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DOCUMENT

Sentinel-5P Commissioning & CalVal Plan

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draft	14 March 2014		new document
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1 INTRODUCTION

The Sentinel-5 Precursor (S5P) mission will represent the first of a series of atmospheric observing systems within the Global Monitoring for Environment and Security (Copernicus, formerly GMES) initiative. While focusing on the chemical composition of the Troposphere and covering spectral bands in the ultra-violet, visible and infrared ranges, the S5P will provide global monitoring capabilities for global air quality and climate. The S5P spacecraft will embark the TROPOMI instrument that will be jointly developed by the Netherlands (for the largest contribution) and ESA. Compared to its predecessor missions GOME (ERS-2), SCIAMACHY (Envisat), OMI (Aura) and GOME-2 (MetOP) S5P will provide enhanced radiometric sensitivity and spatial resolution capabilities thus allowing unprecedented observations of atmospheric species and aerosols, specifically in the lower Troposphere.

With a planned Flight Acceptance Review towards end 2015, leading to a launch in early 2016, S5P is expected to contribute substantially to the understanding of stratospheric ozone chemistry and impacts on surface UV radiation, the sources and sinks of pollutants and climate change. The mission will thus avoid large gaps in the availability of global atmospheric data products between the SCIAMACHY and OMI missions and the launches of Sentinel-4 (part of MTG-S) and Sentinel-5 (part of MetOp Second Generation), scheduled for launch in 2019 or 2020, respectively.

The design lifetime of S5P is 7 years, including an initial 6 months period covering spacecraft and TROPOMI level commissioning activities as well as initial calibration and characterization tasks (Phase E1). During this period observational data will also be provided to ESA external expert teams charged with specific analysis tasks focusing at instrument calibration and geophysical validation of the mission's key data products.

The Phase E1 will be followed by a 6.5 years exploitation period (Phase E2) during which the spacecraft will be operated according to a stable, fully repetitive scenario, with systematic processing and archiving of data products within the S5P Payload Data Ground Segment (PDGS) and dissemination to both operational users (e.g. Copernicus Atmospheric Service, national NWP centres and collaborative ground segments, value adding industry) and the scientific user community.

2 SCOPE AND RELATION TO OTHER DOCUMENTS

Scope of document

This document shall establish an overall planning for the early post-launch functional check-out, characterization and calibration activities for the S5P spacecraft, including the TROPOMI payload instrument. These tasks shall include spacecraft / payload related activities as already defined in the Mission Operations Concept ([RD-4], [RD-5]) and the TROPOMI Operations Plan ([RD-2]), as well as Ground Segment and processor specific tasks. Moreover, it shall cover the planning of the validation of the primary engineering and geo-physical data products both before and after release to a broad user community.

Finally, this document shall

- Compile requirements for implementation of specific calibration and characterization activities in terms of spacecraft operation and on ground processing
- List data generation & circulation requirements (S5P products, auxiliary data, mission planning information)
- Define milestones at which specific subsets of the S5P data products and related diagnostics and auxiliary information will be available for validation projects led by ESA external CalVal expert teams (S5P Validation Teams, S5PVT)
- Support the planning of non-S5P measurement activities (e.g., correlative ground based trace gas measurements, airborne experiments) and coordination with the spacecraft operations
- Define a schedule for required early in-flight processor updates, including processor configuration and auxiliary data
- Provide an initial planning for coordination meetings/workshops involving instrument experts, algorithm developers, PIs of campaign projects and the mission operations teams.

Relation to other documents

This Plan shall ensure that following a successful launch of the S5P spacecraft, initial switch-on and functional check-out of sub-systems all essential in-flight characterization and calibration tasks will be completed in a timely manner. It shall take into account core tasks defined at satellite level (satellite in-flight verification plan, and TROPOMI instrument), at Ground Segment system level and at the level of the ground processing chains. Moreover, the plan shall accommodate dedicated projects concentrating on the geophysical validation of S5P mission products, and to be initiated via an Announcement of Opportunity call.

All tasks specified herein shall be defined and implemented consistency with requirements and the planning compiled in the following documents:

- GMES S5P System Requirements Document, [AD-1]
- S5P Mission Requirements Traceability Document, [RD-1]
- Requirements for the Geophysical Validation of S5P Products, [AD-2]
- S5P Ground Segment Requirements Document, [AD-3]
- S5P Satellite In-Flight Verification Plan, [AD-7]
- TROPOMI Calibration Measurement Plan for Phase E1, [AD-8]
- S5P Mission Operations Concept Document (including Ground Segment), [RD-5]
- S5P Ground Segment Master Schedule, [AD-6].

Detailed mission planning and scheduling requirements will be provided in separate documents ([RD-2] - [RD-5], [AD-10]). These documents also define strategies for the re-scheduling of tasks in case of anomalies, temporary spacecraft unavailability or insufficient quality of acquired observational data.

Planned document updates

A first version (v0) of this document shall be provided with the opening of the Sentinel-5 Precursor CalVal Announcement of Opportunity scheduled for May 2014. An updated version shall be provided in the beginning of 2015, after the evaluation of CalVal proposals has been completed and a consolidated list of CalVal projects supported by ESA external institutes has been established. Additional versions of the CalVal Implementation Plan shall be provided as appropriate, to take into account modified or additional CalVal tasks defined as a result of ongoing pre-launch algorithm development work, as well as findings from pre-launch TROPOMI FM characterization measurements and changes to the project schedule. A new release will also be provided as part of the S5P Flight Acceptance Review (FAR) data package.

A further document update will be provided post-launch at the end of Phase E1, to reflect findings and recommendations obtained during initial functional tests and CalVal analyses. That version shall also identify updated priorities for routine calibration and re-characterization activities as well as long-term geo-physical validation tasks to be covered during Routine Operations (Phase E2).

Additional updates of the S5P Commissioning and CalVal Plan may be provided during routine operations (Phase E2), as required.

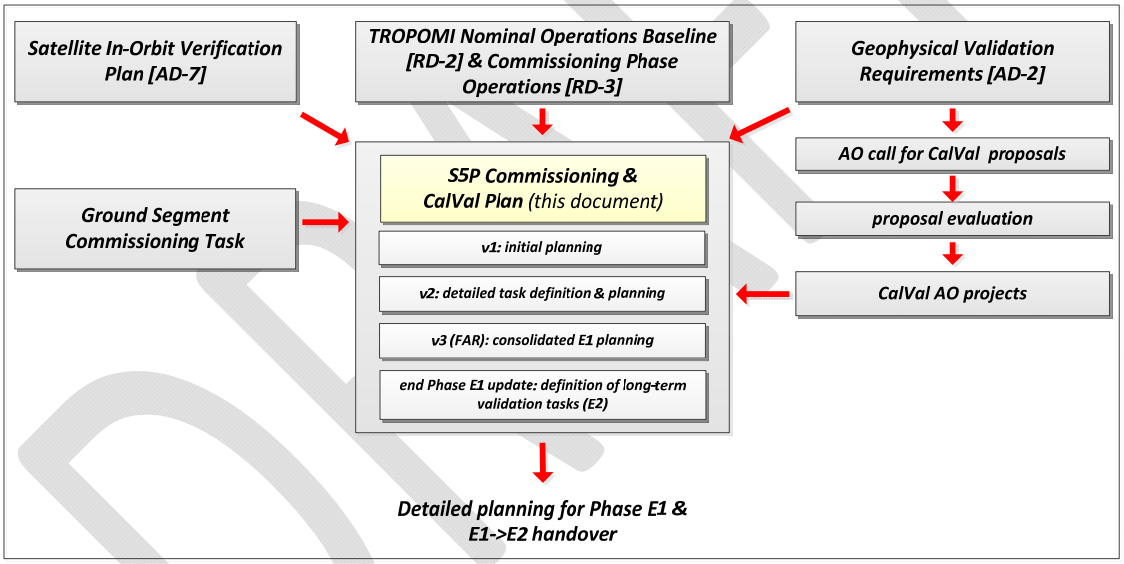

Figure 2-1. Commissioning and CalVal Plan: context and update cycle

Approval

All pre-launch versions of the S5P Commissioning and CalVal Plan shall be approved by the S5P Project Manager (EOP-PJ). The end Phase E1 version shall be part of the Commissioning Phase Review / Mission Handover data package and be jointly approved by the S5P Project Manager and the S5P Mission Manager.

All later releases (Phase E2) shall be approved by the S5P Mission Manager.

3 APPLICABLE & REFERENCE DOCUMENTS

3.1 Applicable documents

	Document	Issue	Title
[AD-1]	S5P-RS-ESA-SY-0002	4.1	GMES S5P System Requirements Document
[AD-2]	S5P-RS-ESA-SY-164	dr	Requirements for the Geophysical Validation of Sentinel-5 Precursor Products
[AD-3]	S5P-RS-ESA-GS-0092	1.0	S5P Ground Segment Requirements Document
[AD-4]	S5P-RS-ESA-SY-0031	2.2	S5P PDGS Technical Requirements
[AD-5]	S5P-PL-ESA-SY-070	1.0	S5P Ground Segment Master ICD
[AD-6]	S5P-PL-ESA-SY-069	1.0	S5P Ground Segment Master Schedule
[AD-7]	tbd		S5P Satellite In-Orbit Verification Plan - document to be written -
[AD-8]	S5P-KNMI-ICAL-0016-PL		Calibration measurement plan for the TROPOMI commissioning phase (E1) - document in preparation -
[AD-9]	S5P-KNMI-ICAL-0005-PL		TROPOMI Overall Calibration Plan - document in preparation -
[AD-10]	tbd		S5P Flight Operations Plan - document to be written -
[AD-11]	QMS-PR-ESRIN-MMAN-2100-EOAD	2.0	Procedure for: Mission Handover
[AD-12]	EO-MA-DMS-GS-0001	4.3	EO Mission CFI Software Conventions Document

3.2 Reference documents

	Document	Issue	Title
General & system level documents			
[RD-1]	EO-SM/2413/BV-bv	1.0	GMES Sentinels 4 and 5 Mission Requirements Traceability Document
[RD-2]	TN-TROPOMI-KNMI-056	3.0.0	TROPOMI Nominal Operations Baseline
[RD-3]	TN-TROPOMI-KNMI-xxx	-/-	TROPOMI Commissioning Phase Operations - document to be written -
[RD-4]	S5P-TN-ASU-SY-0013	3.0	Mission Operations Concept
[RD-5]	S5P-TN-ESA-SY-112	1.1	Sentinel 5 Precursor Mission Operations Concept Document (including Ground Segment)
[RD-6]	S5P-RP-ASU-SY-0011	2.0	S5P Mission Analysis
[RD-7]	S5P-TN-ESA-SY-032	1.0	Sentinel 5 Precursor Mission GS Concept Document
[RD-8]	S5P-PDGS-DLR-DES-3000	1.0	S5P PDGS System Technical Description and Operations Concept
[RD-9]	S5P-PL-ESA-GS-107	1.0	S5P Ground Segment Validation Plan
[RD-10]	TROP-DS-0000-RP-0520	1.0	TROPOMI – Instrument Design Description
[RD-11]	tbd	-/-	S5P PDGS to Phase E1 Users ICD - document to be written -
[RD-12]	tbd	-/-	S5P PDGS to Copernicus User Service Infrastructure ICD - document to be written -
Algorithm & product specific documents			
[RD-13]	S5P-KNMI-L01B-0012-SD	2.0.0	Input/output data specification for the TROPOMI L01b data processor
[RD-14]	S5P-KNMI-L01B-0009-SD	0.0.4	ATBD for the TROPOMI L01b data processor
[RD-15]	S5P-KNMI-OCAL-0005-SD	0.0.4	Algorithm theoretical basis document for TROPOMI UVN on-ground calibration key data calculation
[RD-16]	S5P-L2-DLR-IODD-3002	0.3	Sentinel-5 Precursor Level 2 UPAS Processor Input / Output Definition Document
[RD-17]	S5P- KNMI -L2-0009-SD	1.0.0	Sentinel 5-precursor KNMI Input Output Data Definition
[RD-18]	SRON-S5P-LEV2-RP-001	0.9	ATBD for Sentinel-5 Precursor methane retrieval
[RD-19]	SRON-S5P-LEV2-RP-002	0.9	Carbon Monoxide Columns from the Sentinel-5 Precursor Instrument: ATBD
[RD-20]	S5P- KNMI -L2-0005-RP	0.9.0	TROPOMI ATBD of the total and tropospheric NO2 data products
[RD-21]	S5P- KNMI -L2-0004-RP	0.9.0	TROPOMI ATBD Ozone profile and tropospheric profile
[RD-22]	1. S5P- KNMI -L2-0006-RP 2. S5P-KNMI-L2-0008-RP	0.9.0 0.9.0	TROPOMI Aerosol ATBD: part 1 - Aerosol Layer Height Products part 2 - Aerosol Index Product
[RD-23]	1. S5P-L2-DLR-ATBD-400A 2. S5P-DLR-IUP-L3-400C	0.9.0 0.9.0	S5P/TROPOMI Ozone ATBD: part 1 - total column product part 2 - tropospheric product
[RD-24]	S5P-L2-DLR-ATBD-400I	0.9.0	S5P/TROPOMI ATBD Cloud Products
[RD-25]	S5P-L2- BIRA-ATBD-400E	0.9.0	S5P/TROPOMI SO2 ATBD draft
[RD-26]	S5P-L2-BIRA-ATBD-400F	0.9.0	S5P/TROPOMI HCHO ATBD draft
[RD-27]	S5P-NPPC-RAL-ATBD-0001	0.9.0	S5P-NPP Cloud Processor ATBD
[RD-28]	S5P-KNMI-L01B-0015-PL	1.0.0	Software validation plan for the TROPOMI L01b data processor
[RD-29]	S5P-IUP-L2-ScVP-RP	0.0.4	S5P/TROPOMI Science Verification Plan (Level 2)

4 DEFINITIONS AND ABBREVIATIONS

4.1 Definitions

Definitions and terms introduced in [AD-1] - [AD-4] shall apply to this document. In addition, the following definitions shall apply:

Accuracy

Accuracy is the absolute uncertainty or error of a measurement result, assuming that the 'true' value of a measurable parameter is known exactly. In general, the accuracy of a measurement is affected by both, random and systematic error sources. In many cases the assignment of accuracies is difficult or even impossible as independent, accurate measurements taken under identical conditions are not available. Often, the accuracy of a measured parameter is esti- mated through comparisons with other measurements acquired under variable conditions or indirectly, by means of analyses.

Ancillary data

Ancillary data are additional data complementing the TROPOMI observational data and Engineering data as required for processing and monitoring tasks on ground. In particular, ancillary data include platform provided navigation data (PVT data, attitude data).

Ascending Node Crossing (ANX)

The S5P Ascending Node Crossing point is the location of the intersection point between the spacecraft's ground track and the equator. Accordingly, the ANX time is the UTC time of the ANX passage.

Auxiliary data

Auxiliary data denote all data input to the on ground data processing that originate from sources other than the satellite data stream. Auxiliary input data are required by the various Level 1B & Level 2 processors and include e.g. algorithm settings and meteorology forecast data. Also instrument characterization/calibration data are considered as auxiliary data although they may be derived from in-flight measurements.

Calibration

The Committee on Earth Observation Satellites (CEOS)'s Working Group on Calibration and Validation (WGCV), and ISO 9000, define *Calibration* as the process of quantitatively defining the system responses to known, controlled signal inputs. Accordingly, a calibrated product represents the output from the complete calibrated data generation chain.

In the context of this document '*calibration*' also refers to the process of transforming data represented in arbitrary or instrument specific ('engineering') units into physically meaningful units.

Characterization

The term 'Characterization' shall denote a collection of measurements of a specific quantity under well-defined, variable conditions. The purpose of a *characterization* is to allow the assignment of an expected result valid at a later instant, given the exact conditions valid at that instant and the results of the *characterization* measurements.

Engineering data

The term *Engineering Data* refers to the sum of Housekeeping Telemetry and data supplied by the Instrument Specific Modules (ISMs) of the ICU. These include the three Detection Modules (UVN-DEMs) and the SWIR module Front-End Electronics (FEE). The Engineering Data, i.e. the HKTM and ISM / DEM / FEE supplied data are contained in the X-band telemetry ('science' TM).

Housekeeping (telemetry) data

Housekeeping Telemetry (*HKTM*) data comprise all data generated on board that are required either for health monitoring and diagnostics purposes or for routine processing tasks on ground. Typical HKTM data include temperature, voltage, current

readings from sensors mounted on instrument, platform and critical interfaces. The HKTM forms part of the routinely downlinked S-band telemetry.

Line Of Sight (LOS)

The line of sight (LOS) is defined as the path of propagation of light between the viewed atmospheric target scene and the TROPOMI instrument, either for a given detector pixel in a given spectral channel or for a pre-defined reference pixel. It follows a straight line between the atmospheric target and the instrument's input in case refraction effects are neglected.

Mission operations

This term shall denote the sum of all activities related to operations planning, execution and evaluation of the combined space segment and ground segment during phases E1, E2 and F of the Sentinel-5P mission.

Operational validation

'*Operational validation*' denotes the test activity aiming at establishing the readiness of the complete S5P ground segment, including mission operations data, and operations personnel to support the space mission in–orbit by means of simulations and rehearsals. The result of this process is a qualified ground segment.

Precision

'Precision' is the uncertainty within which a specific measurement can be reproduced. Assuming that fluctuations in the result of a repeated measurement are of pure random origin, precision is given as the estimated standard deviation (1 σ) of the difference (relative or absolute) between individual samples and the average over all measurements.

Reference orbit

The S5P reference orbit is defined in terms of a set of orbit parameters (eccentricity, inclination, sun-synchronous type), an orbit repeat cycle and a set of nominal longitude values defining the (Earth fixed) ascending node crossing positions for all orbits within an orbit repeat cycle. Margins are specified for the tolerable deviations of the actual cross-track position and the mean local solar time (MLST) of the ANX crossings from the reference track.

Science data

Observational data generated by the TROPOMI instrument and transmitted to the ground via the X-band communication channel. The science data also include *housekeeping telemetry* and platform provided *ancillary data* (see below) as required on ground for routine processing tasks.

Validation

The CEOS WGCV and ISO 9000's definition of *Validation* is the process of assessing, by independent means, the quality of the data products as derived from the system outputs. *Geophysical validation* ensures that the quality of geophysical products derived from the system is properly assessed by independent means and via quantification of the uncertainties at any stage of the product processing chain. A *validated product* is thus the output from the complete validated data generation chain.

4.2 Abbreviations

ADF	Auxiliary Data File
AIT	Assembly, Integration & Test
ANX (time)	(time of) Ascending Node crossing
AO	Announcement of Opportunity
AP	Algorithm Provider
AR	Acceptance Review
CalVal	Calibration and Validation
CDS	Coordinated Data access System
CEOS	Committee on Earth Observation Satellites
CFI	Customer Furnished Item
CPR	Commissioning Phase Review
CS CDA	Copernicus Space Component Data Access
DEM	Detector Module
DIFM	Diffuser Mechanism
DLR	Deutsches Zentrum für Luft- und Raumfahrt
EC	European Commission
ECSS	European Cooperation on Space Standardization
EDDS	ESA Ground Operations System (EGOS) Data Dissemination System
FAR	Flight Acceptance Review
FEE	Front-End Electronics
FOM	Flight Operations Manual
FOS	Flight Operations Segment
GCM	Copernicus Space Component Contributing Mission
GMES	Global Monitoring for Environment and Security
GS(O)V	Ground Segment (Overall) Validation
HLOP	High-Level Operations Plan
ICD	Interface Control Document
ICU	(TROPOMI) Instrument Control Unit
IDAF	(TROPOMI) Instrument Data Analysis Facility
IPF	Instrument Processing Facility
ISM	Instrument Specific Module (part of ICU Module)
IUP	Institute for Environmental Research (Univ. of Bremen, D)
JPT	Joint Project Team
KNMI	Royal Netherlands Meteorological Institute
L2-PF	Sentinel-5P Level 2 Processing Facility
LEOP	Launch and Early Orbit Phase
LOS	Loss Of Signal or Line Of Sight
LTA	Long Term Archive
LTDP	Long-Term Data Preservation
Met	Meteorology
MOWG	(S5P) Mission Operations Working Group
MPC	Mission Performance Centre
MPIC	Max Planck Institute for Chemistry
NCR	Non-Conformance Report
ngEO	**n**ext **g**eneration user services for **E**arth **O**bservation
NPPF	Nominal Payload Planning File
NRT	Near Real Time
NWP	Numerical Weather Prediction
NSO	Netherlands Space Office
OBCP	On Board Control Procedure

OBSM	On Board Software Maintenance
OMI	Ozone Monitoring Instrument
OSF	(TROPOMI) Operations Support Facility at KNMI
p	(atmospheric) Pressure
PDGS	(Sentinel-5P) Payload Data Ground Segment
PDHU	Payload Data Handling Unit
RAL	Rutherford Appleton Laboratory (RAL)
S5P	Sentinel-5 Precursor
SAA	South Atlantic Anomaly
SCIAMACHY	SCanning Imaging Absorption SpectroMeter for Atmospheric CartograpHY
SDP	Software Development Plan
SFTP	Secure File Transfer Protocol
SIF	Stack Import File
S-NPP	Suomi National Polar-orbiting Partnership
SRD	System Requirements Document
SRON	Netherlands Institute for Space Research
SSH	Secure Shell (protocol)
SVP	Software (System) Validation Plan
SWIR	Short-Wave InfraRed (spectral channel)
T	(atmospheric) Temperature
TDS	Test Data Set
TPF	Task Parameter File
TROPOMI	TROPOspheric Monitoring Instrument
TRB	Test Review Board
TRR	Test Readiness Review
TTC	Tracking, Telemetry & Command
UVN	Ultraviolet / Visible / Near-infrared (spectral channels)
VIIRS	Visible Infrared Imager Radiometer Suite
WAN	Wide Area Network
WGCV	(CEOS) Working Group on Calibration and Validation

5 PROGRAMMATIC ASSUMPTIONS

The following assumptions shall apply during preparation and conduct of CalVal activities for the Sentinel-5P mission:

1. The development of the S5P Mission, comprising a Space and a Ground Segment component, will be conducted under overall ESA responsibility
2. The TROPOMI instrument will be jointly developed by the Netherlands Space Office (NSO), for the main part covering the UV/VIS/NIR channels, and ESA, providing the SWIR channel module
3. The S5P Payload Data Ground Segment (PDGS) will be developed by DLR-EOC/Oberpfaffenhofen (D). DLR-EOC is also charged with the operation of the PDGS and the provision of services to external users up to end Phase E1
4. The S5P Flight Operations Segment (FOS) will be developed and deployed by ESA / ESOC. ESOC will also operate the FOS up to end Phase E1
5. The overall validation of the S5P Ground Segment, including the Space to Ground interface, will be conducted under ESA responsibility
6. An operations concept for Phase E2 (routine operation) will be provided by the Agency, for approval by the European Commission (EC)
7. During Phases B/C/D/E1 the mission authority will be with the Sentinel-5 Precursor Project Manager (ESA/EOP-PJ). At start of Phase E2 the S5P mission authority will be transferred to ESA/EOP-G in the frame of a Delegation Agreement between the EC and ESA, in accordance with EC rules
8. The handover of the mission authority Phase E1 -> E2 will be executed according to the procedure defined in [AD-11]. A corresponding Mission Handover Plan will be generated by the S5P Mission Manager, in close collaboration with the S5P Project Manager
9. The S5p primary users are the Copernicus Operational Services with dedicated access to the S5p data, together with other users including the scientific community, collaborative ground segments located in ESA member states as well as value adding public and commercial users
10. The S5P Level 1B operational processor and related calibration processors will be developed under the responsibility of the Dutch Space Agency (NSO)
11. The S5P Level 1B & 2 processor developers are responsible for the generation of test data required during pre-launch Level 2 algorithm development and validation activities
12. The S5P Level 2 operational processors will be developed in the frame of dedicated, parallel contract activities, under partial national and ESA responsibility, in accordance with technical / interface requirements issued by ESA
13. The S5P Level 1B, Level 2 processors will be integrated and operated in a centralized PDGS located at DLR-EOC
14. The integration and system level validation of the processors will be conducted under overall coordination of ESA, with appropriate support supplied by the Level 1B and Level 2 developers
15. The Level 1B and Level 2 development contracts cover the post launch functional verification and maintenance of all processor components up to end Phase E1
16. The geophysical validation of S5P data products is not covered by the Level 1B & 2 development contracts but will be implemented under separate activities under overall ESA coordination
17. ESA issues an Announcement of Opportunity (AO) call to stimulate expert teams and research institutes worldwide to propose dedicated projects aiming at the validation of S5P data products
18. Announcement of Opportunity CalVal (AO-CalVal) projects should focus at the geo-physical validation of S5P products but may also address in-flight calibration, characterization and performance monitoring aspects
19. AO-CalVal projects shall be funded via non-ESA (e.g. national) resources.

6 MISSION OVERVIEW

The following sections provide a brfief overview on the S5P spacecraft including the TROPOMI payload, the mission products and the ground segment. For a more detailed description refer to [RD-2] - [RD-10].

6.1 The Sentinel-5P spacecraft and operations concept

Platform

The Sentinel-5P platform is largely based on the Astrobus L 250 M platform, with only few modifications to the various sub-systems. The satellite is equipped with a fixed solar array providing a peak power of ~1,500 W. A mass storage of 480 Gbit will be available for the recording of payload ('science') telemetry, engineering data and platform provided ancillary telemetry. An S-band communication link is used for commanding, ranging and housekeeping TM downlink tasks, allowing an uplink rate up to 64 kbps and TM downlink rate up to 571 kbps. An X-band transmission channel will be used exclusively for the downlink of 'science' telemetry, i.e. TROPOMI measurement data and related housekeeping / ancillary data as required for routine processing tasks on ground.

The TROPOMI Instrument

Sentinel-5P's single payload instrument TROPOMI is a passive grating spectrograph covering a total of 4 spectral channels ranging from the ultra-violet to the short-wave infrared. It consists of two main optical units comprising a so-called UVN module and a short-wave infrared (SWIR) module, both using a common input telescope.

The instrument will be operated in a push-broom configuration (non-scanning), with an instantaneous field of view of 108° cross-track, resulting in a swath width of ~ 2600 km on the Earth surface. A separate port is provided for solar calibration measurements, which will be scheduled typically once per day. The typical pixel size (near nadir) will be 7x7 km² for all spectral bands, with the exception of the UV1 band, for which the nominal size is 21x28 km².

Operations concept

S-5P will be launched into a near-polar, sun-synchronous orbit, with an orbit height of approx. 820 km. The satellite's orbit repeat cycle (16 days / 227 orbits) and the local time of ascending node crossing (LTAN: 13.35 h) have been chosen to facilitate a so-called loose formation operation with NASA's Suomi-NPP spacecraft (LTAN: 13.30 h). This concept will allow the utilization of co-located, high resolution cloud mask data provided by the VIIRS (*Visible Infrared Imaging Radiometer Suite*) instrument on-board Suomi-NPP during routine processing of TROPOMI observations.

VIIRS provided cloud mask data will be used primarily for the processing of methane (off-line Level 2 product), using TROPOMI's SWIR channel. Given the demanding accuracy requirement for retrieved CH4 columns (total error < 2 %) the processing is performed only for cloud free pixels.

The S-5P mission concept is based on the routine operation of the TROPOMI instrument in nominal measurement mode performing either measurements of the atmospheric target scene or calibration activities. Whereas atmospheric radiances measurements will be nominally performed on the day side part of the orbit background image measurements (and all other calibration measurements) will be acquired during eclipse periods.

Solar irradiance measurements (i.e. measurements of the top-of-atmosphere reflectance) will be commanded approximately once every 15 orbits. Various additional calibration activities, including measurements of internal white light and spectral line sources will be scheduled periodically. All data will be recorded in the on-board mass memory and dumped during regular ground station passes.

Ground communication

The spacecraft provides separate communication channels

- an S-band link, used for telecommanding, tracking tasks and for the downlink of housekeeping telemetry
- an X-band link for the downlink of 'science' telemetry, i.e. TROPOMI observational data and related engineering telemetry.

Whereas the ESA ground station in Kiruna (Sweden) is used for spacecraft commanding and monitoring tasks (S-band) the acquisition station Svalbard (Norway) will be used for periodic dumps of recorded S- and X-band telemetry. Use of Inuvik (Canada) as complementary acquisition station is envisaged to reduce the latency for TROPOMI measurement data between

sensing and availability at the Payload Data Ground Segment (PDGS). Use of the dual station downlink scenario will ensure that a sufficiently long station contact time is achieved for all orbits, in line with the near-real-time (NRT) service envisaged for global Level 2 data products. With a volume of approx. 169 Gbits/orbit generated by TROPOMI (including ancillary data and downlink overhead), and a downlink rate of 310 Mbps a dump time of approx. 540 s is required during each X-band station pass.

The Ground Segment

The S-5P Ground Segment comprises two main sub-systems, the Payload Data Ground Segment (PDGS) and the Flight Operations Segment (FOS).

PDGS

The PDGS will be in charge of receiving all recorded S-5P telemetry and conduct tasks related to the systematic processing, archiving and dissemination of mission data products. This will comprise, in particular

- interfacing with the Flight Operations Segment for the scheduling of data dumps using the S-/ X-band acquisition stations Svalbard and Inuvik
- reception of recorded S- and X-band telemetry using the acquisition stations Svalbard and Inuvik
- systematic processing of 'science' (X-band) data with generation of Level 0 / 1B / 2 data products
- archiving of all generated data products and dissemination of products to end users both near-real-time and off-line

The S-5P PDGS will be located at DLR-Oberpfaffenhofen (Germany).

FOS

The FOS will be in charge of the overall satellite monitoring and control tasks, in particular

- Operation of the Telemetry, Tracking and Command (TT&C) station in Kiruna (S)
- monitoring of the S-5P satellite's health status and implementation of corrective / recovery actions in case of anomalies
- interfacing with the PDGS for the reception of ground station related planning information and of S-band telemetry received by the acquisition stations in Svalbard and Inuvik
- interfacing with the TROPOMI Operations Support Facility located at KNMI (The Netherlands) for the reception of instrument level planning information
- execution of flight dynamics analyses and scheduling of orbit control manoeuvres
- routine planning of spacecraft and TROPOMI level activities, and generation/uplink of telecommand data.

The FOS will be located at ESA/ESOC in Darmstadt (Germany).

Data products overview

Table 6-1 provides an overview of the S5P mission's data products and related auxiliary data. A fully detailed description of the S5P data products is included in [RD-13], [RD-16], [RD-17].

Table 6-1. Summary of Sentinel-5P data products

Product	Description	Remarks
Raw X-band telemetry data	Re-constructed X-band source packet data. Data files generated by X-band acquisition stations (Svalbard, Inuvik), for delivery to the PDGS	'science' TM data, time ordered (for PDGS internal use only)
Level 0	Raw, unprocessed instrument measurement data (atmospheric and calibration modes) in all TROPOMI spectral bands, housekeeping data; data files sorted by instrument mode / application process	Product boundaries aligned with downlink segments, time ordered
Level 1B	Calibrated, geo-located Earth radiance spectra in all TROPOMI spectral bands; solar irradiance data Annotation data: • summary of essential observational parameters & settings • processed housekeeping information • health information & product confidence data (PCD's) • others	Systematic processing, both in near-real-time and off-line
L1B auxiliary data	• L1B algorithm configuration parameters, settings • processed TROPOMI calibration/characterization data (subset of calibration key data, as required for Level 1B processing) • parameters used for the conversion/calibration/validation of HK data • settings related for line-of-sight geometry and geo-location computation, pointing correction data • processed calibration data • others	
Level 2	Column densities / profile data for S5P primary atmospheric target species: *UVN products* **O_3** total column & tropospheric column mixing ratio profiles **NO_2** total column & tropospheric column **SO_2, HCHO** total column **aerosols** aerosol index and aerosol layer height **clouds** cloud fraction, top height, optical thickness *SWIR products* **CO, CH_4** total column Annotation data: VIIRS-S5P cloud mask data (if applicable), used Met. forecasts, others Optional products: CHOCHO, H_2O, BrO, OCLO, HDO, surface UV irradiance	Off-line processing for all species, products. Near-real-time processing for all species except methane. Optional products are non-committed but may be added at a later stage
L2 auxiliary data	• L2 algorithm configuration, settings • atmospheric modelling parameters (e.g., atmospheric modelling profiles / climatology data) • pre-tabulated cross-section data, airmass factors, .. • TROPOMI derived cloud mask data • externally provided aux. data - S-NPP/VIIRS cloud data (cloud masks, cirrus data ...)	Details on aux. data requirements, file contents and formats vary for different processor components

Product	Description	Remarks
	- Met forecasts by ECMWF (p, T, …) - global snow/ice data - chemical transport model (TM5) data • others (tbd)	

Ground Segment overview and data flows

Figure 6-1 illustrates the primary elements of the S5P Ground Segment including the main internal and external data flows.

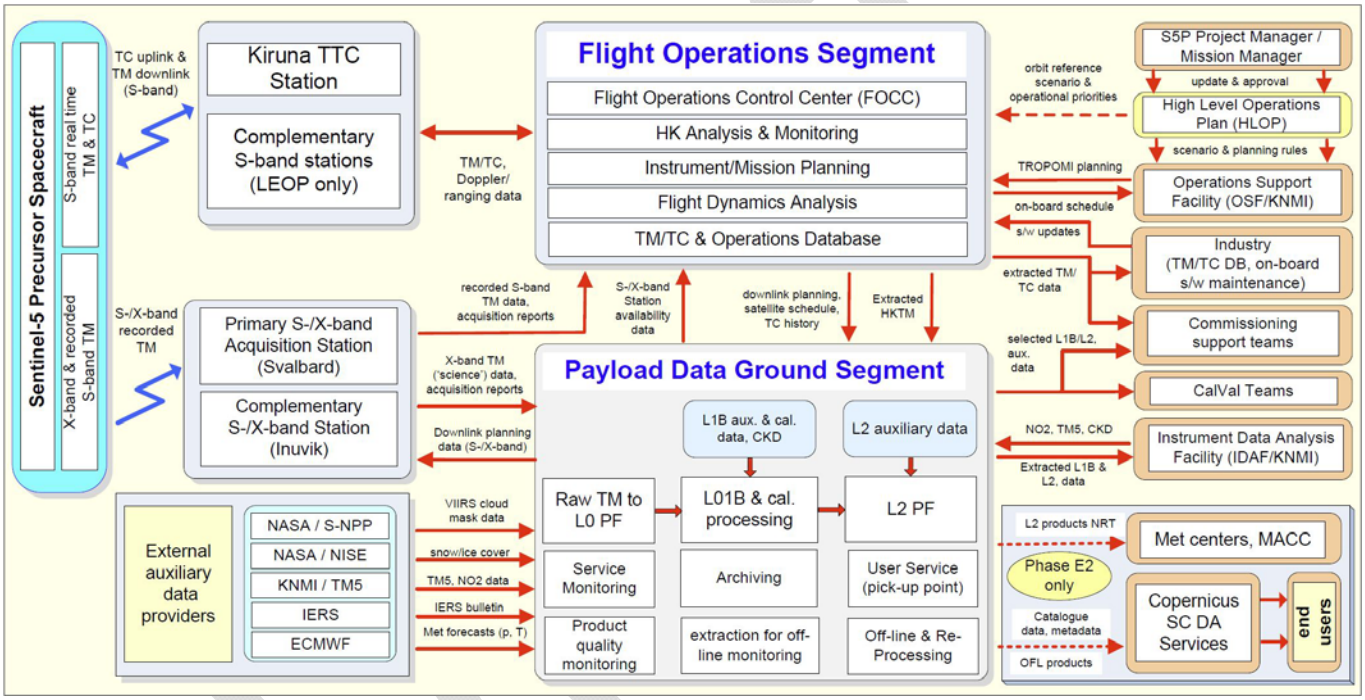

Figure 6-1. Sentinel-5P primary data flows (schematic view)

7 TASK OVERVIEW: PREPARATORY AND EARLY IN-ORBIT ACTIVITIES

The following sub-phases covering preparatory tasks and early post launch activities have been identified.

7.1 Pre-launch tasks (Phase C/D)

The preparatory tasks will cover, besides the procurement, manufacture and integration of the various Space Segment and Ground Segment elements also the validation of the various sub-systems. Testing activities will generally be performed both at the level of individual sub-systems and end-to-end, taking into account all sub-systems and realistic test scenarios.

The pre-launch tasks cover, in particular:

At TROPOMI instrument level

- Development, procurement of components / sub-systems
- Integration and test at sub-system level and at instrument level
- Functional, environmental tests
- Performance verification, pre-launch calibration and characterization
- Preparation of in-flight operations concept and calibration plan.

At satellite level

- Development, procurement of equipment
- Assembly / Integration / Validation of individual sub-systems and at platform level
- Integration of TROPOMI on the platform, alignment verification and functional tests at satellite level
- Satellite to Ground interface tests, System Validation Tests
- Launch preparation

At Ground Segment level

- Development, procurement of FOS and PDGS sub-system
- Development of Level 1B / 2 processors and related calibration processors
- Preparation and verification of verification of interfaces to external entities (e.g., auxiliary data suppliers, CalVal support teams)
- Integration and system validation tests at PDGS / FOS sub-system level and at overall Ground Segment level
- Satellite to Ground interface tests, System Validation Tests
- Launch preparation.

CalVal preparatory tasks

- Pre-launch verification of Level 1B / 2 processors (based, e.g. on simulated data, code comparisons or data acquired during TROPOMI pre-launch calibration campaigns)[1]
- End to end error budget compilation for Level 1B / 2 processor components, based on realistic atmospheric scenes observational scenarios[1]
- Definition of validation requirements and release of CalVal AO call
- Definition of initial in-flight functional tests and tuning tasks for Level 1B / 2 and calibration algorithms
- Consolidation of the overall Phase E1 planning, taking into account CalVal projects proposed via the CalVal AO call
- Participation in pre-launch CalVal rehearsal activities (access to CalVal data repository, upload of correlative data, ..).

[1] Activities covered under Level 1B & Level 2 development contracts

7.2 Post-launch tasks (Phase E1)

The purpose of Phase E1 is to deploy, switch on and initialize all satellite sub-systems. Also, a functional check-out of all vital mission components will be performed, including the platform, the TROPOMI payload instrument and the various elements of the Ground Segment. These checks will include comparisons with test results obtained during pre-launch activities, both at satellite / TROPOMI instrument level and at Ground Segment level.

The Phase E1 activities will include, in particular:

At satellite / TROPOMI level

- Launch and Early Operations Phase (LEOP)
- equipment switch on, covering platform and TROPOMI instrument (approx. 4-6 weeks after launch)
- functional verification of platform and instrument sub-systems
- operation & monitoring of spacecraft & instrument
- early in-orbit characterization & instrument-level calibration tasks.

At Ground Segment level

- Conduct of mission planning tasks including preparation of on-board settings and scheduling of satellite & TROPOMI level tasks
- Acquisition of S- (and X-) band telemetry and verification of on ground circulation
- Functional check-out of Level 1B / 2 and related calibration processors, including optimization / tuning of critical code elements
- Initial processing of calibration & scene data
- Optimization of periodic in-flight calibration scenarios (TROPOMI settings, calibration cycles ..)
- Updating of TROPOMI calibration key data
- Support of early Calibration and Validation (CalVal) activities
- Generation of initial test data ('pre-release' products) for use in specific CalVal projects
- Geophysical validation of Level 1b and Level 2 products based on 'pre-release' products (see below)
- Maintenance and evolution of Level 1b and Level 2 processors
- Initialization of monitoring tasks: routine health checks & detection of degradations
- Initialization of routine mission planning, processing and data dissemination tasks
- Preparation of Phase E1-E2 hand-over.

7.3 Data processing & dissemination tasks during Phase E1

In line with functional checks and specific calibration, characterization tasks various types of calibration data and Level 1B products will be generated during Phase E1. Whereas the PDGS will be in charge of nominal processing tasks specific tasks will be supported by the TROPOMI Instrument Data Analysis Facility (IDAF) located at KNMI and by additional support facilities located outside the PDGS. The latter will include the Level 1B / 2 algorithm development teams who will conduct specific analyses aiming at the optimization of algorithm configuration data and the preparation of software updates for later integration in the operational system.

A dissemination of S5P data to CalVal teams contributing via the Announcement of Opportunity process during Phase E1 is foreseen. The extent to which such an early access to S5P data can be provided will depend on the nature of the proposed tasks, the expected contributions to the product validation during early in-flight operation and the overall maturity required quality of the requested data products.

Overall, the PDGS will support a dissemination of S5P data (L1B, L2 products, auxiliary data, diagnostics data) to a limited number of recipients during Phase E1. Moreover, Level 0 data will be delivered to the IDAF (KNMI) to support processing tasks covering specific Phase E1 objectives. Accordingly, all interfaces to identified user typologies will be tested, including the Copernicus Operational Services, science community and potential collaborative ground segments and value adding industry.

The available access mechanisms are discussed in chapter 10.

7.4 Routine operations (Phase E2)

During routine operation the S5P mission will be operated according to a stable, repetitive background scenario. Whereas global measurements of the atmospheric scene will be acquired continuously for the dayside part periodic instrument calibration tasks and occasional maintenance activities will be scheduled during the eclipse periods. The S5P Ground Segment will acquire all generated telemetry and conduct routine processing, monitoring and planning tasks. The generated mission products will be systematically archived and be made available to the user community by means of the Copernicus Space Component Coordinated Data Access System (GS-CDA) and additional dissemination mechanisms.

Phase E2 activities include the routine operation and monitoring of the S5P spacecraft, planning tasks as well as the systematic processing, archiving and delivery of mission products to end users. The supported applications cover, in particular:

- Routine analyses of air quality parameters, including the issuing of quality forecasts and alerts in support of health services
- Global monitoring of constituents relevant for climate forcing, i.e. greenhouse gases, including their tracers, and aerosols
- Observations of atmospheric pollutants both at global and regional scales, at high spatial resolution, to allow determination of sources and sinks of pollutants (of primary interest for protocol verification and monitoring)
- Monitoring and forecasting of stratospheric ozone and surface UV radiation
- Support of services provided by operational weather forecast centres and the EC funded *MACC* project (*Monitoring of Atmospheric Composition and Climate*).

7.5 Post-launch validation of algorithms and data products

The primary purpose of post-launch product validation tasks is to verify the performance overall ground processing chain and to assess the quality of the generated data products covering both engineering level and geo-physical data products.

These tasks shall include

- Functional check-out of the L1B & L2 processors and related calibration functions based on observational data acquired in flight
- Validation of satellite and instrument provided ancillary data and their use in routine processing tasks
- Assessment of algorithm components in terms of robustness and performance given the actual quality of S5P measurement data
- Comparisons of calibration data generated in flight with data acquired before launch or with modelled data
- Verification of the consistency and quality of auxiliary data used in routine processing tasks including dynamic data provided by external sources (Met forecasts, snow/ice data, S-NPP data …)
- Initial assessment of error sources (random, systematic) in calibration data and their propagation into L1B/L2 products
- Initial assessment of Level 1b and Level 2 error sources (random, systematic) for intermediate, auxiliary and final products
- Identification and implementation of necessary modifications / optimizations in algorithms and configuration data
- As appropriate, conduct of initial CalVal activities based on early TROPOMI test data ('pre-release' products)
- Definition of refined priorities for routine / long-term validation tasks
- Organisation of workshops jointly supported by instrument/operations teams, algorithm developers, calibration experts and PIs of CalVal projects
- Preparation of a long-term product validation and evolution plan covering Phase E2.

Figure 7-1 illustrates the sequence of commissioning and CalVal tasks.

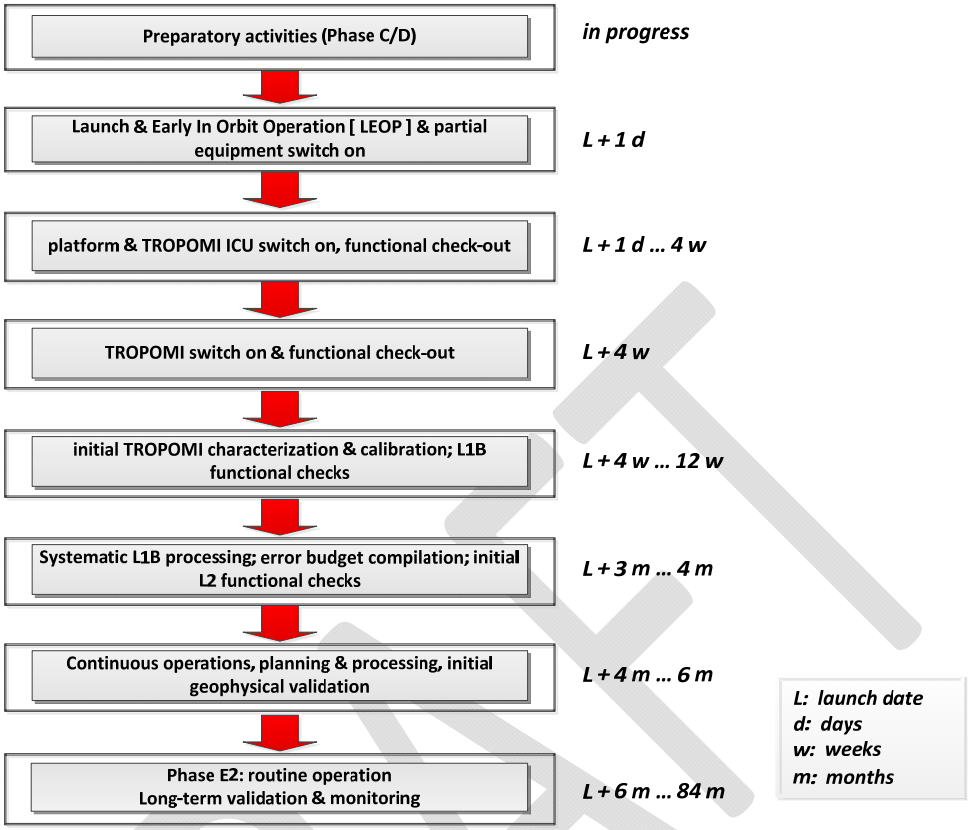

Figure 7-1. Sequence of commissioning and CalVal tasks (schematic, simplified view)

8 ROLE OF AO-CALVAL PROJECTS

Various core activities related to the Calibration and Validation listed in the previous sections are already covered under ongoing procurement and development contracts. Those activities focus primarily at the functional verification, characterization and optimization of Level 1B & 2 algorithm components. Also, they will cover the updating and maintenance of processor elements and configuration data in response to findings from Phase E1 testing activities.

In view of generated geo-physical products additional tasks need to be addressed

- inter-comparisons of key product parameters with correlative data from satellite / ground-based / airborne sensors, models …
- quantification of Level 1B and Level 2 end-to-end error budgets and consistency with performance predictions
- provision of feedback between Level 1B and Level 2 developers (potential algorithm problems, consistency of L1B error quantifiers with L2 results, …)
- assessment of the S5p product consistency, e.g. based on assimilation experiments
- support to the initial verification of achievement of mission objectives
- definition of priorities and strategies for long-term validation activities covering the entire mission lifetime.

In order to cover these complementary tasks ESA will issue an Announcement of Opportunity (AO) call to stimulate expert teams and research institutes worldwide to propose contributing CalVal projects. In general, such projects should focus at the geo-physical validation of S5P products. Projects may, however, also address in-flight calibration, characterization and performance monitoring aspects.

After evaluation of CalVal proposals submitted in response to the AO call approved projects will be taken into account in the final, consolidated planning for the post launch operation of the S5P mission.

9 DATA ACCESS FOR CALVAL TEAMS

9.1 Purpose, scope of test data

Depending on the exact nature of proposed AO projects access to various types of test data / data products needs to be provided during the different mission phases. In general, data made available prior to launch or during Phase E1 shall be used only for specific limited, and well-defined, applications, in particular:

- verification of data circulation, handling and ingestion functions
- support development and verification of tools for data extraction, display, analyses
- validation of Level 1b and Level 2 operational data products

It is expected that access to the following data sets may be required:

Pre-launch data set

1. Test data sets on S5P mission products (L1B / L2), in representative file formats
2. Processor auxiliary data (example data)

Post-launch data set

1. S5P mission products (Level 1B / Level 2), in representative file formats, pre-product release data sets
2. Inventory information for archived products, auxiliary data
3. Processor auxiliary data (static data and externally provided, dynamic data)
4. Mission planning data (e.g., information on scheduled specific measurement / calibration tasks)
5. Predicted TROPOMI ground tracks / swaths
6. To be confirmed
   - subsets of instrument calibration data
   - diagnostics information from specific processing tasks.

9.2 Data access during early in-orbit operation

During Phase E1 access to S5P data will be provided using two different methods:

1. *Delivery via Copernicus Wide Area Network (Copernicus Dissemination WAN)*

   S5P data will be delivered to a data server (***Sentinel Data Hub***) that can be accessed by a pre-configured group of end users. This mechanism, which will be used also for other Sentinel missions (e.g. Sentinel-1, -3) will be used nominally for the delivery of L1B / L2 data and auxiliary data to end users during both Phase E1 and routine operation (E2)

2. *Dissemination via dedicated S5P Commissioning Phase Server*

   This mechanism will be based on the access of S5P data using a repository (ESA operated) located outside the PDGS. This mechanism will be used for the delivery of specific calibration data, products and diagnostics data to external facilities and CalVal teams. The ***Commissioning Phase Server*** is planned to be operated during Phase E1 only.

Both mechanisms will support retrieval of data via simple ftp download. The dissemination will, however, be controlled to reflect restrictions applicable to S5P products data (e.g., no general access to pre-release product data) and the limited network capacities available during Phase E1.

Further details regarding the data access will be worked out as part of the detailed design and procurement activities for the S5P PDGS.

See also [RD-11], [RD-12].

10 DETAILED TASKS LIST

The following sections shall compile an overall list of preparatory tasks, post-launch commissioning and CalVal tasks in line with the mission phases discussed in Chapter 7.

10.1 Preparatory tasks (pre-launch)

Table 10-1 lists tasks covering pre-launch CalVal preparatory activities.

Table 10-1. S5P preparatory tasks (CalVal related)

ID / Task	Purpose / Approach	Responsibility	Remarks / references
Level 1B & 2 development & verification			
PF_AL_10 L1B development, validation & verification	Development of Level 1B processing algorithm & in-flight calibration processors; validation & verification	KNMI/SRON[2]	Partially based on tools developed for TROPOMI pre-launch calibration & performance assessment
PF_AL_20 Test data generation	Generation of L0 / L1B test data for use in L2 algorithm development and end-to-end algorithm validation tasks	KNMI[2]	L1B test data will primarily support processor interfacing and format compatibility aspects
PF_AL_30 CKD generation	Generation of Calibration Key Data (CKD) / initial in-flight data set	KNMI / SRON[2]	
PF_AL_40 L2 development, validation & verification	Development of Level 2 prototype processor components, scientific verification activities	KNMI with SRON[2]; DLR[3] with IUP/MPIC[4]; BIRA with RAL[5]	Task includes the generation of scientifically representative L1B inputs as required in L2 testing activities
PF_AL_50 L2 operational processors	Development of Level 2 operational processor components	KNMI[2]; DLR[3]; /RAL[5]	Operational processors provided by KNMI, DLR (L2 components) and RAL (S-NPP cloud processor)
PF_AL_60 In-flight analysis & monitoring tools	Development of analysis / performance monitoring tools for use during post-launch operation	KNMI, DLR	
PF_AL_70 PDGS validation support	Support during integration and system level validation of L1B / L2 processor components in the PDGS	KNMI[3]; DLR[3]; RAL[5]	
PF_AL_80 In-flight configuration data preparation	Preparation of initial in-flight configuration data for the L1B / L2 algorithm chains	KNMI[2]; DLR[3]; RAL[5]	

2 TROPOMI Activities For S5P (KNMI), NSO Contract 001/2012/PG
3 S5P Level 2 Processor Component Development (DLR), ESA contract 4000107711/13/NL/IB; complementary funding provided through Bavarian grant for DLR and additional, DLR internal resources
4 Activities by IUP and MPIC are funded via grants by DLR, no. 50EE1247 and 50EE1248, respectively
5 S5P Level 2 Processor Component Development (BIRA), ESA contract 4000107744/13/NL/IB

ID / Task	Purpose / Approach	Responsibility	Remarks / references
PF_AL_90 S5P Missson Performance Centre	Implementation of a Mission Performance Centre (MPC)[6]	ESA / KNMI / DLR / others (tbd)	The MPC shall cover the monitoring and evolution of the product content during routine operations
	Additional tasks - tbd		
TROPOMI related tasks			
PF_TR_10 Pre-flight calibration campaign	Conduct and analysis of TROPOMI pre-launch calibration & characterization tasks; prediction of in-flight performance	KNMI / SRON[2]; Instrument contractor (Dutch Space)	
PF_TR_20 TROPOMI planning tools	Development of tools to support TROPOMI operations planning (instrument settings & scheduling of in-flight calibration and atmospheric scene measurements)	KNMI	
Satellite level tasks			
PF_TR_30 Satellite level tests	Tasks covering: - RF compatibility tests (satellite to ground radio frequency compatibility tests for S- and X-band communication channels) - System Validation Tests (verify satellite commandability, observability and in-flight operational procedures)	Satellite Prime contractor (Airbus D & S) / ESA	
PF_TR_40 Mission Timeline (MTL) test	Spacecraft operation over multiple orbits, with all platform sub-systems active (including AOCS in closed loop). Test to include generation of mission planning data, TC upload, on-board recording of telemetry and downlink.	Satellite Prime contractor (Airbus D & S) / ESA	Duration & scope of test to be detailed. Possible combination of test with SVT activities.
	Additional tasks - tbd		
Ground Segment tasks			
PF_GS_10 PDGS and FOS level tests	Pre-launch validation & verification of PDGS and FOS sub-systems (covering all facilities and internal interfaces)	DLR-OP (PDGS) ESA/ESOC (FOS)	
PF_GS_20 Ground Segment System GSV tests	Ground Segment overall Validation (GSV) tests. All internal and external interfaces covered, including product dissemination to end users	DLR-OP, ESOC, S5P Project, external auxiliary data suppliers, Copernicus Atmospheric Service, other identified end users	
PF_GS_30 Launch preparation	Post-GSV maintenance, accomodation of late facility updates & preparation of Phase E1 operation	DLR-OP, ESA	
PF_GS_40 CalVal rehearsal test	Perform test to verify 1. dissemination of TROPOMI data (L0/1B/2, diagnostics data, planning data) to	DLR-OP, ESA, CalVal support teams	Test to involve external data users / CalVal teams; use of actual communication

[6] Activity not started yet

ID / Task	Purpose / Approach	Responsibility	Remarks / references
	CalVal teams 2. upload of correlative data (simulated, synthetic) by CalVal teams to the S5P CalVal database 3. use of validation tools (e.g. for product handling / extraction)		networks, support tools, data servers and protocols
	Additional tasks - tbd		

10.2 Post-launch tasks (Phase E1)

10.2.1 LEOP, in-orbit verification (IOV) and spacecraft commissioning

Table 10-2. S5P LEOP, IOV and spacecraft/instrument commissioning tasks

ID / Task	Purpose / Approach	Responsibility	Remarks / references
LEOP & equipment check-out			
IF_EQ_10 LEOP and equipment switch on	Launch and Early Operations Phase (LEOP) including: - launch and orbit injection - solar array deployment - correction of orbit injection errors - partial equipment switch on (star trackers, GPS) - nominal attitude acquisition - start of TROPOMI de-contamination (radiator door closed)	Airbus D & S, FOS	L … L + 48 h Satellite in nominal (nadir) pointing at end op LEOP
IF_EQ_20 Platform check-out	Platform equipment check-out, covering - start trackers, reaction wheels - power subsystem & thermal control - on-board orbit determination & attitude control - X-band sub-system	Airbus D & S, FOS	L + 2 days … L + 2 weeks TROPOMI remains off / in de-contamination during initial 4 weeks
IF_EQ_30 TROPOMI decontamination	TROPOMI decontamination & initial instrument functional checks	Instrument contractor (Dutch Space), Airbus D & S, FOS	L + 2 days … L + 4 weeks
IF_EQ_40 TROPOMI: functional check-out	TROPOMI: switch on and functional check-out of sub-systems - ICU Diffuser Mechanism (DIFM) - Instrument Specific and Detector Modules (ISM, DEM) - internal calibration sources - communication with Payload Data Handling Unit (PDHU)	Dutch Space, KNMI, FOS	L + 4 weeks … L + 8 weeks
IF_EQ_50 OBCP verification	Check out of on board control procedures (OBCPs) for different calibration tasks and for nominal measurement	KNMI, FOS	L + 4 weeks … L + 8 weeks
IF_EQ_60 Signal processing verification & optimization	Verification of detector operations / signal processing. Optimization of signal levels for calibration and atmospheric/Earth radiance measurements	KNMI, FOS	L + 4 weeks … L + 8 weeks
	Additional tasks - tbd		
TROPOMI initial verification & calibration tasks (list still preliminary)			
IF_TR_10 Temperature deependency of calibration parameters	Characterization of temperature dependency of TROPOMI calibration parameters (by means of systematic variation of Active Thermal Control settings about the nominal settings)	KNMI	L + 5 weeks … L + 12 weeks
IF_TR_20 Solar	Characterisation of solar diffuser spectral	KNMI	L + 6 weeks … L + 6 months

ID / Task	Purpose / Approach	Responsibility	Remarks / references
diffuser reflectance characterization	reflectance characteristics as function of illumination geometry (Sun angle)		(extension into Phase E2 - tbc) Detailed approach, procedure and duration tbd
IF_TR_30 Detector radiometric response characterisation	In-flight verification & characterisation of detector radiometric response for UVN and SWIR modules (response linearity, offset, saturation level, pixel-to-pixel uniformity, dark current, quantum efficiency ...)	KNMI / SRON	L + 5 weeks ... L + 4 months Scope, procedure tbd
IF_TR_40 Detector spectral response characterisation	In-flight verification & characterisation of spectral response for UVN and SWIR modules (spectral response, spectral axis linearity, ...)	KNMI	L + 5 weeks ... L + 4 months Scope, procedure tbd
IF_TR_50 Instrument spatial response characterisation	In-flight verification & characterisation of the pixel spatial response in terms of - pixel size / spatial overlap on ground - intra- and inter-channel co-alignment	KNMI	Scope, procedure tbd
IF_TR_60 Instrument spatial response characterisation	In-flight characterisation of the line-of-sight (LOS) mispointing, intra- and inter-channel co-alignment characterization for UVN and SWIR modules (spectral response, spectral axis linearity, ...)	KNMI	L + 8 weeks ... L + 6 months Scope, procedure tbd
IF_TR_70 Routine operations	Conduct routine scene measurement and calibration tasks according to a stable operations scenario; include - monitoring of instrument health - detection of drifts, performance degradations - additional optimization of instrument settings	KNMI / FOS	L + 8 weeks ... L + 6 months Instrument operated according to 'background' scenario, interrupted only by additional, specific calibration activities (IF_S_10)
IF_TR_80 Extended in-flight calibration & characterization	Conduct of Earth reflectance, sun calibration and additional calibration measurements (for both internal and external calibration targets), in line with TROPOMI in-flight calibration plan.	KNMI / FOS	L + 8 weeks ... L + 6 months
	Additional tasks - tbd		
Satellite level verification tasks			
IF_ST_10 TM & TC link verification	verification of S-band communication link (TC&TM) by checking link margins and bit error rates against predefined margins for command uplink (Kiruna) and telemetry reception, using the Kiruna / Svalbard / Inuvik)	Airbus D & S, FOS, PDGS	L + 2 days ... L + 2 weeks
IF_ST_20 Initial orbit correction manoeuvre	Flight dynamics analysis; correction of launcher injection dispersion and acquisition of nominal orbit	FOS, Airbus D & S	L + 2 days ... L + 2 weeks
IF_ST_30 X-band downlink verification	verification of X-band downlink performance by checking link margins and bit error rates against pre-defined margins for received X-band telemetry, using the Svalbard acquisition	Airbus D & S, FOS, PDGS	L + 2 days ... L + 6 weeks

ID / Task	Purpose / Approach	Responsibility	Remarks / references
	station		
IF_ST_40 Platform long-term characterization	Long term characterization tasks on platform equipment: - navigation and attitude control functions - power sub-system - thermal control sub-system - telemetry budgets (as a function of spacecraft commanding, instrument settings)	Airbus D & S, FOS	L + 2 weeks ... L + 6 months
IF_ST_50 Routine flight dynamics analysis & orbit maintenance	Routine flight dynamics analysis and scheduling of orbit control manoeuvres, based on S5P nominal ground track / reference orbit	FOS	L + 2 days ... L + 6 months
IF_ST_60 Loose formation operation with S-NPP	Monitoring of S5P ground track / orbit parameters with respect to Suomi-NPP. Modified scheduling of orbit control manoeuvres taking into account 1. Nominal S5P ground track / LTAN tolerances (IF_ST_50) 2. Along-track separation requirement between the S5P and S-NPP (loose formation operation)	FOS	L + 3 months ... L + 6 months (extension into Phase E2 - tbc)
IF_ST_70 Routine health check & monitoring tasks	Routine acquisition & analysis of S-band telemetry; conduct of periodic health checks and monitoring of housekeeping / engineering parameters; implementation of corrective actions according to Flight Operations Manual	Airbus D & S, FOS	L + 2 days ... L + 6 months
	Additional tasks - tbd		

10.2.2 Ground Segment Commissioning

Table 10-3. S5P Ground Segment commissioning tasks

ID / Task	Purpose / Approach	Responsibility	Remarks / references
Data acquisition, data circulation & planning tasks			
IF_GS_10 Scheduling of S-band acquisition & on-ground circulation	Scheduling, acquisition of S- band telemetry using the Svalbard and Inuvik Ground Stations; transfer of TM data and acquisition reports to FOS	PDGS, FOS	
IF_GS_20 Scheduling of X-band acquisition & on-ground circulation	Scheduling and acquisition of X-band telemetry using the Svalbard and Inuvik Ground Stations and transfer of TM data, acquisition reports to the PDGS	PDGS, FOS	
IF_GS_30 TM downlink verification & monitoring	Verification of data downlink (S-/X-band) in terms of - analysis of station acquisition reports and verification against FOS generated downlink schedules - completeness of received packets (in terms of sensing time, packet counter continuity, ..) - potential gaps in available S-/X-band telemetry (due to unsuccessful downlink, station unavailability, etc. ...) - quality of received telemetry (bit transmission errors, others (tbd))	PDGS, FOS	
IF_GS_40 Verification of TROPOMI planning tasks	Delivery of TROPOMI planning data by the Operations Support Facility (OSF/KNMI) to the FOS; execution of mission planning tasks by FOS and command uplink; task to cover - scheduling of nominal measurements - calibration tasks - OBCP updates (via Stack Import File, SIF) - instrument parameter updates (via Task Parameter File, TPF) - specific operations requests	OSF/KNMI, FOS	
IF_GS_50 Operations plan verification	periodic verification of spacecraft operations; tasks to cover: 1. analysis of FOS provided operations plans (TC history) and verification against planning generated by the OSF(KNMI) 2. Analysis of spacecraft anomalies, conflicts between planned tasks and specific operations, orbit control manoeuvres	OSF/KNMI, FOS	
IF_GS_60 Re-scheduling of high priority tasks	Analysis of TC history and generated X-band telemetry to verify successful execution of high priority Phase E1 tasks; if required, re-scheduling of tasks	PDGS, OSF/KNMI, FOS	
IF_GS_70 Interfacing verification – external auxiliary data providers	Verification of the delivery and ingestion of externally supplied auxiliary data to the PDGS: - Met forecast data (ECMWF) - TM5 chemistry model profile data (KNMI)	PDGS, IDAF/KNMI, external auxiliary data suppliers	

ID / Task	Purpose / Approach	Responsibility	Remarks / references
	- NPP/VIIRS cloud data (NASA) - NISE snow / ice cover data (NASA) - TM5 profiles, NO2 data (IDAF/KNMI) - IERS bulletins (IERS publisher)		
IF_GS_80 Interfacing verification – L1B & calibration data for off-line processing & monitoring	In-flight verification of delivery of extracted L1B product data and calibration data from the PDGS to the IDAF/KNMI	PDGS, IDAF/KNMI	
IF_GS_90 PDGS internal calibration processing	Verification of - generation, storage of calibration data handled by PDGS internal calibration processors - ingestion and use of calibration data in the L1B processing chain	PDGS, IDAF/KNMI	
IF_GS_100 Interfacing verification – externally generated CKD and algorithm configuration data (Level 1B)	In-flight verification of delivery of updated CKD and algorithm configuration data (L1B and calibration processor related) from theIDAF/KNMI to the PDGS	PDGS, IDAF/KNMI	
IF_GS_110 Interfacing verification – externally generated algorithm configuration data (Level 2)	In-flight verification of delivery of updated Level 2 algorithm configuration data from theIDAF/KNMI and DLR (L2 developer, tbc) to the PDGS	PDGS, IDAF/KNMI	
IF_GS_120 Interfacing verification – NO2 processing loop PDGS <-> IDAF/KNMI	In-flight verification of the delivery of : 1) fractional NO2 off-line product (slant columns) from PDGS to IDAF/KNMI 2) annotated NO2 product (with airmass factors/vertical column densities) from IDAF/KNMI to PDGS	PDGS, IDAF/KNMI	
	Additional tasks - tbd		
Processing tasks – L1B & calibration algorithms			
IF_AL_10 TROPOMI processing verification	Decoding and processing of TROPOMI observational data; verification of - generation of Level 0 data products, including header/metadata and annotation data - platform ancillary data (PVT, housekeeping data) - TROPOMI housekeeping / engineering data - detection data	PDGS, IDAF/ KNMI	
IF_AL_20 In-flight calibration processing – internal sources	Processing and analysis of TROPOMI calibration measurements using internal targets: - White Light Source (WLS) - common calibration LED/detector LEDs - Spectral Light Sources (SLS)	PDGS, IDAF/ KNMI, MPC	
IF_AL_30 In-flight calibration processing – external targets	Processing and analysis of TROPOMI calibration measurements using external targets:	PDGS, IDAF/ KNMI, MPC	

ID / Task	Purpose / Approach	Responsibility	Remarks / references
	- solar calibration (extraterrestrial irradiance) - dark current measurement (for daylight and eclipse orbit segments)		
IF_AL_40 Line of sight error characterization	Processing of in-flight LOS misalignment measurements and characterization of absolute pixel geo-location errors; verification against allocated budget	PDGS, IDAF/ KNMI, MPC	Procedure and processing approach tbd
IF_AL_50 Channel alignment verification	Processing and analysis of intra- and inter-channel alignment / co-registration measurements; verification against allocated budget	PDGS, IDAF/ KNMI, MPC	Procedure and processing approach tbd
IF_AL_60 TROPOMI to S-NPP VIIRS pixel co-alignment verification	Verification of co-alignment errors between Suomi-NPP/VIIRS pixels and TROPOMI SWIR and UVN (tbc) pixels	PDGS, IDAF/ KNMI, MPC	Procedure and processing approach tbd
IF_AL_70 Generation of L1B calibration products	Generation of calibration products for use in L1B processing tasks	PDGS, IDAF/ KNMI	L + 6 weeks … L + 12 weeks
IF_AL_80 CKD generation (in-flight update)	Generation of Calibration Key Data (CKD) update/ initial in-flight data set; based on observational data acquired during acquisition period L + 4 weeks … L + 12 weeks	IDAF/ KNMI	L + 8 weeks … L + 12 weeks Based on tasks IF_S_6, IF_S_7
IF_AL_90 Level 1B generation (NRT mode)	Functional verification of Level 1B processing stage in NRT mode; verification of generated data in terms of - formats - validity of headers, metadata - validity of timestamps, geo-location data - quality parameters - measurement data - annotation data In addition, verification of - correc t use of auxiliary data, CKD data - coverage of product vs Level 0 coverage and commanded measurement/calibration tasks predicted swath	PDGS, IDAF/ KNMI, MPC	L + 6 weeks … L + 8 weeks
IF_AL_100 Level 1B generation (OFL mode)	Functional verification of Level 1B processing stage in off-line mode; checks as for L1B NRT test (IF_G_15); additional checks concerning - use of calibration data (from current & adjacent orbits, ..) - generation of additional fields specific for L1B OFL product	PDGS, IDAF/ KNMI, MPC	L + 8 weeks … L + 12 weeks
	Additional tasks - tbd		
Processing tasks –L2 processing			
IF_AL_110	Functional verification of Level 2 processing components in NRT mode; verification of generated data in terms of - formats - validity of headers, metadata - quality parameters	PDGS, L2 developers, MPC	Tasks partially based on use of an off-line test platform (PDGS 'sandbox')

ID / Task	Purpose / Approach	Responsibility	Remarks / references
	- measurement data - annotation data		
IF_AL_120 Verification of external auxiliary data use and correlation	Verification of the correct use of external auxiliary data by the L2 components, in particular, temporal & statial correlation of aux. parameters with TROPOMI observations (e.g., Met forecast fields, VIIRS cloud mask data)	PDGS, L2 developers, MPC	
IF_AL_130 L2 product coverage	Verification of coverage of generated L2 product vs Level 1B coverage and commanded measurement/ calibration tasks	PDGS, L2 developers, MPC	
IF_AL_140 Tuning of critical L1B & L2 algorithm settings	Analysis of generated product parameters and optimization of critical configuration data; specifically - tuning of validation thresholds used to compute quality flags - tuning of algorithm settings (e.g. parameters controlling iterative loops)	L1B & L2 developers, MPC	
	Additional tasks - tbd		
Specific and routine processing tasks			
IF_PR_10 Initialize systematic L1B/L2 processing tasks	Initialize systematic processing tasks of the L1B, L2 chains; verify, in particular: - correct (data driven) triggering of the execution of all processor elements - extraction of data products, processing reports, log data - overall aux. data management - disk clean-up tasks (removal of temporal files, intermediate results) - handling of warnings, errors, non-nominal termination of processing tasks - others (tbd)	PDGS, L1B & L2 developers, MPC	
IF_PR_20 Initialization of routine quality monitoring	Initialize quality monitoring tasks in terms of - optimized choice of parameters subject to routine monitoring / trend analyses - (if necessary) optimization of reporting functions (statistical outputs, plots ...) - optimized validity thresholds	PDGS, L1B & L2 developers, MPC	
IF_PR_30 Support to external CalVal projects	Conduct processing tasks to support specific CalVal projects; generate data products and diagnostics data for delivery to the PIs of ESA external CalVal projects	PDGS, L1B & L2 developers	Task to be based on specific data requirements for AO CalVal projects; feasibility to be checked in each case
IF_PR_40 Geophysical validation	Geophysical validation of Level 1b and Level 2 products based on 'pre-release' products	AO CalVal Teams, KNMI	
IF_PR_50 L1B & L2 processor maintenance & evolution	Implementation of Level 1b and Level 2 algorithm updates based on the initial validation results	L1B & L2 developers	
	Additional tasks - tbd		

10.2.3 Phase E2 preparatory tasks

The tasks compiled in this section shall focus at the preparation of the routine operation and exploitation of the S5P mission. They shall cover, in particular:

- Consolidation of the operations concept for the S5P mission, supporting atmospheric measurements and routine calibration and monitoring activities
- Definition of optimized instrument key parameters for use in routine health and performance checks and implementation of corresponding monitoring functions in the FOS and PDGS
- A refined planning for a partial release of data products at the start of Phase E2
- A planning for a full release of remaining data products during early Phase E2
- The establishment of a planning for the evolution of processing algorithms over the mission lifetime, including possible extensions of the list of global mission products
- A re-configuration of processing and planning facilities on ground to support a stable, repetitive 'background' scenario, including the periodic scheduling of calibration, re-characterization measurements
- The definition of priorities for long-term validation tasks taking into account recommendations by the CalVal teams.

Table 10-4. Phase E1-E2 handover & E2 preparatory tasks

ID / Task	Purpose / Approach	Responsible team / Project	Remarks / references
planning & operations related tasks			
HO_E2_10 Definition of 'background' operations scenario	definition of 'background' mission scenario and default spacecraft and instrument settings covering - atmospheric scene / Earth reflectance measurements - periodic calibration /characterization measurements - (if necessary) updated procedures to be used in case of spacecraft anomalies, major performance degradations	FOS, OSF/KNMI, PDGS, Project support team, Mission Management	
HO_E2_20 Update and activation of Phase E2 planning functions	Update and activate TROPOMI planning functions in the Operations Support Facility for routine operations (Phase E2)	OSF / KNMI, FOS	
HO_E2_30 Satellite operations & orbit maintenance	Refinement & activation of routine Phase E2 maintenance tasks including - periodic functional checks of satellite sub-systems - instrument functional & performance checks - scheduling of decontamination intervals (for optical benches & detectors) and annealing intervals (SWIR detectors) - flight dynamics analyses - scheduling of orbit control manoeuvres - monitoring of propellant budgets, satellite inertia	FOS, Project support team, OSF/KNMI, Mission Management	
HO_E2_40 Refinement of routine health & performance monitoring – Satellite operations	Definition of refined Phase E2 health & performance monitoring functions, including definition of - housekeeping parameters to be included in routine, FOS provided trend monitoring	FOS, Airbus D & S, Dutch Space, Commissioning Phase team, Mission	

ID / Task	Purpose / Approach	Responsible team / Project	Remarks / references
	reports - threshold values to be applied to other selected HK parameters used for detection of anomalies or major performance degradations ...) - others (tbd)	Management, MPC	
HO_E2_50 Routine performance monitoring tasks – PDGS	Definition of refined Phase E2 performance monitoring functions, covering - data acquisition (S-/X-band) - data flows PDGS – acquisition stations and PDGS-FOS - PDGS internal data circulation & network performance - interfacing to external auxiliary data providers - processing tasks (including handling of internal calibration tasks) - archiving & data retrieval sub-systems - data dissemination - overall task scheduling and timeliness aspects - others (tbd)	PDGS, S5P Commissioning Phase team, processor developers, MPC	
HO_E2_60 PDGS re-configuration for Phase E2	Phase E2 re-configuration of the PDGS, including - integration of L1B / L2 processor updates in the PDGS - adaptation of PDGS processing, archiving and dissemination resources in accordance with Phase E2 requirements - re-configuration of external aux. data suppliers (as appropriate) - activation of routine monitoring and reporting functions	PDGS, processor developers, Commissioning Phase team, MPC	
HO_E2_70 PDGS external processing & monitoring functions	Update & re-configuration of PDGS external processing & monitoring functions, including - instrument performance monitoring - long term monitoring functions (L1B algorithm related) - CKD updating, maintenance functions - external processing functions, L2 related (e.g., NO2 off-line tasks)	IDAF/KNMI, DLR, MPC, other facilities (tbd)	
HO_E2_80 Release of S5P mission products	Release of S5P mission products to end users; release to follow an incremental approach, with respect to recipients (end users) and list of products (L1B, L2 NRT / OFL) detailed procedure to be worked out	Project support team, JPT, Mission Management, L1B & L2 algorithm developers, CalVal team, MPC	decision for a partial or full release of products on a case by case basis, taking into account completed and planned validation activities
HO_E2_90 Activation of algorithm updates	Implementation of algorithm updates and release of updated processor components	L1B, L2 algorithm developers, MPC	

ID / Task	Purpose / Approach	Responsible team / Project	Remarks / references
(operational L1B & L2 processors)	(L1B, L2, calibration processors) for integration in the PDGS; including code, documentation, test data, default configuration & auxiliary data		
	Additional tasks - tbd		
Algorithm evolution & long-term monitoring, validation tasks			
HO_E2_100 Activation of algorithm updates (operational L1B & L2 processors)	Implementation of algorithm updates and release of updated processor components (L1B, L2, calibration processors) for integration in the PDGS; including code, documentation, test data, default configuration & auxiliary data	L1B, L2 algorithm developers	
HO_E2_110 Refinement and activation of L1B/L2 performance monitoring functions	Implementation of refined performance monitoring functions for L1B & L2 processors and calibration processors, including - selection of quality parameters to be extracted or derived from L1B, L2 products and calibration products, for inclusion in routine performance reports - definition of thresholds values used to trigger alerts, or the execution of specific health checks, calibration tasks - definition of monitoring functions for externally supplied auxiliary data	L1B, L2 algorithm developers, MPC	
HO_E2_120 Priorities for product / algorithm enhancements	Definition of priorities for future evolution of data products and processing algorithms	Mission Management, L1B, L2 algorithm developers, CalVal teams, Copernicus Operational Sevices and other identified end users	
HO_E2_130 Definition of long-term validation tasks	Definition of priorities for long-term validation of S5P products (correlative campaigns, satellite inter-comparisons, long-term assimilation experiments, ...); formulation of correlative measurement requirements, S5P planning requirements	Mission Management, L1B, L2 algorithm developers, CalVal teams, Copernicus Operational Sevices and other identified end users	
	Additional tasks - tbd		

Loose formation operation S5P with S-NPP (VIIRS)

The concept of a loose formation of the S5P and Suomi-NPP spacecraft needs to be re-assessed during Phase E1 and an operational strategy for the routine phase (Phase E2) will be presented as part of the Phase E1-E2 handover.

A refined formation concept for Phase E2 will depend on

- the exact launch date of S5P
- the expected operational lifetime of Suomi-NPP (or its VIIRS payload)
- the results of in-flight performance analyses for S5P data products (specifically methane) using VIIRS cloud mask data
- a timely realization of a follow up mission of S-NPP (i.e., JPSS-1) and its compliance with orbit constraints (in terms of ground track / LTAN tolerances) of the S5P spacecraft
- other fasctors (tbc).

10.2.4 Geo-physical validation - AO projects

Table 6-1 lists specific calibration and validation projects proposed via the CalVal Announcement of Opportunity process. The project specific information will be included after ther selection process for AO projects has been completed.

Table 10-5. Geo-physical validation tasks – AO projects

ID / Task	Project Title / Purpose	Responsible team / PI	Remarks / references
AO projects – Level 1B processing, calibration & validation			
AO_L1B_10			
AO_L1B_20			
AO_L1B_30			
AO_L1B_40			
AO projects – Level 2 validation			
Validation based on alternative processing schemes			
AO_L2_10			
AO_L2_20			
AO_L2_30			
AO_L2_40			
Geo-physical validation / correlative data analysis			
ground-based in-situ and remote sensing campaigns / networks / systems			
AO_L2_50			
AO_L2_60			
AO_L2_70			
airborne campaigns / systems			
AO_L2_80			
AO_L2_90			
AO_L2_100			
satellite data inter-comparisons			
AO_L2_110			
AO_L2_120			
AO_L2_130			
Numerical modelling studies, assimilation experiments			
AO_L2_140			
AO_L2_150			
AO_L2_160			
Other geo-physical validation projects			
AO_GEN_10			
AO_GEN_20			
AO_GEN_30			

11 CALVAL SCHEDULE

The overall planning for the completion of CalVal tasks needs to take into account dependencies between individual projects as well as requirements on mission planning, processing and data dissemination tasks.

A preliminary schedule is provided in Table 11-1, Table 11-2.

Figure 11-1, Figure 11-2 depict the planning of pre-launch and early post-launch activities, respectively.

Updated and more detailed planning information will be added in a later version of this document. Moreover, an overall list of CalVal projects will be included as soon as a consolidated planning of such activities has been established.

Table 11-1. Schedule overview: Pre-launch tasks

Milestone	Date	Remarks
Satellite & TROPOMI payload		
Platform Integration & Test	June '13 – Dec. '14	
TROPOMI calibration campaign	Sept. – Dec. '14	
L1B & L2 Processor Development		
Algorithm prototyping	Jan. '13 – April '15	
Scientific Verification (Level 2)	Oct. '13 – April '15	
Operational Code Development (L1B & L2)	April '14 – June '15	
S5P Ground Segment		
GS System Validation	Feb. – Aug. '15	
post-GSV maintenance	Sept. – Nov. '15	
PDGS & FOS in-flight configuration, late facility updates incorporated	Nov. '15	
GS Operations Readiness Review	Dec. '15	Combined FOS & PDGS review
CalVal Projects: pre-launch tasks		
CalVal AO: call for proposals	May '14	
CalVal Plan iss. 2	Feb. '15	Updated release of this document
Test Products set # 1 available to CalVal Teams	Feb. '15	**TDS_PF1:** Level 1B / L2 test data, in representative format (for use during tests of CalVal tools etc)
CalVal AO project start	March '15	Earliest start date (actual date depending on project)
CalVal PI Workshop # 1	July '15	
Test Products set # 2 available to CalVal Teams	Sept. '15	**TDS_PF2:** Level 1B / L2 test data, representative in terms of format and contents; late updates included
Cal/Val rehearsal	Oct. – Nov. '15	
S5P Flight Acceptance Review (FAR)	Oct. '15	
CalVal PI Workshop # 2 (optional)	Dec. '15	
Launch	**January '16**	

Table 11-2. Schedule overview: Post-launch tasks

Milestone	Date	Remarks
Phase E1		
LEOP & Commissioning	L ... L + 6 months	
LEOP & equipment switch-on (except TROPOMI)	L ... L + 2 weeks	
Platform functional check-out; TROPOMI decontamination and initial checks	L + 2 days ... L + 4 weeks	
Extended platform level verification tasks	L + 2 weeks ... L + 6 months	
Availability of initial X-band TM data for PDGS internal commissioning tasks	L + 4 weeks	**TDS_IF1 (internal):** Verification of PDGS internal acquisition, circulation and storage tasks
TROPOMI switch-on, functional verification of sub-systems	L + 4 weeks ... L + 8 weeks	
Availability of TM data for initial algorithm level checks	L + 6 weeks	**TDS_IF2 (internal):** Verification of PDGS processing sub-system, internal data handling tasks
Initial TROPOMI in-flight calibration & characterization; functional check-out of on ground processing and planning tasks	L + 5 weeks ... L + 4 months	
Availability of TM data for initial algorithm level checks (L1B)	L + 8 weeks	**TDS_IF3 (internal):** Initial functional verification of L1B & calibration processors
Extended TROPOMI in-flight calibration & characterization; alternating with routine operations sequences	L + 8 weeks ... L + 6 months	
CalVal Workshop # 3	L + 4 months	Review of functional check-out tasks, spacecraft & Ground Segment
Availability of test data for advanced performance analyses (L1B & L2 chains)	L + 4 months	**TDS_IF4 (internal):** Extended functional verification and performance tests of L1B / L2 end to end chain
Start of TROPOMI routine planning & ground processing tasks	L + 4 months ... L + 5 months	TROPOMI operated according to stable background scenario, interrupted by dedicated calibration, verification tasks
Start of long-term CalVal projects	L + 4 months ... L + 6 months	Scope, duration of projects tbd
Availability of selected data products for early CalVal tasks and specific applications (e.g. MACC); data in representative product format, engineering & geo-physical contents non-validated	L + 4 months ... L + 6 months	**TDS_IF5 (CalVal):** Verification of data dissemination & ingestion; functional verification of CalVal tools
Implementation and verification of 'clean-up' versions of L1B/L2 processors and re-configuration for Phase E2	L + 5 months ... L + 7 months	L1B / L2, calibration processors
CalVal Workshop # 4	L + 6 months	Review of L1B validation results; status of early L2 related tasks

Milestone	Date	Remarks
Commissioning Phase Review	L + 6 months	
Start of quasi-routine delivery of data products, aux. data (subsets, tbc) for geo-physical CalVal projects; engineering & geo-physical contents non-validated	L + 6 months	**TDS_IF6 (CalVal):** Support of long- term CalVal projects
Phase E1 -> E2 hand over	L + 6 months	Transfer of mission authority from S5P Project Manager to Mission Manager
Phase E2		
Phase E2 start	L + 6 months	
Routine operations & services	L + 6 months ... L + 84 months	
Routine health checks, performance monitoring of spacecraft and ground processing chains; long-term calibration & validation projects	L + 6 months ... L + 84 months	
Phase F		
Spacecraft de-orbiting & Long-Term Data Preservation (LTDP)	> L + 84 months	

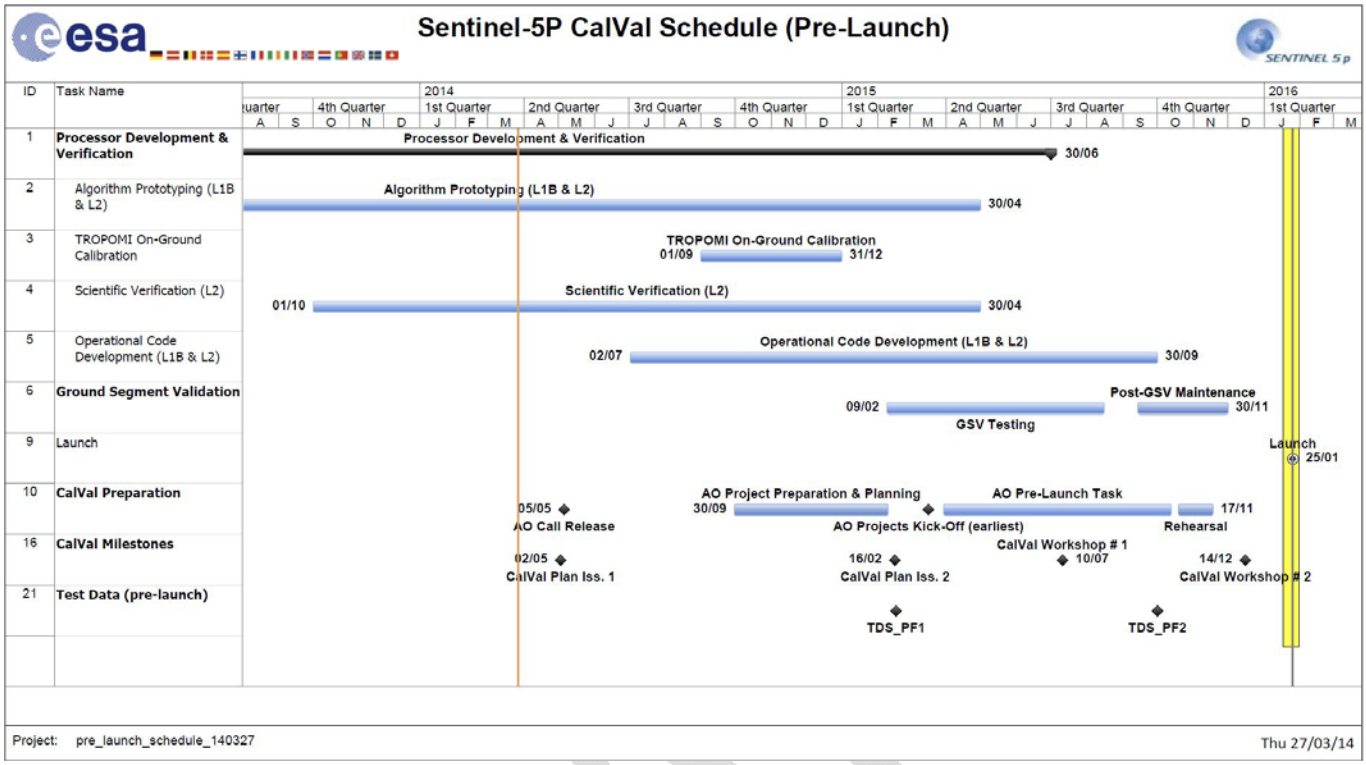

Figure 11-1. CalVal Schedule – pre-launch tasks

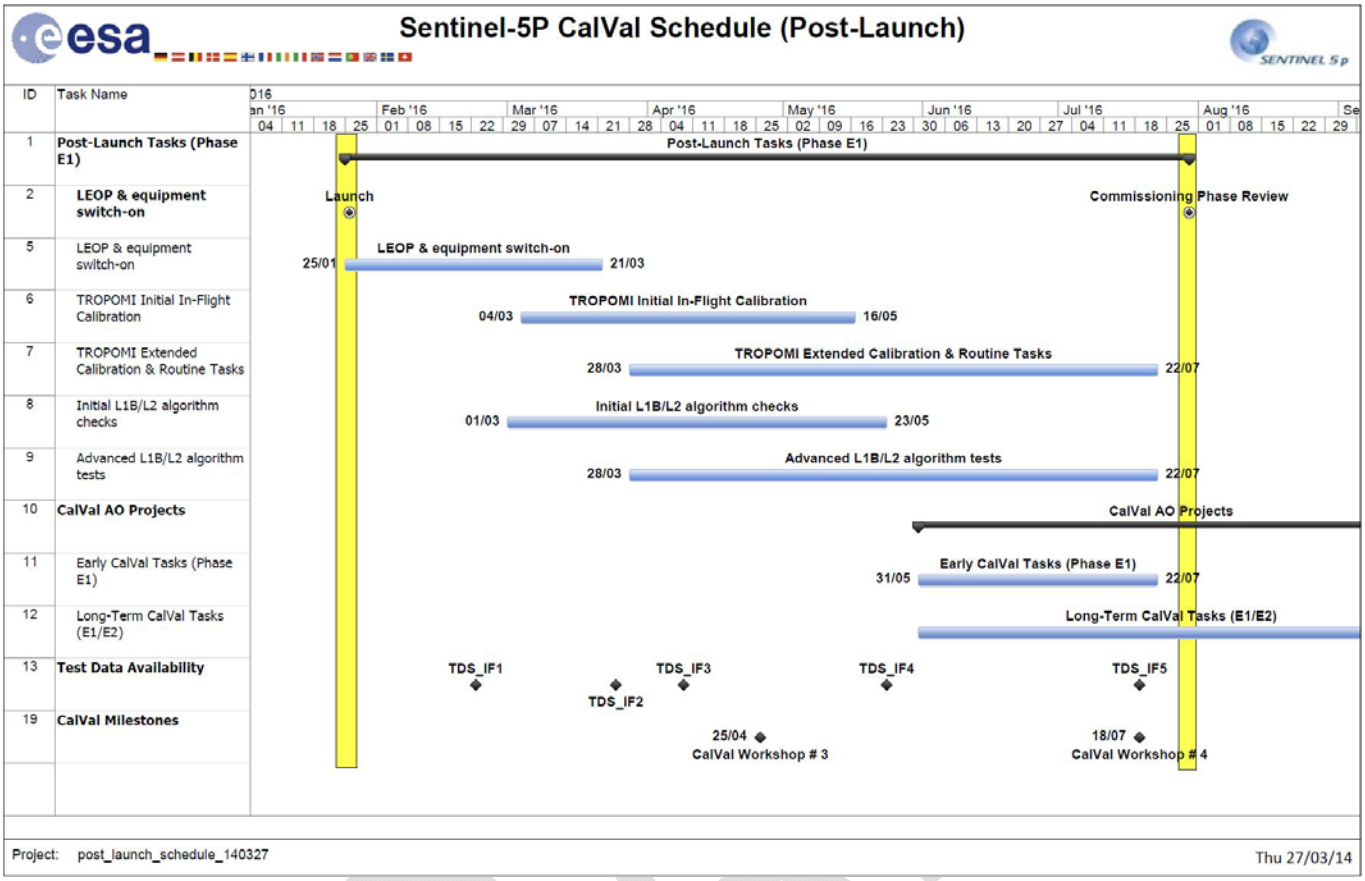

Figure 11-2. CalVal Schedule – post-launch tasks

12 COMMISSIONING & CALVAL PHASE - TEAM ORGANIZATION

Table 12-1 outlines the organization of the CalVal team, including both ESA staff and external experts / support groups / institutes.

Table 12-1. S5P Commissioning & CalVal team organization (to be completed)

Team / function	Project / role	Name	Affiliation / Remarks
Sentinel-5P / ESA team			
S5P Project Manager	Overall Project responsibility (up to end Phase E1)	K. McMullan	EOP-PJ
S5P Satellite and Launcher Manager	Launch preparation, LEOP and satellite level commissioning tasks		EOP-PJE
S5P Commissioning Manager	overall coordination of commissioning tasks		TEC-EDD
S5P Ground Segment Manager	Ground Segment development & CalVal tasks		EOP-PJD
S5P Product Assurance Manager	Product assurance		EOP-PJQ
S5P Mission Management / ESA	Preparation of Phase E1-E2 mission hand-over. Mission authority during Phase E2		EOP-GS
S5P Mission Scientist	Mission Scientist		EOP-SMA
PDGS Engineering	PDGS support & user services (ESRIN)		EOP-GSG
S5P / EC team			
S5P Mission Management / EC	Mission authority during Phase E2		European Commission
S5P – FOS team (ESA/ESOC)			
S5P FOS Manager	FOS Development and Management		HSO-OES
S5P Operations Manager	FOS Development and Operations		HSO-OEV
S5P – PDGS team (DLR-EOC)			
PDGS Project Manager	PDGS development, operation & commissioning tasks		
PDGS System & Test Engineer	PDGS system engineering & testing		
PDGS Data System Engineer	Phase E1 data handling & dissemination		
PDGS System Engineer	system engineering & support to CalVal teams		
S5P - TROPOMI / NSO team			
TROPOMI Program Manager	Overall program management at NSO		
TROPOMI Payload Manager	Payload level commissioning tasks		
S5P - TROPOMI / KNMI&SRON team			
TROPOMI Science Manager	Overall coordination of planning, calibration & data analysis tasks		
TROPOMI Lead	TROPOMI in-flight calibration &		

Team / function	Project / role	Name	Affiliation / Remarks
Instrument Scientist	characterization		
TROPOMI Operations Expert	Instrument operations & mission planning		
TROPOMI Data Analysis Experts	In flight data analysis tasks for UVN and SWIR		
TROPOMI Software Support Engineers	Software development and maintenance for UVN and SWIR (L1B & calibration processors)		
S5P – L1B & L2 algorithm teams			
Level 1B Development Manager	Level 1B & calibration processor development and post-launch verification & validation tasks		
Level 2 Working Group Leaders at KNMI & DLR	Overall coordination of Level 2 development and post-launch verification & validation tasks		
L:evel 2 Manager / KNMI & SRON	Coordination of Level 2 tasks at KNMI/SRON, including post-launch validation & processor maintenance		
L:evel 2 Manager / DLR	Coordination of Level 2 tasks at DLR, including post-launch validation & processor maintenance		
Processor Performance Analysis Experts	Performance analyses at KNMI/SRON, DLR & support to CalVal teams		
Sentinel-5P – Satellite development & commissioning			
Satellite Engineering Manager	System engineering & commissioning tasks		
Operations Engineer	In-flight operations & planning support		
TROPOMI / Dutch Space team			
TROPOMI Calibration Engineer	Engineering & in-flight calibration support		
TROPOMI Operations Engineer	Instrument operations & maintenance tasks		
Sentinel-5P Mission Performance Centres (MPC)			
S5P-MPC Project Manager	Instrument & product quality level monitoring (Phases E1 & E2)		

13 LONG-TERM VALIDATION & DEFINITION OF MISSION PRIORITIES

Based on results of Phase E1 performance analyses and product validation results priorities for long term validation tasks shall be formulated.

These tasks shall cover the formulation of:

- updated requirements for overall trend monitoring functions and the surveillance of critical spacecraft (AOCS, thermal control, ..) and TROPOMI sub-systems (optical transmission characteristics, detector performance, signal processing, alignment, ...)
- enhanced strategies for quality monitoring of geophysical products and key auxiliary databases (e.g., climatology data, digital elevation model, ..)
- updated requirements on Phase E2 geophysical validation projects (correlative campaigns, satellite inter-comparisons, long-term assimilation experiments)
- recommendations regarding the future evolution to processing algorithms and data products.

14 S5P CALVAL CORRELATIVE DATABASE

A dedicated database will be established to support the preparation and execution of the various CalVal tasks. The database shall be used to archive and disseminate:

- correlative data generated in conjunction with individual AO projects (data from experimental campaigns, co-located satellite observations, modelling results, ...)
- information on TROPOMI observational parameters and planned calibration / maintenance activities.

Additional data and functionalities could be provided, if required for specific measurement activities or in support of correlative measurement campaigns:

- S5P Level 1B / 2 processor auxiliary data (including externally supplied aux. data) used for specific measurement activities
- predicted satellite ground track / TROPOMI swath data (if required for the planning of correlative measurement campaigns)
- overpass tables for selected sites / ground stations
- sub-setting of Level 1 or Level 2 data over selected sites / ground stations.

The CalVal Correlative Database will be maintained during the commissioning and CalVal phase (Phase E1) and during the entire routine operations period (Phase E2). Access will be provided to all CalVal teams including PIs of individual AO projects.

Further details will be provided with a later release of this document.

15 ESA PROVIDED TOOLS

CalVal support tools & test data

In support of CalVal tasks outlined in this document ESA will provide a set of tools and test data. These comprise

- a set of tools (stand alone) for the reading of S5P data products (Level 1B / 2) and auxiliary data, including the extraction and display of selected data fields
- a set of Earth Explorer mission CFI (orbit propagator, pointing software library, …) for use in specific applications designed by CalVal teams
- S5P example Level 1B / 2 products (for use during functional tests with analysis tools developed by CalVal teams)
- a set of default L1B / 2 auxiliary products
- reading routines for S5P products that can be embedded in specific applications designed by CalVal teams
- tools for graphical display all or subsets of key product parameters.

To be confirmed:

- stand-alone routine to generate S5P ground track / TROPOMI swath coverage data
- others.

A consolidated list of support tools will be provided in a later issue of this document.

All data and tools will be made available via a specific CalVal data server accessible to ESA external support teams and AO project PIs.

Anomaly tracking tool

The ESA ARTS (Anomaly Report Tracking System) will be used for the registry and maintenance of any anomalies encountered during the planning and execution of commissioning and CalVal tasks. The ARTS database, located on an ESA internal server, provides a web interface and is accessible also to clients outside the ESA firewall. Visibility to the ARTS system will be provided to all CalVal Principle Investigators for all anomalies affecting the preparation and conduct of CalVal tasks.

- end of document -

APPENDIX A S5P CALVAL DATA PROCESSING & CIRCULATION REQUIREMENTS

Table A- 1 shall compile requirements on data processing / dissemination for individual CalVal tasks listed in this document.

- details to be provided in a later issue of this document -

Table A- 1 CalVal Data Processing & Circulation Requirements

CalVal Task	Measurement ID	Data sets / file type	Estimated volume	Remarks
Core tasks				
IOV & spacecraft commissioning				
Ground Segment commissioning				
Level 1B & 2 processor functional check out				
AO projects				
calibration & instrument performance				
Ground based campaigns & network based projects				
NWP analyses & assimilation experiments				
satellite inter-comparisons				

correlative campaigns (ground based, airborne, …)				
other, general CalVal projects				