

Sentinel-5 Precursor: Early In-Flight Operation & Calibration

Nett, H.⁽¹⁾, Ekholm, S.⁽¹⁾, McMullan, K.⁽¹⁾, Veeffkind, P.⁽²⁾, Kleipool, Q.⁽²⁾, Ludewig, A.⁽²⁾
 (1) ESA / ESTEC, Keplerlaan 1, NL-2201 AZ Noordwijk (2) KNMI, Utrechtseweg 297, NL-3731 GA De Bilt

Abstract

The Sentinel-5 Precursor (S-5P) satellite was launched on **13 October '17**. Carrying as single payload the **TROPOspheric Monitoring Instrument (TROPOMI)** S-5P is first in a series of atmospheric missions in the European Commission's **Copernicus** Programme.

The spacecraft was injected into its near-polar, sun-synchronous orbit by a **Rocket launcher from Plesetsk (Russia)**. Following a flawless functional check-out of the satellite's main components, and a 25 days initial outgassing period, the instrument's cooler was activated and TROPOMI started delivering Earth radiance spectra as well as different types of Phase E1 specific calibration measurements. Observational data were downlinked using two high latitude ground stations, Svalbard (N) and Inuvik (Ca), and transferred to the Payload Data Ground Segment (PDGS). Depending on measurement type acquired data were used to verify the instrument's performance and to update calibration key data.

During the 6 months commissioning phase excellent performance of S-5P has been demonstrated and key parameters regarding the payload's radiometric sensitivity, spatial resolution and sampling capabilities were verified. Phase E1 activities were completed with the mission hand over to routine operations (Phase E2), on 24 April '18.

Satellite & Operations

Satellite (contractor: ADS-UK)

- Based on Astrobus AS250 platform
- Mass: 820 Kg
- Fixed solar arrays, peak power 1.5 kW
- Commanding & HKTM via S-band
- 'Science' data downlink via X-band
- In-orbit lifetime > 7 years

Launch & Orbit

- launcher: Rocket (Plesetsk)
- Orbit height: 824 km
- Orbit period: 101.5 min

Commanding & data downlink

- Svalbard (Norway) & Inuvik (Canada)
- Kiruna (Sweden) - S-band TM & TC
- Troll (Antarctica) - only during launch

Out-of-Band straylight: in-flight test

Nominal sun calibration - SSP in CAP (local normal pointing)

delayed calibration + pitch manoeuvre (LOS intersects atmosphere at tangent height h)

Delay between Sun zenith angle = 90 deg and h = 15 km positions ~ 450 s

- Use modified geometry for solar irradiance calibration (signal acquisition via sun port & diffuser)
- Pitch rotation ~28 deg to re-center irradiance signal wrt sun calibration port field-of-view
- Measurement for variable LOS tangent heights, short integration time (270 ms)

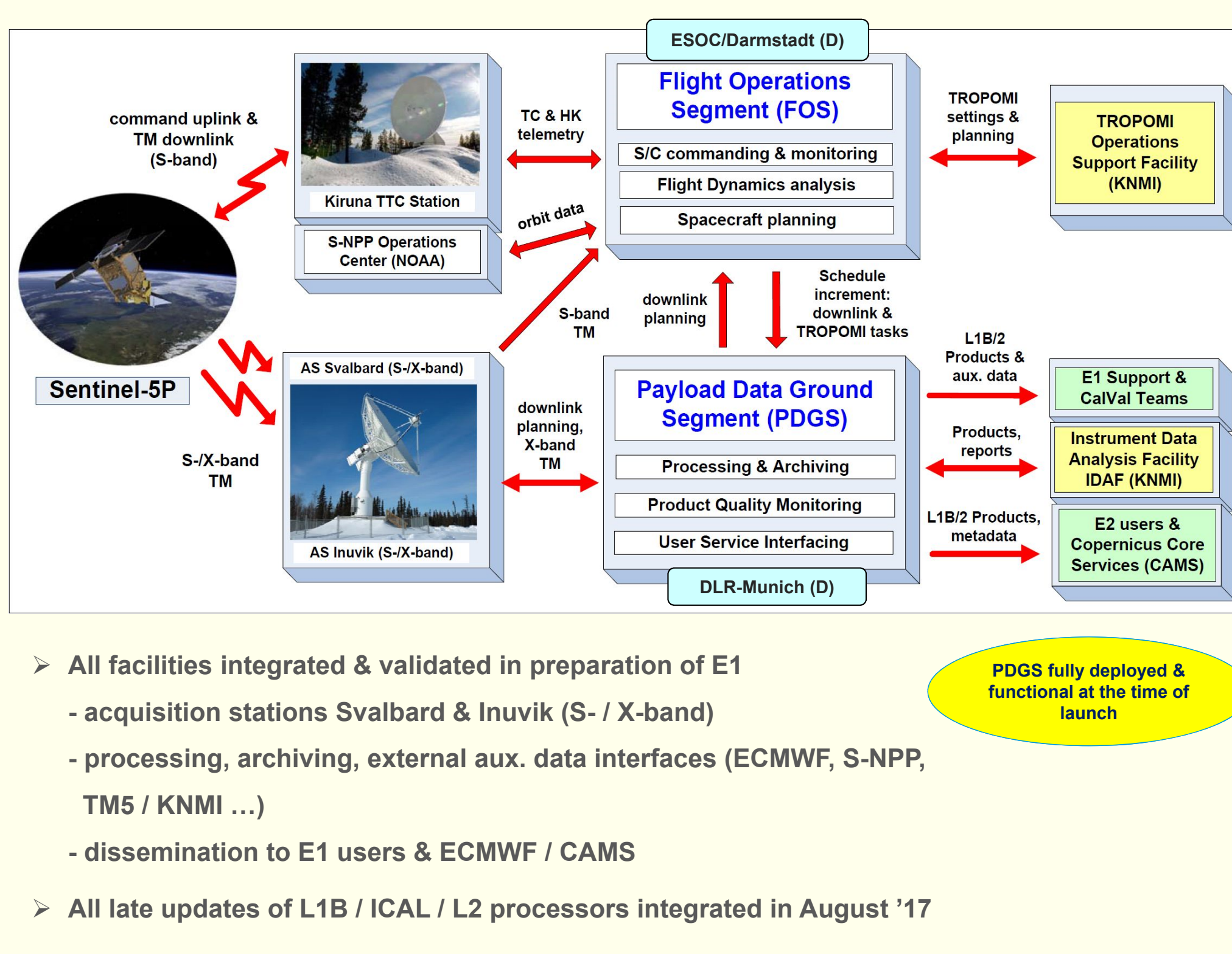
Mission objectives & data products

S-5P will deliver routine, global observations of atmospheric constituents, serving environmental themes and user requirements:

- observations of atmospheric pollutants at global & regional scales, at high spatial resolution
- routine analyses & forecasting of air quality parameters & UV irradiance
- global monitoring of constituents relevant for climate forcing
- delivery of key products to forecast services, specifically ECMWF-CAMS.

Sentinel 5P data products		
Product	Description	Remarks
Level 1B	Calibrated, geo-located Earth radiance & solar irradiance spectra in all bands	systematic processing
Level 2	Column densities/profiles for SSP primary species: UVN channel products O ₃ total & trop. columns, profiles NO ₂ , SO ₂ , HCHO total columns aerosols aerosol index & layer height clouds cloud fraction, top height, OT	Off-line - all products Near Real Time - all species except CH ₄ & tropospheric O ₃
	SWIR channel products CO, CH ₄ total columns	NRT: delivery within 3 h after sensing OFL: delivery within 14 days

S-5P Ground Segment



OOB SL correction in L1B & validation

Correction image:

$$S^{corr}(\lambda^b, x^b) = \int_{\lambda^{ob}} f(\lambda^b, x^b) S_0(\lambda^{ob})$$

Integrate over oob spectral interval in range 805 - 825 nm, ref. signal at 780 nm for intensity scaling

correction requires knowledge of spectral shape & radiance level in OOB source interval

use pre-defined spectral shape & reference radiance at $\lambda^{ref} = 780$ nm

In-flight measurement

Measurement sequence (band 6) for variable LOS tangent heights, short integration time (270 ms)

For tangent heights < 15 km saturation observed near O₂-A absorption band (wavelengths 760.2-761.3 nm)

TROPOMI payload

TROPOspheric Monitoring Instrument

- Grating spectrometer covering 8 bands (UV - short-wave IR)
- common telescope for UVN & SWIR
- Detectors operated at 208 K (UVIS) & 140 K (SWIR)
- pushbroom configuration, wide swath (108° → 2,600 km on surface)

Ground pixel size (near-nadir)

- 3.6 x 7 km² UVIS & NIR
- 21 x 29 km² UV1 (270-300 nm)

band	wavelength range [nm]	channel
1	270 - 300	UV
2	300 - 320	UV
3	320 - 405	UVIS
4	405 - 500	UVIS
5	675 - 725	NIR
6	725 - 775	NIR
7	2305 - 2345	SWIR
8	2345 - 2385	SWIR

UV-VIS-NIR spectrometers developed by The Netherlands Space Office (NSO); contractor Airbus D&S (NL)
 SWIR module: ESA

Early in-flight operation

Sentinel-5P: Phase E1 Tasks

- Launch & Early in Orbit Operation [LEOP] orbit injection & platform check-out
- equipment switch-on (TROPOMI at L + 4 weeks), verification & Si/C commissioning
- TROPOMI calibration, L1B verification & error budgets; extended L2 checks
- stable TROPOMI operations & processing
- E2: routine operations & long-term validation

13 Oct, 09:27:30 h UTC

- Launch & Early Orbit Phase (LEOP) L ... L + 33 h
- Instrument outgassing L ... L + 25 days
- Radiant Cooler door release & instrument switch on (SWIR detector: 8 Nov.) 7 Nov. '17
- TROPOMI functional verification (ADS-NL) 7 - 18 Nov. '17
- Phase E1 operation from 7 Nov. '17
 - systematic generation of L1B products
 - check out of L1B - L2 processing chains in PDGS

Summary & Outlook

With launch on 13 October '17 Sentinel-5P provides continuity in the delivery of global atmospheric products following the SCIAMACHY (Envisat) and OMI (AURA) missions. Following a flawless launch and early operations phase S-5P started delivering routine atmospheric scene and calibration measurements on 7 November '17.

The TROPOMI payload's predicted, excellent radiometric performance and sampling capabilities were fully verified during analyses of the in-flight measurement data.

The commissioning tasks include a full deployment and functional verification of the Level 1B/2 processing and dissemination services in preparation of routine operations (Phase E2).

The Phase E1 tasks were completed with the In-Orbit Commissioning Review on 24 April '18, immediately followed by the handover to routine operations.

The release of the data products will follow a staggered approach

- end June '18 release of Level 1B + Level 2 (subset)
- end 2018 release of remaining Level 2 products.

The S-5P mission was implemented in the frame of the Copernicus Space Component Programme. The TROPOMI instrument was developed under a co-operation agreement between ESA and the Netherlands. The procurement of the S-5P platform as well as the satellite level integration and validation program were covered under an ESA contract with Airbus Defense & Space (UK).

The Level 1B processor was developed by KNMI and SRON, under a contract with the Netherlands Space Office (NSO). The Level 2 processors were developed under parallel, coordinated contract activities involving institutes located in the Netherlands (KNMI/SRON), Germany (DLR-EOC, IUP/Bremen, MPIC/Mainz), Belgium (BIRA) and UK (RAL). Funding resources were provided both by national entities and ESA.

Instrument pre-launch calibration

1st campaign in period 22 Dec '14 - 4 May '15

Location Centre Spatial de Liège (CSL), Liège (B)

Objectives validate instrument performance vs specified values under operational conditions (vacuum & cooled)

collect calibration key data for in-flight tasks (L1B processing & monitoring)

2nd campaign in period Dec. '16 - Jan. '17

Location Airbus D&S UK (Stevenage)

Purpose characterise response to out-of-band (OOB) spectral straylight for NIR bands 5 & 6

Measurements at satellite level, TROPOMI at ambient, close-loop control of detector temperature (297 K)

Tunable laser (600 - 680 nm & 710 - 945 nm) used as stimulus; OOB response characterised for 11 cross-track positions.

First in-flight results

NIR (band 6)

Orbit # 450 (14 Nov)

Level 1B radiance - band 6

Level 1B Earth radiance spectra for nadir & off-nadir (54 deg) pixel position; band 6 (includes Oxygene-A absorption band).

Level 1B processing covers radiometric corrections & spectral axis calibration based on pre-flight characterization data.

Quick-look Earth radiance spectra - band 6 725 - 775 nm

Horizontal axis spectral axis (non-calibrated)

Vertical axis cross track position East->West (full swath = 108 deg)

[from: TROPOMI monitoring site (KNMI)]

References

- [1] 2nd Sentinel-5 Precursor Validation Team Meeting and First Results Workshop, ESTEC, 5-6 February 2018; <https://atpi.eventsair.com/QuickEventWebsitePortal/2nd-sentinel-5-precursor-validation-team-and-early-results-meeting/website/>
- [2] Sentinel-5P on ESA website: http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Sentinel-5P
- [3] Early Results from TROPOMI on the Copernicus Sentinel 5 Precursor, P. Veeffkind et al., EGU General Assembly 2018 (EGU2018-12216)
- [4] Sentinel-5 Precursor: Early in-flight operation & results, H. Nett et al., EGU General Assembly 2018 (EGU2018-5165)
- [5] TROPOMI in-flight calibration and commissioning phase first results, Q. Kleipool et al., EGU General Assembly 2018 (EGU2018-8524)
- [6] Status of the operational Copernicus Sentinel-5 Precursor Geophysical Products, D. Loyola et al., EGU General Assembly 2018 (EGU2018-19693)
- [7] Measuring carbon monoxide with TROPOMI: First results and a comparison with ECMWF-IFS analysis data, T. Borsdorff et al., manuscript submitted to Geophysical Research Letters.