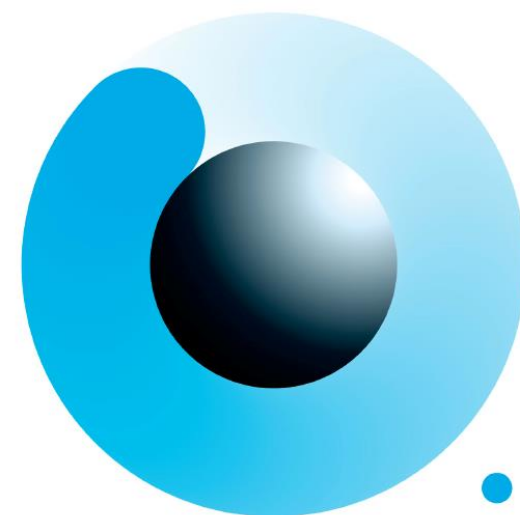


The Validation Needs of the Sentinel-5 Precursor Mission



Ferran Gascon, ESA
on behalf of the Sentinel-5 Precursor Project Team



Sentinel-5 Precursor

- The ESA Sentinel-5 Precursor (S5P) is a pre-operational mission focusing on global observations of the atmospheric composition for Air Quality and Climate.
- The TROPospheric Monitoring Instrument (TROPOMI) is the payload of the S-5P mission and is jointly developed by The Netherlands and ESA.
- The planned launch date for S5P is Q4/2016 with 7 year design lifetime.
- Background mission with global daily coverage.

TROPOMI

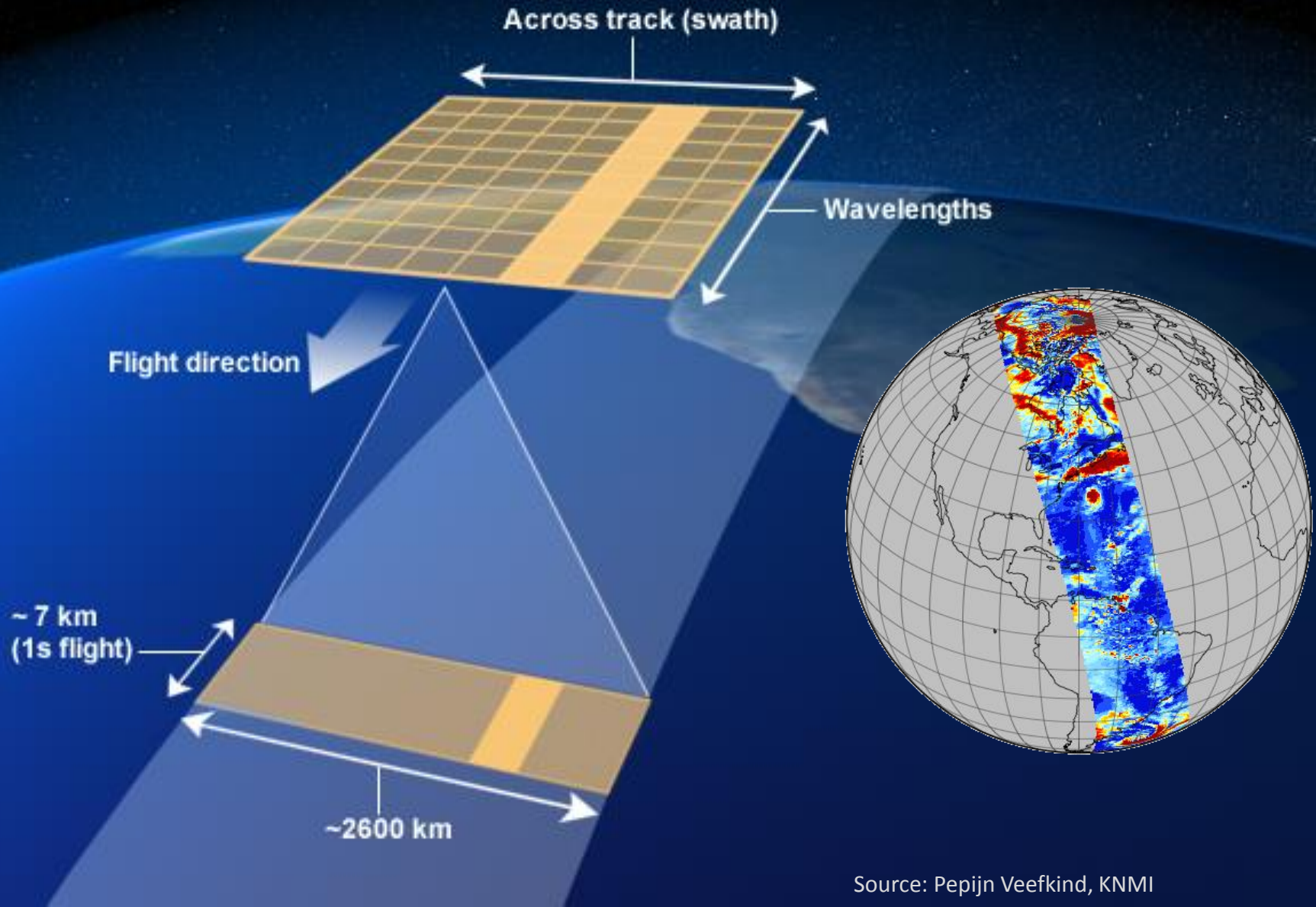
- ▶ UV-VIS-NIR-SWIR push-broom grating spectrometer.
- ▶ Spectral range: 270-500 nm, 675-775 nm, 2305-2385 nm
- ▶ Spectral Resolution: 0.25-1.1 nm
- ▶ Observation Mode: Nadir, global daily coverage, ground pixel 7x3.5 km² at nadir
- ▶ Orbit: Sun synchronous, 824 km, 13:30 hr dayside equator crossing time.



Contribution to Copernicus

- ▶ O₃: total and tropospheric column, profile
- ▶ NO₂: tropospheric and total column
- ▶ CO: total column
- ▶ SO₂: total column
- ▶ CH₄: total column
- ▶ Aerosol: absorbing index, type, optical depth
- ▶ H₂O: tropospheric column
- ▶ H₂O: total column
- ▶ BrO: total column

TROPOMI: Measurement Principle



Tropomi: Performance Parameters

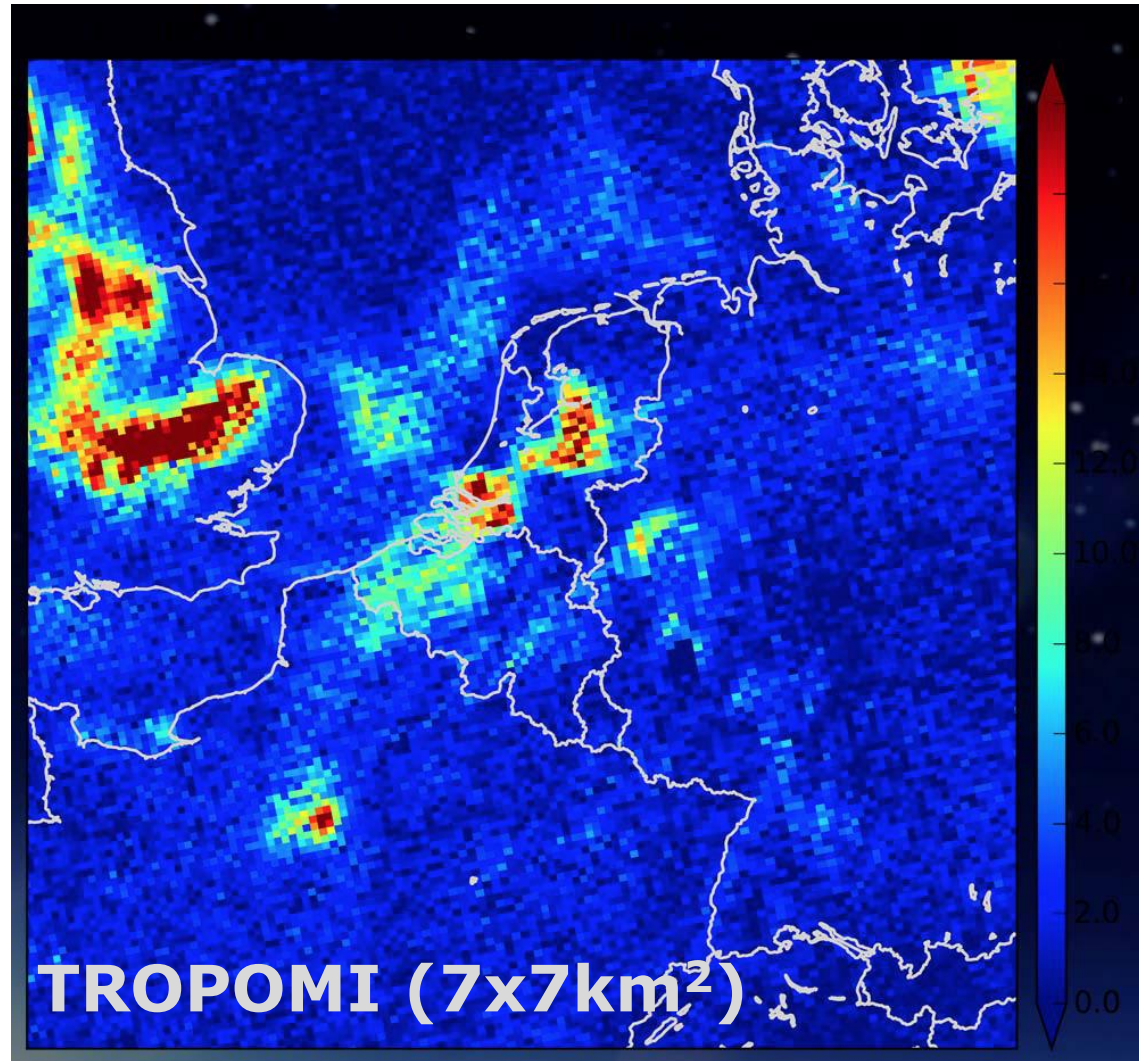


Spectrometer	UV		UVVIS		NIR		SWIR	
Band ID	1	2	3	4	5	6	7	8
Spectral Coverage [nm]	270-320		310-495		675-775		2305-2385	
Full Spectral Coverage [nm]	267 - 332		303 - 499		660 - 784		2299 - 2390	
Spectral Resolution [nm] FWHM	0.49		0.54		0.38		0.25	
Spectral Sampling Ratio	6.7		2.5		2.8		2.5	
Spatial Sampling [km²] at nadir	28x7	3.5x7					7x7	

Source: S5P JPT, KNMI



Spatial Resolution



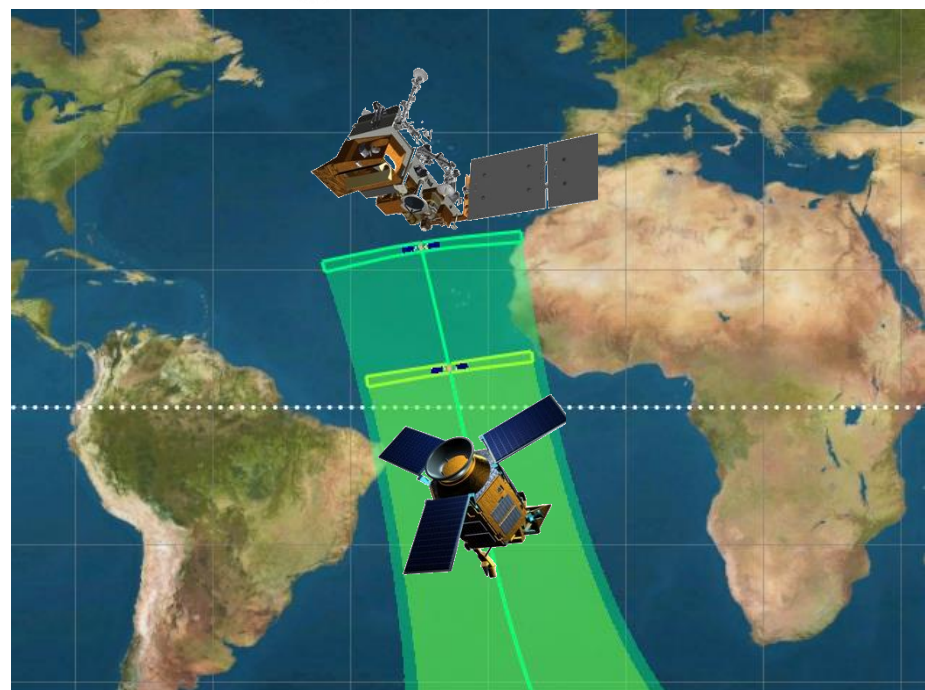
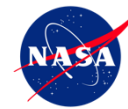
Source: ISOTROP Project, P. Veeffkind



S-5P and S-NPP Loose Formation Flight
















- In particular, Methane requires a very reliable cloud clearing of optically thin layers (e.g. cirrus)
- Synergistic use S-NPP & S-5p products improve the S5P cloud information
- “Loose formation” with separation 5 min +/- 5 min
- Routine delivery of S-NPP/VIIRS products to the S-5P Ground Segment
- Tailored VIIRS cloud products for S5P
- Close technical cooperation between ESA and NOAA/NASA



Level 2 Products and Requirements



<div></div> <div></div> <div></div> <div></div> <div></div>	Parameter	Data Product	Vertical Resolution	Accuracy	Precision
	Ozone 	Ozone Profile	6 km	10-30%	10%
		Total Ozone	total column	3.5-5%	1.6-2.5%
		Tropospheric Ozone	trop column		
	NO ₂ 	Stratospheric NO ₂	strat column	<10%	0.5e15
		Tropospheric NO ₂	trop column	25-50%	0.7e15
	SO ₂ 	SO ₂ enhanced	total column	30%	0.15-0.3 (0.06-0.12) DU
		Total SO ₂	total column	30-50%	1-3 (0.4-1.2) DU
	Formaldehyde 	Total HCHO	total column	40-80%	1.2e16 (4e15)
	CO 	Total CO	total column	15%	<10%
	Methane 	Total CH ₄	total column	1.5%	1%
	Cloud 	Cloud Fraction	total column	<20%	0.05
		Albedo (Optical Thickness)	total column	<20%	0.05 (10)
		Cloud Height (Pressure)	total column	<20%	<0.5 km (<30hPa)
		SNPP VIIRS Cloud data			
Aerosol 	Aerosol Layer Height	total column	<100hPa	<50hPa	
	Absorbing Aerosol Index	total column	~1 AAI	<0.1 AAI	
Surface UV	Provided by FMI as in frame of the Finnish Collaborative Sentinel Ground Segment				

Source: S5P Level 2 Working Group

Source: S5P Level 2 Working Group

All ATBDs (L1 and L2) will be made available to the user community



- High variability in space (horizontally and vertically) and time
- Diverse anthropogenic and natural sources
- Distribution is characterised by strong gradients
- Complex chemistry
- Active photochemistry leading to diurnal variations
- Distribution driven by local and possibly transient emissions
- Local, regional and global scale
- Retrievals depending on a-priori information

➔ Validation approach needs to respond to these challenges



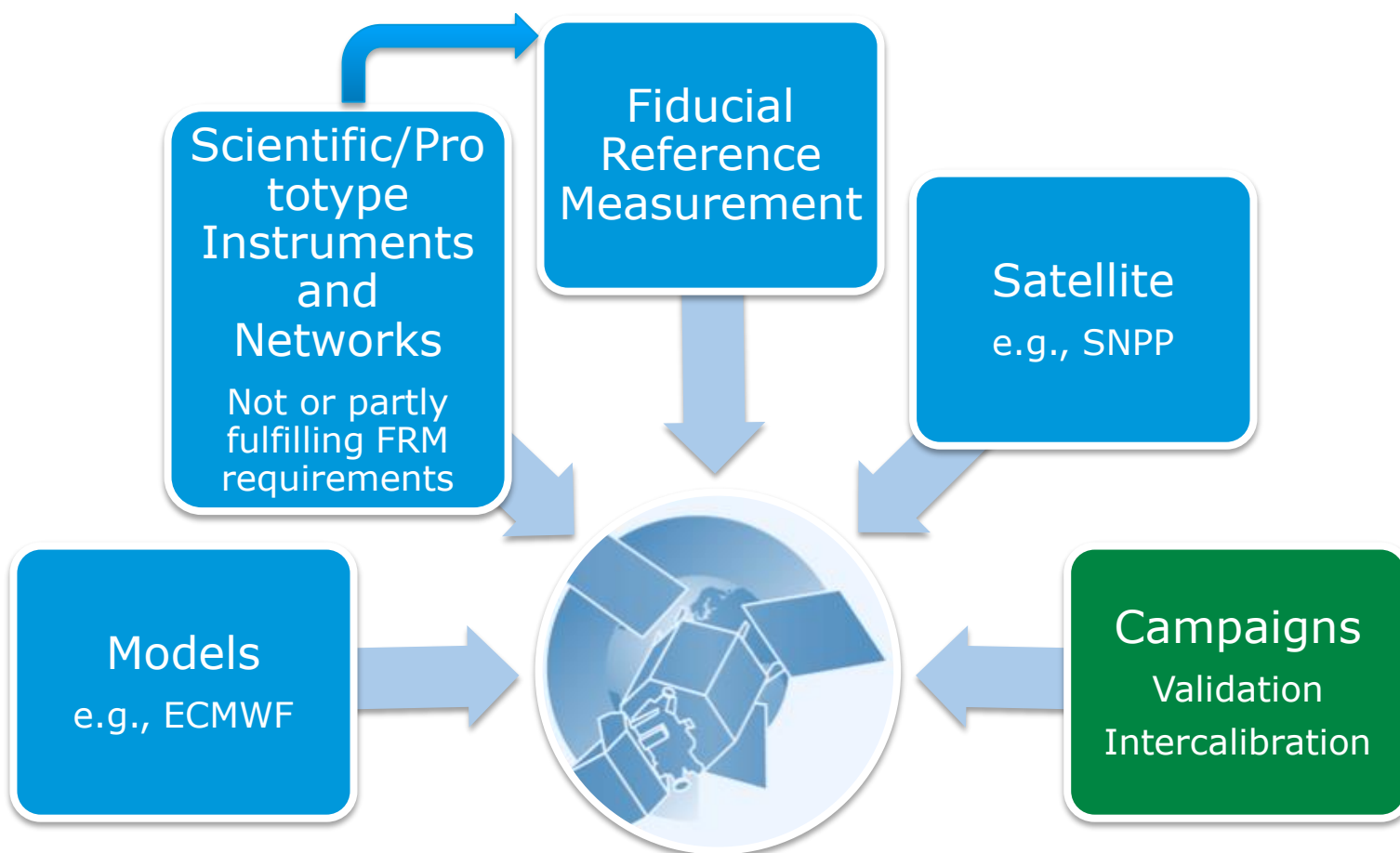
Validation Needs: Traceable Measurements



- High quality and fully characterised (air quality) measurements
- Fully (SI) traceable and documented data products
- Long-term, high-frequency and satellite specific measurements
- Regular absolute instrument calibration
- Daily dataset reporting and central processing of *standard* products for Cal/Val
- Cooperative nature with station PIs

➔ **Fiducial Reference Measurements (FRM)**





S5P Validation Team



- Independent validation using satellite, airborne or ground-based experiments providing independent measurements
- complementary to the operational S5P Mission Performance Centre
- Comprehensive set of 36 projects have been proposed with more than 150 datasets to be provided
 - PIs and Co-PIs covering Western Europe, USA, Korea (and beyond)
 - Basically all standard ground based reference
 - Excellent use of satellite data
 - Instrument networks are well covered, including EARLINET, AERONET and TCCON
 - A number of (non-ESA led) campaigns are proposed



- General requirements insufficient to ensure mission targets can be met
- Product-specific additional requirements were defined in cooperation with algorithm experts to ensure that validation activities address
 - product validation needs and
 - traceability
- For each Level 1b and Level 2 product, a total of 128 requirements have been identified, e.g., Aerosol Layer Height

VAL-ALH-01	Aerosol Layer Height Accuracy: <100 hPa
VAL-ALH-02	Aerosol Layer Height Precision: <50 hPa
VAL-ALH-03	Validation at retrieval wavelength of 760 nm
VAL-ALH-04	Validation of a-priori aerosol parameters (SSA, phase function)
VAL-ALH-05	Validation of a-priori chlorophyll fluorescence assumption.
VAL-ALH-06	Validation of secondary AOT product
VAL-ALH-07	Validation using high resolution aerosol extinction profiles providing high accuracy and precision (e.g., Lidar)

- In addition generic requirements” were included, e.g., “validation of a full seasonal cycle” or “variable cloud conditions”



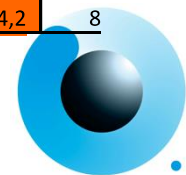
Aerosol Layer Height:

Requirements		Pre-Launch			Comiss.			Year 1			Year 2			Year > 2			Overall		
		$\overline{P_{j,k}}$	$P_{j,k}$	N	$\overline{P_{j,k}}$	$P_{j,k}$	N	$\overline{P_{j,k}}$	$P_{j,k}$	N	$\overline{P_{j,k}}$	$P_{j,k}$	N	$\overline{P_{j,k}}$	$P_{j,k}$	N	$\overline{P_{j,k}}$	$P_{j,k}$	N
Aerosol Layer Height																			
VAL-ALH-01	Aerosol Layer Height Accuracy: <100 hPa	91%	9,1	10	78%	9,3	12	84%	9,3	11	84%	9,2	11	84%	9,2	11	84%	9,2	11
VAL-ALH-02	Aerosol Layer Height Precision: <50 hPa	91%	9,1	10	75%	9,8	13	81%	9,7	12	82%	9,9	12	82%	9,9	12	82%	9,9	12
VAL-ALH-03	Validation at retrieval wavelength of 760 nm	91%	6,4	7	82%	8,2	10	82%	8,2	10	84%	8,4	10	84%	8,4	10	84%	8,4	10
VAL-ALH-04	Validation of a-priori aerosol parameters (SSA, phase function)	90%	8,1	9	78%	8,6	11	87%	8,7	10	85%	8,5	10	86%	8,6	10	86%	8,6	10
VAL-ALH-05	Validation of a-priori chlorophyll fluorescence assumption.	0%	0,0	0	0%	0,0	0	0%	0,0	0	0%	0,0	0	0%	0,0	0	0%	0,0	0
VAL-ALH-06	Validation of secondary AOT product	92%	5,5	6	77%	6,9	9	87%	6,9	8	87%	7,0	8	89%	7,1	8	89%	7,1	8
VAL-ALH-07	Validation using high resolution aerosol extinction profiles providing high accuracy and precision (e.g., Lidar)	91%	5,5	6	74%	5,9	8	84%	5,9	7	84%	5,9	7	84%	5,9	7	84%	5,9	7



Methane Total Column:

Requirements		Pre-Launch			Comiss.			Year 1			Year 2			Year > 2			Overall		
		$\overline{P}_{j,k}$	$P_{j,k}$	N	$\overline{P}_{j,k}$	$P_{j,k}$	N	$\overline{P}_{j,k}$	$P_{j,k}$	N	$\overline{P}_{j,k}$	$P_{j,k}$	N	$\overline{P}_{j,k}$	$P_{j,k}$	N	$\overline{P}_{j,k}$	$P_{j,k}$	N
Methane Total Column (CH₄)																			
VAL-CH4-01	Accuracy: 1.5%	56%	5,0	9	62%	7,4	12	63%	10,0	16	59%	7,1	12	58%	7,0	12	58%	7,0	12
VAL-CH4-02	Precision: 1%	56%	5,0	9	62%	7,4	12	61%	9,2	15	58%	6,4	11	57%	6,2	11	57%	6,2	11
VAL-CH4-03	Validation of the vertical CH ₄ profile.	84%	5,0	6	82%	4,9	6	81%	6,5	8	83%	5,0	6	77%	3,1	4	77%	3,1	4
VAL-CH4-04	Validation of H ₂ O and CO columns	83%	1,7	2	81%	2,4	3	82%	3,3	4	81%	2,4	3	81%	2,4	3	81%	2,4	3
VAL-CH4-05	Validation of cirrus cloud detection, in particular in the tropics.	92%	2,8	3	93%	3,7	4	92%	3,7	4	88%	3,5	4	88%	3,5	4	88%	3,5	4
VAL-CH4-06	Global over land.	23%	0,5	2	46%	1,4	3	45%	1,3	3	41%	1,2	3	41%	1,2	3	41%	1,2	3
VAL-CH4-07	Humid atmospheric conditions	60%	6,0	10	64%	7,7	12	65%	9,8	15	61%	6,7	11	61%	6,7	11	61%	6,7	11
VAL-CH4-08	Dry atmospheric conditions	60%	6,0	10	66%	8,5	13	65%	10,4	16	61%	6,7	11	61%	6,7	11	61%	6,7	11
VAL-CH4-09	High albedo conditions.	52%	4,2	8	56%	5,1	9	59%	7,0	12	53%	4,2	8	53%	4,2	8	53%	4,2	8
VAL-CH4-10	Low albedo conditions.	52%	4,2	8	56%	5,1	9	59%	7,0	12	53%	4,2	8	53%	4,2	8	53%	4,2	8



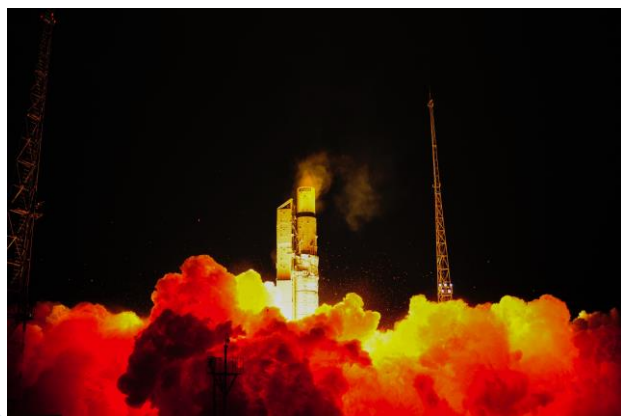
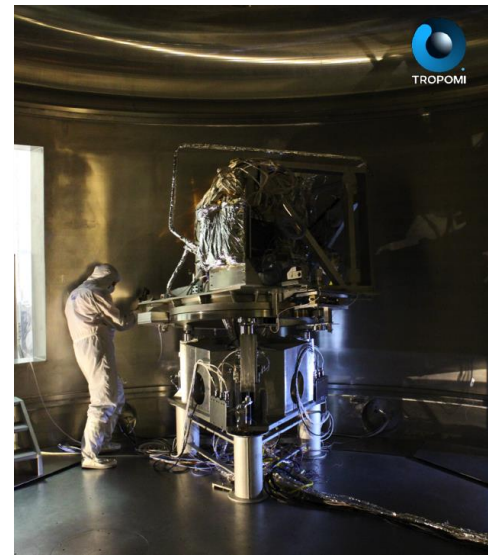
- **Ozone profile and total column** well covered, except for the required measurement spatial representativity and specific environmental conditions (biomass burning/strat. intrusion)
- **Tropospheric ozone, NO₂ and formaldehyde** well covered but lacking global validation and in particular for the tropics
- **SO₂** lacks redundancies and validation capabilities for high SO₂ pollution
- **CO and methane validation at risk**, in particular as a result of funding issues for validation
- **Clouds and aerosol layer height** well covered, also thanks to ACTRIS-2 participating teams
- **Level 1b** lacks redundancy (only few projects)
- Only in few cases the validation capabilities are foreseen to decrease along the mission lifetime



- S5PVT has provided comprehensive information on the projects
 - input is still being analysed
- Scientific Validation Implementation Plan (SVIP) to be completed in March 2016 covering among other topics
 - Validation Requirements
 - Detailed S5PVT projects descriptions
 - Risk Assessment
 - FRMs
- Support to S5PVT projects in the discussion with the funding agencies
- Dedicated projects on ESA side to support atmospheric composition FRMs (e.g., DOAS, FTIR, PANDONIA)
- Preparation of intercomparison and validation campaigns
- Satellite data for expert teams 4-6 months after launch

Overall Project Status

- TROPOMI was delivered in May 2015
- Level 1b and Level 2 processors delivered in November 2015, operational codes are being integrated and further optimisations are ongoing to be integrated before launch
- Ground Segment Acceptance Review (GS-AR) to be completed in March 2016



- S5P Satellite Qualification and Acceptance Review to be completed in April 2016
- Due to delay with the ROKOT system launch is delayed to earliest end October 2016



Thank you for your attention.

<http://sentinel.esa.int/s5p/>

<http://www.tropomi.eu>

<http://www.copernicus.eu>

