbit.
Pass/Fail Criteria	Goniometry of the solar diffuser characterised to a Level sufficient to allow the overall irradiance calibration error to be compliant with the requirements.
Comments	NOTE: Dedicated platform operations required. Duration TBC with flight dynamics.
Test Procedure	Based on the tools outlined above, the test performs following steps in an automated fashion: 1. Ingest the Level 1 irradiance products read the relevant variables. 2. Ingest the on-ground CKD data and read the relevant variables. 3. Read available data from a dedicated database (DB). 4. Run a statistical analysis tool. 5. Update the DB. 6. Prepare the test report.

Validation of the Average Solar Irradiance Spectrum (A5.5)

Item	Description
Test Name	S4_S5_L1_IRR
Test Title	Validation of the Average Solar Irradiance Spectrum (A5.5)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To validate the Average Solar Irradiance Spectrum.
Test Sequence Description	The Average Solar Irradiance spectrum shall be compared to selected independent reference spectra. The following steps are required: Normalise Average Solar Irradiance spectra and reference spectral solar irradiance data to an Earth-Sun distance of 1 AU. Interpolate SMR and reference spectra to a common high resolution (e.g. 0.025 nm) wavelength grid using Akima or Spline interpolation. Convolve both interpolated spectra with a convolution kernel of ~1 nm FWHM. Calculate the difference spectrum. Compare the difference spectrum to the root mean square sum of the relative errors.
Requirements	Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017 [AD3] Sentinel-4/UVN - Instrument Requirements Specification, GS4.ASG.UVN.RS.00001 [AD6]

	Sentinel-5/UVNS - Instrument Requirements Specification, GS5.RS.ASG.UVNS.00012 [AD7]: **IRS-28, IRS-434, IRS-435, IRS-3772, IRS-4004, IRS-4571**
Prerequisites	Successfully verified instrument functioning and validated geolocation and wavelength calibration performance.
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Calibration Key Data Readers and Display (T1.2) Static Data Set Readers and Subset Selection (T1.3) Normalisation of Solar Spectra (T4) Simple Mathematical Functions (T5) Statistical Analysis Tools (T6) Interpolation Tools (Linear, Spline and Akima) (T7) Image Display Tools (T11) Report Generation Tools (T16)
Required Test Data	Sentinel-4/UVN and/or Sentinel-5/UVNS Level 1 Solar measurements High Resolution Reference Solar Irradiance Spectrum (D1.2) Total and Solar Spectral Irradiance Sensor (TSIS): Spectral Solar Irradiance Data (D4.1) The Sentinel-5/UVNS Precursor TROPOspheric Monitoring Instrument (TROPOMI) (D4.4)
Entry Conditions	Successfully executed S4_S5_L1_GEO_EARTH and S4_S5_L1_SPEC_CAL.
Exit Conditions	Validate Average Solar Irradiance spectrum.
Deliverables	Report on validation of Average Solar Irradiance spectrum.
Team Involved	EUMETSAT/RSP ACh CA and ESA.
Periodicity	During commissioning phase once per day until acceptable validation results are achieved.
Initial Duration	Commissioning phase.
Recurrent Duration	During routine operations once per month covering all latitudes and seasons subject to co-incidence criteria with selected reference irradiance data. Thereafter see the related monitoring activity, Monitor Instrument Throughput using Solar Measurements (A4.3.5).
Pass/Fail Criteria	Difference between Average Solar Irradiance measurements and reference spectral solar irradiance measurements, processed as above, less than the root mean square sum of the relative errors on both.

Comments	
Test Procedure	Based on the tools outlined above, the test for Sentinel-5 performs following steps in an automated fashion: 1. Ingest Sentinel-5 L1B irradiance product from the EPS-SG rolling buffer folder and read the relevant variables. 2. Read high-resolution reference solar irradiance spectrum. 3. Read available data from a dedicated database (DB). 4. Run normalisation, interpolation, statistical analysis tools. 5. Update the DB. 6. Prepare the test report.

Preliminary Validation of Earthshine Radiance Spectra and Albedo (A5.6)

Confidence Check Using UV Albedo (Sentinel-5/UVNS) (A5.6.1)

Item	Description
Test Name	S5_L1_UV
Test Title	Confidence Check Using UV Albedo (Sentinel-5/UVNS) (A5.6.1)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To provide a preliminary confidence check on the UV albedo from Sentinel-5/UVNS.
Test Sequence Description	Interpolate the radiance spectrum to the wavelength grid of the Average Solar Irradiance spectrum using Spline or Akima interpolation for all Earthshine measurements in a fixed number of scans (TBD) per orbit. Calculate the UV albedo as a ratio of the calibrated radiance spectrum to the Average Solar Irradiance spectrum in the wavelength range ~265-290nm. Compare the calculated UV albedo to coarse limits that define a physically reasonable range (exact values to be tuned according to in-flight experience). The spectral and temporal continuity of the UV albedo shall also be analysed to provide an independent estimate of the accuracy of the noise and dark current corrections.
Requirements	Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017[AD3] Sentinel-5/UVNS - Instrument Requirements Specification, GS5.RS.ASG.UVNS.00012[AD7]
Prerequisites	Successfully verified instrument functioning and validated geolocation and wavelength calibration performance.
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.

Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Normalisation of Solar Spectra (T4) Simple Mathematical Functions (T5) Statistical Analysis Tools (T6) Interpolation Tools (Linear, Spline and Akima) (T7) Image Display Tools (T11) Report Generation Tools (T16)
Required Test Data	Sentinel-4/UVN and/or Sentinel-5/UVNS Level 1 data
Entry Conditions	Successfully executed S4_S5_L1_GEO_EARTH, S4_S5_L1_SPEC_CAL and S4_S5_L1_IRR.
Exit Conditions	Confidence checked Sentinel-5 UV Albedo.
Deliverables	Confidence checks on the pre-flight characterisation of the radiance and irradiance response of the instrument and on the in-flight calibration of the radiance and irradiance spectra themselves Independent estimates of noise and dark signal correction
Team Involved	EUMETSAT/RSP ACh CA and ESA.
Periodicity	During commissioning phase five (TBC) scans per day until acceptable validation results are achieved.
Initial Duration	Commissioning phase.
Recurrent Duration	During routine operations per month and per year.
Pass/Fail Criteria	UV albedo falls within a pre-specified range. Independent estimates of noise and dark signal correction are consistent with in-flight calibration parameters.
Comments	
Test Procedure	Based on the tools outlined above, the test for Sentinel-5 performs following steps in an automated fashion: 1. Ingest Sentinel-5 L1B radiance and irradiance products from the EPS-SG rolling buffer folder and read the relevant variables. 2. Read available data from a dedicated database (DB). 3. Run normalisation, interpolation, statistical analysis tools. 4. Update the DB. 5. Prepare the test report.

Verification of Radiometric Accuracy using Imager Satellite Inter-Comparisons (A5.6.2)

Item	Description
Test Name	S4_S5_L1_RAD_SAT_IMG

Test Title	Verification of Radiometric Accuracy using Imager Satellite Inter-Comparisons (A5.6.2)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To compare the Sentinel-4/UVN and Sentinel-5/UVNS Level 1 radiance data with other independently validated imager satellite data.
Test Sequence Description	Select collocated Earth radiance spectra from other satellite-based sensors which satisfy user defined coincidence criteria including geographical and temporal collocation and equivalence of viewing geometry. Ideally use nadir ground pixels for the comparison. Furthermore, only cloud-free scenes should be selected. Interpolate the Sentinel-4/UVN and/or Sentinel-5/UVNS and validation spectra to a common high resolution wavelength grid using Akima or Spline interpolation in they are of comparable spectral resolution. Convolve both interpolated spectra with a convolution kernel of predefined FWHM. Calculate the necessary metrics to compare the instruments and estimate radiometric bias
Requirements	Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017 [AD3] Sentinel-4/UVN - Instrument Requirements Specification, GS4.ASG.UVN.RS.00001 [AD6] Sentinel-5/UVNS - Instrument Requirements Specification, GS5.RS.ASG.UVNS.00012 [AD7]:
Prerequisites	Successfully verified instrument functioning and validated geolocation and wavelength calibration performance. EPS-SG MICMICS installed
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	MICMICS (Mission Integrated Calibration Monitoring & Inter-Calibration System)
Required Test Data	Sentinel-4/UVN and/or Sentinel-5/UVNS Level 1 data Sentinel-3 OLCI and SLSTR data MTG-I FCI data NOAA VIIRS data
Entry Conditions	Successfully executed S4_S5_L1_GEO_EARTH, S4_S5_L1_SPEC_CAL and S4_S5_L1_IRR.
Exit Conditions	Cross-compared Sentinel-4/UVN and/or Sentinel-5 UVNS Level 1 radiance data.

Deliverables	Cross-comparison report for Sentinel-4/UVN and/or Sentinel-5 UVNS Level 1 radiance spectra as compared to independent satellite-based nadir radiance spectra.
Team Involved	EUMETSAT/RSP INRC and ACh CAs and ESA.
Periodicity	Per scan/orbit during commissioning phase for selected ground pixels. Note: The analysis requires a time series of data (e.g., several weeks to months) for meaningful evaluation.
Initial Duration	Commissioning phase.
Recurrent Duration	During routine operations for selected orbits and ground scenes.
Pass/Fail Criteria	Difference between Sentinel-4/UVN and/or Sentinel-5 UVNS radiance spectra and independent nadir radiance spectra larger than user requirement bias. Note: this may be extremely difficult to achieve given the high temporal and spatial variability of the observed scene and the dependence on viewing geometry.
Comments	
Test Procedure	The test performs following steps in an automated fashion: 1. Ingest the Level 1 products read the relevant variables. 2. Ingest other satellite Level 1 products as reference data and read the relevant variables. 3. Read available data from a dedicated database (DB). 4. Run dedicated MICMICS workflows. 5. Update the DB. 6. Prepare the test report.

Verification of Radiometric Accuracy using Hyperspectral Satellite Inter-Comparisons (A5.6.3)

Item	Description
Test Name	S4_S5_L1_RAD_SAT_HYP
Test Title	Verification of Radiometric Accuracy using Hyperspectral Satellite Inter-Comparisons (A5.6.3)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To compare the Sentinel-4/UVN and Sentinel-5/UVNS Level 1 radiance data with other independently validated hyperspectral satellite data.
Test Sequence Description	Select collocated Earth radiance spectra from other satellite-based sensors which satisfy user defined coincidence criteria including geographical and temporal collocation and equivalence of viewing geometry. Ideally use nadir ground pixels for the comparison. Furthermore, only cloud-free scenes should be selected.

	Interpolate the Sentinel-4/UVN and/or Sentinel-5/UVNS and validation spectra to a common high resolution (e.g. 0.025 nm) wavelength grid using Akima or Spline interpolation in they are of comparable spectral resolution. Convolve both interpolated spectra with a convolution kernel of ~1 nm FWHM. If the Sentinel-4/UVN and/or Sentinel-5/UVNS measurements are of higher spectral resolution than the validation spectra, convolve the Sentinel-4/UVN and/or Sentinel-5/UVNS measurements with the spectral response function of the validation spectra. Calculate the necessary metrics to compare the instruments and estimate radiometric bias The utility of this method may be restricted to the Ultra-Violet region where the sensitivity to clouds and surface albedo is reduced.
Requirements	Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017 [AD3] Sentinel-4/UVN - Instrument Requirements Specification, GS4.ASG.UVN.RS.00001 [AD6] Sentinel-5/UVNS - Instrument Requirements Specification, GS5.RS.ASG.UVNS.00012 [AD7]:
Prerequisites	Successfully verified instrument functioning and validated geolocation and wavelength calibration performance. EPS-SG MICMICS installed
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	MICMICS (Mission Integrated Calibration Monitoring & Inter-Calibration System)
Required Test Data	Sentinel-4/UVN and/or Sentinel-5/UVNS Level 1 data The Global Ozone Monitoring Experiment (GOME-2) on MetOp (D4.2) The Sentinel-5/UVNS Precursor TROPOspheric Monitoring Instrument (TROPOMI) (D4.4) The Ozone Mapping and Profiler Suite (OMPS) (D4.5) Geostationary Environment Monitoring Spectrometer (GEMS) (D4.6) Tropospheric Emissions: Monitoring of POllution (TEMPO) (D4.7)
Entry Conditions	Successfully executed S4_S5_L1_GEO_EARTH, S4_S5_L1_SPEC_CAL and S4_S5_L1_IRR.
Exit Conditions	Cross-compared Sentinel-4/UVN and/or Sentinel-5 UVNS Level 1 radiance data.
Deliverables	Cross-comparison report for Sentinel-4/UVN and/or Sentinel-5 UVNS Level 1 radiance spectra as compared to independent satellite-based nadir radiance spectra.
Team Involved	EUMETSAT/RSP INRC and ACh CAs and ESA.

Periodicity	Per scan/orbit during commissioning phase for selected ground pixels. Note: The analysis requires a time series of data (e.g., several weeks to months) for meaningful evaluation.
Initial Duration	Commissioning phase.
Recurrent Duration	During routine operations for selected orbits and ground scenes.
Pass/Fail Criteria	Difference between Sentinel-4/UVN and/or Sentinel-5 UVNS radiance spectra and independent nadir radiance spectra larger than user requirement bias. Note: this may be extremely difficult to achieve given the high temporal and spatial variability of the observed scene and the dependence on viewing geometry.
Comments	
Test Procedure	The test performs following steps in an automated fashion: 1. Ingest the Level 1 products read the relevant variables. 2. Ingest other satellite Level 1 products as reference data and read the relevant variables. 3. Read available data from a dedicated database (DB). 4. Run dedicated MICMICS workflows. 5. Update the DB. 6. Prepare the test report.

Verification of Radiometric Accuracy using Pseudo-Invariant Calibration Targets (PICTs) (A5.6.4)

Item	Description
Test Name	S4_S5_L1_RAD_PICTs
Test Title	Verification of Radiometric Accuracy using Pseudo-Invariant Calibration Targets (PICTs) (A5.6.4)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To compare the Sentinel-4/UVN and Sentinel-5/UVNS Level 1 radiance data against reference spectra over Pseudo-Invariant Calibration Targets (PICTs)
Test Sequence Description	Subset Sentinel-4/UVN and/or Sentinel-5/UVNS radiance over predefined PICTs. Collect relevant atmospheric and surface variables per each observation Calculated simulated spectra using a reference model (e.g. radiative transfer), for the exact viewing geometry of the Sentinel-4/UVN and/or Sentinel-5/UVNS ground pixel to be compared. Convolve the simulated spectrum with the spectral response function of the Sentinel-4/UVN and/or Sentinel-5/UVNS instrument and bin the data to predefined spectral resolution. Calculate the absolute radiometric bias and compare the bias with absolute accuracy requirements for Sentinel-4/UVN and/or Sentinel-5/UVNS Calculate the stability over time (when applicable)

	Note: stability validation oftens requires longer time series (e.g. 6 months)
Requirements	Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017 [AD3] Sentinel-4/UVN - Instrument Requirements Specification, GS4.ASG.UVN.RS.00001 [AD6] Sentinel-5/UVNS - Instrument Requirements Specification, GS5.RS.ASG.UVNS.00012 [AD7]
Prerequisites	Successfully verified instrument functioning and validated geolocation and wavelength calibration performance. EPS-SG MICMICS installed
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	MICMICS (Mission Integrated Calibration Monitoring & Inter-Calibration System)
Required Test Data	Sentinel-4/UVN and/or Sentinel-5/UVNS Level 1 data Trace Gas Climatology Data (D1.3) Data from Ground-based Sensors (D3)
Entry Conditions	Successfully executed S4_S5_L1_GEO_EARTH, S4_S5_L1_SPEC_CAL and S4_S5_L1_IRR.
Exit Conditions	Cross-compared Sentinel-4/UVN and/or Sentinel-5 UVNS Level 1 radiance data.
Deliverables	Cross-comparison report for Sentinel-4/UVN and/or Sentinel-5 UVNS radiance spectra as compared to simulated spectra calculated using a reference model.
Team Involved	EUMETSAT/RSP INRC and ACh CAs and ESA.
Periodicity	Per scan/orbit during commissioning phase for selected orbits and sites. Note: The analysis requires a time series of data (e.g., several weeks to months) for meaningful evaluation
Initial Duration	Commissioning phase.
Recurrent Duration	During routine operations for selected orbits and sites.
Pass/Fail Criteria	Difference between Sentinel-4/UVN and/or Sentinel-5 UVNS radiance spectra and simulated spectra less than the absolute error (and when applicable relative error) on the Sentinel-4/UVN and/or Sentinel-5 UVNS radiance spectra.
Comments	
Test Procedure	The test performs following steps in an automated fashion: 1. Ingest the Level 1 products read the relevant variables.

	2. Ingest simulated spectra from reference data and read the relevant variables. 3. Read available data from a dedicated database (DB). 4. Run dedicated MICMICS workflows. 5. Update the DB. 6. Prepare the test report.

Verification of Radiometric Performance using Moon Observations (A5.6.5)

Item	Description
Test Name	S4_S5_L1_MOON
Test Title	Verification of Radiometric Performance using Moon Observations (A5.6.5)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To verify the radiometric accuracy of Level 1 radiance data.
Test Sequence Description	Using moon observations, if and when available, for Sentinel-4/UVN and Sentinel-5/UVNS select observations that satisfy defined lunar phase, fraction and lunar observation angle requirements. Verify the radiometric calibration of the moon observations by comparison to the GSICS Implementation of the ROLO model (GIRO) and LESSR model (based on SCIAMACHY and RELAB). For more information, see http://gsics.atmos.umd.edu/bin/view/Development/LunarWorkArea.
Requirements	Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017[AD3] Sentinel-4/UVN - Instrument Requirements Specification, GS4.ASG.UVN.RS.00001 [AD6]
Prerequisites	Successfully verified instrument functioning and validated geolocation and wavelength calibration performance. EPS-SG MICMICS installed
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Validation Data Product Readers and Subset Selection (T1.6) Simple Mathematical Functions (T5) Interpolation Tools (Linear, Spline and Akima) (T7) Image Display Tools (T11) MICMICS Vicarious calibration and Inter-Calibration (T15)
Required Test Data	Sentinel-4/UVN and/or Sentinel-5/UVNS Level 1 data, including time, attitude and orbit files.

	Typical SRFs for the instruments
Entry Conditions	Successfully executed S4_S5_L1_GEO_EARTH, S4_S5_L1_SPEC_CAL.
Exit Conditions	Partially validated Sentinel-4/UVN and/or Sentinel-5 UVNS Level 1 radiance data.
Deliverables	Report on partial validation of Sentinel-4/UVN and/or Sentinel-5 UVNS Level 1 radiance data.
Team Involved	EUMETSAT/RSP INRC and ACh CAs and ESA.
Periodicity	For all moon observation periods available during commissioning (S5/UVNS & S4/UVN) and operational phase (S4/UVN).
Initial Duration	Commissioning phase.
Recurrent Duration	During routine operations for selected orbits and ground scenes.
Pass/Fail Criteria	Agreement between calibrated moon observations and output of the GIRO and LESSR with an expected accuracy of between 5% and 10% (1σ) for the GIRO and about 2% for LESSR.
Comments	
Test Procedure	Based on the tools outlined above, the test performs following steps in an automated fashion: 1. Ingest the Level 1 products and extract the relevant variables to prepare the input files to the GIRO. 2. Run sequentially i) the GIRO and ii) the LESSR models 3. Ingest GIRO and LESSR reference data in the MICMICS Calibration Output database. 4. Read available data from a dedicated database (DB). 5. Run the MICMICS Data and Reporting Analysis module to analyse the results. 6. Prepare the test report.

Reporting Level 1 Verification, Confidence Checking and Validation Activities (A5.7)

Item	Description
Test Name	S4_S5_L1_REPORT
Test Title	Reporting Level 1 Verification, Confidence Checking and Validation Activities (A5.7)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To report the instrument monitoring activities in a summary report.

Test Sequence Description	Report all results of Level 1 Verification, Confidence Checking and Validation activities in summary format. Summarise results in the following categories: Verification and Validation of Geolocation Information (A5.1) Validation of Geolocation Information for Earth Measurements (Sentinel-5/UVNS) (A5.1.4) Verification of Straylight Performance (A5.3) Verification of the Goniometry of the Solar Diffuser (A5.4) Validation of the Average Solar Irradiance Spectrum (A5.5) Preliminary Validation of Earthshine Radiance Spectra and Albedo (A5.6) Where appropriate results shall be presented as a function of: observation mode Solar Zenith Angle viewing angle latitude and longitude Results shall at a minimum be presented in the form of: Time series plots and analysis Spectral plots 2-dimensional maps Scatter plots Recommendations for update of degradation correction factors shall be made where appropriate including reference to the updated verified degradation correction factor file and a description of the analysis which justifies the update.
Requirements	None.
Prerequisites	Successfully verified instrument function.
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Report Generation Tools (T16)
Required Test Data	Output of Level 1 Verification, Confidence Checking and Validation activities.
Entry Conditions	Successful completion of instrument functional verification.
Exit Conditions	None – monitoring function.
Deliverables	Summary report on Level 1 Verification, Confidence Checking and Validation activities. Recommendations for upgrades to Level 0 to 1 processing algorithms and software Recommendations for update of degradation correction factors where appropriate.

Team Involved	EUMETSAT/RSP ACh CA and ESA.
Periodicity	Per month, and per year.
Initial Duration	N/A.
Recurrent Duration	N/A.
Pass/Fail Criteria	No pass/fail criteria - monitoring purposes only.
Comments	Required for complete lifetime of the missions.
Test Procedure	Based on the tools outlined above, the test for Sentinel-5 performs following steps in an automated fashion:6 1. Read all the variables (A5.1-A5.6) from DB. 2. Run analysis. 3. Generate the daily/weekly/monthly results. 4. Prepare the test report.

Geophysical Parameter Verification and Validation (A6)

Validation of Ozone Profile Measurements (A6.1)

Validation of Ozone Profiles using Ground-Based Measurements (A6.1.1)

Item	Description
Test Name	S4_S5_L2_O3P_GROUND
Test Title	Validation of Ozone Profiles using Ground-Based Measurements (A6.1.1)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To validate the O_3 profile products using ground-based reference data.
Test Sequence Description	The O_3 profile information shall be compared to independent validated O_3 profile information obtained from ground-based measurements. The following steps are required: collocated data are selected on the basis of user configurable coincidence criteria which will vary depending on the characteristics of the individual data sets. the collocated data are sorted per instrument and per instrument class and/or station. collocated profiles must be sampled at the same vertical resolution, appropriate only to the ozone profile information – typically this will require that the profile with higher vertical resolution is convolved with the averaging kernel of the lower vertical resolution profile. the difference between the collocated profile pairs should be calculated and compared to their expected accuracy. the results for all collocated profiles are to be sorted on the basis of: Solar Zenith Angle viewing angle

	cloud fraction atmospheric aerosol loading total column ozone amount latitude and longitude and a statistical analysis carried out. particular attention is to be paid to correlations between any of the above quantities and the differences in the collocated data pairs. In the event that differences in spatial or temporal collocation are greater than the user defined tolerances access to Chemical Transport Models and/or Data Assimilation Models will be required to aid interpretation. For the purposes of long-term validation and trend assessment, time series of collocated data at selected locations and in the zonal mean shall also be analysed.
Requirements	Sentinel-4 Level-2 Processor Requirements Specification, S4.ESA.UVN.RS.0093, Issue 2, Revision 1, 27/11/2018 [AD4] Sentinel-5 Level-2 Prototype Processor Development Requirements Specification, S5-RS-ESA-GR-0131, Issue 1, Revision 8, 15 July 2019 [AD5] Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017 [AD3]: **A1, A2, A3, B1, B2, B3, C1, C2, C3** See also Table 5.4 and Table 5.10
Prerequisites	Successfully verified and partially validated Level 1 products
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Validation Data Product Readers and Subset Selection (T1.6) Collocation Tool (T3) Simple Mathematical Functions (T5) Statistical Analysis Tools (T6) Interpolation Tools (Linear, Spline and Akima) (T7) Image Display Tools (T11) Report Generation Tools (T16)
Required Test Data	**Level 2 Ozone Profile Product comprising:** O_3 profile information Vertical retrieval grid Averaging kernel Date/time information Geolocation information **Validated O_3 Profiles from Ground-based Measurements**

	The World Meteorological Global Atmosphere Watch Program (GAW) (D3.1) The Network for the Detection of Atmospheric Composition Change (NDACC) (D3.3) The Pandonia Global network (PGN) (D3.5) The Tropospheric Ozone Lidar Network (TOLNet) (D3.6) The Aerosol, Clouds and Trace Gases Research Infrastructure (ACTRIS) (D3.14) **For further information see D3 on page 91.** **Ozone Profile Information from Chemical Data Assimilation Analysis Fields** European Centre for Medium Range Weather Forecasting (ECMWF) and Copernicus Atmosphere Monitoring Service (CAMS) Analysis & Forecast Fields (D6)
Entry Conditions	At successful completion of Level 1 checking and verification activities. Carried out in parallel to Level 1 validation activities
Exit Conditions	Validated ozone profile product with respect to ground-based data.
Deliverables	Ozone profile validation report including feedback to the Sentinel-4/UVN and Sentinel-5/UVNS Level 1b validation activities.
Team Involved	EUMETSAT/RSP ACh CA and ESA.
Periodicity	During commissioning phase for selected orbits corresponding to availability of ground-based ozone profile measurements, until satisfactory agreement is reached within the constraints of the characteristics of both measurement data and the expected product accuracy.
Initial Duration	Commissioning phase.
Recurrent Duration	Continue during routine operations until O_3 profile information has been validated for all representative latitudes and seasons. Thereafter continue monitoring activities at a reduced frequency.
Pass/Fail Criteria	Difference between O_3 profiles generated from Sentinel-4/UVN and Sentinel-5/UVNS data and those from ground-based measurements less than the root mean square sum of the absolute errors on both, for all latitudes and seasons, taking into account differences in representativeness and collocation. See also requirements.
Comments	Required for complete lifetime of the missions.
Test Procedure	Based on the tools outlined above, the test performs following steps in an automated fashion: 1. Ingest ozone profile products and read the relevant variables. 2. Ingest ozone profile data from ground-based measurements. 3. Read available data from a dedicated database (DB). 4. Run colocation tool and statistical analysis tool.

5. Update the DB.
6. Prepare the test report.

Validation of Ozone Profiles using Validated Satellite Measurements (A6.1.2)

Item	Description
Test Name	S4_S5_L2_O3P_SAT
Test Title	Validation of Ozone Profiles using Validated Satellite Measurements (A6.1.2)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To validate the O_3 profile products using validated satellite data.
Test Sequence Description	The O_3 profile information shall be compared to independent validated O_3 profile information obtained from satellite measurements. The following steps are required: collocated data are selected on the basis of user configurable coincidence criteria which will vary depending on the characteristics of the individual data sets the collocated data are sorted per instrument collocated profiles must be sampled at the same vertical resolution, appropriate only to the ozone profile information – typically this will require that the profile with higher vertical resolution is convolved with the averaging kernel of the lower vertical resolution profile the difference between the collocated profile pairs should be calculated and compared to their expected accuracy the results for all collocated profiles are to be sorted on the basis of: Solar Zenith Angle viewing angle cloud fraction atmospheric aerosol loading total column ozone amount latitude and longitude and a statistical analysis carried out particular attention is to be paid to correlations between any of the above quantities and the differences in the collocated data pairs. In the event that differences in spatial or temporal collocation are greater than the user defined tolerances access to Chemical Transport Models and/or Data Assimilation Models will be required to aid interpretation. For the purposes of long-term validation and trend assessment, time series of collocated data at selected locations and in the zonal mean shall also be analysed.
Requirements	Sentinel-4 Level-2 Processor Requirements Specification, S4.ESA.UVN.RS.0093, Issue 2, Revision 1, 27/11/2018 [AD4]

	Sentinel-5 Level-2 Prototype Processor Development Requirements Specification, S5-RS-ESA-GR-0131, Issue 1, Revision 8, 15 July 2019 [AD5] Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017 [AD3]: **A1, A3, B1, B2, C2, C3** See also Table 5.4 and Table 5.10
Prerequisites	Successfully verified and partially validated Level 1 products
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Validation Data Product Readers and Subset Selection (T1.6) Collocation Tool (T3) Simple Mathematical Functions (T5) Statistical Analysis Tools (T6) Interpolation Tools (Linear, Spline and Akima) (T7) Image Display Tools (T11) Report Generation Tools (T16)
Required Test Data	**Level 2 Ozone Profile Product comprising:** O_3 profile information Vertical retrieval grid Averaging kernel Date/time information Geolocation information **Six months of validated O_3 profiles from satellite measurements:** The Global Ozone Monitoring Experiment (GOME-2) on MetOp (D4.2) The Sentinel-5/UVNS Precursor TROPOspheric Monitoring Instrument (TROPOMI) (D4.4) The Ozone Mapping and Profiler Suite (OMPS) (D4.5) Geostationary Environment Monitoring Spectrometer (GEMS) (D4.6) Tropospheric Emissions: Monitoring of POllution (TEMPO) (D4.7)) **For further information see D4 on page 97.** **Ozone Profile Information from Chemical Data Assimilation Analysis Fields** European Centre for Medium Range Weather Forecasting (ECMWF) and Copernicus Atmosphere Monitoring Service (CAMS) Analysis & Forecast Fields (D6)
Entry Conditions	At successful completion of Level 1 checking and verification activities. Carried out in parallel to Level 1 validation activities

Exit Conditions	Validated ozone profile product with respect to other validated satellite data.
Deliverables	Ozone profile validation report including feedback to the Sentinel-4/UVN and Sentinel-5/UVNS Level 1b validation activities.
Team Involved	EUMETSAT/RSP ACh CA and ESA.
Periodicity	During commissioning phase for selected orbits, until satisfactory agreement is reached within the constraints of the characteristics of both measurement data and the expected product accuracy.
Initial Duration	Commissioning phase.
Recurrent Duration	Continue during routine operations until O_3 profile information has been validated for all representative latitudes and seasons. Thereafter continue monitoring activities at a reduced frequency.
Pass/Fail Criteria	Difference between O_3 profiles generated from Sentinel-4/UVN and Sentinel-5/UVNS data and those from independent satellite measurement less than the root mean square sum of the absolute errors on both, for all latitudes and seasons, taking into account differences in representativeness and collocation. See also requirements.
Comments	Required for complete lifetime of the missions.
Test Procedure	Based on the tools outlined above, the test performs following steps in an automated fashion: 1. Ingest ozone profile products and read the relevant variables. 2. Ingest ozone profile data from other satellite measurements. 3. Read available data from a dedicated database (DB). 4. Run colocation tool and statistical analysis tool. 5. Update the DB. 6. Prepare the test report.

Validation of Ozone Profiles using Campaign, Aircraft and Balloon Measurements (A6.1.3)

This activity will be carried out in the frame of an AO Call to be initiated by ESA, with the support of EUMETSAT. Detailed activity descriptions will depend on the contributions to the AO Call.

Validation of Ozone Profiles using Chemical Data Assimilation Analysis Fields (A6.1.4)

Item	Description
Test Name	S4_S5_L2_O3P_CDA
Test Title	Validation of Ozone Profiles using Chemical Data Assimilation Analysis Fields (A6.1.4)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To validate the O_3 profile products using Chemical Data Assimilation Analysis fields.

Test Sequence Description	The O_3 profile information shall be compared to CAMS O_3 analysis fields. The following steps are required: collocated analysis fields are selected on the basis of user configurable coincidence criteria model fields are interpolated in the horizontal to the measurement location model fields are interpolated in the vertical to the vertical resolution of the measurement the difference between the model and measurement profile pairs should be calculated and compared to the expected measurement accuracy the results for all pairs of model and measurement profiles are to be sorted on the basis of: Solar Zenith Angle (of the Sentinel-4/UVN and Sentinel-5/UVNS measurements) viewing angle cloud fraction atmospheric aerosol loading total column ozone amount latitude and longitude land/sea season and a statistical analysis carried out. particular attention is to be paid to correlations between any of the above quantities and the differences in the collocated data pairs.
Requirements	Sentinel-4 Level-2 Processor Requirements Specification, S4.ESA.UVN.RS.0093, Issue 2, Revision 1, 27/11/2018 [AD4] Sentinel-5 Level-2 Prototype Processor Development Requirements Specification, S5-RS-ESA-GR-0131, Issue 1, Revision 8, 15 July 2019 [AD5] Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017 [AD3]: **A1, A2, A3, B1, B2, B3, C1, C2, C3** See also Table 5.4 and Table 5.10
Prerequisites	Successfully verified and partially validated Level 1 products
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Validation Data Product Readers and Subset Selection (T1.6) Grib and BUFR Readers (T1.7) Collocation Tool (T3) Simple Mathematical Functions (T5) Statistical Analysis Tools (T6)

	Interpolation Tools (Linear, Spline and Akima) (T7) Image Display Tools (T11) Report Generation Tools (T16)
Required Test Data	**Level 2 Ozone Profile Product comprising:** O_3 profile information Vertical retrieval grid Averaging kernel Date/time information Geolocation information **Ozone Profile Information from Chemical Data Assimilation Analysis Fields** European Centre for Medium Range Weather Forecasting (ECMWF) and Copernicus Atmosphere Monitoring Service (CAMS) Analysis & Forecast Fields (D6) **For further information see D6 on page 105.**
Entry Conditions	At successful completion of Level 1 checking and verification activities. Carried out in parallel to Level 1 validation activities
Exit Conditions	Validated ozone profile product with respect to Chemical Data Assimilation analysis fields.
Deliverables	Ozone profile validation report including feedback to the Sentinel-4/UVN and Sentinel-5/UVNS Level 1b validation activities.
Team Involved	EUMETSAT/RSP ACh CA and ESA.
Periodicity	During commissioning phase for selected days, until satisfactory agreement is reached within the constraints of the characteristics of both measurement data and the expected product accuracy.
Initial Duration	Commissioning phase.
Recurrent Duration	Continue during routine operations until O_3 profile information has been validated for all representative latitudes and seasons. Thereafter continue monitoring activities at a reduced frequency.
Pass/Fail Criteria	Mean difference between O_3 profiles generated from Sentinel-4/UVN and Sentinel-5/UVNS data and those from analysis fields less than the root mean square sum of the measurement error for all latitudes and seasons. See also requirements.
Comments	Required for complete lifetime of the missions. In the case that operational Level 2 products are monitored by CAMS, all data is used for the lifetime of the mission and the activity is performed at CAMS.
Test Procedure	Based on the tools outlined above, the test performs following steps in an automated fashion:

	1. Ingest ozone profile products and read the relevant variables. 2. Ingest ozone profile information from CAMS. 3. Read available data from a dedicated database (DB). 4. Run colocation tool and statistical analysis tool. 5. Update the DB. 6. Prepare the test report.

Validation of Total Column Ozone Measurements (A6.2)

Validation of Total Column Ozone using Ground-Based Measurements (A6.2.1)

Item	Description
Test Name	S4_S5_L2_TCO_GROUND
Test Title	Validation of Total Column Ozone using Ground-Based Measurements (A6.2.1)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To validate the total column ozone products using ground-based reference data.
Test Sequence Description	The total column ozone information shall be compared to independent validated total column ozone information obtained from ground-based measurements. The following steps are required: collocated data are selected on the basis of user configurable coincidence criteria which will vary depending on the characteristics of the individual data sets the collocated data are sorted per instrument and per instrument class and/or station the difference between the collocated measurement pairs should be calculated and compared to their expected accuracy the results for all collocated measurements are to be sorted on the basis of: Solar Zenith Angle viewing angle cloud fraction atmospheric aerosol loading total column ozone amount latitude and longitude and a statistical analysis carried out particular attention is to be paid to correlations between any of the above quantities and the differences in the collocated data pairs. In the event that differences in spatial or temporal collocation are greater than the user defined tolerances access to Chemical Transport Models and/or Data Assimilation Models will be required to aid interpretation.

	For the purposes of long-term validation and trend assessment, time series of collocated data at selected locations and in the zonal mean shall also be analysed.
Requirements	Sentinel-4 Level-2 Processor Requirements Specification, S4.ESA.UVN.RS.0093, Issue 2, Revision 1, 27/11/2018 [AD4] Sentinel-5 Level-2 Prototype Processor Development Requirements Specification, S5-RS-ESA-GR-0131, Issue 1, Revision 8, 15 July 2019 [AD5] Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017 [AD3]: **A1, A2, B1, B2, C2, C3** See also Table 5.4 and Table 5.10
Prerequisites	Successfully verified and partially validated Level 1 products
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Validation Data Product Readers and Subset Selection (T1.6) Collocation Tool (T3) Simple Mathematical Functions (T5) Statistical Analysis Tools (T6) Interpolation Tools (Linear, Spline and Akima) (T7) Image Display Tools (T11) Report Generation Tools (T16)
Required Test Data	**Level 2 Total Column Ozone Product comprising:** Total column ozone information Averaging kernel Date/time information Geolocation information **Validated Total Column Ozone data from Ground-based Measurements** The World Meteorological Global Atmosphere Watch Program (GAW) (D3.1) The Network for the Detection of Atmospheric Composition Change (NDACC) (D3.3) The Pandonia Global network (PGN) (D3.5) The Tropospheric Ozone Lidar Network (TOLNet) (D3.6) The Aerosol, Clouds and Trace Gases Research Infrastructure (ACTRIS) (D3.14) **For further information see D3 on page 91.** **Total Column Ozone Information from Chemical Data Assimilation Analysis Fields**

	European Centre for Medium Range Weather Forecasting (ECMWF) and Copernicus Atmosphere Monitoring Service (CAMS) Analysis & Forecast Fields (D6)
Entry Conditions	At successful completion of Level 1 checking and verification activities. Carried out in parallel to Level 1 validation activities
Exit Conditions	Validated total column ozone product with respect to ground-based data.
Deliverables	Total column ozone validation report including feedback to the Sentinel-4/UVN and Sentinel-5/UVNS Level 1b validation activities.
Team Involved	EUMETSAT/RSP ACh CA and ESA.
Periodicity	During commissioning phase for selected days corresponding to availability of ground-based total column ozone measurements, until satisfactory agreement is reached within the constraints of the characteristics of both measurement data and the expected product accuracy.
Initial Duration	Commissioning phase.
Recurrent Duration	Continue during routine operations until total column ozone information has been validated for all representative latitudes and seasons. Thereafter continue monitoring activities at a reduced frequency.
Pass/Fail Criteria	Difference between total column ozone data generated from Sentinel-4/UVN and Sentinel-5/UVNS data and those from ground-based measurements less than the root mean square sum of the absolute errors on both, for all latitudes and seasons, taking into account differences in representativeness and collocation. See also requirements.
Comments	Required for complete lifetime of the missions.
Test Procedure	Based on the tools outlined above, the test for Sentinel-5 performs following steps in an automated fashion: 1. Ingest Sentinel-5 total ozone products from the EPS-SG rolling buffer folder and read the relevant variables. 2. Ingest the total ozone column data from ground-based measurements. 3. Read available data from a dedicated database (DB). 4. Run colocation tool and statistical analysis tool. 5. Update the DB. 6. Prepare the test report.

Validation of Total Column Ozone using Validated Satellite Measurements (A6.2.2)

Item	Description
Test Name	S4_S5_L2_TCO_SAT
Test Title	Validation of Total Column Ozone using Validated Satellite Measurements (A6.2.2)

WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To validate the total column ozone products using validated satellite reference data.
Test Sequence Description	The total column ozone information shall be compared to independent validated total column ozone information obtained from satellite measurements. The following steps are required: collocated data are selected on the basis of user configurable coincidence criteria which will vary depending on the characteristics of the individual data sets the collocated data are sorted per instrument the difference between the collocated measurements pairs should be calculated and compared to their expected accuracy the results for all collocated profiles are to be sorted on the basis of: Solar Zenith Angle viewing angle cloud fraction atmospheric aerosol loading total column ozone amount latitude and longitude and a statistical analysis carried out particular attention is to be paid to correlations between any of the above quantities and the differences in the collocated data pairs. In the event that differences in spatial or temporal collocation are greater than the user defined tolerances access to Chemical Transport Models and/or Data Assimilation Models will be required to aid interpretation. For the purposes of long-term validation and trend assessment, time series of collocated data at selected locations and in the zonal mean shall also be analysed.
Requirements	Sentinel-4 Level-2 Processor Requirements Specification, S4.ESA.UVN.RS.0093, Issue 2, Revision 1, 27/11/2018 [AD4] Sentinel-5 Level-2 Prototype Processor Development Requirements Specification, S5-RS-ESA-GR-0131, Issue 1, Revision 8, 15 July 2019 [AD5] Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017 [AD3]: **A1, A2, B1, B2, C2, C3** See also Table 5.4 and Table 5.10
Prerequisites	Successfully verified and partially validated Level 1 products
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.

Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Validation Data Product Readers and Subset Selection (T1.6) Collocation Tool (T3) Simple Mathematical Functions (T5) Statistical Analysis Tools (T6) Interpolation Tools (Linear, Spline and Akima) (T7) Image Display Tools (T11) Report Generation Tools (T16)
Required Test Data	**Level 2 Total Column Ozone Product comprising:** Total column ozone information Averaging kernel Date/time information Geolocation information **Six months of validated total column ozone from satellite measurements:** The Global Ozone Monitoring Experiment (GOME-2) on MetOp (D4.2) The Sentinel-5/UVNS Precursor TROPOspheric Monitoring Instrument (TROPOMI) (D4.4) The Ozone Mapping and Profiler Suite (OMPS) (D4.5) Geostationary Environment Monitoring Spectrometer (GEMS) (D4.6) Tropospheric Emissions: Monitoring of POllution (TEMPO) (D4.7)) **For further information see D4 on page 97.** **Total Column Ozone Information from Chemical Data Assimilation Analysis Fields** European Centre for Medium Range Weather Forecasting (ECMWF) and Copernicus Atmosphere Monitoring Service (CAMS) Analysis & Forecast Fields (D6)
Entry Conditions	At successful completion of Level 1 checking and verification activities. Carried out in parallel to Level 1 validation activities
Exit Conditions	Validated total column ozone product with respect to other validated satellite data.
Deliverables	Total column ozone validation report including feedback to the Sentinel-4/UVN and Sentinel-5/UVNS Level 1b validation activities.
Team Involved	EUMETSAT/RSP ACh CA and ESA.
Periodicity	During commissioning phase for selected orbits, until satisfactory agreement is reached within the constraints of the characteristics of both measurement data and the expected product accuracy.
Initial Duration	Commissioning phase.

Recurrent Duration	Continue during routine operations until total column ozone products have been validated for all representative latitudes and seasons. Thereafter continue monitoring activities at a reduced frequency.
Pass/Fail Criteria	Difference between total column ozone observations generated from Sentinel-4/UVN and Sentinel-5/UVNS data and those from independent satellite measurement less than the root mean square sum of the absolute errors on both, for all latitudes and seasons, taking into account differences in representativeness and collocation. See also requirements.
Comments	Required for complete lifetime of the missions.
Test Procedure	Based on the tools outlined above, the test for Sentinel-5 performs following steps in an automated fashion: 1. Ingest Sentinel-5 total ozone products from the EPS-SG rolling buffer folder and read the relevant variables. 2. Ingest the total ozone column data from other satellites e.g. GOME-2, TROPOMI. 3. Read available data from a dedicated database (DB). 4. Run colocation tool and statistical analysis tool. 5. Update the DB. 6. Prepare the test report.

Validation of Total Column Ozone using Campaign, Aircraft and Balloon Measurements (A6.2.3)

This activity will be carried out in the frame of an AO Call to be initiated by ESA, with the support of EUMETSAT. Detailed activity descriptions will depend on the contributions to the AO Call.

Validation of Total Column Ozone using Chemical Data Assimilation Analysis Fields (A6.2.4)

Item	Description
Test Name	S4_S5_L2_TCO_CDA
Test Title	Validation of Total Column Ozone using Chemical Data Assimilation Analysis Fields (A6.2.4)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To validate the total column products using Chemical Data Assimilation Analysis fields.
Test Sequence Description	The total column ozone information shall be compared to CAMS total column ozone analysis fields. The following steps are required: collocated analysis fields are selected on the basis of user configurable coincidence criteria model fields are interpolated in the horizontal to the measurement location model fields are interpolated in the vertical to the vertical resolution of the measurement

	the difference between the model and measurement profile pairs should be calculated and compared to the expected measurement accuracy the results for all pairs of model and measurement profiles are to be sorted on the basis of: Solar Zenith Angle (of the Sentinel-4/UVN and Sentinel-5/UVNS measurements) viewing angle cloud fraction atmospheric aerosol loading total column ozone amount latitude and longitude land/sea season and a statistical analysis carried out. particular attention is to be paid to correlations between any of the above quantities and the differences in the collocated data pairs.
Requirements	Sentinel-4 Level-2 Processor Requirements Specification, S4.ESA.UVN.RS.0093, Issue 2, Revision 1, 27/11/2018 [AD4] Sentinel-5 Level-2 Prototype Processor Development Requirements Specification, S5-RS-ESA-GR-0131, Issue 1, Revision 8, 15 July 2019 [AD5] Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017 [AD3]: **A1, A2, B1, B2, B3, C2, C3** See also Table 5.4 and Table 5.10
Prerequisites	Successfully verified and partially validated Level 1 products
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Validation Data Product Readers and Subset Selection (T1.6) Grib and BUFR Readers (T1.7) Collocation Tool (T3) Simple Mathematical Functions (T5) Statistical Analysis Tools (T6) Interpolation Tools (Linear, Spline and Akima) (T7) Image Display Tools (T11) Report Generation Tools (T16)
Required Test Data	**Level 2 Total Column Ozone product comprising:** Total column ozone information Averaging kernel

	Date/time information Geolocation information **Total Column Ozone Information from Chemical Data Assimilation Analysis Fields** European Centre for Medium Range Weather Forecasting (ECMWF) and Copernicus Atmosphere Monitoring Service (CAMS) Analysis & Forecast Fields (D6) **For further information see D6 on page 105.**
Entry Conditions	At successful completion of Level 1 checking and verification activities. Carried out in parallel to Level 1 validation activities
Exit Conditions	Validated total column ozone product with respect to Chemical Data Assimilation analysis fields.
Deliverables	Total column ozone validation report including feedback to the Sentinel-4/UVN and Sentinel-5/UVNS Level 1b validation activities.
Team Involved	EUMETSAT/RSP ACh CA and ESA.
Periodicity	During commissioning phase for selected days, until satisfactory agreement is reached within the constraints of the characteristics of both measurement data and the expected product accuracy.
Initial Duration	Commissioning phase.
Recurrent Duration	Continue during routine operations until total column ozone information has been validated for all representative latitudes and seasons. Thereafter continue monitoring activities at a reduced frequency.
Pass/Fail Criteria	Mean difference between total column ozone data generated from Sentinel-4/UVN and Sentinel-5/UVNS data and those from analysis fields less than the root mean square sum of the measurement error for all latitudes and seasons. See also requirements.
Comments	Required for complete lifetime of the missions. In the case that operational Level 2 products are monitored by CAMS, all data is used for the lifetime of the mission and the activity is performed at CAMS.
Test Procedure	Based on the tools outlined above, the test for Sentinel-5 performs following steps in an automated fashion: 1. Ingest Sentinel-5 total ozone products from the EPS-SG rolling buffer folder and read the relevant variables. 2. Ingest the total column ozone information from chemical data assimilation analysis fields. 3. Read available data from a dedicated database (DB). 4. Run colocation tool and statistical analysis tool. 5. Update the DB. 6. Prepare the test report.

Validation of Trace Gas Column Measurements (A6.3)

Validation of Trace Gas Column using Ground-Based Measurements (A6.3.1)

Item	Description
Test Name	S4_S5_L2_TRG_GROUND
Test Title	Validation of Trace Gas Column using Ground-Based Measurements (A6.3.1)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To validate the column trace gas products using ground-based reference data.
Test Sequence Description	The column trace gas information shall be compared to independent validated column information obtained from ground-based measurements. The following steps are required: collocated data are selected on the basis of user configurable coincidence criteria which will vary depending on the characteristics of the individual data sets the collocated data are sorted per instrument and per instrument class and/or station the difference between the collocated measurement pairs should be calculated and compared to their expected accuracy the results for all collocated measurements are to be sorted on the basis of: Solar Zenith Angle viewing angle cloud fraction atmospheric aerosol loading total column ozone amount latitude and longitude and a statistical analysis carried out particular attention is to be paid to correlations between any of the above quantities and the differences in the collocated data pairs. In the event that differences in spatial or temporal collocation are greater than the user defined tolerances access to Chemical Transport Models and/or Data Assimilation Models will be required to aid interpretation. For the purposes of long-term validation and trend assessment, time series of collocated data at selected locations and in the zonal mean shall also be analysed. Note that in the case of NO_2 where tropospheric and stratospheric sub-columns are reported, the stratospheric NO_2 information should be validated as a stand-alone product and not only as a corrective term for deriving tropospheric columns from total columns.
Requirements	Sentinel-4 Level-2 Processor Requirements Specification, S4.ESA.UVN.RS.0093, Issue 2, Revision 1, 27/11/2018 [AD4]

	Sentinel-5 Level-2 Prototype Processor Development Requirements Specification, S5-RS-ESA-GR-0131, Issue 1, Revision 8, 15 July 2019 [AD5] Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017 [AD3]: **A2, A3, B1, B2, C1, C2, C3** See also Table 5.4 and Table 5.10
Prerequisites	Successfully verified and partially validated Level 1 products
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Validation Data Product Readers and Subset Selection (T1.6) Collocation Tool (T3) Simple Mathematical Functions (T5) Statistical Analysis Tools (T6) Interpolation Tools (Linear, Spline and Akima) (T7) Image Display Tools (T11) Report Generation Tools (T16)
Required Test Data	**Level 2 Trace Gas Column Product comprising:** Trace gas column information Averaging kernel Date/time information Geolocation information **Validated Trace Gas Column data from Ground-based Measurements** The World Meteorological Global Atmosphere Watch Program (GAW) (D3.1) The Network for the Detection of Atmospheric Composition Change (NDACC) (D3.3) The Pandonia Global network (PGN) (D3.5) The Atmospheric Radiation Measurements User Facility (ARM) (D3.10) The Total Carbon Column Observing Network (TCCON) (D3.11) The Aerosol, Clouds and Trace Gases Research Infrastructure (ACTRIS) (D3.14) **For further information see D3 on page 91.** **Note that for the support may be required from a 1D stacked-box photochemical model to account for diurnal variation effects.**
Entry Conditions	At successful completion of Level 1 checking and verification activities. Carried out in parallel to Level 1 validation activities
Exit Conditions	Validated trace gas column product with respect to ground-based data.

Deliverables	Trace gas column validation report including feedback to the Sentinel-4/UVN and Sentinel-5/UVNS Level 1b validation activities.
Team Involved	EUMETSAT/RSP ACh CA and ESA.
Periodicity	During commissioning phase for selected days corresponding to availability of ground-based trace gas column measurements, until satisfactory agreement is reached within the constraints of the characteristics of both measurement data and the expected product accuracy.
Initial Duration	Commissioning phase.
Recurrent Duration	Continue during routine operations until trace gas column information has been validated for all representative latitudes and seasons. Thereafter continue monitoring activities at a reduced frequency.
Pass/Fail Criteria	Difference between trace gas column data generated from Sentinel-4/UVN and Sentinel-5/UVNS data and those from ground-based measurements less than the root mean square sum of the absolute errors on both, for all latitudes and seasons, taking into account differences in representativeness and collocation. See also requirements.
Comments	Required for complete lifetime of the missions.
Test Procedure	Based on the tools outlined above, the test for Sentinel-5 performs following steps in an automated fashion: 1. Ingest Sentinel-5 trace gas products from the EPS-SG rolling buffer folder and read the relevant variables. 2. Ingest the trace gas column data from ground-based measurements. 3. Read available data from a dedicated database (DB). 4. Run colocation tool and statistical analysis tool. 5. Update the DB. 6. Prepare the test report.

Validation of Trace Gas Column using Validated Satellite Measurements (A6.3.2)

Item	Description
Test Name	S4_S5_L2_TRG_SAT
Test Title	Validation of Trace Gas Column using Validated Satellite Measurements (A6.3.2)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To validate the trace gas column products using validated satellite reference data.

Test Sequence Description	The trace gas column information shall be compared to independent validated trace gas column information obtained from satellite measurements. The following steps are required: collocated data are selected on the basis of user configurable coincidence criteria which will vary depending on the characteristics of the individual data sets the collocated data are sorted per instrument the difference between the collocated measurements pairs should be calculated and compared to their expected accuracy the results for all collocated profiles are to be sorted on the basis of: Solar Zenith Angle viewing angle cloud fraction atmospheric aerosol loading total column ozone amount latitude and longitude and a statistical analysis carried out particular attention is to be paid to correlations between any of the above quantities and the differences in the collocated data pairs. In the event that differences in spatial or temporal collocation are greater than the user defined tolerances access to Chemical Transport Models and/or Data Assimilation Models will be required to aid interpretation. For the purposes of long-term validation and trend assessment, time series of collocated data at selected locations and in the zonal mean shall also be analysed.
Requirements	Sentinel-4 Level-2 Processor Requirements Specification, S4.ESA.UVN.RS.0093, Issue 2, Revision 1, 27/11/2018 [AD4] Sentinel-5 Level-2 Prototype Processor Development Requirements Specification, S5-RS-ESA-GR-0131, Issue 1, Revision 8, 15 July 2019 [AD5] Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017 [AD3]: **A2, A3, B1, B2, C1, C2, C3** See also Table 5.4 and Table 5.10
Prerequisites	Successfully verified and partially validated Level 1 products
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Validation Data Product Readers and Subset Selection (T1.6) Collocation Tool (T3)

	Simple Mathematical Functions (T5) Statistical Analysis Tools (T6) Interpolation Tools (Linear, Spline and Akima) (T7) Image Display Tools (T11) Report Generation Tools (T16)
Required Test Data	**Level 2 Trace Gas Column Product comprising:** Trace gas column information Averaging kernel Date/time information Geolocation information **Six months of validated Trace Gas Column from satellite measurements:** The Global Ozone Monitoring Experiment (GOME-2) on MetOp (D4.2) The (D4.3) MTG-S IRS and EPS-SG IASI-NG Trace Gas, Temperature & Pressure Information (D4.14) The Sentinel-5/UVNS Precursor TROPOspheric Monitoring Instrument (TROPOMI) (D4.4) The Ozone Mapping and Profiler Suite (OMPS) (D4.5) Geostationary Environment Monitoring Spectrometer (GEMS) (D4.6) Tropospheric Emissions: Monitoring of POllution (TEMPO) (D4.7) Greenhouse Gases Observing Satellite (GOSAT (D4.8) MTG-S IRS and EPS-SG IASI-NG Trace Gas, Temperature & Pressure Information (D4.14) **For further information see D4 on page 97.** **Total Column Ozone Information from Chemical Data Assimilation Analysis Fields** European Centre for Medium Range Weather Forecasting (ECMWF) and Copernicus Atmosphere Monitoring Service (CAMS) Analysis & Forecast Fields (D6)
Entry Conditions	At successful completion of Level 1 checking and verification activities. Carried out in parallel to Level 1 validation activities
Exit Conditions	Validated trace gas column product with respect to other validated satellite data.
Deliverables	Trace gas column validation report including feedback to the Sentinel-4/UVN and Sentinel-5/UVNS Level 1b validation activities.
Team Involved	EUMETSAT/RSP ACh CA and ESA.
Periodicity	During commissioning phase for selected days until satisfactory agreement is reached within the constraints of the characteristics of both measurement data and the expected product accuracy.

Initial Duration	Commissioning phase.
Recurrent Duration	Continue during routine operations until trace gas column products have been validated for all representative latitudes and seasons. Thereafter continue monitoring activities at a reduced frequency.
Pass/Fail Criteria	Difference between trace gas column observations generated from Sentinel-4/UVN and Sentinel-5/UVNS data and those from independent satellite measurement less than the root mean square sum of the absolute errors on both, for all latitudes and seasons, taking into account differences in representativeness and collocation. See also requirements.
Comments	Required for complete lifetime of the missions.
Test Procedure	Based on the tools outlined above, the test for Sentinel-5 performs following steps in an automated fashion: 1. Ingest Sentinel-5 trace gas Level 2 products (e.g. Tropspheric NO_2, HCHO) from the EPS-SG rolling buffer folder and read the relevant variables. 2. Ingest the trace gas products from other satellites e.g. GOME-2, TROPOMI. 3. Read available data from a dedicated database (DB). 4. Run colocation tool and statistical analysis tool. 5. Update the DB. 6. Prepare the test report.

Validation of Trace Gas Column using Campaign, Aircraft and Balloon Measurements (A6.3.3)

This activity will be carried out in the frame of an AO Call to be initiated by ESA, with the support of EUMETSAT. Detailed activity descriptions will depend on the contributions to the AO Call.

Validation of Trace Gas Column using Chemical Data Assimilation Analysis Fields (A6.3.4)

Item	Description
Test Name	S4_S5_L2_TRG_CDA
Test Title	Validation of Trace Gas Column using Chemical Data Assimilation Analysis Fields (A6.3.4)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To validate the trace gas column products using Chemical Data Assimilation Analysis fields.
Test Sequence Description	The trace gas column information shall be compared to CAMS total column ozone analysis fields. The following steps are required: collocated analysis fields are selected on the basis of user configurable coincidence criteria model fields are interpolated in the horizontal to the measurement location

	model fields are interpolated in the vertical to the vertical resolution of the measurement the difference between the model and measurement profile pairs should be calculated and compared to the expected measurement accuracy the results for all pairs of model and measurement profiles are to be sorted on the basis of: Solar Zenith Angle (of the Sentinel-4/UVN and Sentinel-5/UVNS measurements) viewing angle cloud fraction atmospheric aerosol loading total column ozone amount latitude and longitude land/sea season and a statistical analysis carried out. particular attention is to be paid to correlations between any of the above quantities and the differences in the collocated data pairs.
Requirements	Sentinel-4 Level-2 Processor Requirements Specification, S4.ESA.UVN.RS.0093, Issue 2, Revision 1, 27/11/2018 [AD4] Sentinel-5 Level-2 Prototype Processor Development Requirements Specification, S5-RS-ESA-GR-0131, Issue 1, Revision 8, 15 July 2019 [AD5] Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017 [AD3]: **A3, B1, B2, B3, C1, C2, C3** See also Table 5.4 and Table 5.10
Prerequisites	Successfully verified and partially validated Level 1 products
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Validation Data Product Readers and Subset Selection (T1.6) Grib and BUFR Readers (T1.7) Collocation Tool (T3) Simple Mathematical Functions (T5) Statistical Analysis Tools (T6) Interpolation Tools (Linear, Spline and Akima) (T7) Image Display Tools (T11) Report Generation Tools (T16)
Required Test Data	**Level 2 trace gas column product comprising:**

	Trace gas column information Averaging kernel Date/time information Geolocation information **Total Trace Gas Column Information from Chemical Data Assimilation Analysis Fields** European Centre for Medium Range Weather Forecasting (ECMWF) and Copernicus Atmosphere Monitoring Service (CAMS) Analysis & Forecast Fields (D6) **For further information see D6 on page 105**
Entry Conditions	At successful completion of Level 1 checking and verification activities. Carried out in parallel to Level 1 validation activities
Exit Conditions	Validated trace gas column product with respect to Chemical Data Assimilation analysis fields.
Deliverables	Trace gas column validation report including feedback to the Sentinel-4/UVN and Sentinel-5/UVNS Level 1b validation activities.
Team Involved	EUMETSAT/RSP ACh CA and ESA.
Periodicity	During commissioning phase for selected days until satisfactory agreement is reached within the constraints of the characteristics of both measurement data and the expected product accuracy.
Initial Duration	Commissioning phase.
Recurrent Duration	Continue during routine operations until total column ozone information has been validated for all representative latitudes and seasons. Thereafter continue monitoring activities at a reduced frequency.
Pass/Fail Criteria	Mean difference between trace gas column data generated from Sentinel-4/UVN and Sentinel-5/UVNS data and those from analysis fields less than the root mean square sum of the measurement error for all latitudes and seasons. See also requirements.
Comments	Required for complete lifetime of the missions. In the case that operational Level 2 products are monitored by CAMS, all data is used for the lifetime of the mission and the activity is performed at CAMS.
Test Procedure	Based on the tools outlined above, the test for Sentinel-5 performs following steps in an automated fashion: 1. Ingest Sentinel-5 trace gas Level 2 products from the EPS-SG rolling buffer folder and read the relevant variables. 2. Ingest the total trace gas column information from chemical data assimilation analysis fields. 3. Read available data from a dedicated database (DB). 4. Run colocation tool and statistical analysis tool.

5. Update the DB. 6. Prepare the test report.

Validation of Aerosol Parameters (A6.4)

Validation of Aerosol Absorbing Index (AAI) (A6.4.1)

Item	Description
Test Name	S4_S5_L2_AAI
Test Title	Validation of Aerosol Absorbing Index (AAI) (A6.4.1)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To validate the AAI products using other validated satellite data.
Test Sequence Description	The AAI shall be compared to independent validated AAI information obtained from other satellite measurements. The following steps are required: collocated data are selected on the basis of user configurable coincidence criteria which will vary depending on the characteristics of the individual data sets the collocated data are sorted per instrument the difference between the collocated AAI pairs should be calculated and compared to their expected accuracy the results for all collocated AAI pairs are to be sorted on the basis of: Solar Zenith Angle viewing angle cloud fraction atmospheric aerosol loading total column ozone amount latitude and longitude land/sea season and a statistical analysis carried out particular attention is to be paid to correlations between any of the above quantities and the differences in the collocated data pairs. For the purposes of long-term validation and trend assessment, time series of collocated data at selected locations and in the zonal mean shall also be analysed.
Requirements	Sentinel-4 Level-2 Processor Requirements Specification, S4.ESA.UVN.RS.0093, Issue 2, Revision 1, 27/11/2018 [AD4] Sentinel-5 Level-2 Prototype Processor Development Requirements Specification, S5-RS-ESA-GR-0131, Issue 1, Revision 8, 15 July 2019 [AD5]

	Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017 [AD3]: **A2, A3, B1, B2, B3, C1, C2, C3** See also Table 5.4 and Table 5.10
Prerequisites	Successfully verified and partially validated Level 1 products
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Validation Data Product Readers and Subset Selection (T1.6) Collocation Tool (T3) Simple Mathematical Functions (T5) Statistical Analysis Tools (T6) Interpolation Tools (Linear, Spline and Akima) (T7) Image Display Tools (T11) Report Generation Tools (T16)
Required Test Data	**Level 2 AAI product comprising:** AAI information Date/time information Geolocation information **Six months of AAI information from satellite measurements:** The Global Ozone Monitoring Experiment (GOME-2) on MetOp (D4.2) The Sentinel-5/UVNS Precursor TROPOspheric Monitoring Instrument (TROPOMI) (D4.4) The Ozone Mapping and Profiler Suite (OMPS) (D4.5) Geostationary Environment Monitoring Spectrometer (GEMS) (D4.6) Tropospheric Emissions: Monitoring of POllution (TEMPO) (D4.7)) For further information see D4 on page 97
Entry Conditions	At successful completion of Level 1 checking and verification activities. Carried out in parallel to Level 1 validation activities
Exit Conditions	Validated AAI product with respect to other validated satellite data.
Deliverables	AAI validation report including feedback to the Sentinel-4/UVN and Sentinel-5/UVNS Level 1b validation activities.
Team Involved	EUMETSAT/RSP ACh CA and ESA.
Periodicity	During commissioning phase for selected days until satisfactory agreement is reached within the constraints of the characteristics of the expected AAI accuracy.

	Continue during routine operations until AAI information has been validated for all representative latitudes and seasons. Thereafter continue monitoring activities.
Initial Duration	Commissioning phase.
Recurrent Duration	Continue during routine operations until AAI information has been validated for all representative latitudes and seasons. Thereafter continue monitoring activities.
Pass/Fail Criteria	Mean difference between AAI generated from Sentinel-4/UVN and Sentinel-5/UVNS data and those from analysis fields less than the root mean square sum of the measurement error for all latitudes and seasons. See also requirements.
Comments	Required for complete lifetime of the missions.
Test Procedure	Based on the tools outlined above, the test for Sentinel-5 performs following steps in an automated fashion: 1. Ingest Sentinel-5 AUI products from the EPS-SG rolling buffer folder and read the relevant variables. 2. Ingest the AAI products from other satellites e.g. GOME-2, TROPOMI. 3. Read available data from a dedicated database (DB). 4. Run colocation tool and statistical analysis tool. 5. Update the DB. 6. Prepare the test report.

Validation of Aerosol Optical Depth (A6.4.2)

Item	Description
Test Name	S4_S5_L2_AOD
Test Title	Validation of Aerosol Optical Depth (A6.4.2)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To validate the AOD products using ground-based data.
Test Sequence Description	The AOD products shall be compared to independent AOD information obtained from ground-based data. The following steps are required: collocated data are selected on the basis of user configurable coincidence criteria which will vary depending on the characteristics of the individual data sets the collocated data are sorted per instrument the difference between the collocated AOD pairs should be calculated and compared to their expected accuracy the results for all collocated AOD pairs are to be sorted on the basis of:

	Solar Zenith Angle viewing angle cloud fraction atmospheric aerosol loading latitude and longitude land/sea surface type season and a statistical analysis carried out • particular attention is to be paid to correlations between any of the above quantities and the differences in the collocated data pairs For the purposes of long-term validation and trend assessment, time series of collocated data at selected locations and in the zonal mean shall also be analysed.
Requirements	Sentinel-4 Level-2 Processor Requirements Specification, S4.ESA.UVN.RS.0093, Issue 2, Revision 1, 27/11/2018 [AD4] Sentinel-5 Level-2 Prototype Processor Development Requirements Specification, S5-RS-ESA-GR-0131, Issue 1, Revision 8, 15 July 2019 [AD5] Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017 [AD3]: **A3, B1, B2, B3, C1, C2, C3** See also Table 5.4 and Table 5.10
Prerequisites	Successfully verified and partially validated Level 1 products
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Validation Data Product Readers and Subset Selection (T1.6) Collocation Tool (T3) Simple Mathematical Functions (T5) Statistical Analysis Tools (T6) Interpolation Tools (Linear, Spline and Akima) (T7) Image Display Tools (T11) Report Generation Tools (T16)
Required Test Data	**Level 2 AOD Product comprising:** AOD information Date/time information Geolocation information **Validated AOD data from Ground-based Measurements**

	The World Meteorological Global Atmosphere Watch Program (GAW) (D3.1) The Network for the Detection of Atmospheric Composition Change (NDACC) (D3.3) The Aerosol Robotic Network (AERONET) (D3.4) The Pandonia Global network (PGN) (D3.5) The Aerosol, Clouds and Trace Gases Research Infrastructure (ACTRIS) (D3.14) **For further information see D3 on page 91.** **Auxiliary cloud information** MTG-I FCI and EPS-SG METimage Cloud Information (D4.13)
Entry Conditions	At successful completion of Level 1 checking and verification activities. Carried out in parallel to Level 1 validation activities
Exit Conditions	Validated AOD product with respect to other validated satellite data.
Deliverables	AOD validation report including feedback to the Sentinel-4/UVN and Sentinel-5/UVNS Level 1b validation activities.
Team Involved	EUMETSAT/RSP ACh CA and ESA.
Periodicity	During commissioning phase for selected days until satisfactory agreement is reached within the constraints of the characteristics of the expected AOD accuracy.
Initial Duration	Commissioning phase.
Recurrent Duration	Continue during routine operations until AOD information has been validated for all representative latitudes and seasons. Thereafter continue monitoring activities.
Pass/Fail Criteria	Mean difference between AOD generated from Sentinel-4/UVN and Sentinel-5/UVNS data and those from analysis fields less than the root mean square sum of the measurement error for all latitudes and seasons. See also requirements.
Comments	Required for complete lifetime of the missions.
Test Procedure	Based on the tools outlined above, the test performs following steps in an automated fashion: 1. Ingest AOD products and read the relevant variables. 2. Ingest the AOD data from ground-based measurements. 3. Read available data from a dedicated database (DB). 4. Run colocation tool and statistical analysis tool. 5. Update the DB. 6. Prepare the test report.

Validation of Aerosol Layer Height (A6.4.3)

Item	Description
Test Name	S4_S5_L2_ALH
Test Title	Validation of Aerosol Layer Height (A6.4.3)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To validate the aerosol layer height products using lidar data.
Test Sequence Description	The aerosol layer height products shall be compared to independent information obtained from ground-based or space-based data. The following steps are required: collocated data are selected on the basis of user configurable coincidence criteria which will vary depending on the characteristics of the individual data sets the collocated data are sorted per instrument the aerosol layer height difference between the collocated pairs should be calculated and compared to their expected accuracy the results for all collocated aerosol layer height pairs are to be sorted on the basis of: Solar Zenith Angle viewing angle cloud fraction atmospheric aerosol loading latitude and longitude land/sea surface type season and a statistical analysis carried out • particular attention is to be paid to correlations between any of the above quantities and the differences in the collocated data pairs For the purposes of long-term validation and trend assessment, time series of collocated data at selected locations and in the zonal mean shall also be analysed.
Requirements	Sentinel-4 Level-2 Processor Requirements Specification, S4.ESA.UVN.RS.0093, Issue 2, Revision 1, 27/11/2018 [AD4] Sentinel-5 Level-2 Prototype Processor Development Requirements Specification, S5-RS-ESA-GR-0131, Issue 1, Revision 8, 15 July 2019 [AD5] Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017 [AD3]: **B1, B2, B3, C1, C2, C3** See also Table 5.4 and Table 5.10
Prerequisites	Successfully verified and partially validated Level 1 products

Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Validation Data Product Readers and Subset Selection (T1.6) Collocation Tool (T3) Simple Mathematical Functions (T5) Statistical Analysis Tools (T6) Interpolation Tools (Linear, Spline and Akima) (T7) Image Display Tools (T11) Report Generation Tools (T16)
Required Test Data	**Level 2 Aerosol Layer Height Product comprising:** Aerosol layer height information Date/time information Geolocation information **Validated aerosol layer height data from ground-based and space based lidar measurements:** The European Aerosol Research Lidar Network (EARLINET) (D3.7) The NASA Micro-Pulse Lidar Network (MPLNET) (D3.8) The Asian Dust and aerosol lidar observation NETwork (AD-Net) (D3.9) The Network for Observation of Volcanic and Atmospheric Change (NOVAC) (D3.13) Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) (D4.9) Earth Clouds, Aerosols and Radiation Explorer (EarthCARE) (D4.10) **For further information see D3 on page 91.** **Auxiliary cloud information** MTG-I FCI and EPS-SG METimage Cloud Information (D4.13)
Entry Conditions	At successful completion of Level 1 checking and verification activities. Carried out in parallel to Level 1 validation activities
Exit Conditions	Validated aerosol layer height product with respect to other ground-based and validated satellite data.
Deliverables	Aerosol layer height validation report including feedback to the Sentinel-4/UVN and Sentinel-5/UVNS Level 1b validation activities.
Team Involved	EUMETSAT/RSP ACh CA and ESA.
Periodicity	During commissioning phase for selected days until satisfactory agreement is reached within the constraints of the characteristics of the expected aerosol layer height accuracy.

Initial Duration	Commissioning phase.
Recurrent Duration	Continue during routine operations until AOD information has been validated for all representative latitudes and seasons. Thereafter continue monitoring activities.
Pass/Fail Criteria	Mean difference between aerosol layer height generated from Sentinel-4/UVN and Sentinel-5/UVNS data and those from ground-based and satellite lidar less than the root mean square sum of the measurement error for all latitudes and seasons. See also requirements.
Comments	Required for complete lifetime of the missions. The aerosol amount and microphysical parameters that are by-products or for which assumptions are made in the retrieval need to be compared with reference data, e.g. from ground-based sun-photometer measurements.
Test Procedure	Based on the tools outlined above, the test performs following steps in an automated fashion: 1. Ingest Aerosol Layer Height products and read the relevant variables. 2. Ingest the ALH data from ground-based measurements and other satellite observations. 3. Read available data from a dedicated database (DB). 4. Run colocation tool and statistical analysis tool. 5. Update the DB. 6. Prepare the test report.

Validation of Cloud Parameters (A6.5)

Validation of Cloud Parameters using Imager Data (A6.5.1)

Item	Description
Test Name	S4_S5_L2_CLD_IMG
Test Title	Validation of Cloud Parameters using Imager Data (A6.5.1)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To validate the cloud information using imager data.
Test Sequence Description	Select those imager pixels that are collocated with the Sentinel-4/UVN and/or Sentinel-5/UVNS ground pixel Calculate an effective cloud fraction and cloud top temperature from the resulting imager pixels. Convert the cloud top temperature to cloud top pressure using an appropriate collocated temperature profile. Compare the post-processed imager cloud parameters with those obtained from Sentinel-4/UVN and/or Sentinel-5/UVNS.
Requirements	Sentinel-4 Level-2 Processor Requirements Specification, S4.ESA.UVN.RS.0093, Issue 2, Revision 1, 27/11/2018 [AD4]

	Sentinel-5 Level-2 Prototype Processor Development Requirements Specification, S5-RS-ESA-GR-0131, Issue 1, Revision 8, 15 July 2019 [AD5] Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017 [AD3]: **A1 (Aux)** See also Table 5.4 and Table 5.10
Prerequisites	Successfully verified and partially validated Level 1 products
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Product Readers for Other Sensors on MTG and EPS-SG and Subset Selection (T1.4) Simple Mathematical Functions (T5) Statistical Analysis Tools (T6) Interpolation Tools (Linear, Spline and Akima) (T7) Image Display Tools (T11) Report Generation Tools (T16)
Required Test Data	**Level 2 Cloud Product comprising:** Cloud information Date/time information Geolocation information **Auxiliary cloud information** MTG-I FCI and EPS-SG METimage Cloud Information (D4.13)
Entry Conditions	At successful completion of Level 1 checking and verification activities. Carried out in parallel to Level 1 validation activities
Exit Conditions	Validated cloud product with respect to other ground-based and validated satellite data.
Deliverables	Cloud validation report including feedback to the Sentinel-4/UVN and Sentinel-5/UVNS Level 1b validation activities.
Team Involved	EUMETSAT/RSP ACh CA and ESA.
Periodicity	During commissioning phase for selected days until satisfactory agreement is reached within the constraints of the characteristics of the expected cloud product accuracy.
Initial Duration	Commissioning phase.

Recurrent Duration	Continue during routine operations until cloud information has been validated for all representative latitudes and seasons. Thereafter continue monitoring activities.
Pass/Fail Criteria	Mean difference between cloud information generated from Sentinel-4/UVN and Sentinel-5/UVNS data and those from ground-based and satellite lidar less than the root mean square sum of the measurement error for all latitudes and seasons. See also requirements.
Comments	Required for complete lifetime of the missions. The METimage cloud parameters that are relevant to Sentinel-5/UVNS are the cloud flag and cloud top pressure, in particular that derived from the O2 A-band. These parameters are available on the Sentinel-5/UVNS spatial grid as output of the internal Sentinel-5/UVNS METimage cloud co-registration function. Note that the cloud data products generated by FRESCO should not be used over snow or ice covered surfaces or for solar zenith angles greater than 85°. Any dependence of the differences on viewing angle or solar zenith angle shall be investigated. Similarly, MTG-I FCI cloud information is co-registered to the Sentinel-4/UVN grid internally to the Sentinel-4/UVN Level 2 operational processor and may be used for validation of Sentinel-4/UVN cloud products.
Test Procedure	Based on the tools outlined above, the test for Sentinel-5 performs following steps in an automated fashion: 1. Ingest Sentinel-5 cloud products from the EPS-SG rolling buffer folder and read the relevant variables. 2. Ingest METimage cloud products from the EPS-SG rolling buffer as reference data and read the same variables as step 1. 3. Read available data from a dedicated database (DB). 4. Run colocation tool and statistical analysis tool. 5. Update the DB. 6. Prepare the test report.

Emission Source Estimation (A6.6)

Item	Description
Test Name	S4_S5_L2_EMIS
Test Title	Emission Source Estimation (A6.6)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To validate emissions estimations.
Test Sequence Description	Estimates of emissions of e.g. NO_2 and SO_2 and Volatile Organic Compounds, constrained by observations of HCHO and CHOCHO, will be compared and possibly be used to update existing emission inventories. Satellite observations of known isolated sources should be analysed.

	Satellite based emission estimates can be compared to the prior knowledge of the source and to estimates made using other methods. Ground based observations of the column density together with wind information on the boundary around the source can be used to estimate the flux across the boundary and the source strength within this boundary. Aircraft imaging spectrometers can provide reference data for the spatial gradients measured by the satellite. Also, reference emission estimates can be made based on such aircraft data. Detailed methods are TBD.
Requirements	Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017 [AD3]: **A1, B1, B2, B3, C1**
Prerequisites	Successfully verified and partially validated Level 1 products
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Simple Mathematical Functions (T5) Statistical Analysis Tools (T6) Interpolation Tools (Linear, Spline and Akima) (T7) Image Display Tools (T11) Report Generation Tools (T16) Additional tools TBC
Required Test Data	TBD
Entry Conditions	At successful completion of Level 1 checking and verification activities. Carried out in parallel to Level 1 validation activities
Exit Conditions	Validated emissions estimates with respect to other independent sources.
Deliverables	Report on verification of emissions estimates.
Team Involved	EUMETSAT/RSP ACh CA and ESA.
Periodicity	During routine operations for specific test cases.
Initial Duration	TBD.
Recurrent Duration	TBD.
Pass/Fail Criteria	TBD.
Comments	This is a specialised analysis that would likely best be served through a dedicated study.
Test Procedure	Not required.

Reporting Geophysical Parameter Verification and Validation Activities (A6.7)

Item	Description
Test Name	S4_S5_L2_REPORT
Test Title	Reporting Geophysical Parameter Verification and Validation Activities (A6.7)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To report the geophysical parameter product validation activities in a summary report.
Test Sequence Description	Report all results of Geophysical Parameter Verification and Validation (A6) activities in summary format. Summarise results in the following categories: Validation of Ozone Profile Measurements (A6.1) Validation of Total Column Ozone Measurements (A6.2) Validation of Trace Gas Column Measurements (A6.3) Validation of Aerosol Parameters (A6.4) Validation of Cloud Parameters (A6.5) Emission Source Estimation (A6.6) (TBC) Where appropriate results shall be presented as a function of: Solar Zenith Angle viewing angle cloud fraction atmospheric aerosol loading latitude and longitude land/sea surface type season Results shall at a minimum be presented in the form of: Time series plots and analysis Spectral plots 2-dimensional maps Scatter plots
Requirements	None.
Prerequisites	Successfully verified and partially validated Level 1 products.
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Report Generation Tools (T16)

Required Test Data	**Output of Level 1 Verification, Confidence Checking and Validation activities.**
Entry Conditions	Verified and partially validated Level 1 products.
Exit Conditions	Validated geophysical parameter products.
Deliverables	Summary report on Geophysical Parameter Verification, Confidence Checking and Validation activities Recommendations for upgrades to Level 0 to 1 processing algorithms and software Recommendations for update of degradation correction factors where appropriate.
Team Involved	EUMETSAT/RSP ACh CA and ESA.
Periodicity	Determined by frequency of Geophysical Parameter Verification and Validation activities required after product processor upgrades. During routine operations, at a minimum monthly and annual reports anticipated.
Initial Duration	Commissioning phase.
Recurrent Duration	N/A.
Pass/Fail Criteria	No pass/fail criteria - reporting purposes only.
Comments	Required for complete lifetime of the missions.
Test Procedure	Based on the tools outlined above, the test for Sentinel-5 performs following steps in an automated fashion: 1. Read all the variables (A6.1-6.6) from DB. 2. Run analysis. 3. Generate the daily/weekly/monthly results. 4. Prepare the test report.

Cross-Comparison with other CEOS AC-VC Missions (A7)

CEOS AC-VC Level 1b Average Solar Irradiance (A7.1)

Item	Description
Test Name	S4_S5_AC-VC_L1_IRR
Test Title	CEOS AC-VC Level 1b Average Solar Irradiance (A7.1)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To compare the Level 1b Average Solar Irradiance measurements of Sentinel-4/UVN and Sentinel-5/UVNS products with those of other missions from the AC-VC constellation.

Test Sequence Description	The Average Solar Irradiance spectrum shall be directly compared to independent solar irradiance spectra from other missions in the AC-VC constellation. Comparison with reference solar spectra shall be performed. The following steps are required: Normalise Average Solar Irradiance spectra and reference spectral solar irradiance data to an Earth-Sun distance of 1 AU. Interpolate Average Solar Irradiance spectra and reference spectra to a common high resolution (e.g. 0.025 nm) wavelength grid using Akima or Spline interpolation Convolve both interpolated spectra with a convolution kernel of ~1 nm FWHM Calculate the difference spectrum Compare the difference spectrum to the root mean square sum of the relative errors See Section 6.2.2.5 for more details. Methods developed within the frame of the WMO GSICS initiative should be applied and radiometric inter-calibration factors derived as appropriate (http://gsics.atmos.umd.edu/bin/view/Development/20161201)
Requirements	Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017 [AD3] Sentinel-4/UVN - Instrument Requirements Specification, GS4.ASG.UVN.RS.00001 [AD6] Sentinel-5/UVNS - Instrument Requirements Specification, GS5.RS.ASG.UVNS.00012 [AD7]: **IRS-28, IRS-434, IRS-435, IRS-3772, IRS-4004, IRS-4571**
Prerequisites	Successfully verified and partially validated Level 1 products.
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Calibration Key Data Readers and Display (T1.2) Static Data Set Readers and Subset Selection (T1.3) Validation Data Product Readers and Subset Selection (T1.6) Simple Mathematical Functions (T5) Statistical Analysis Tools (T6) Image Display Tools (T11) Report Generation Tools (T16)
Required Test Data	Sentinel-4/UVN and/or Sentinel-5/UVNS Level 1 data High Resolution Reference Solar Irradiance Spectrum (D1.2) Total and Solar Spectral Irradiance Sensor (TSIS): Spectral Solar Irradiance Data (D4.1) The Global Ozone Monitoring Experiment (GOME-2) on MetOp (D4.2)

	The Sentinel-5/UVNS Precursor TROPOspheric Monitoring Instrument (TROPOMI) (D4.4) The Ozone Mapping and Profiler Suite (OMPS) (D4.5) Geostationary Environment Monitoring Spectrometer (GEMS) (D4.6) Tropospheric Emissions: Monitoring of POllution (TEMPO) (D4.7)
Entry Conditions	Successfully validated Level 1 products.
Exit Conditions	Demonstrated consistency with other solar irradiance data from other CEOS-AC-VC missions.
Deliverables	Summary report on CEOS AC-VC irradiance products.
Team Involved	EUMETSAT/RSP ACh CA.
Periodicity	N/A
Initial Duration	During routine operations.
Recurrent Duration	N/A
Pass/Fail Criteria	Difference between Average Solar Irradiance measurements and spectral solar irradiance measurements from AC-VC missions less than the root mean square sum of the relative errors on both.
Comments	This is a community activity which is not intended to supersede the activities described in Section 6.2.2. It will be performed during routine operations and requires cooperation with all constellation partners.
Test Procedure	Based on the tools outlined above, the test performs following steps in an automated fashion: 1. Ingest Level 1 irradiance products and read the relevant variables. 2. Ingest the irradiance products from AC-VC missions as reference. 3. Read available data from a dedicated database (DB). 4. Run interpolation tool and statistical analysis tool. 5. Update the DB. 6. Prepare the test report.

CEOS AC-VC Level 1b Earth Radiance (A7.2)

Item	Description
Test Name	S4_S5_AC-VC_L1_RAD
Test Title	CEOS AC-VC Level 1b Earth Radiance (A7.2)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To compare the Level 1b Earth radiance measurements of Sentinel-4/UVN and Sentinel-5/UVNS products with those of other missions from the AC-VC constellation.

Test Sequence Description	Various approaches are needed to address the imperfect matching of sun-satellite geometries between any of the pairs of satellite sensors, and the non-overlapping fields of view of the Geo-AQ missions. Comparison of data acquired over known targets such as very bright clouds and dark ocean scenes shall be performed as described in Section 6.2.2.6. Statistical analyses of a large collection of measurements with a variety of sun-satellite geometries and conditions are needed to isolate instrument effects from geophysical effects. This approach has the potential to verify the radiometric consistency between the missions at minimum and maximum signal levels. For collocated geostationary and polar orbiting measurements these comparisons can be applied to a wider range of target scenes. Precise and approximate ray matching techniques as explored by Doelling et al. (2013) [SCD13], can be applied to the sub-set of data with comparable sun-satellite geometries. Collocated measurements acquired with different viewing geometries are also valuable for this purpose, as long as the scene directionality can be modelled sufficiently accurately. This could be the case for bright clouds and dark ocean scenes or at radiometric calibration sites used for vicarious calibration of spaceborne imagers, relying on accurate knowledge of surface reflectance and its directionality. The intermission consistency of the geostationary missions should be assessed indirectly by using polar orbiting mission data as a travelling standard. Methods developed within the frame of the WMO GSICS initiative should be applied and radiometric inter-calibration factors derived (http://gsics.atmos.umd.edu/bin/view/Development/WebHome).
Requirements	Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017[AD3] Sentinel-4/UVN - Instrument Requirements Specification, GS4.ASG.UVN.RS.00001[AD6] Sentinel-5/UVNS - Instrument Requirements Specification, GS5.RS.ASG.UVNS.00012[AD7]
Prerequisites	Successfully verified and partially validated Level 1 products.
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Validation Data Product Readers and Subset Selection (T1.6) Simple Mathematical Functions (T5) Statistical Analysis Tools (T6) Image Display Tools (T11) Report Generation Tools (T16)
Required Test Data	Sentinel-4/UVN and/or Sentinel-5/UVNS Level 1 data

	The Global Ozone Monitoring Experiment (GOME-2) on MetOp (D4.2) The Sentinel-5/UVNS Precursor TROPOspheric Monitoring Instrument (TROPOMI) (D4.4) The Ozone Mapping and Profiler Suite (OMPS) (D4.5) Geostationary Environment Monitoring Spectrometer (GEMS) (D4.6) Tropospheric Emissions: Monitoring of POllution (TEMPO) (D4.7)
Entry Conditions	Successfully validated Level 1 products.
Exit Conditions	Demonstrated consistency with other Earth radiance data from other CEOS-AC-VC missions.
Deliverables	Summary report on CEOS AC-VC Earth radiance products.
Team Involved	EUMETSAT/RSP ACh CA.
Periodicity	N/A
Initial Duration	During routine operations.
Recurrent Duration	N/A
Pass/Fail Criteria	Difference between Earth radiance measurements and radiance measurements from AC-VC missions less than the root mean square sum of the relative errors on both.
Comments	This is a community activity which is not intended to supersede the activities described in Section 6.2.2. It will be performed during routine operations and requires cooperation with all constellation partners.
Test Procedure	Based on the tools outlined above, the test performs following steps in an automated fashion: 1. Ingest Level 1 radiance products and read the relevant variables. 2. Ingest the radiance products from AC-VC missions as reference. 3. Read available data from a dedicated database (DB). 4. Run interpolation tool and statistical analysis tool. 5. Update the DB. 6. Prepare the test report.

CEOS AC-VC Level 2 Product Comparison with FRMs (A7.3)

Item	Description
Test Name	S4_S5_AC-VC_L2_FRM
Test Title	CEOS AC-VC Level 2 Product Comparison with FRMs (A7.3)
WBS Reference	EPS-SG 924950; MTG COM-835730

Purpose	To compare the validated Level 2 measurements of Sentinel-4/UVN and Sentinel-5/UVNS products with those of other missions from the AC-VC constellation.
Test Sequence Description	It is expected that validation by comparison with FRM are performed for all AC-VC missions using inter-calibrated reference data from global networks of ground based instruments, such as the NDACC network with Brewer, DOAS, Dobson and lidar instruments and the Pandonia Global Network (PGN) with Pandora instruments as described in Section 6.2.3. Inter-mission consistency is assessed indirectly by a global analysis of these comparisons and should be performed to infer the inter-mission consistency of Level 2 products.
Requirements	Sentinel-4 Level-2 Processor Requirements Specification, S4.ESA.UVN.RS.0093, Issue 2, Revision 1, 27/11/2018 [AD4] Sentinel-5 Level-2 Prototype Processor Development Requirements Specification, S5-RS-ESA-GR-0131, Issue 1, Revision 8, 15 July 2019 [AD5] Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017 [AD3]: **A1, A2, A3, B1, B2, B3, C1, C2, C3** See also Table 5.4 and Table 5.10
Prerequisites	Successfully validated Level 2 products.
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Report Generation Tools (T16)
Required Test Data	Sentinel-4/UVN and/or Sentinel-5/UVNS Level 2 validation reports CEOS AC-VC missions Level 2 constellation reports
Entry Conditions	Successfully validated Level 2 products.
Exit Conditions	Demonstrated consistency with other Level 2 products from other CEOS-AC-VC missions.
Deliverables	Summary report on CEOS AC-VC Level 2 products.
Team Involved	EUMETSAT/RSP ACh CA.
Periodicity	N/A
Initial Duration	During routine operations.
Recurrent Duration	N/A
Pass/Fail Criteria	N/A
Comments	This is a community activity which is not intended to supersede the activities described Section 6.2.3. It will be performed during routine operations and requires cooperation with all constellation partners.

Test Procedure	Based on the tools outlined above, the test performs following steps in an automated fashion: 1. Ingest Level 2 products and read the relevant variables. 2. Ingest FRMs products from AC-VC missions as reference. 3. Read available data from a dedicated database (DB). 4. Run statistical analysis tool. 5. Update the DB. 6. Prepare the test report.

CEOS AC-VC Level 2 Product Comparison using Polar Orbiting Missions as a Travelling Standard (A7.4)

Item	Description
Test Name	S4_S5_AC-VC_GEO_GEO
Test Title	CEOS AC-VC Level 2 Product Comparison using Polar Orbiting Missions as a Travelling Standard (A7.4)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To infer the inter-mission consistency of AC-VC geostationary constellation missions using polar orbiting missions as a travelling standard.
Test Sequence Description	The inter-mission consistency between the geostationary air quality missions is verified indirectly by using polar orbiting missions as a travelling standard. When inter-comparing satellite measurements, special care has to be taken with differences in spatial resolutions, resulting in possible offsets between satellite observations [SCD14]. For an accurate interpretation of polar orbiting versus geostationary comparisons of Level 2 products, scene knowledge is crucial. Therefore, these comparisons should be made systematically at all Level 2 validation sites for which comprehensive auxiliary information on horizontal and vertical distributions of trace gases, aerosol amount and vertical distribution, surface reflectance and cloud conditions is collected.
Requirements	Sentinel-4 Level-2 Processor Requirements Specification, S4.ESA.UVN.RS.0093, Issue 2, Revision 1, 27/11/2018 [AD4] Sentinel-5 Level-2 Prototype Processor Development Requirements Specification, S5-RS-ESA-GR-0131, Issue 1, Revision 8, 15 July 2019 [AD5] Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017 [AD3]: **A1, A2, A3, B1, B2, B3** See also Table 5.4 and Table 5.10
Prerequisites	Successfully validated Level 2 products.

Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Validation Data Product Readers and Subset Selection (T1.6) Simple Mathematical Functions (T5) Statistical Analysis Tools (T6) Image Display Tools (T11) Report Generation Tools (T16)
Required Test Data	Sentinel-4/UVN and/or Sentinel-5/UVNS Level 2 data products The World Meteorological Global Atmosphere Watch Program (GAW) (D3.1) The Network for the Detection of Atmospheric Composition Change (NDACC) (D3.3) The Aerosol Robotic Network (AERONET) (D3.4) The Pandonia Global network (PGN) (D3.5) The Atmospheric Radiation Measurements User Facility (ARM) (D3.10) The Total Carbon Column Observing Network (TCCON) (D3.11) The Aerosol, Clouds and Trace Gases Research Infrastructure (ACTRIS) (D3.14) The Global Ozone Monitoring Experiment (GOME-2) on MetOp (D4.2) The Infrared Atmospheric Sounding Interferometer (IASI) on MetOp (D4.3) The Sentinel-5/UVNS Precursor TROPOspheric Monitoring Instrument (TROPOMI) (D4.4) The Ozone Mapping and Profiler Suite (OMPS) (D4.5) Geostationary Environment Monitoring Spectrometer (GEMS) (D4.6) Tropospheric Emissions: Monitoring of POllution (TEMPO) (D4.7)
Entry Conditions	Successfully validated Level 2 products.
Exit Conditions	Demonstrated consistency between Level 2 data products from geostationary CEOS-AC-VC missions.
Deliverables	Summary report on consistency of CEOS AC-VC geostationary Level 2 products.
Team Involved	EUMETSAT/RSP ACh CA.
Periodicity	N/A
Initial Duration	During routine operations.
Recurrent Duration	N/A
Pass/Fail Criteria	N/A

Comments	This is a community activity which is not intended to supersede the activities described Section 6.2.3. It will be performed during routine operations and requires cooperation with all constellation partners.
Test Procedure	Based on the tools outlined above, the test performs following steps in an automated fashion: 1. Ingest Level 2 products and read the relevant variables. 2. Ingest trace gas products data from ground-based measurements and other satellites. 3. Read available data from a dedicated database (DB). 4. Run statistical analysis tool. 5. Update the DB. 6. Prepare the test report.

CEOS AC-VC Level 2 Algorithm Cross-validation (A7.5)

Item	Description
Test Name	S4_S5_AC-VC_ALG
Test Title	CEOS AC-VC Level 2 Algorithm Cross-validation (A7.5)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To cross-compare and validate the algorithms used within the AC-VC constellation missions.
Test Sequence Description	Level 2 algorithms are cross validated by applying them to a common set of Level 1b data. A number of issues need to be addressed to make the Level 2 processors developed for one mission fit for ingesting Level 1b products from another mission, e.g. the handling of the different Level 1b product formats, the treatment of flags, and approaches to background correction or the use of reference radiance or irradiance spectra might have to be adapted. If such issues can be addressed, the analysis of Level 2 data thus obtained is valuable for identifying Level 2 algorithm issues and discrepancies. In the particular case of stratospheric ozone, the inter-mission consistency is assessed by comparing monthly zonal mean values of the stratospheric sub-column from the ozone profile [SCD15], with a consistent definition of the tropopause height. Sampling difference effects need to be taken into account [SCD16].
Requirements	Sentinel-4 Level-2 Processor Requirements Specification, S4.ESA.UVN.RS.0093, Issue 2, Revision 1, 27/11/2018 [AD4] Sentinel-5 Level-2 Prototype Processor Development Requirements Specification, S5-RS-ESA-GR-0131, Issue 1, Revision 8, 15 July 2019 [AD5] Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017 [AD3]: **A1, A2, B1, C1, C3**

	See also Table 5.4 and Table 5.10
Prerequisites	Successfully validated Level 2 products.
Required Resources	Common hosted platform for community data analysis and product evaluation.
Required Test Tools	Level 2 product processors for CEOS AC-VC missions Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Validation Data Product Readers and Subset Selection (T1.6) Simple Mathematical Functions (T5) Statistical Analysis Tools (T6) Image Display Tools (T11) Report Generation Tools (T16)
Required Test Data	Sentinel-4/UVN and/or Sentinel-5/UVNS Level 1 data products The Global Ozone Monitoring Experiment (GOME-2) on MetOp (D4.2) The Sentinel-5/UVNS Precursor TROPOspheric Monitoring Instrument (TROPOMI) (D4.4) The Ozone Mapping and Profiler Suite (OMPS) (D4.5) Geostationary Environment Monitoring Spectrometer (GEMS) (D4.6) Tropospheric Emissions: Monitoring of POllution (TEMPO) (D4.7)
Entry Conditions	Successfully validated Level 1 and Level 2 products.
Exit Conditions	Demonstrated consistency between CEOS AC-VC mission Level 2 algorithms and recommendations for algorithms to be used for constellation products.
Deliverables	Summary report on consistency of CEOS AC-VC mission Level 2 algorithms.
Team Involved	EUMETSAT/RSP ACh CA.
Periodicity	N/A
Initial Duration	During routine operations.
Recurrent Duration	N/A
Pass/Fail Criteria	N/A
Comments	This is a very intensive community activity which is expected to be performed on a hosted processing environment (TBC). It will only be performed during routine operations and requires cooperation with all constellation partners. These activities do not supersede or replace the activities described Section 6.2.2 and 6.2.3. The availability of resources to support such an activity is TBC.
Test Procedure	Based on the tools outlined above, the test performs following steps in an automated fashion:

	1. Ingest Level 1 products and run Level 2 processors for CEOS AC-VC missions and read the relevant variables. 2. Ingest satellite operational Level 2 products as reference. 3. Read available data from a dedicated database (DB). 4. Run statistical analysis tool. 5. Update the DB. 6. Prepare the test report.

CEOS AC-VC Level 2 Constellation Products (A7.6)

Item	Description
Test Name	S4_S5_AC-VC_PRD
Test Title	CEOS AC-VC Level 2 Constellation Products (A7.6)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To cross-compare and validate the algorithms used within the AC-VC constellation missions.
Test Sequence Description	A common set of Level 2 algorithms should be agreed for the Level 2 constellation products (O_3 total column, NO_2 total column, NO_2 tropospheric column, SO_2 total column, HCHO total column, CHOCHO total column). This set of common Level 2 algorithms should be used to process Level 1b data from the various missions, ideally also from one or more of the polar orbiting missions. The systematic generation of Level 2 constellation products generated using the agreed common set of algorithms should be considered. The analysis of the Level 2 data thus obtained is expected to be valuable to identify possible Level 1b issues related to instrument, calibration and processing. Direct comparisons of Level 2 data from co-located LEO and GEO observations are expected to be meaningful, even when the viewing geometries differ, since Level 2 processing ideally removes viewing angle dependencies.
Requirements	Sentinel-4 Level-2 Processor Requirements Specification, S4.ESA.UVN.RS.0093, Issue 2, Revision 1, 27/11/2018 [AD4] Sentinel-5 Level-2 Prototype Processor Development Requirements Specification, S5-RS-ESA-GR-0131, Issue 1, Revision 8, 15 July 2019 [AD5] Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017 [AD3]: **A2, A3, B1, B2, C1, C2, C3** See also Table 5.4 and Table 5.10
Prerequisites	Successfully validated Level 2 products.

Required Resources	Common hosted platform for community data analysis and product evaluation.
Required Test Tools	Level 2 product processors for CEOS AC-VC constellation products. Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Validation Data Product Readers and Subset Selection (T1.6) Simple Mathematical Functions (T5) Statistical Analysis Tools (T6) Image Display Tools (T11) Report Generation Tools (T16)
Required Test Data	Sentinel-4/UVN and/or Sentinel-5/UVNS Level 1 data products The Global Ozone Monitoring Experiment (GOME-2) on MetOp (D4.2) The Sentinel-5/UVNS Precursor TROPOspheric Monitoring Instrument (TROPOMI) (D4.4) The Ozone Mapping and Profiler Suite (OMPS) (D4.5) Geostationary Environment Monitoring Spectrometer (GEMS) (D4.6) Tropospheric Emissions: Monitoring of POllution (TEMPO) (D4.7)
Entry Conditions	Recommendations for CEOS AC-VC constellation product algorithms.
Exit Conditions	CEOS AC-VC constellation products produced.
Deliverables	CEOS AC-VC constellation products.
Team Involved	EUMETSAT/RSP ACh CA.
Periodicity	N/A
Initial Duration	During routine operations.
Recurrent Duration	N/A
Pass/Fail Criteria	N/A
Comments	This is a very resource intensive community activity which is expected to be performed on a hosted processing environment (TBC). It will only be performed during routine operations and requires cooperation with all constellation partners. These activities do not supersede or replace the activities described Section 6.2.2 and 6.2.3. The availability of resources to support such an activity is TBC.
Test Procedure	Based on the tools outlined above, the test performs following steps in an automated fashion: 1. Ingest Level 1 products and run the Level 2 product processors for CEOS AC-VC constellation products. 2. Ingest constellation Level 2 products and read the relevant variables. 3. Read available data from a dedicated database (DB). 4. Run statistical analysis tool.

5. Update the DB.
6. Prepare the test report.

CEOS AC-VC Joint Validation Campaigns (A7.8)

This activity will be linked to the AO Call to be initiated by ESA and EUMETSAT. Detailed activity descriptions will depend on the contributions to the AO Call. Any validation campaigns, as outlined in Section 6.1.3.2, will be conducted with exchange of reference airborne and ground-based instruments between the mission teams including TEMPO and GEMS.

Tandem Operations of Recurrent Instruments (A8)

Cross-Comparison of Instrument Monitoring Data (A8.1)

Item	Description
Test Name	S4_S5_TND_MON
Test Title	Cross-Comparison of Instrument Monitoring Data (A8.1)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To cross-compare instrument monitoring data from Sentinel-4/UVN and/or Sentinel-5/UVNS recurrent instruments.
Test Sequence Description	Comparison of the output from Monitoring of Housekeeping Data (A4.1), Monitoring using Internal Calibration Sources (A4.2), Monitoring of In-Flight Calibration Parameters (A4.3), Monitoring of Radiance Measurements (A4.4) will provide information on the relative quality of the Level 1 data products. Specifically, Monitor Instrument Throughput using Solar Measurements (A4.3.5) and Monitor Instrument Throughput using Earthshine Measurements (A4.4.1) will provide information on the relative degradation characteristics of the two instruments including their time-dependent behaviour. Continuous cross-comparison of monitoring information from Sentinel-4/UVN and/or Sentinel-5/UVNS recurrent instruments in tandem operations shall be carried out to identify any differences in instrument performance and their evolution with time.
Requirements	Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017 [AD3] Sentinel-4/UVN - Instrument Requirements Specification, GS4.ASG.UVN.RS.00001 [AD6] Sentinel-5/UVNS - Instrument Requirements Specification, GS5.RS.ASG.UVNS.00012 [AD7]: **IRS-3608, IRS-3357**
Prerequisites	Successfully verified instrument function for Sentinel-4/UVN and/or Sentinel-5/UVNS recurrent instruments.
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.

Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Calibration Key Data Readers and Display (T1.2) Simple Mathematical Functions (T5) Report Generation Tools (T16)
Required Test Data	Monitoring data from Sentinel-4/UVN and/or Sentinel-5/UVNS recurrent instruments. Summary information on life-limited items and usage statistics, thermal performance, electrical performance, scanner performance, internal light source performance, and diffuser reflectivity stability. Summary information on electronic offset and dark signal performance, PRNU stability and performance, spectral stability and performance, and instrument throughput stability from solar measurements. Summary information on throughput stability from Earthshine (and albedo) measurements.
Entry Conditions	N/A
Exit Conditions	N/A
Deliverables	Summary report on cross-comparison of instrument monitoring data
Team Involved	EUMETSAT/RSP ACh CA.
Periodicity	Per orbit/product, per day, per week, per month, and per year.
Initial Duration	N/A
Recurrent Duration	N/A
Pass/Fail Criteria	No pass/fail criteria - monitoring purposes only
Comments	
Test Procedure	Based on the tools outlined above, the test performs following steps in an automated fashion: 1. Ingest monitoring data from Sentinel-4 and Sentinel-5 and read the relevant variables. 2. Read available data from a dedicated database (DB). 3. Run statistical analysis tool. 4. Update the DB. 5. Prepare the test report.

Cross-Validation of Level 1 Data (A8.2)

Item	Description
Test Name	S4_S5_TND_L1
Test Title	Cross-Validation of Level 1 Data (A8.2)

WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To cross-compare Level 1 data from Sentinel-4/UVN and/or Sentinel-5/UVNS recurrent instruments.
Test Sequence Description	The quality of the geolocation parameters for Sentinel-4/UVN and/or Sentinel-5/UVNS shall be compared using the output of Verification and Validation of Geolocation Information (A5.1) Cross-validation of the degradation corrected Average Solar Irradiance spectra shall be carried out on a daily basis by evaluation of the differences between the spectra. In addition, on a longer time scale, the seasonal variation of differences between the Average Solar Irradiance spectra will provide information on the azimuth dependence of differences in the Average Solar Irradiance spectra and therefore differences in the performance of the solar diffuser. Select spatially collocated Sentinel-4/UVN and/or Sentinel-5/UVNS degradation corrected ground pixels from recurrent instruments with a temporally separation of less than TBC minutes. Simulated Earthshine spectra for selected collocated ground pixels shall be calculated as described in **Error! Reference source not found.**. The differences between the simulated and measured spectra for each collocated ground pixel can be compared and analysed as a function of viewing and solar geometry and scan position. This will provide information regarding the relative performance of the two instruments.
Requirements	Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017 [AD3] Sentinel-4/UVN - Instrument Requirements Specification, GS4.ASG.UVN.RS.00001 [AD6] Sentinel-5/UVNS - Instrument Requirements Specification, GS5.RS.ASG.UVNS.00012 [AD7]
Prerequisites	Validated Level 1 data for Sentinel-4/UVN and/or Sentinel-5/UVNS recurrent instruments.
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Simple Mathematical Functions (T5) Statistical Analysis Tools(T6) Interpolation Tools (Linear, Spline and Akima) (T7) Image Display Tools (T11) Radiative Transfer Models (T14) Report Generation Tools (T16)
Required Test Data	Level 1 data from Sentinel-4/UVN and/or Sentinel-5/UVNS recurrent instruments.

Entry Conditions	Successfully validated Level 1 data from Sentinel-4/UVN and/or Sentinel-5/UVNS recurrent instruments.
Exit Conditions	N/A
Deliverables	Summary report on cross-validation of Level 1 data and to inform the decision on the optimal tandem operation mode for Sentinel-4/UVN and/or Sentinel-5/UVNS recurrent instruments.
Team Involved	EUMETSAT/RSP ACh CA.
Periodicity	Per orbit/product, per day, per week, per month, and per year.
Initial Duration	N/A
Recurrent Duration	N/A
Pass/Fail Criteria	Difference between Level 1 data products for collocated ground pixels from Sentinel-4/UVN and/or Sentinel-5/UVNS recurrent instruments less than the root mean square sum of the absolute errors on both, for all latitudes and seasons, taking into account differences in representativeness and collocation.
Comments	
Test Procedure	Based on the tools outlined above, the test performs following steps in an automated fashion: 1. Ingest Level 1 data products from Sentinel-4 and Sentinel-5 and read the relevant variables. 2. Read available data from a dedicated database (DB). 3. Run interpolation tool and statistical analysis tool. 4. Update the DB. 5. Prepare the test report.

Cross-Validation of Geophysical Parameter Data (A8.3)

Item	Description
Test Name	S4_S5_TND_L2
Test Title	Cross-Validation of Geophysical Parameter Data (A8.3)
WBS Reference	EPS-SG 924950; MTG COM-835730
Purpose	To cross-compare Level 2 data from Sentinel-4/UVN and/or Sentinel-5/UVNS recurrent instruments.
Test Sequence Description	Select spatially collocated ground pixels from Sentinel-4/UVN and/or Sentinel-5/UVNS recurrent instruments with a temporally separation of less than 50 minutes.

	Relevant Level 2 products are ozone profile, total column ozone, column trace gases and aerosol absorbing index, aerosol optical depth and aerosol layer height. Differences in Level 2 products for collocated ground pixels should be analysed in terms of mean and standard deviation as a function of latitude, solar zenith angle, view angle (or scan position), scattering angle and time. For the purposes of long-term validation and trend assessment, time series of collocated data at selected locations and in the zonal mean shall also be analysed.
Requirements	Copernicus Sentinels 4 and 5 Mission Requirements Traceability Document (MRTD), EOP-SM/2413/BV-bv, Issue 2, Revision 0, 7 July 2017 [AD3]: **A1, A2, A3, B1, B2, B3, C1, C2, C3** Sentinel-4 Level-2 Processor Requirements Specification, S4.ESA.UVN.RS.0093, Issue 2, Revision 1, 27/11/2018 [AD4] Sentinel-5 Level-2 Prototype Processor Development Requirements Specification, S5-RS-ESA-GR-0131, Issue 1, Revision 8, 15 July 2019 [AD5] See also Table 5.4 and Table 5.10
Prerequisites	Validated Level 2 data for Sentinel-4/UVN and/or Sen-tinel-5/UVNS recurrent instruments.
Required Resources	EUMETSAT offline operational environment and/or EUMETSAT TCE plus successfully functioning MTG IDPF-S and/or EPS-SG PDAP.
Required Test Tools	Sentinel-4/UVN and Sentinel-5/UVNS Product Readers and Subset Selection (T1.1) Simple Mathematical Functions (T5) Statistical Analysis Tools(T6) Interpolation Tools (Linear, Spline and Akima) (T7) Image Display Tools (T11) Report Generation Tools (T16)
Required Test Data	Validated Level 2 data products from Sentinel-4/UVN and/or Sentinel-5/UVNS recurrent instruments.
Entry Conditions	Successfully validated Level 2 data from Sentinel-4/UVN and/or Sentinel-5/UVNS recurrent instruments.
Exit Conditions	N/A
Deliverables	Summary report on cross-validation of Level 2 data and to inform the decision on the optimal tandem operation mode for Sentinel-4/UVN and/or Sentinel-5/UVNS recurrent instruments.
Team Involved	EUMETSAT/RSP ACh CA.
Periodicity	Per orbit/product, per day, per week, per month, and per year.
Initial Duration	N/A

Recurrent Duration	N/A
Pass/Fail Criteria	Difference between Level 2 data products for collocated ground pixels from Sentinel-4/UVN and/or Sentinel-5/UVNS recurrent instruments less than the root mean square sum of the absolute errors on both, for all latitudes and seasons, taking into account differences in representativeness and collocation.
Comments	
Test Procedure	Based on the tools outlined above, the test performs following steps in an automated fashion: 1. Ingest Level 2 data products from Sentinel-4 and Sentinel-5 and read the relevant variables. 2. Read available data from a dedicated database (DB). 3. Run colocation tool and statistical analysis tool. 4. Update the DB. 5. Prepare the test report.

APPENDIX C CAL/VAL TOOLBOXES

The tool functionalities described in section 7.4 are implemented across various Cal/Val toolboxes. The table below lists these Cal/Val toolboxes and indicates which generic tool functionalities are covered by each.
For further information and updates see:
https://eumetsat.atlassian.net/wiki/spaces/RSPC/pages/37782019/Sentinel-5+Tools

Toolbox/ Framework Name	Tool IDs covered	Level	Priority (Mandatory or Beneficial)	Under Configuration Management?	Application (Commissioning and /or Operations)
AnaLiza	T1. x T3 T5 T6 T7 T8 T9 T11	L0/1/2	M	Yes (gitlab) https://intgitlab.opscloud.eumetsat.int/acteam/analiza/	C and O
Satpy	T1	L1/2	B	Yes (gitlab) https://gitlab.eumetsat.int/acTeam/uvn_reader	C and O
EO-CFI	T2	L1/2	M		
MICMICS	T3 T14 T15	L1	B	Yes	C and O
SpecFUN	T4 T10	L1/L2	M	Yes (gitlab) https://gitlab.eumetsat.int/acTeam/specfun	C and O
MONALiSA	T1.6 T3	L2	M	Yes (gitlab) https://gitlab.eumetsat.int/acTeam/monalisa_ac	C and O
UVN-STAR (for S4) /		L1/2	M	Yes (gitlab)	C and O

UVNS-STAR (for S5)					
PIQMICS	T12	L1	M	Yes	C and O
Metview	T13	L2	M	Yes https://github.com/ecmwf/metview-python	C and O
CHART	T16	L1/2	M		C and O