



Royal Netherlands
Meteorological Institute
*Ministry of Infrastructure and the
Environment*

TROPOMI on Sentinel 5 Precursor

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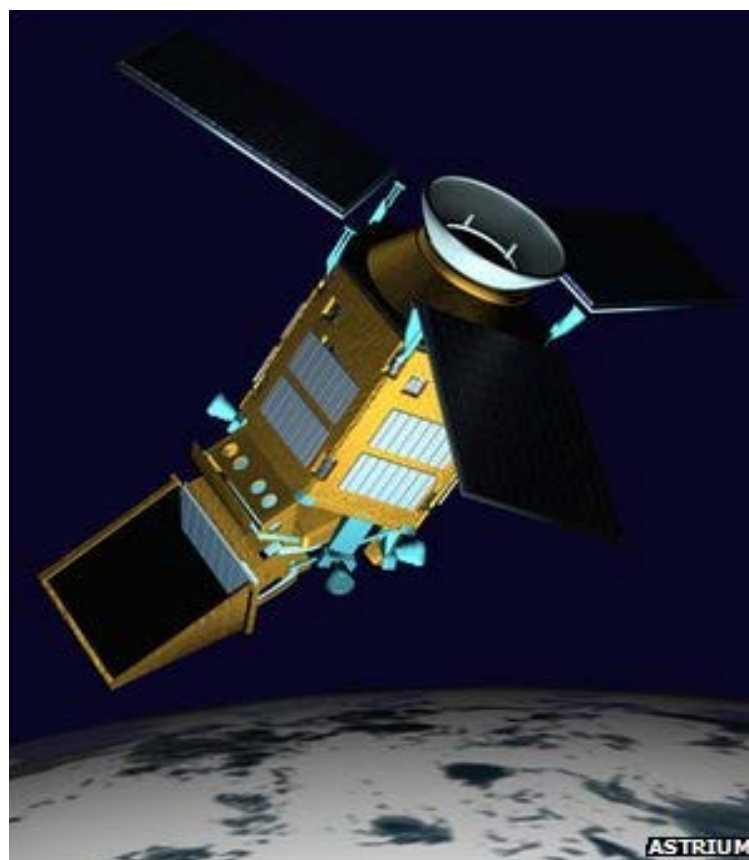
sentinel-5 precursor

COPERNICUS/GMES ATMOSPHERE MISSION IN POLAR ORBIT

- The ESA Sentinel-5 Precursor (S-5P) is a pre-operational mission focussing 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 S-5P is 2016 with a 7 year design lifetime.

TROPOMI

- ▶ UV-VIS-NIR-SWIR nadir view grating spectrometer.
- ▶ Spectral range: 270-500, 675-775, 2305-2385 nm
- ▶ Spectral Resolution: 0.25-1.1 nm
- ▶ Spatial Resolution: 7x7km²
- ▶ Global daily coverage at 13:30 local solar time.



CONTRIBUTION TO GMES

- ▶ Total column
O₃, NO₂, CO, SO₂, CH₄,
CH₂O, H₂O, BrO
- ▶ Tropospheric column
O₃, NO₂
- ▶ O₃ profile
- ▶ Aerosol absorbing index,
type, optical depth



sentinel-5 precursor

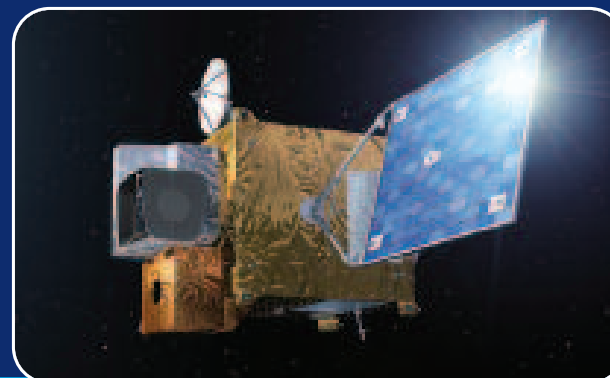
→ GMES LOW EARTH ORBIT ATMOSPHERE MISSION

→ GMES LOW EARTH ORBIT ATMOSPHERE MISSION

2015-2022
daily global
coverage

EUMETSAT Polar System

2019 - ~2030
hourly over
Europe



sentinel-4

→ GMES GEOSTATIONARY ATMOSPHERIC MISSION

→ GMES GEOSTATIONARY ATMOSPHERIC MISSION

2017 - ...
hourly over SE
- ASIA

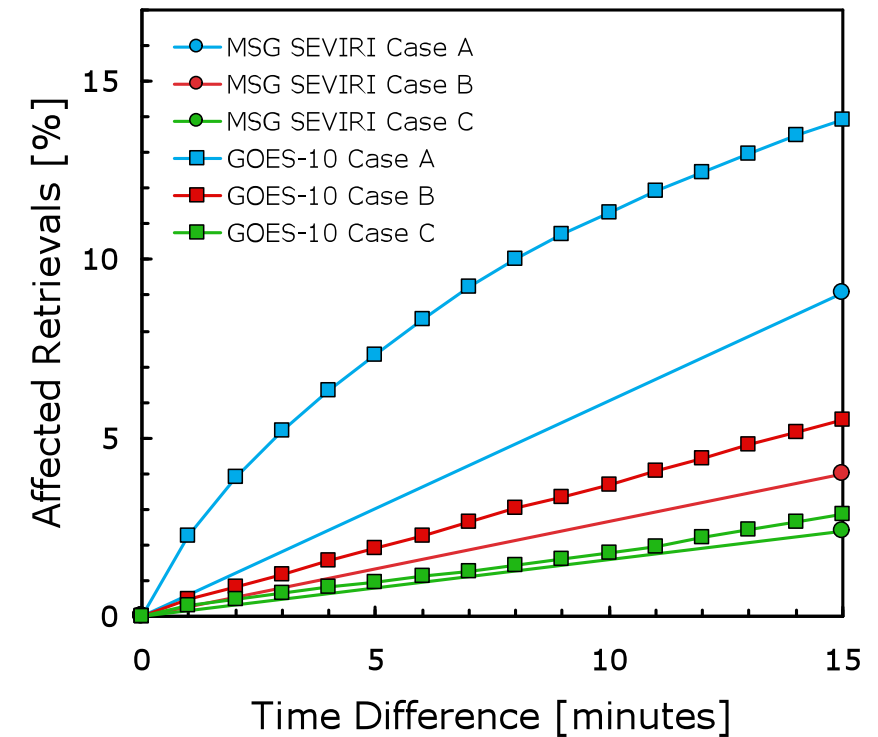
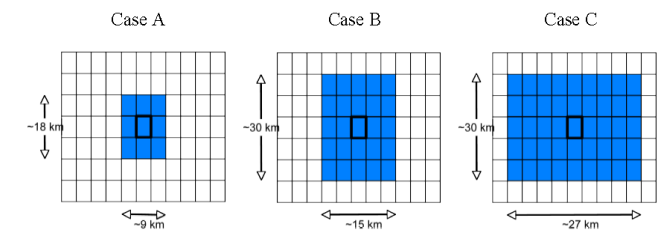
gems | tempo

KARI | NASA

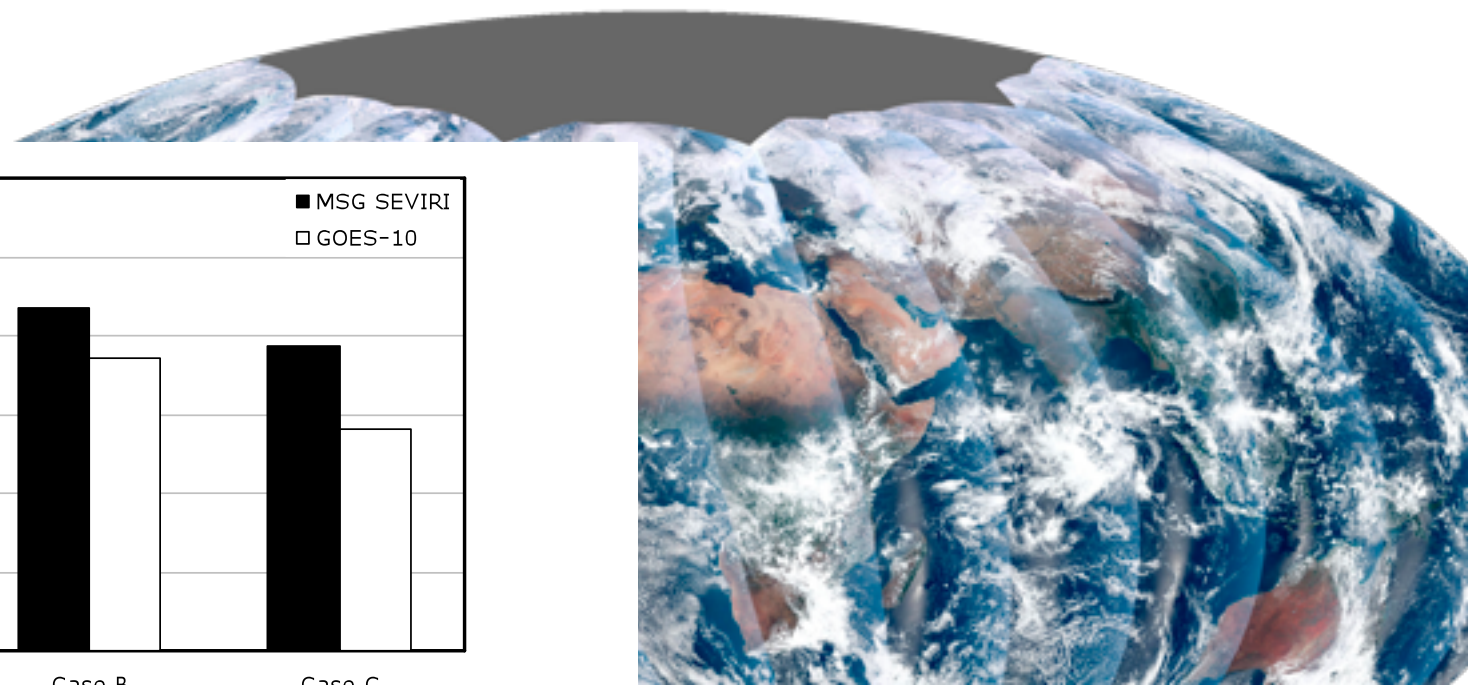
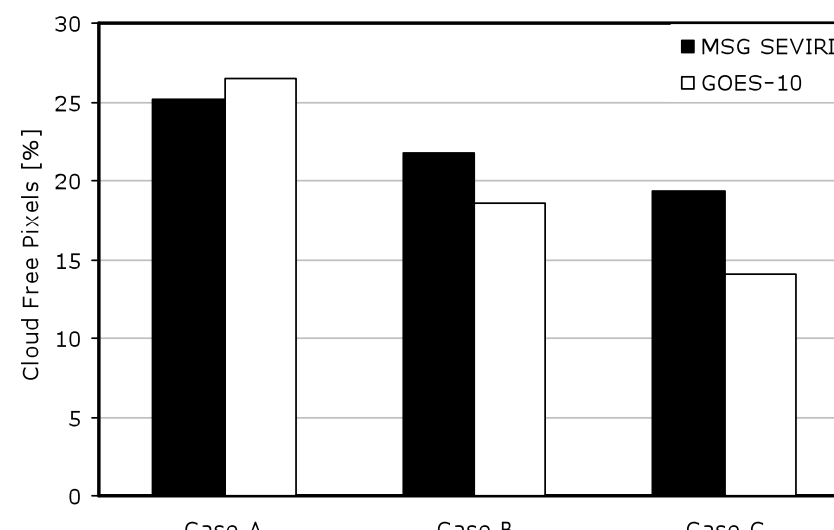
2019 - ...
hourly over N-
America

Suomi-NPP - S5P formation Flying

- S-5P is planned to observe within 5 min. of Suomi-NPP.
- Primary goal is to use VIIRS cloud mask for S-5P methane observations.
- Other opportunities:
 - ▶ TROPOMI-VIIRS cloud and aerosol combined products.
 - ▶ TROPOMI-OMPS-CRIS ozone profiles.
 - ▶ TROPOMI-OMPS inter-calibration.

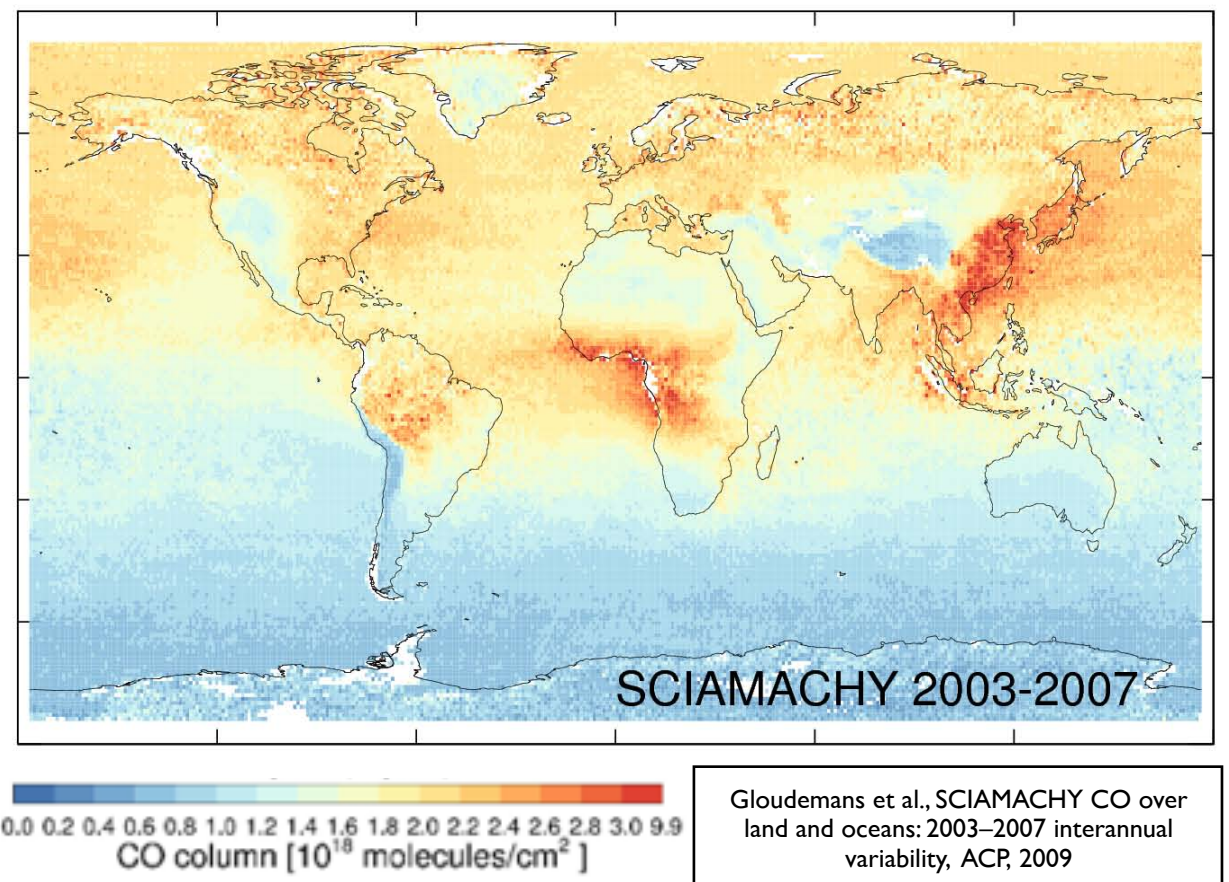
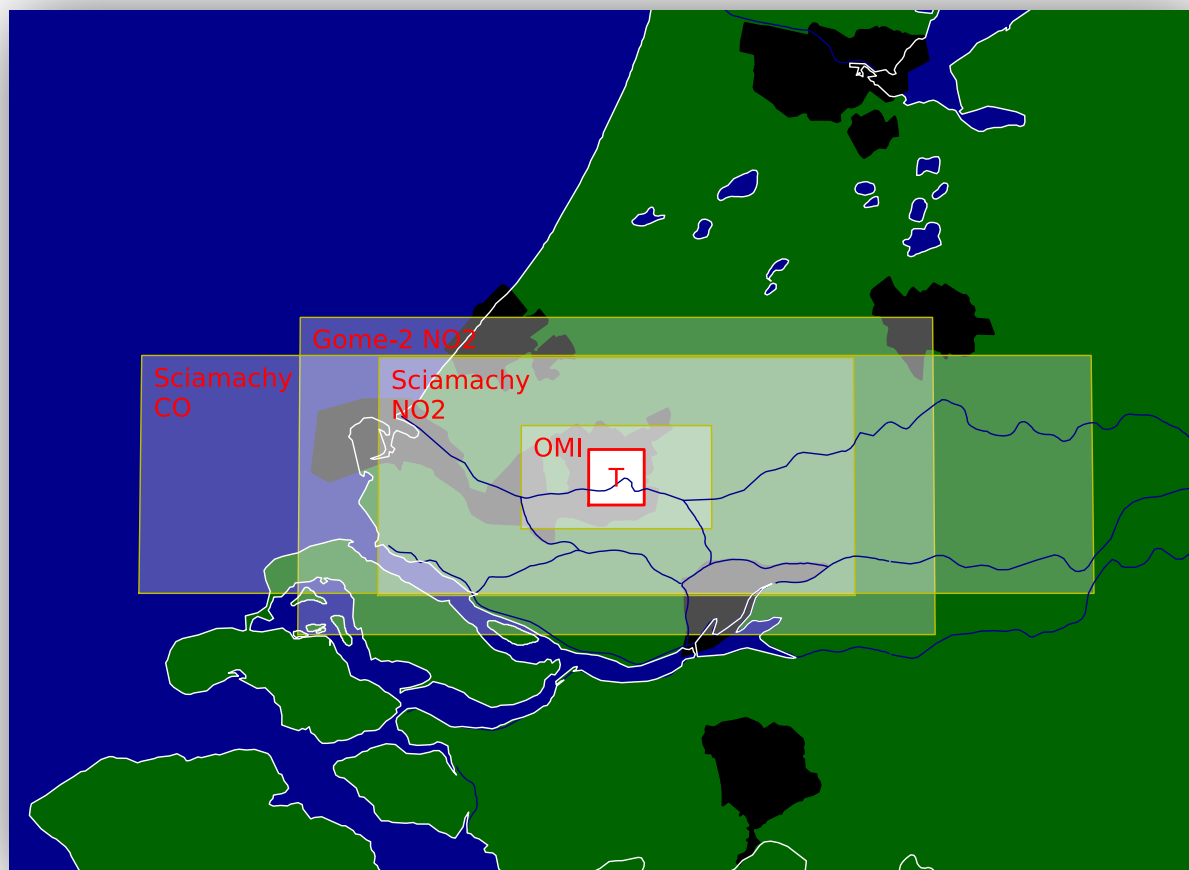


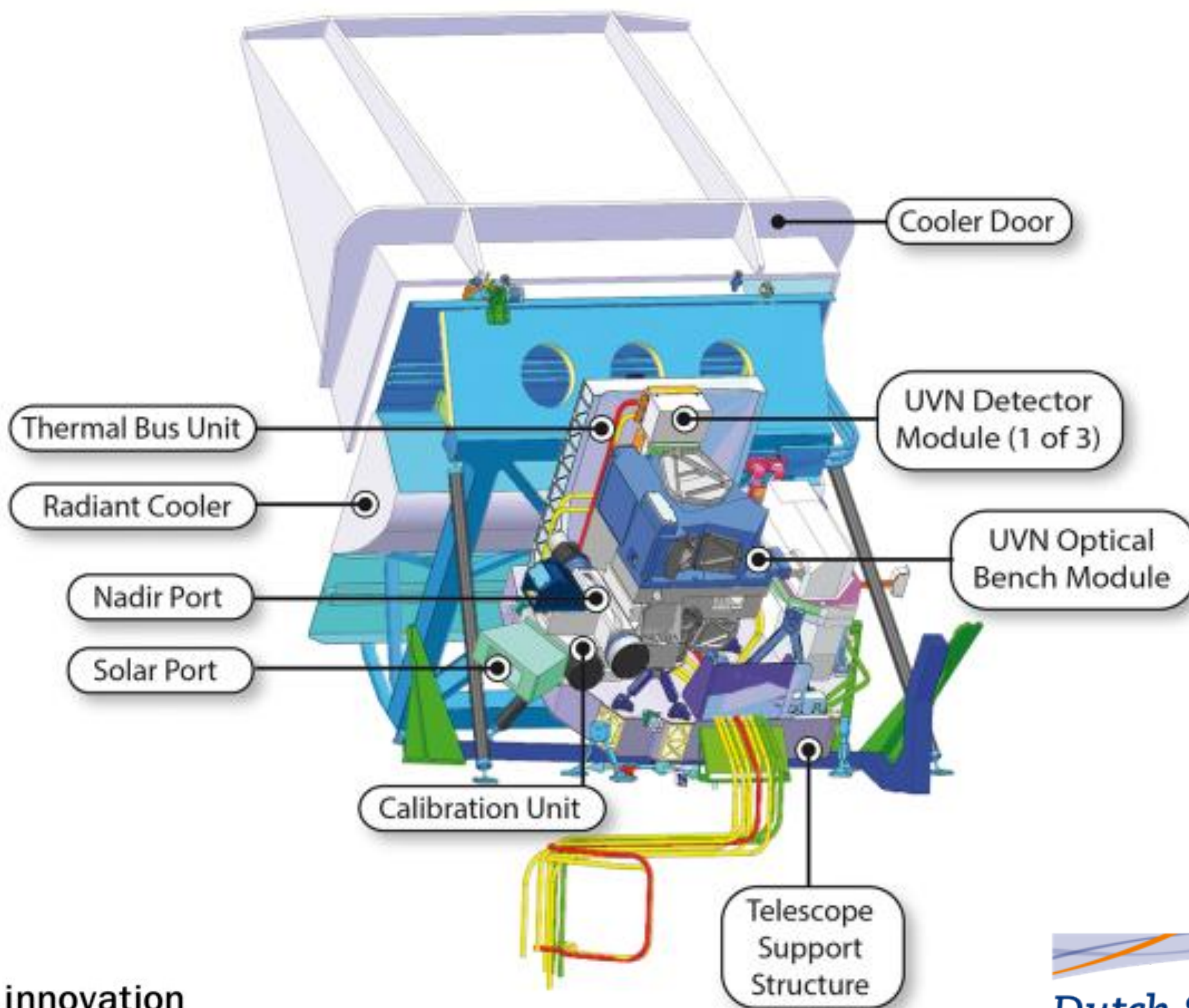
Genkova et al., AMT, 2012



From OMI to TROPOMI

- **6x higher spatial resolution**
7x7 km² vs. 13x24 km²
- **1-5x higher signal-to-noise**
- **Variable binning scheme**
- **better cloud information**
from the oxygen A+B bands
- **CO and CH₄ observations**
from the SWIR band
- **Data rate ~20x OMI**

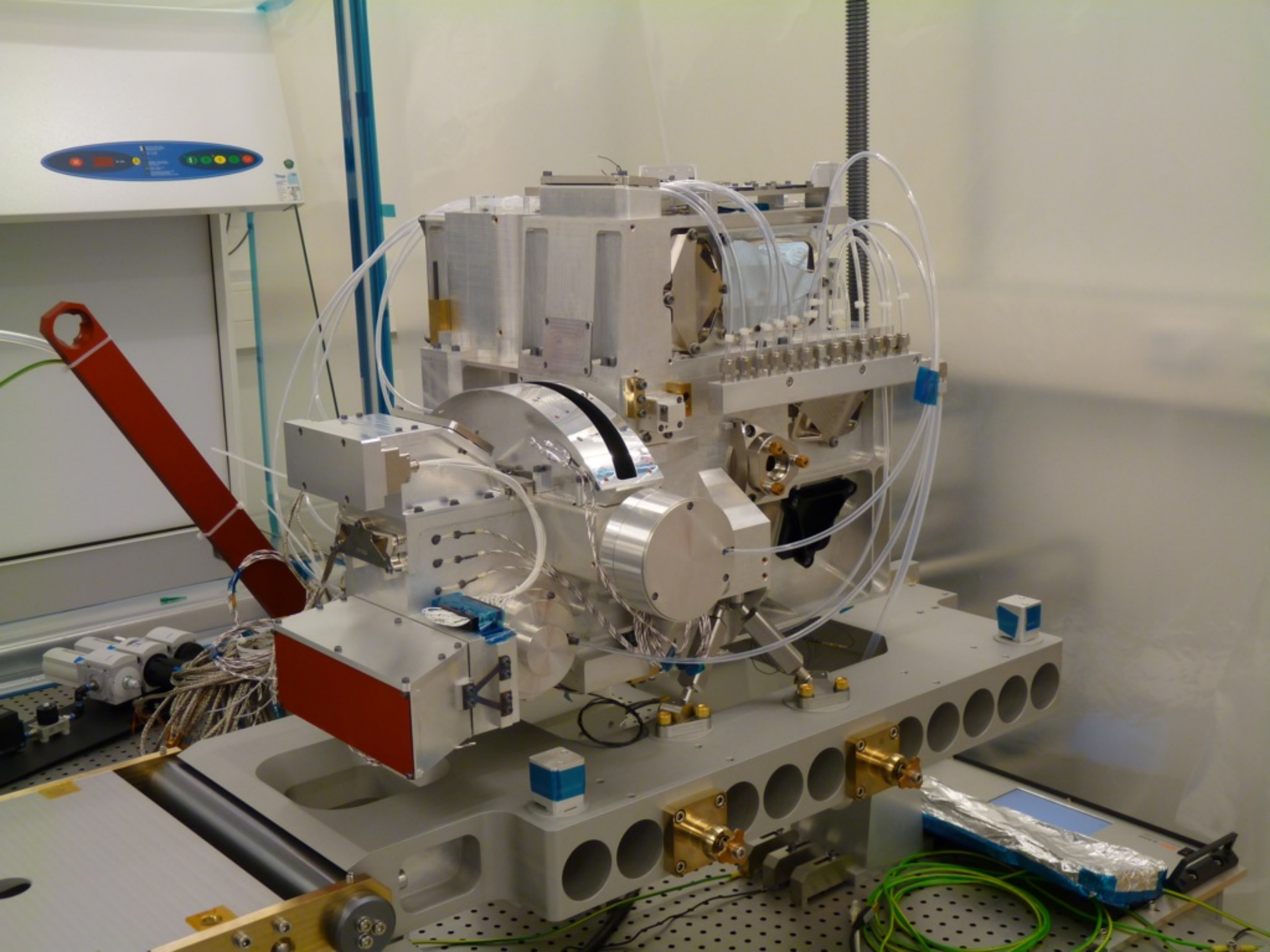


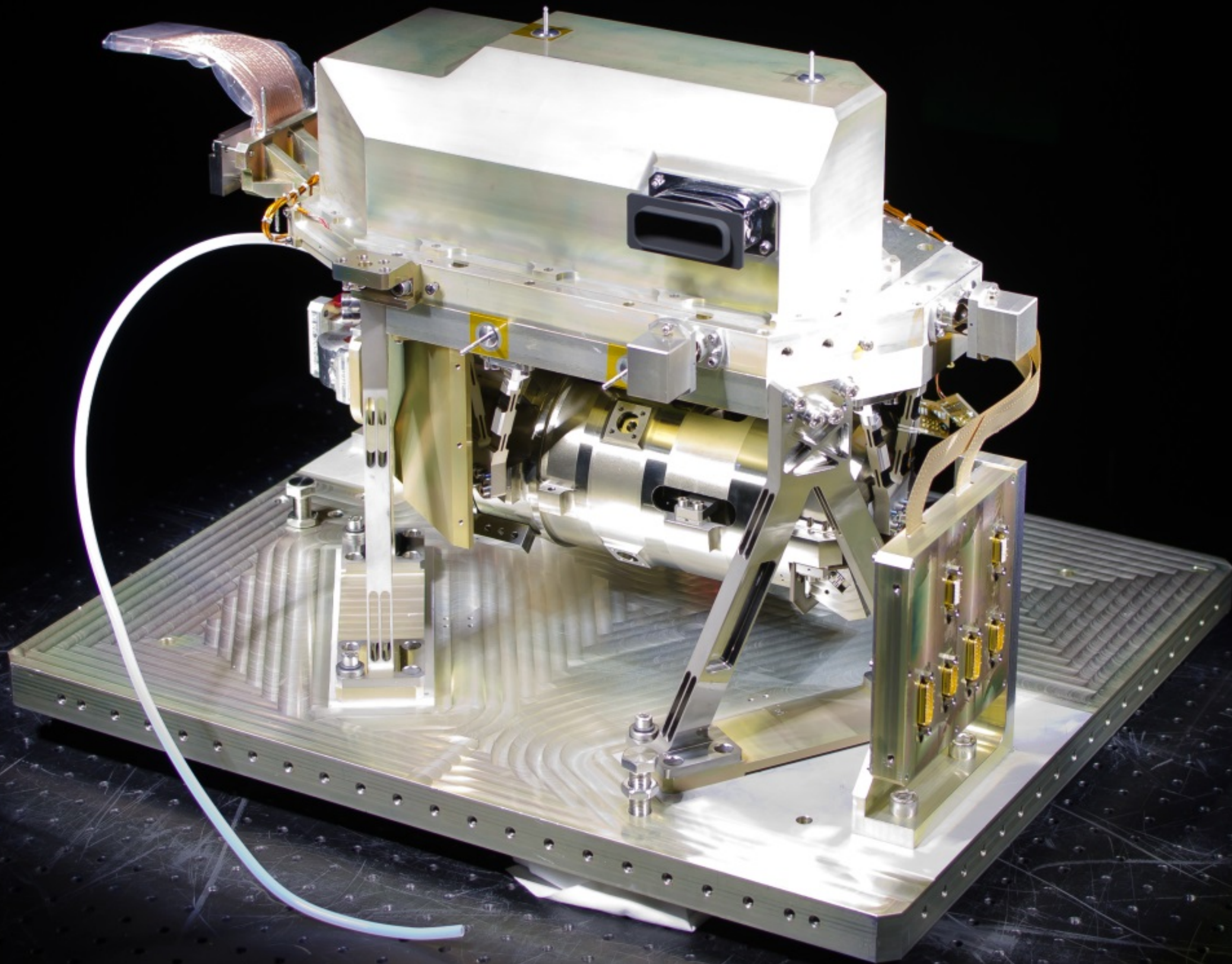


Instrument Status



- UVN module delivered
 - SWIR module delivered
 - ICU delivered
 - TSS delivered
 - Cooler in AIT
-
- TROPOMI ready for performance testing and calibration in July 2014.
 - TROPOMI delivery early 2015.
 - Earliest launch opportunity early 2016







Performance Overview

Spectrometer	UV		UVIS		NIR		SWIR	
Band ID	1	2	3	4	5	6	7	8
Full Range [nm]	270 – 320		310 - 495		675 - 775		2305 - 2385	
Performance range [nm]	270-300	300-320	320-405	405-495	675-725	725-775	2305-2345	2345-2385
Spectral Resolution FWHM[nm]	0.48	0.49	0.54	0.54	0.38	0.38	0.25	0.25
Spectral Sampling [nm]	0.071	0.073	0.22	0.22	0.14	0.14	0.10	0.10
Spectral Sampling Ratio ¹	6.8	6.7	2.5	2.5	2.8	2.8	2.5	2.5
Slit Width (μm)	560	560	280	280	280	280	560	560
Spectral magnification	0.327	0.319	0.231	0.231	0.263	0.263	TBD	TBD
Spatial Sampling at nadir [km ²]	28x7	7x7	7x7		7x7	3.5x7	7x7	
Required Signal-to-noise	100-800 ^{2,3}	90-700 ²	800-1000 ²		100-500 ^{2,4}		100-120 ⁵	

Required signal-to-noise	800 ₅ ³ 100-	100 ₅ 90-	800-1000 ₅	100-200 ₅ ⁴		100-150 ₂
[km ₅] Spatial Sampling at nadir	28x7	7x7	7x7	7x7	3.5x7	7x7

TROPOMI Data Products

Product	Accuracy :: Precision
Ozone total column profile (incl. troposphere) trop. column	3.5-5% :: 1.6-2.5% 10-30% :: 10% TBD :: TBD
NO total column trop. column	10-25% :: 1 · 10 25-50% :: 7 · 10
CO total column	15% :: 10%
CH total column	1.5% :: 1%
SO volcanic plume top. column	TBC :: 1-3 DU 30-50% :: 1-3 DU
Aerosol AAI aerosol layer height* <i>aerosol optical thickness</i> <i>single scattering albedo</i>	<1 AAI :: 0.1 AAI 1 km :: 0.5 km <i>0.1 (20%) :: 0.05</i> <i>(10%)0.05 :: 0.01</i>
Cloud fraction pressure albedo Regridded NPP-VIIRS	20% :: 0.05 20% :: 30 hPa 20% :: 0.05

Product	Accuracy :: Precision
CH total column	40-80% :: 1.2 · 10
CHO-CHO total column	TBD
BrO total column	TBD
HDO total column	TBD
H₂ total column	20% :: 10%
OCIO total column	TBD
UV surface flux	10% :: 5%
Surface Reflectance monthly climatology	3% :: 1%

*The operational data products will be developed by a collaboration of European institutes.
KNMI/DLR-IMF/IUP/BIRA-IASB/SRON/MPIC/RAL/FMI*



L0-1B Development

- KNMI is developing the L0-1B processor
- SW Architecture is multi-threading & multipass
- The data rate is extremely challenging
- The L0-1B is used throughout the on-ground testing and calibration
- Challenging algorithms: spectral calibration, stray light, detector smear

TROPOMI L2 PRODUCTS

L2 Working Group

PROTOTYPE

VERIFICATION

OPERATIONAL SW

GOME-SCIAMACHY-OMI

KNMI | DLR | IUP-Bremen | BIRA | SRON | MPIC | RAL



L1-2 Development

- L1-2 processors are defined by consortium of European institutes
- ATBD review was completed successfully in 2013.
- L2-CDR is planned for June 2014.
- First verification cycle has been completed.
- Data rate in combination with complexity of some of the algorithms is challenging.
- File format is NetCDF 4 with CF-metadata. Tailoring of the CF standards is necessary.

Validation



- ESA is planning an announcement of opportunity for TROPOMI/S5P
- Approved projects can have access to early L1B and L2 products.
- The AO is expected to be released in May 2014.
<https://earth.esa.int/web/guest/pi-community/apply-for-data/ao-s>
- A preparation campaign will take place in Romania , focussing on NO2 vertical profile information, using sonde, UAVs and aircraft data



Summary & Outlook



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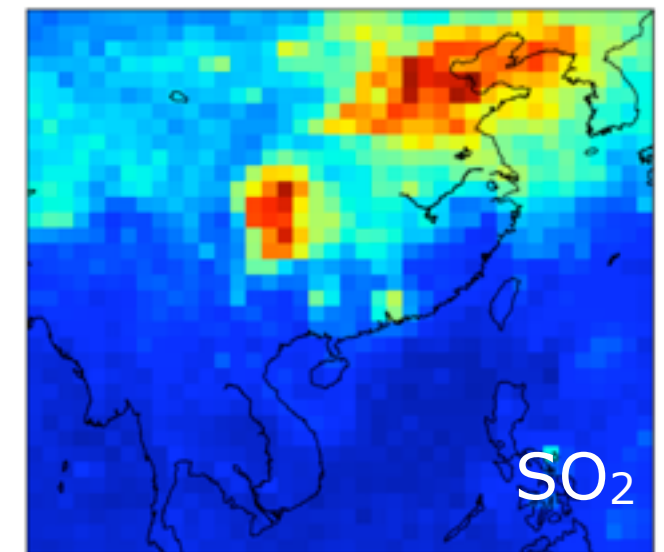
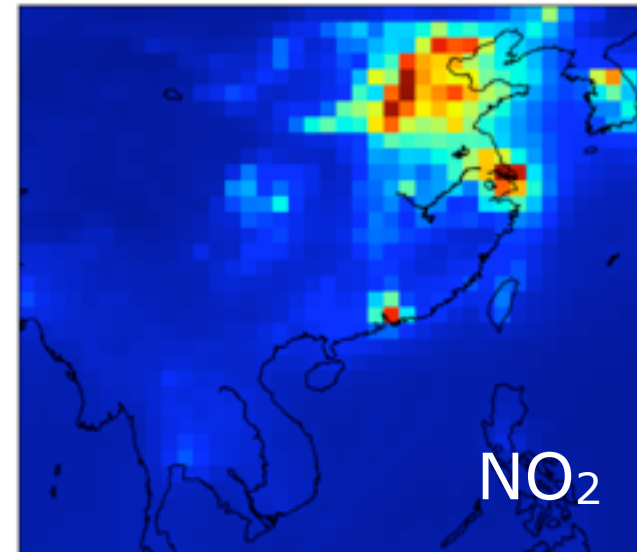
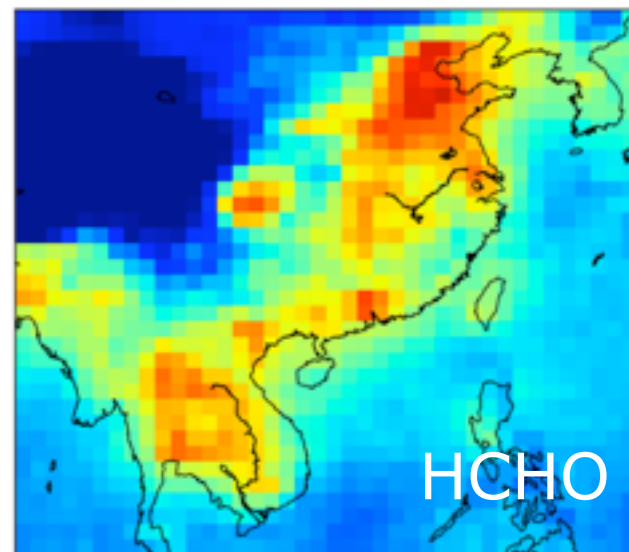
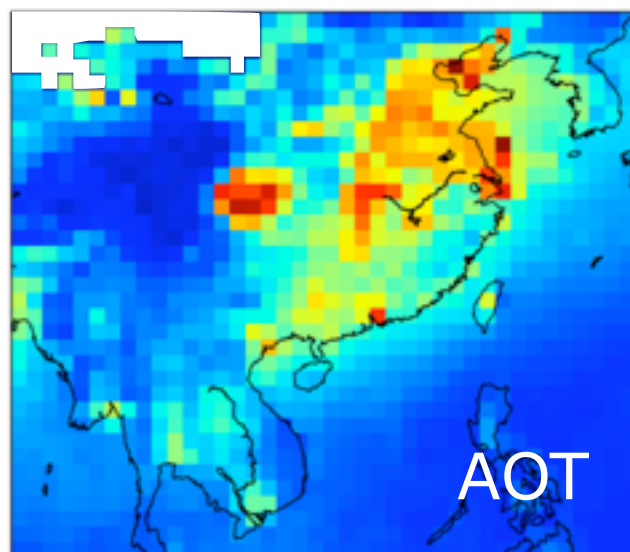
www.tropomi.eu

www.temis.nl

www.knmi.nl/omi

<http://www.esa.int/esaLP>

- TROPOMI will be a major step forward for atmospheric composition observations due to improved spatial resolution & sensitivity.
- The high spatial resolution provides new opportunities, while at the same time being challenging for the Level 2 product development.
- Sentinel 5 Precursor will connect to the geostationary missions providing in-flight CAL/VAL and inter-comparison opportunities.





Contents lists available at [SciVerse ScienceDirect](http://www.sciencedirect.com)

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse



TROPOMI on the ESA Sentinel-5 Precursor: A GMES mission for global observations of the atmospheric composition for climate, air quality and ozone layer applications

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<http://dx.doi.org/10.1016/j.rse.2011.09.027>

TROPOMI

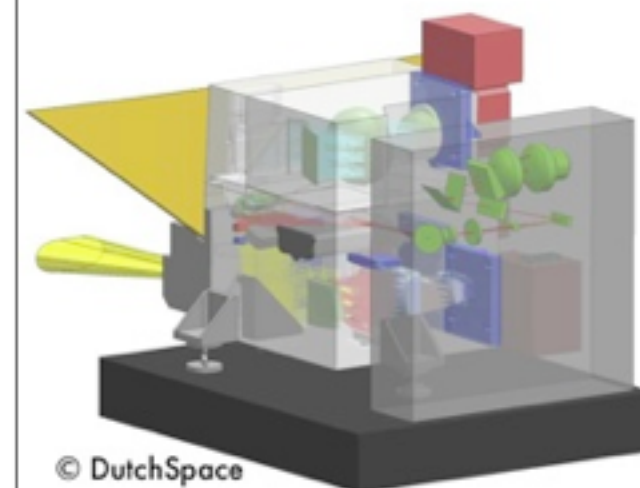
TROPOspheric Monitoring Instrument

www.tropomi.eu

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The TROPOspheric Monitoring Instrument (TROPOMI) is a spaceborne nadir viewing spectrometer with bands in the ultraviolet, the visible, the near infrared and the shortwave infrared. TROPOMI is the payload for the ESA/GMES Sentinel 5 Precursor mission, planned for launch in 2014 with 7 years design lifetime. The objective of the mission is to provide high-quality and timely information on the global atmospheric composition for climate and air quality applications. TROPOMI will make daily global observations of key atmospheric constituents, including ozone, nitrogen dioxide, sulfur dioxide, carbon monoxide, methane, formaldehyde and aerosol properties. The Sentinel-5 Precursor mission will extend the current data records from OMI (Ozone Monitoring Instrument) on NASA EOS Aura and SCIAMACHY (SCanning Imaging Absorption spectroMeter for Atmospheric Cartography) on ESA Envisat and is the link between the current scientific missions and the operational Sentinel-4/-5 missions.

TROPOMI is an initiative from the Netherlands and is developed in cooperation



Principal Investigator

KNMI (PI), SRON (co-PI)

Validation

ESA, KNMI, SRON, ...

Level 1-2

KNMI, SRON, DLR, IUP-Bremen
BIRA-IASB, MPI Mainz, RAL

Level 0-1B

KNMI

Ground Segment

DLR

Operations

KNMI, ESOC

Calibration

KNMI / SRON
Dutch Space / TNO

Instrument

prime Dutch Space

Project Man.

JPT (ESA-NSO)





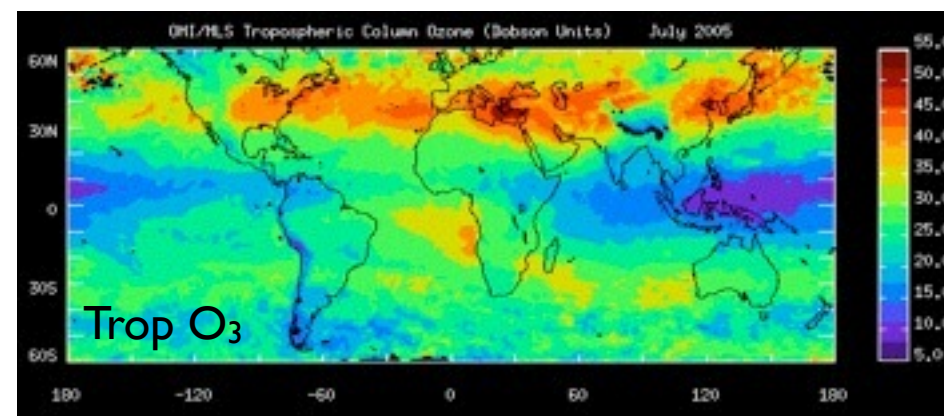
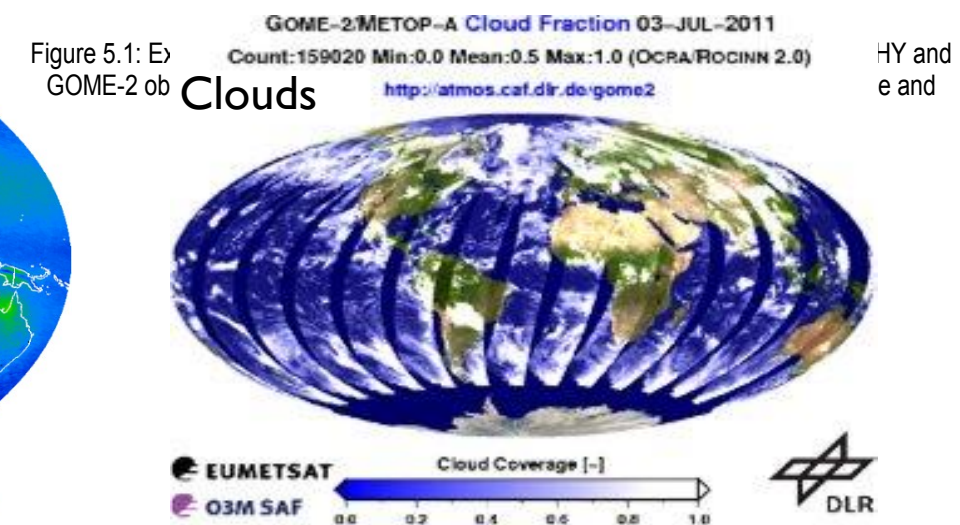
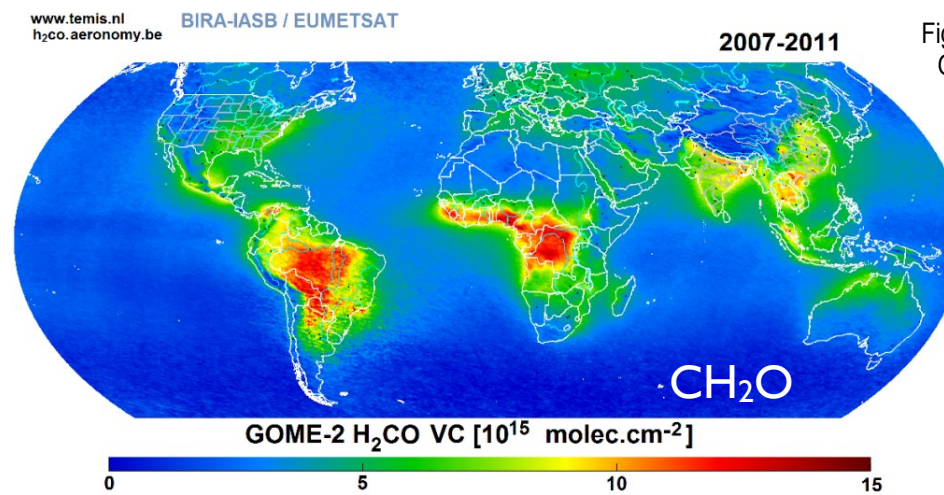
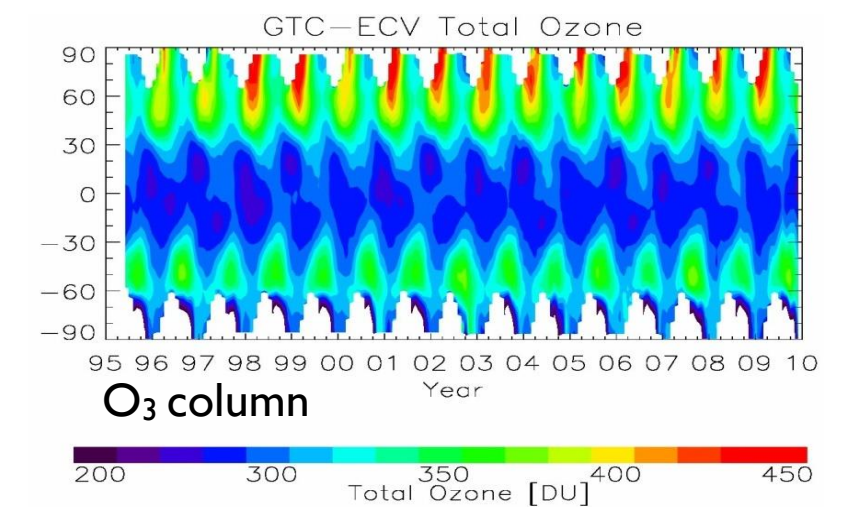
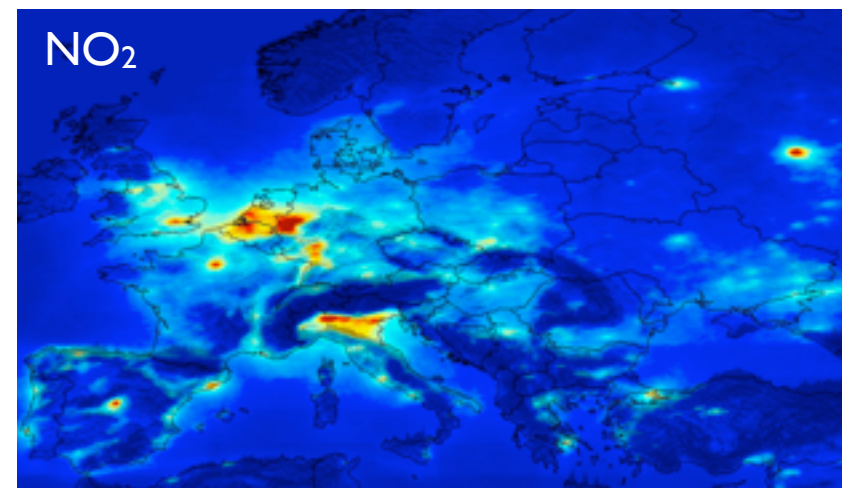
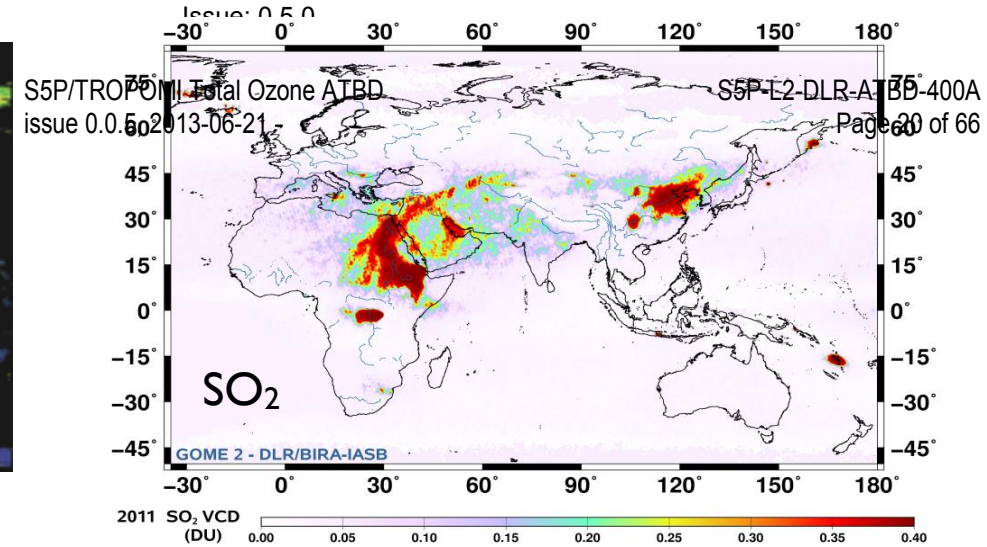
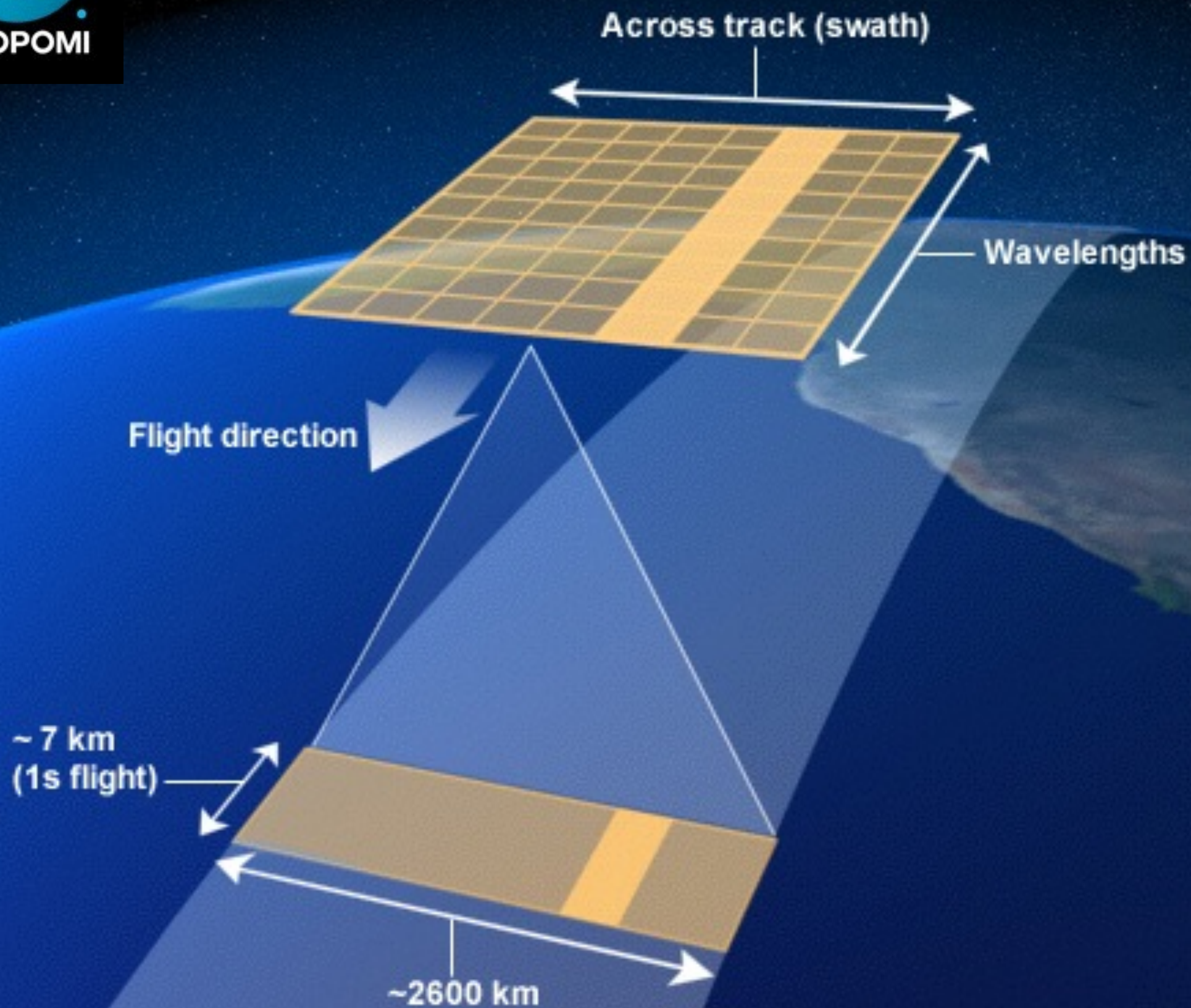


Figure 5.1: (a) Cloud fraction, (b) c



The TROPOMI Measurement Principle



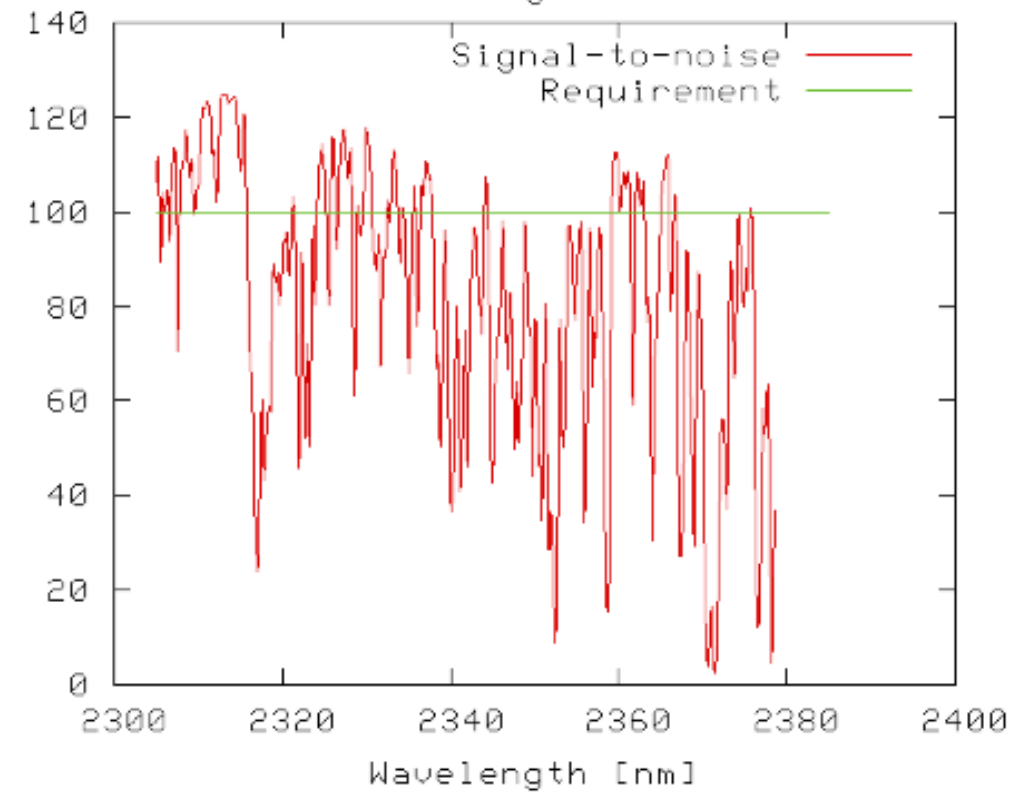
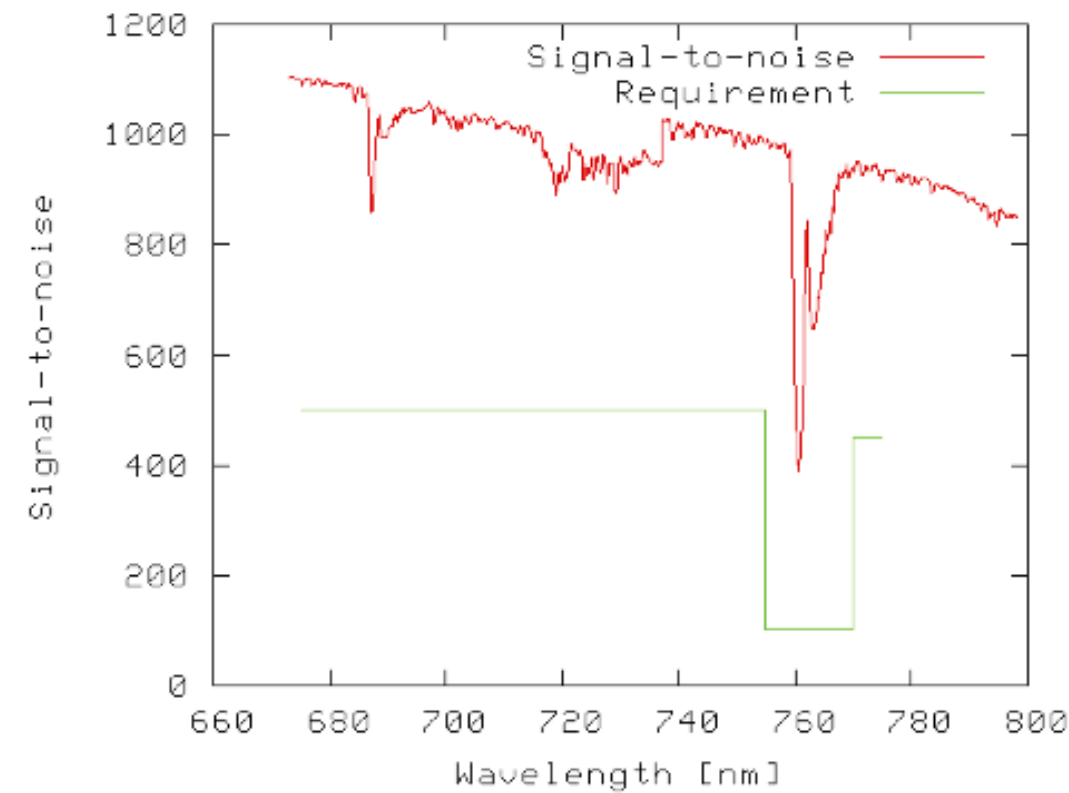
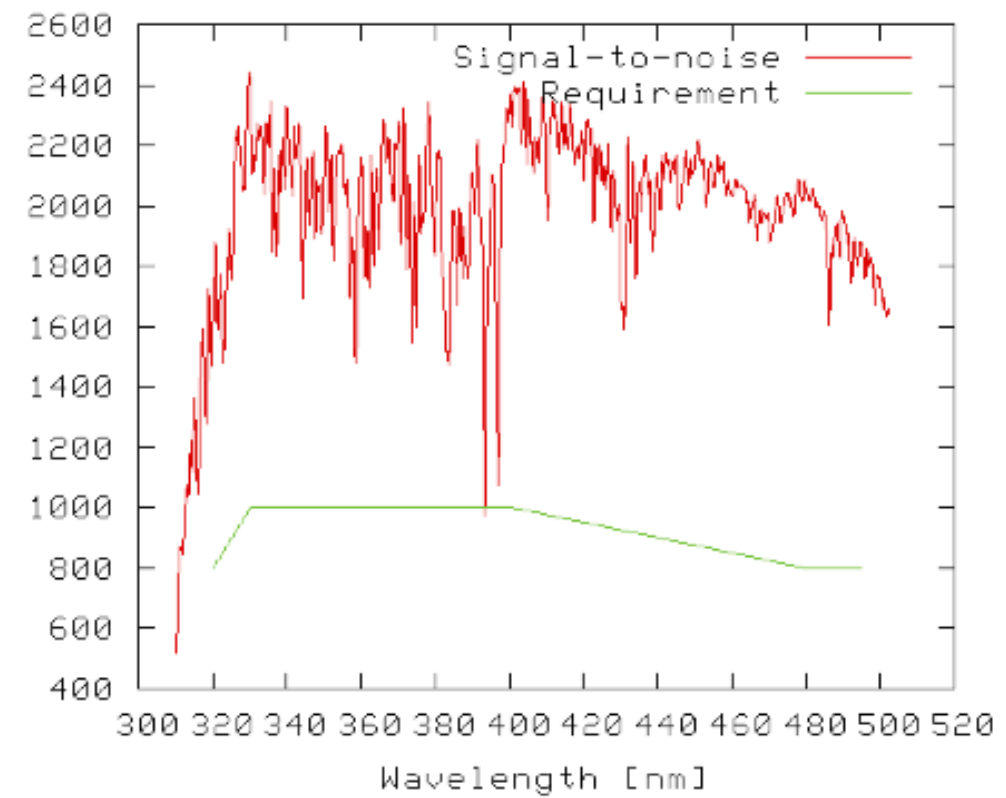
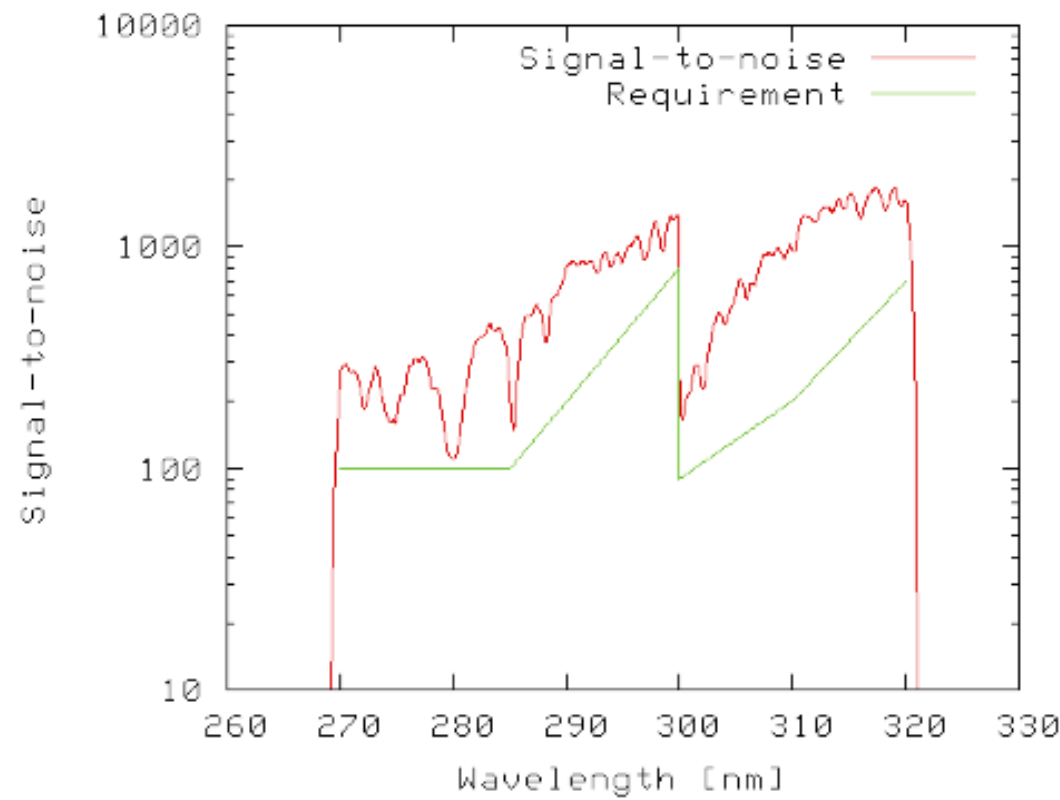
The Role of TROPOMI in the GEO Constellation

- Open data policy, including L1B data.
- Harmonize L1B and L2 formats to easily exchange data.
- Use similar on-ground calibration standards and exchange in-flight CAL/VAL procedures.
- Harmonize L1-2 algorithms as far as practically possible (e.g. cross sections, DEM, AMF LUTs)

OMI Lessons Learned

- CCD in NIMO mode and at $\sim 220\text{K}$ because of random telegraph signals (RTS).
- No MLI close to the primary mirror field of view [row anomaly].
- Improve the image quality of the polarization scrambler (Req. pol. sens. 0.5%)
- Two identical QVD solar diffusers measuring over the first mirror.
- No channel breaks around 300 nm.
- Optical bench temperature stabilized.
- One-team approach to L01b, on-ground calibration and in-flight calibration.
- - *many more* -

SNR - CDR Status



Level 1-2 Algorithm Challenges

- Data rate (300 spectra/s, 750 GB L1B per day) in combination with NRT requirements requires multi-threading processing.
- Surface albedo / clouds / aerosol are linked. Spatial variations have to be taken into account in the trace gas retrievals.
- Provide realistic diagnostic information and user-friendly product.

