9. Air quality monitoring using Sentinel-5 data

Copernicus Services

Services monitoring Earth systems

Land Monitoring

Marine Monitoring

Atmosphere Monitoring

AIR QUALITY MONITORING

Horizontal services

Emergency Management

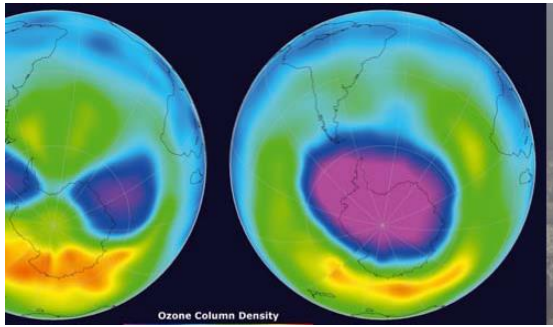
Security

Climate Change

Copernicus Requirements

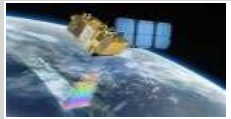
Drivers for operational space-borne atmospheric composition observations:

- Facilitation and improvement of operational applications and services related to atmospheric composition
- Provision of information on treaty verification and protocol monitoring
- Contribution to scientific understanding for environmental assessments to support policies
- Support the Copernicus Atmospheric Core and Downstream services



The Sentinel Family

Sentinel-1 (A/B/C/D) – SAR imaging
All weather, day/night applications, interferometry

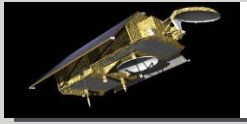


Sentinel-2 (A/B/C/D) – Multi-spectral imaging Land applications: urban, forest, agriculture,… Continuity of Landsat, SPOT

Sentinel-3 (A/B/C/D) – Ocean and global land monitoring
Wide-swath ocean color, vegetation, sea/land surface temperature, altimetry

Sentinel-4 (A/B) – Geostationary atmospheric (on MTG)
Atmospheric composition monitoring, trans-boundary pollution

Sentinel-5 Precursor/ Sentinel-5 (A/B/C) – Low-orbit atmospheric (on MetOp-SG Series A)
Atmospheric composition monitoring



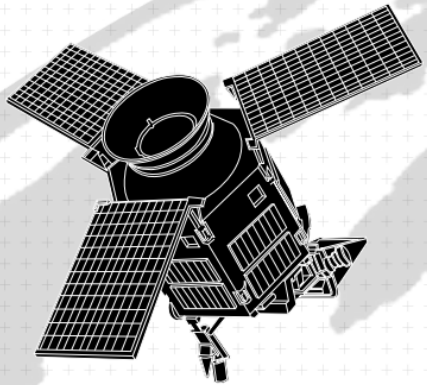
Sentinel-6 [Jason-CS] (A/B) – Low inclination altimetry
Sea-level, wave height and marine wind speed

Sentinel-5P and Sentinel-5

SENTINEL-5P

THE FORERUNNER TO THE SENTINEL-5

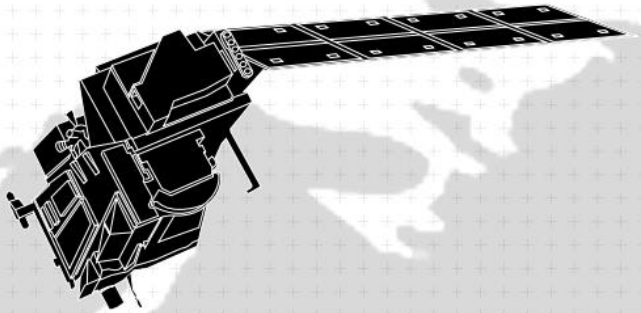
- **Global observation of key atmospheric constituents, including ozone, nitrogen dioxide, sulphur dioxide and other environmental pollutants**
- Improves climate models and weather forecasts
- Provides data continuously during five-year gap between the retirement of Envisat and the launch of Sentinel-5
- Airbus Defence and Space prime contractor for satellite and TROPOMI instrument



SENTINEL-5

- **Measures air quality and solar radiation, monitors stratospheric ozone and the climate**
- Global coverage of Earth's atmosphere with an unprecedented spatial resolution
- Airbus Defence and Space prime contractor for instrument

- Carried aboard EUMETSAT's MetOp Second Generation satellites



Sentinel-5 Precursor (S-5P)

- The ESA 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 launch date: 2016 with a 7 year design lifetime

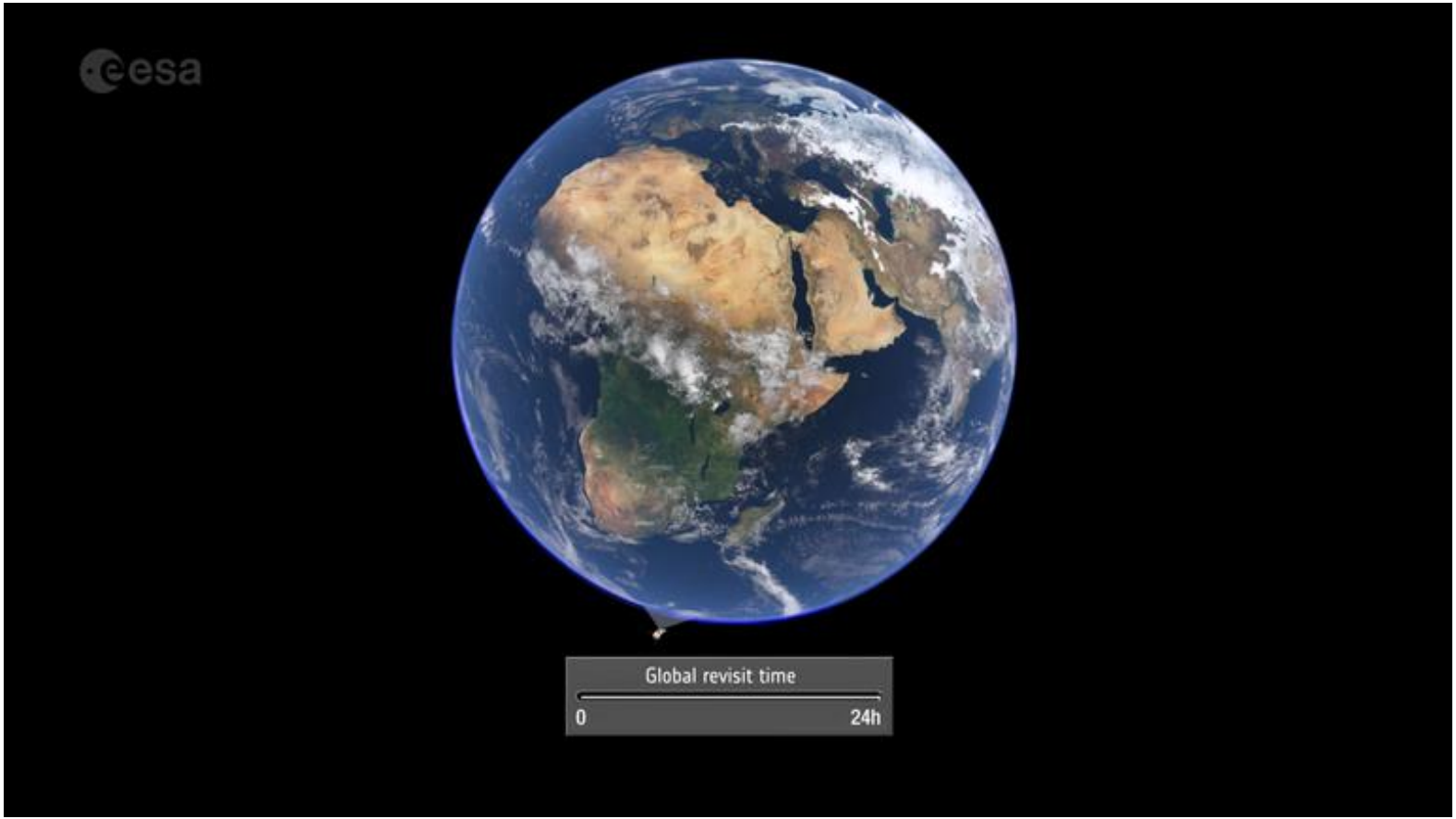
TROPOMI

- 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 Copernicus

- Total column O_3, NO_2, CO, SO_2, CH_4, CH_2O, H_2O, BrO
- Tropospheric column O_3, NO_2
- O_3 profile
- Aerosol absorbing index & layer height

Sentinel-5P Tropomi instrument to map trace gases



Sentinel-5P Tropomi instrument to map trace gases

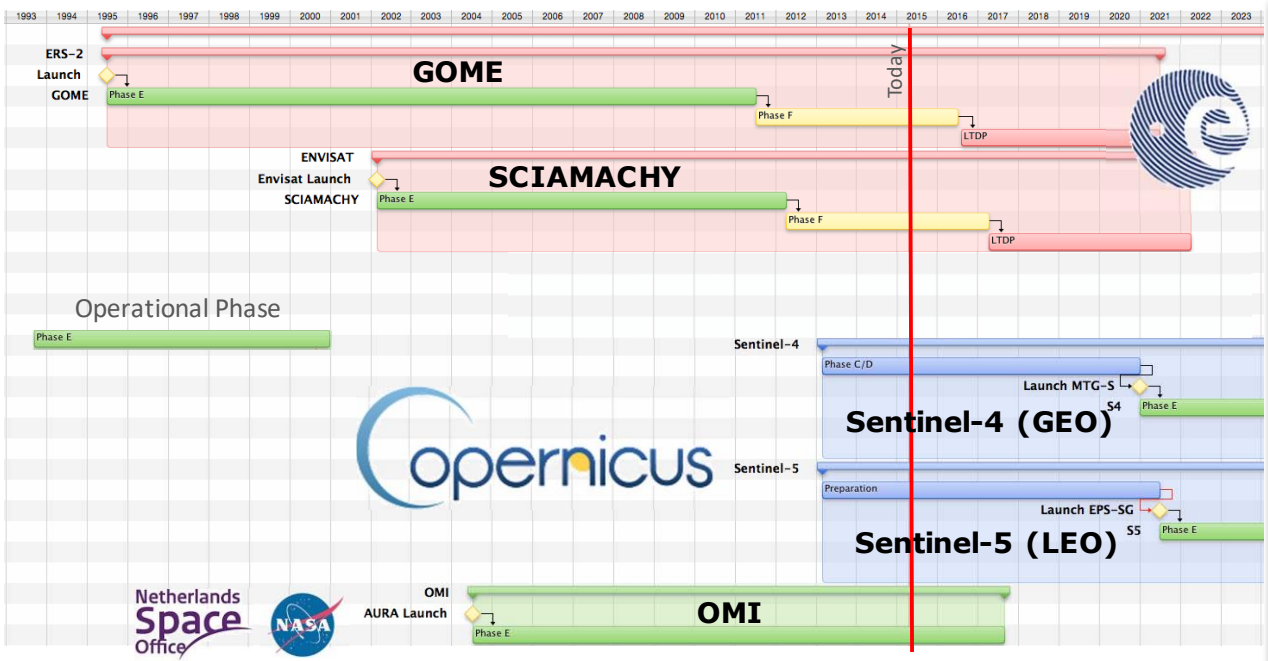
Level 2 Products and the L2 WG

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
	Aerosol Type	total column	~1 AAI	<0.1 AAI

Source: S5P Level 2 Working Group

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

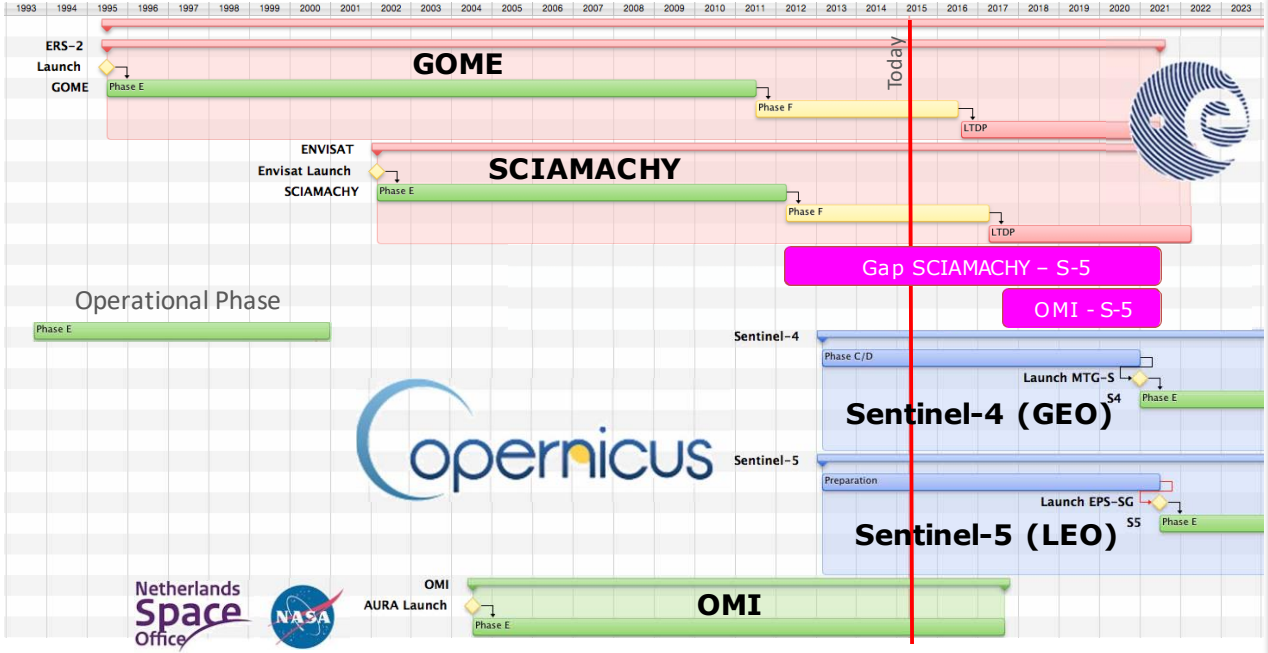
Sentinel-5 „Precursor“?



The Sentinel-5 (5-P) mission continues a series of spectrometers measuring atmospheric properties since 1995:

- The Global Ozone Monitoring Experiment (GOME) on ESA's ERS-2 - operated between 1995 and 2011
- GOME-2 on EUMETSAT's Met-OP-A satellite, launched in 2006, still in service; operating since 2012 on MetOp-B satellite
- SCanning Imaging Absorption spectroMeter for Atmospheric CartograpHY (SCIAMACHY) on ESA's ENVISAT mission which operated between 2002 and 2012
- Ozone Monitoring Instrument (OMI) since 2004 on NASA's AURA spacecraft, still in service

Sentinel-5 „Precursor“?



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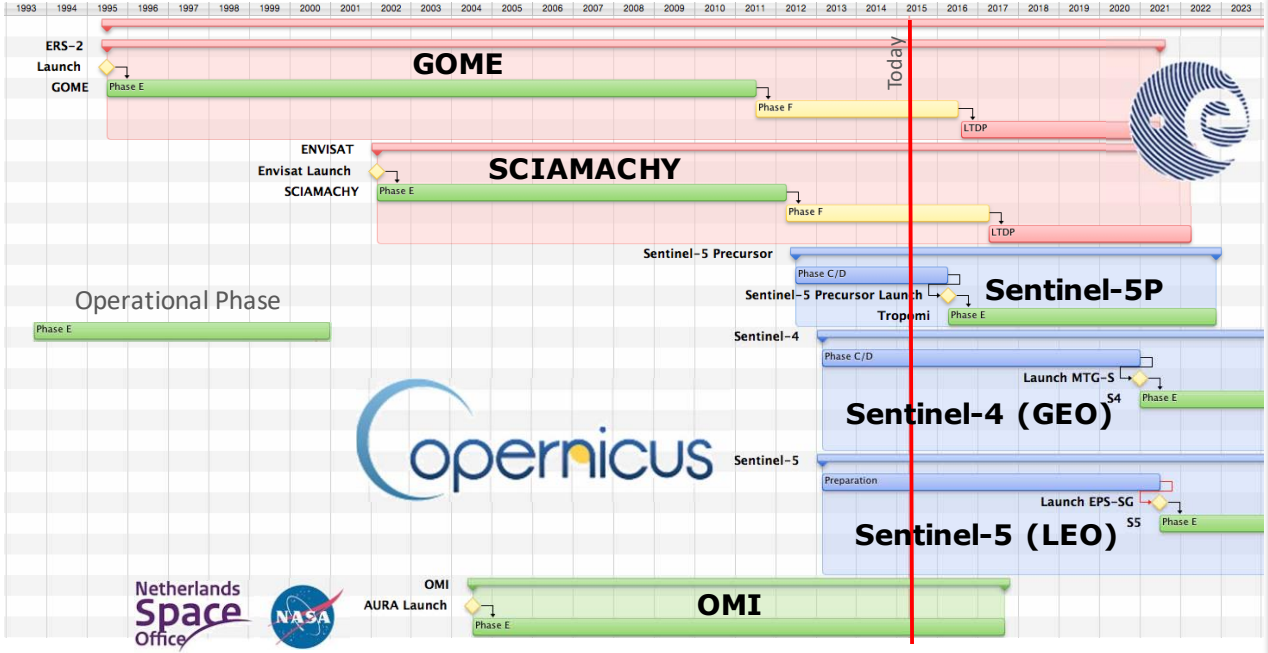

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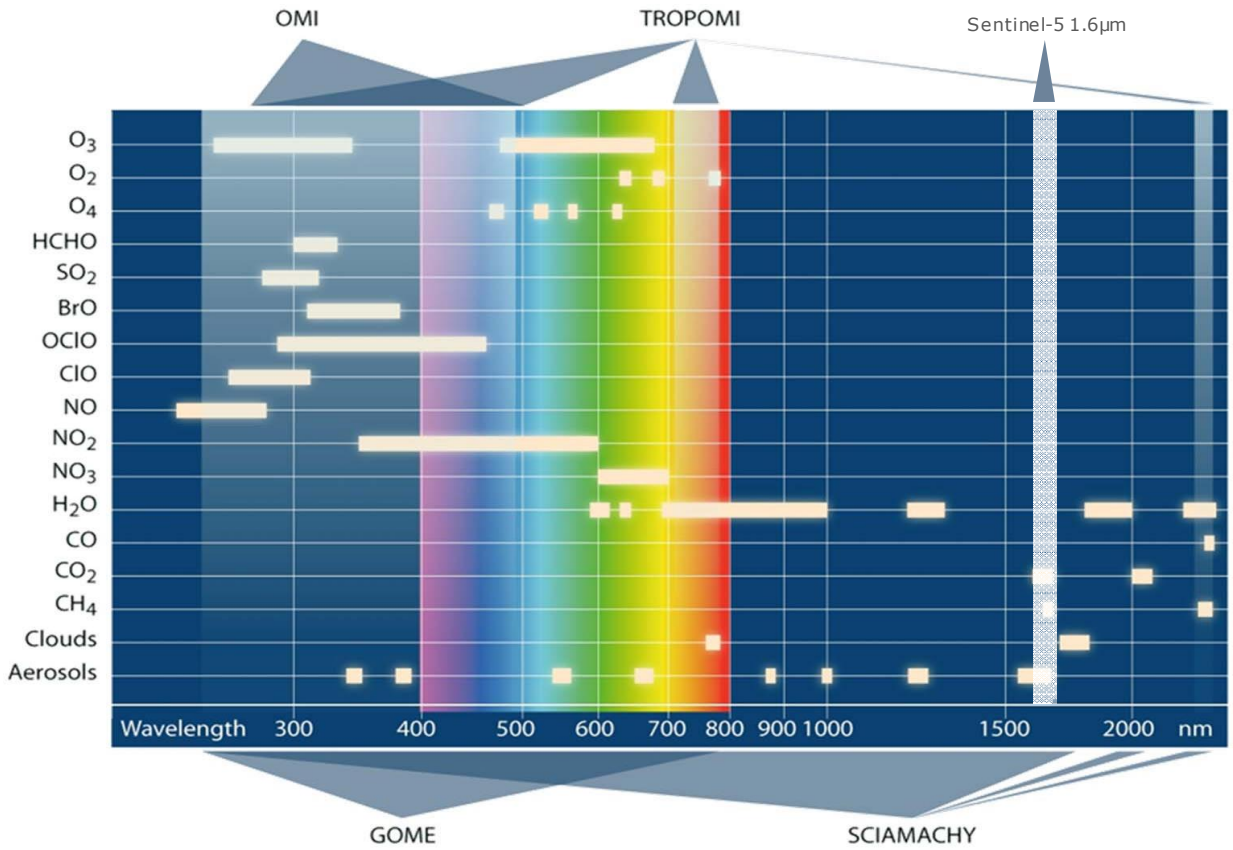
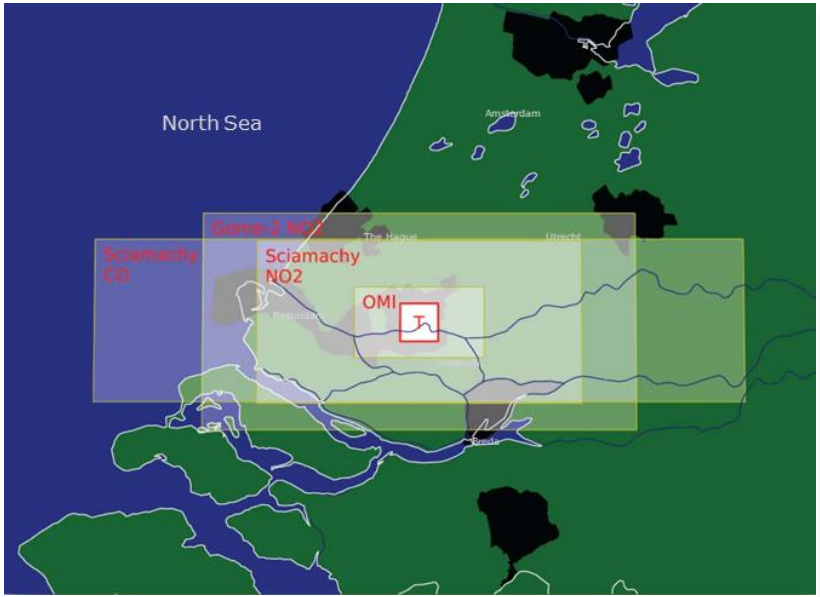
Spectral Range Comparison



SCIAMACHY measurements cover almost the entire solar irradiance spectrum from UV to SWIR (240 to 2 400 nm) whereas GOME(-2) and OMI are scaled down in terms of wavelength range covering the UV-VIS-NIR range (270-790 nm) and the UV-VIS range (270-500 nm) respectively.

Source: http://www.tropomi.eu

Spatial Resolution Comparison

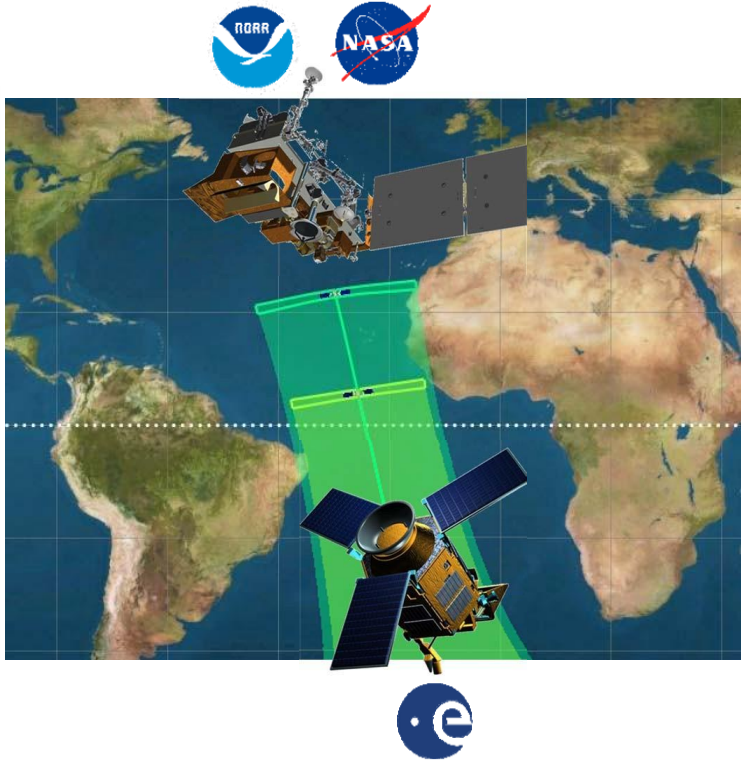


Source: KNMI

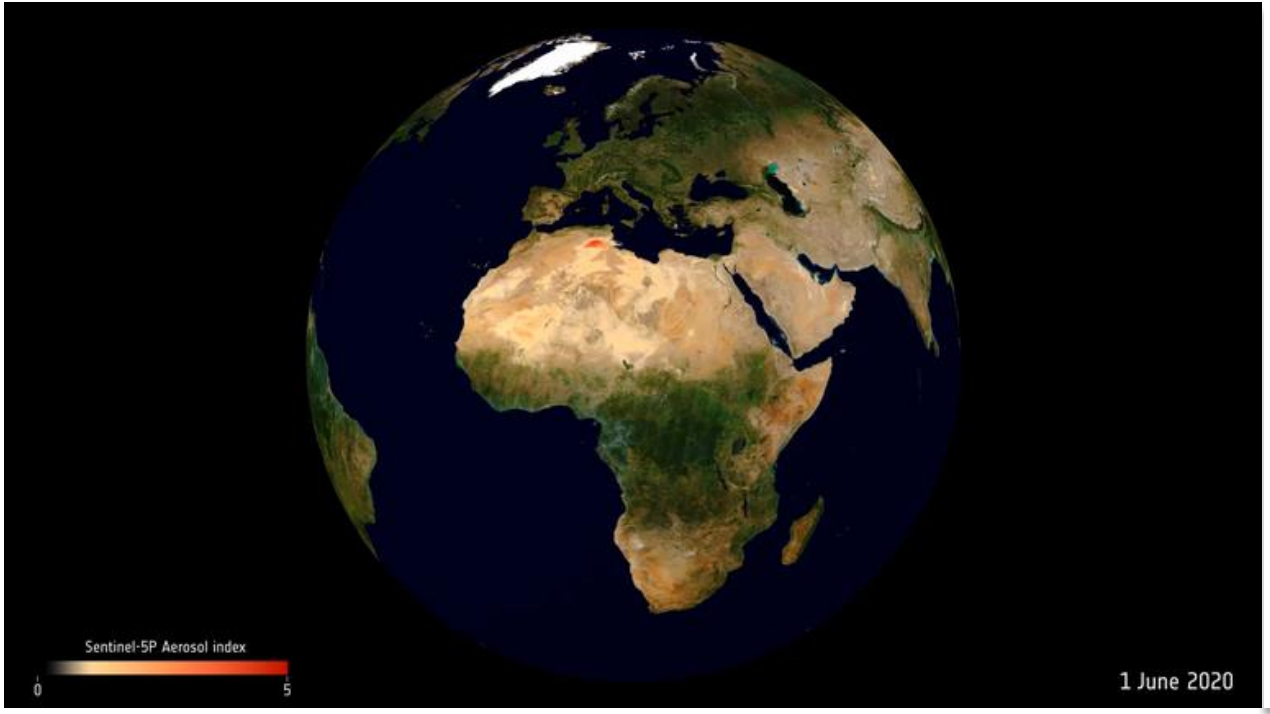
Instrument	Spectral Range	Spatial resolution (km x km)	Swath (km)	Overpass time	Operational
GOME	UV-VIS-NIR (240-790 nm)	320 × 40	960	10:30 local time	1995-2011
GOME-2	UV-VIS-NIR (240-790 nm)	80 × 40	1920	9:30 local time	2006-present
SCIAMACHY	UV to SWIR (240-2400 nm)	30 × 215	1000	10:00 local time	2002-2012
OMI	UV-VIS (270-500 nm)	13 ×24	2600	13:30 local time	2004-present
TROPOMI	UV-VIS-NIR-SWIR (270 – 2385 nm)	7 × 7	2600	13:30 local time	Launch scheduled for 2016
Sentinel-4	UV-VIS-NIR (305- 775 nm)	8 × 8	NA	Geostationary	Launch scheduled for 2021
Sentinel-5	UV-VIS-NIR-SWIR (270 – 2385 nm)	7 × 7	2670	9:30 local time	Launch scheduled for 2021

S-5p and S-NPP Loose Formation Flight

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



Tracking Saharan dust plume



This animation shows the spread of aerosols from the Saharan dust plume moving westward across the Atlantic Ocean from 1 June to 26 June 2020. This plume has reached the Caribbean, South America and the United States.

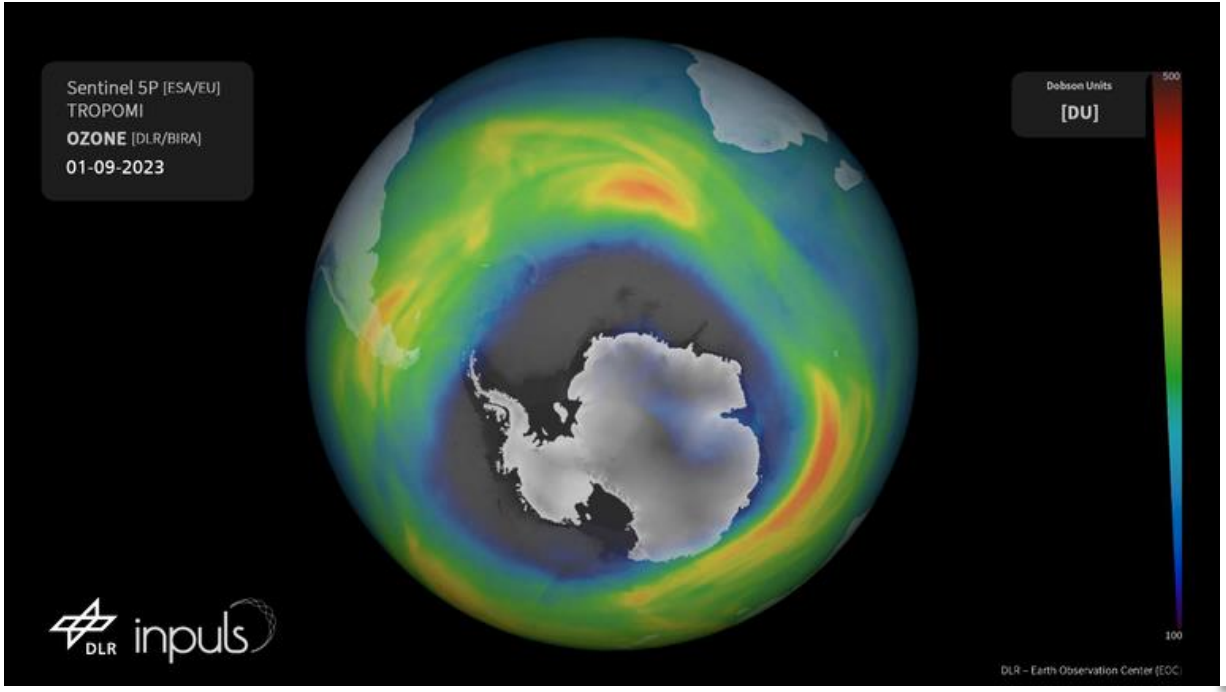
Source: contains modified Copernicus Sentinel data (2020), processed by ESA, CC BY-SA 3.0 IGO

Volcano eruption seen from space

Litli-Hrútur eruption seen from space

Sentinel-5P – Ozone Hole Monitoring

https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-5P/Ozone_hole_goes_large_again



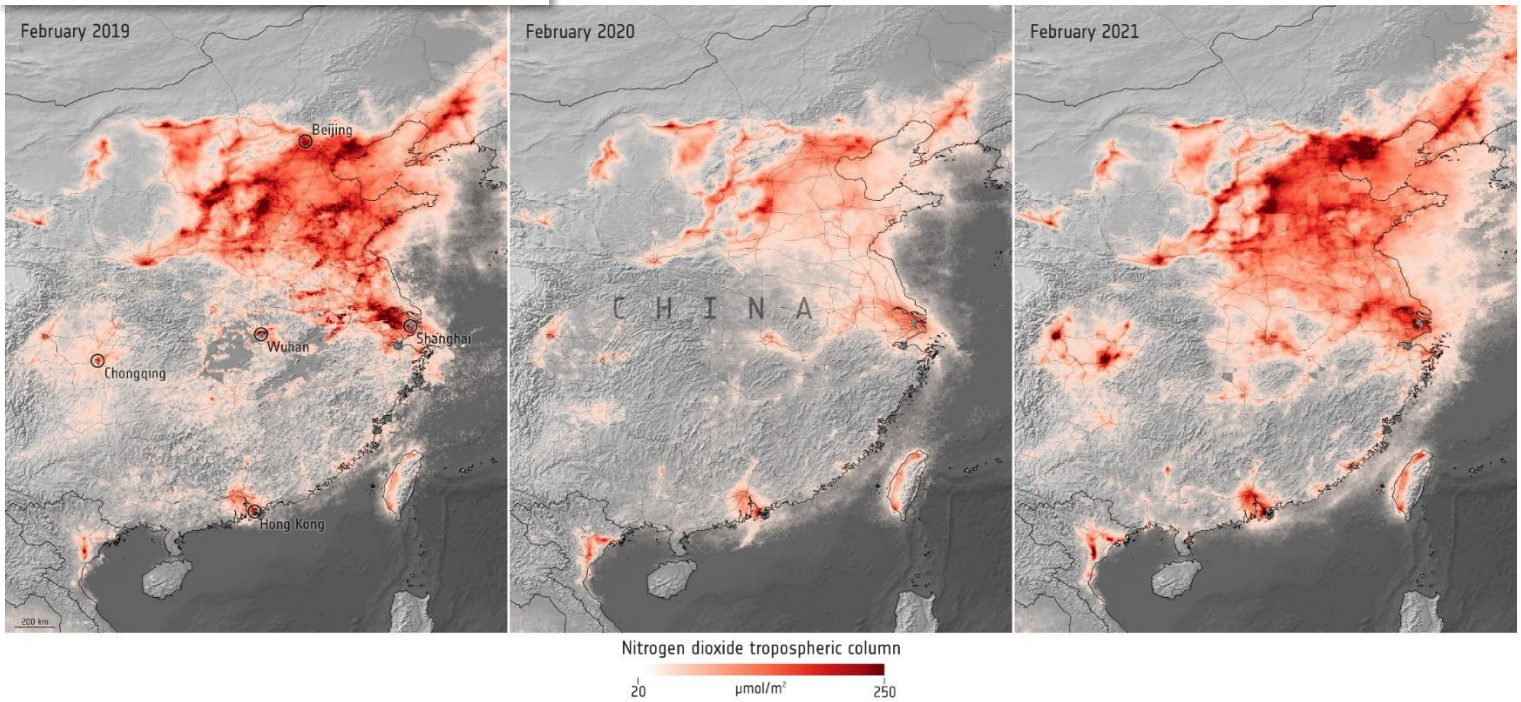
This animation uses Sentinel-5P total ozone measurements and shows the evolution of the ozone hole over the South Pole from 1 September to 29 September 2023.

Measurements from the Copernicus Sentinel-5P satellite show that this year's ozone hole over the Antarctica is one of the biggest on record. The hole, which is what scientists call an 'ozone depleting area,' reached a size of 26 million sq km on 16 September 2023. This is roughly three times the size of Brazil.

Source: contains modified Copernicus Sentinel data (2023)/processed DLR

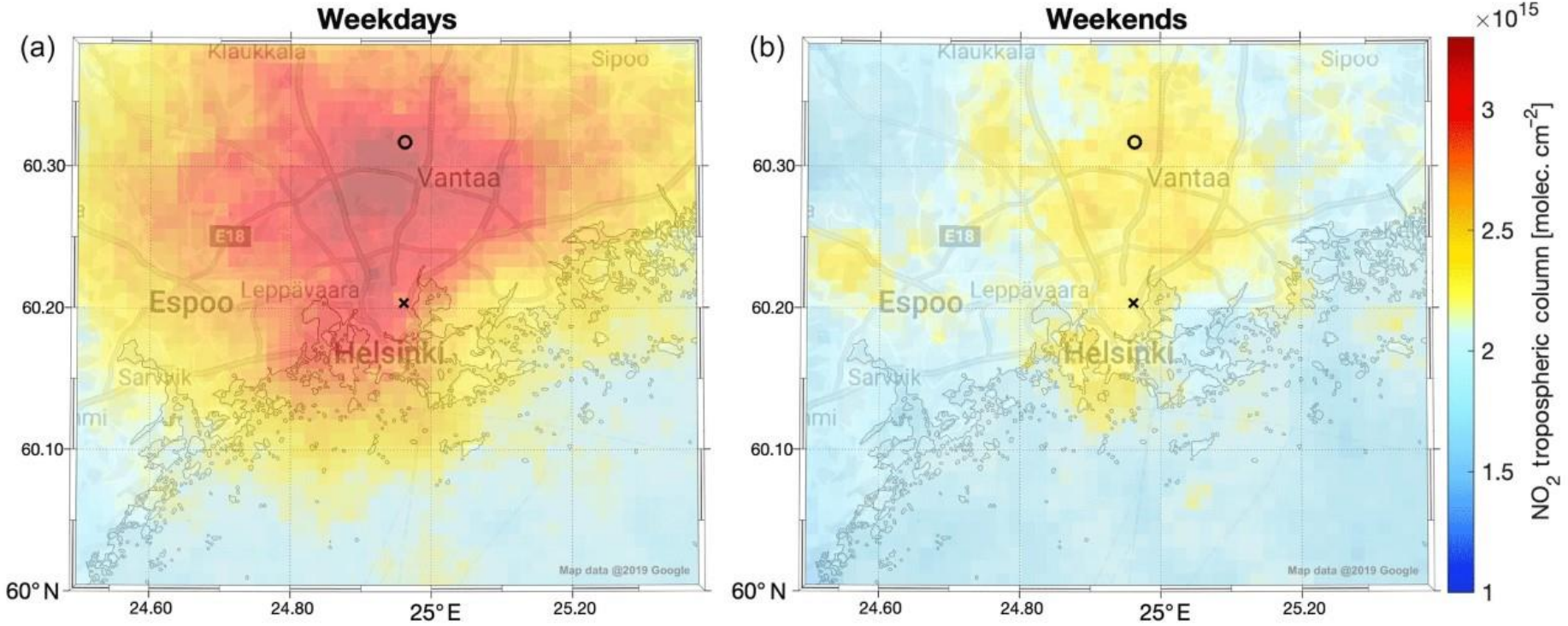
COVID-19 impact as ‘seen’ by Sentinel-5P

Nitrogen dioxide concentrations over China



These images, using data from the Copernicus Sentinel-5P satellite, show the monthly average nitrogen dioxide concentrations over China in February 2019, 2020 and 2021. In early 2020, data from satellites were used to show a decline in air pollution over China coinciding with nationwide lockdowns put in place to stop the spread of COVID-19. One year later, nitrogen dioxide levels in China have risen back to pre-COVID levels according to new data from the Sentinel-5P satellite.

Sentinel-5P data map nitrogen dioxide in Finland



Urban Helsinki shows a drop in pollutants during weekends. This research showed that overall, levels of nitrogen dioxide during weekends were 30% lower than those observed during weekdays, and that spatial distribution was partially affected by systematic wind patterns.

NO2 emissions from oil refineries in the Mississippi Delta

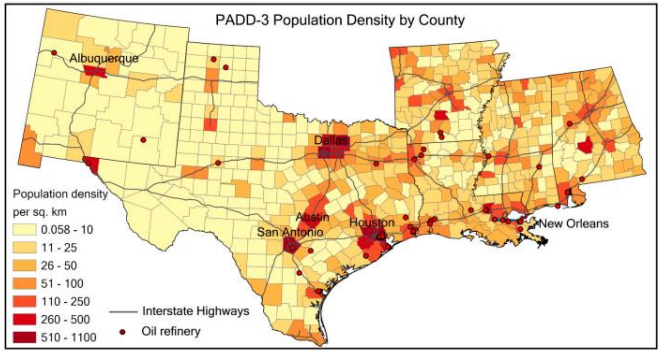


Fig. 3. Petroleum Administration for Defense Districts 3 (PADD-3) population density by county.

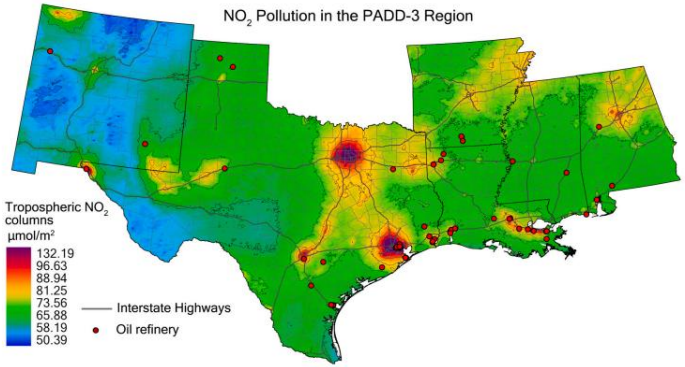


Fig. 4. Spatial distribution of TROPOMI NO_2 VCD (µmol/m²) during 2019–2022 over the US PADD-3 region. Red dots indicate the location of a refinery.

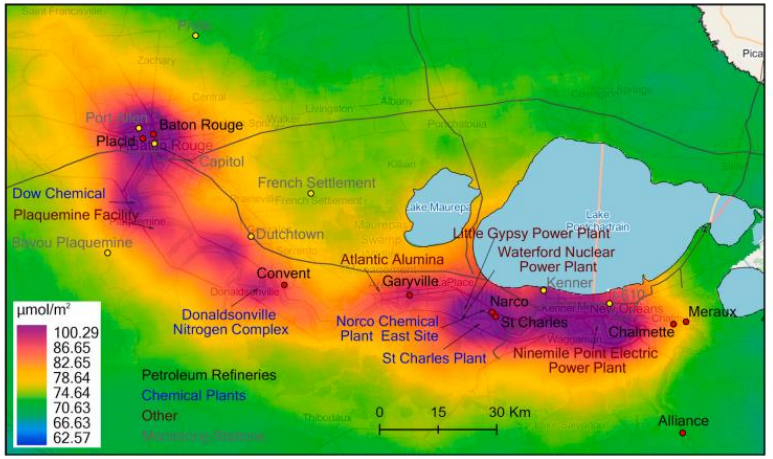


Fig. 5. Spatial distribution of TROPOMI NO_2 VCD during 2019–2022. Red dots indicate the location of a refinery, while yellow dots indicate the location of air quality monitoring stations. Background map from OpenStreetMap©.

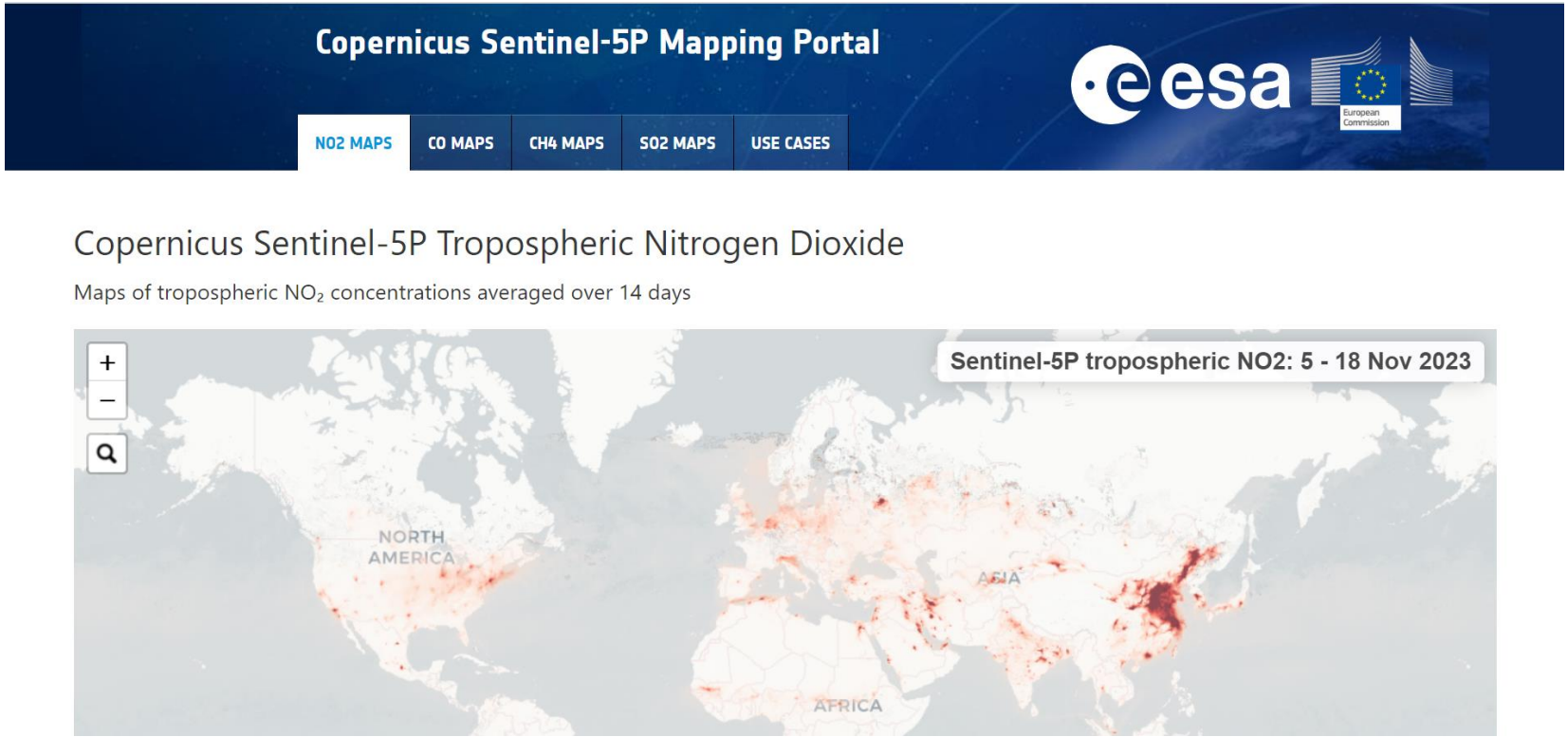
This study uses TROPOMI data to observe the spatial patterns of NO2 pollution within the PADD-3 region of the lower Mississippi Delta, an area characterized by high industrial activity associated with oil refining and petrochemicals. The results show that TROPOMI captures small-scale spatial heterogeneities associated with industrial and other activities, such as emissions from oil refining and the chemical industry, as well as emissions from coal-fired power plants and vehicular traffic.

Methane Emission Source Detection by Sentinel-5P

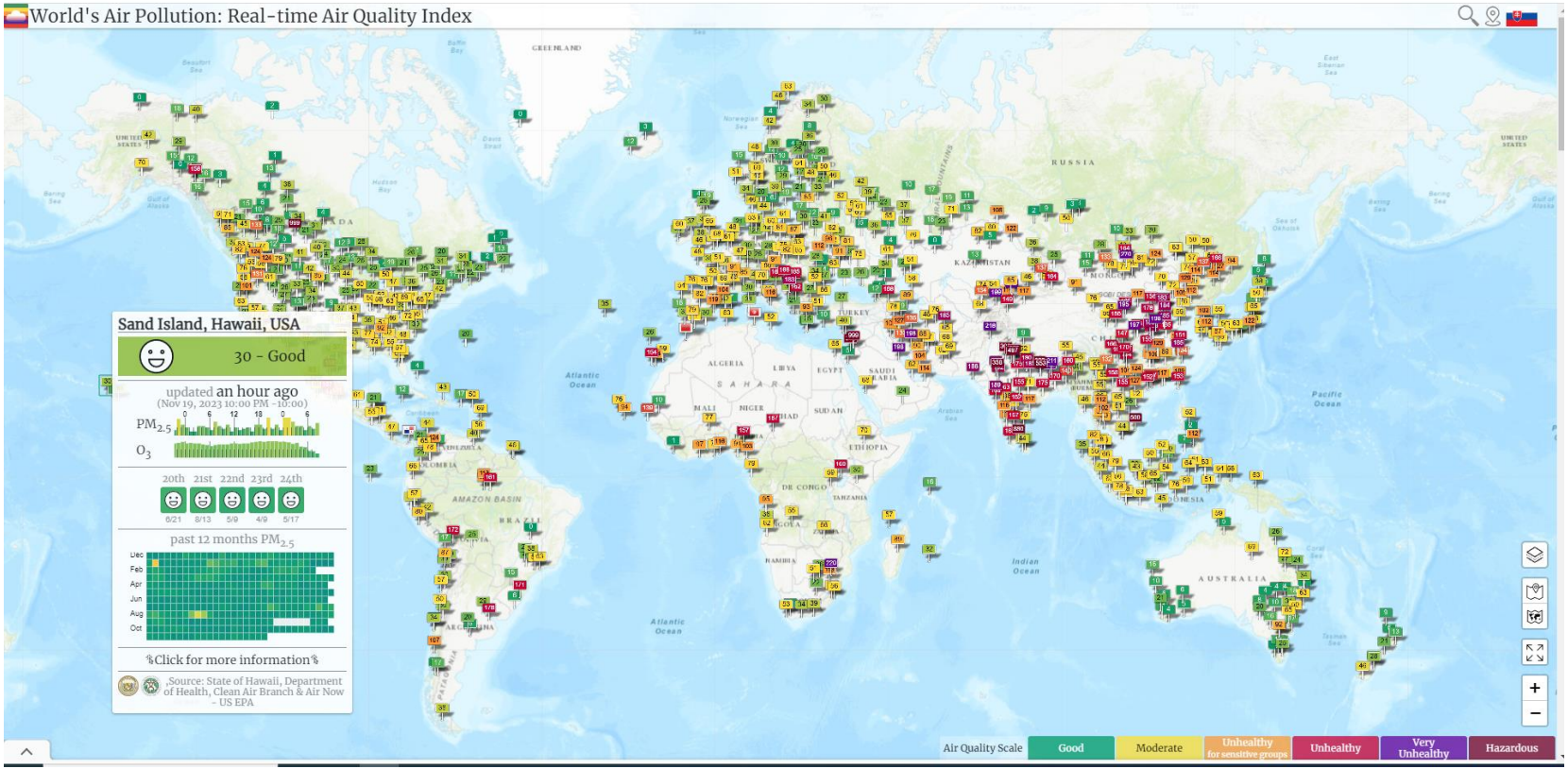
Methane enhancement over Libya

Methane Emission Source Detection by Sentinel-5P

Copernicus Sentinel-5P Mapping Portal



World's Air Pollution: Real-time Air Quality Index



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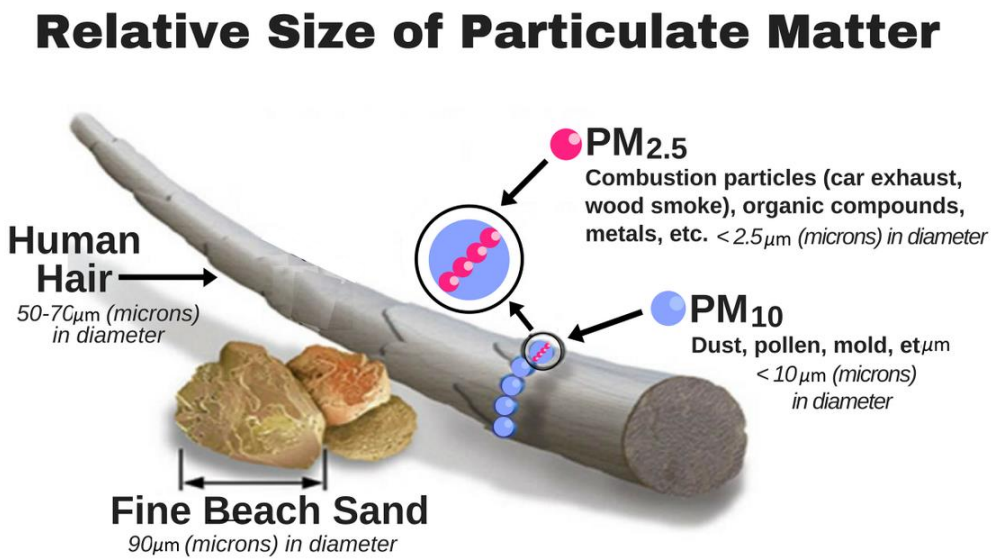
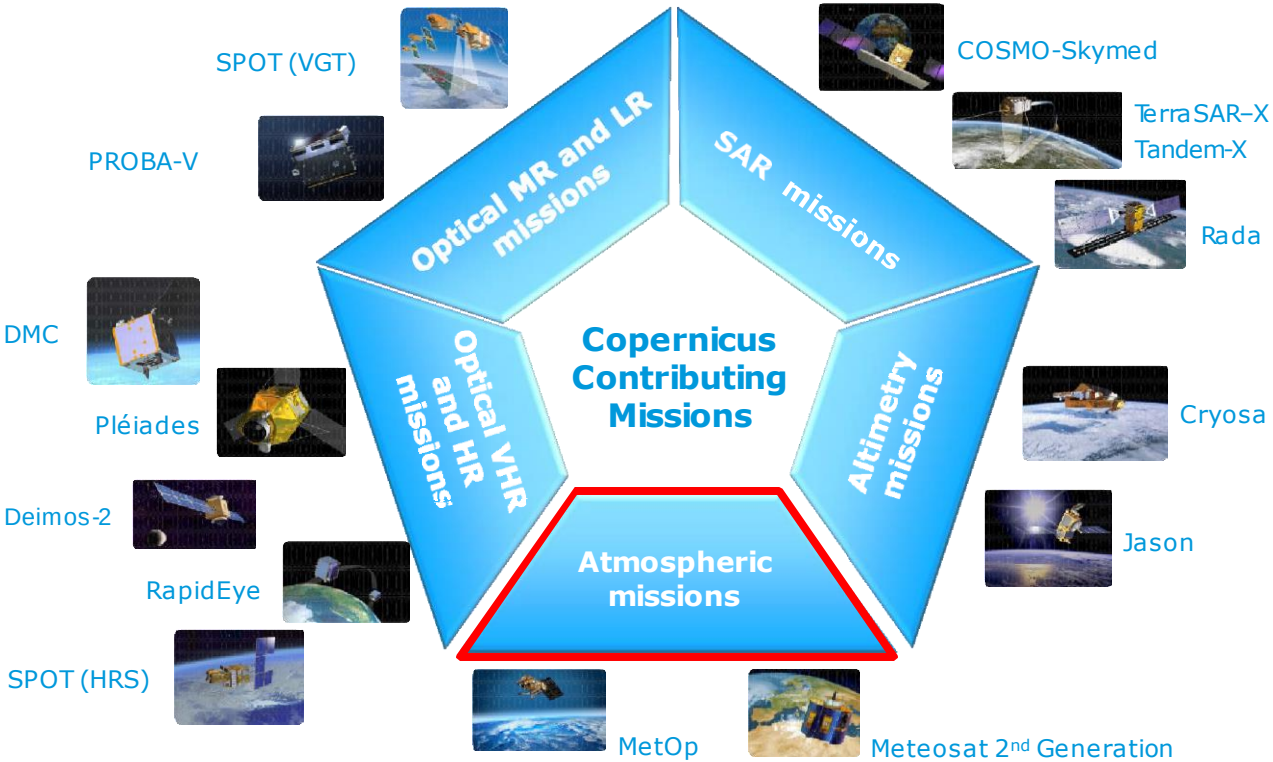


Why are PM particles harmful?

Airborne PM particles have an adverse effect on human health and the environment. Both PMPM2.5 and PM10 particles can be inhaled, while some settle in the respiratory system. PM2.5 gets deeper into the lungs (pulmonary alveoli), where it settles and enters the bloodstream. They can cause acute and chronic bronchitis or asthma.

… and Contributing Missions



Thank you for the attention