Koninklijk Nederlands
Meteorologisch Instituut
Ministerie van Infrastructuur en Waterstaat

TROPOMI Data: Where to get it & How to use it

19 June 2023

Amigo Workshop

Uccle, Belgium

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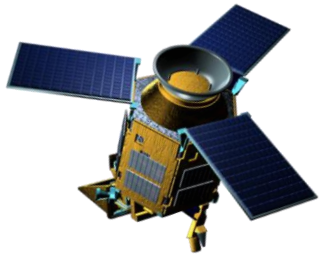
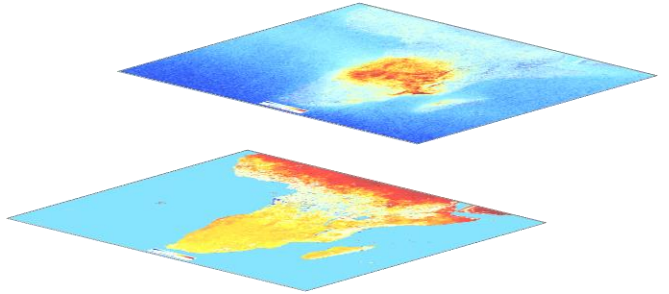
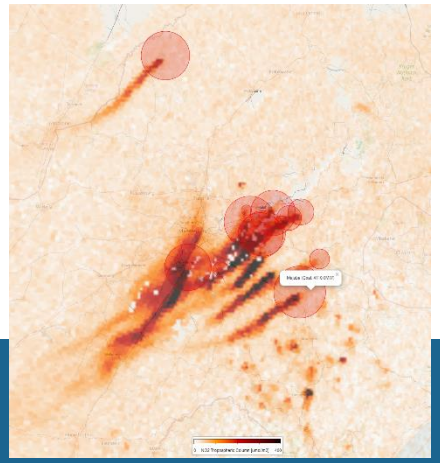
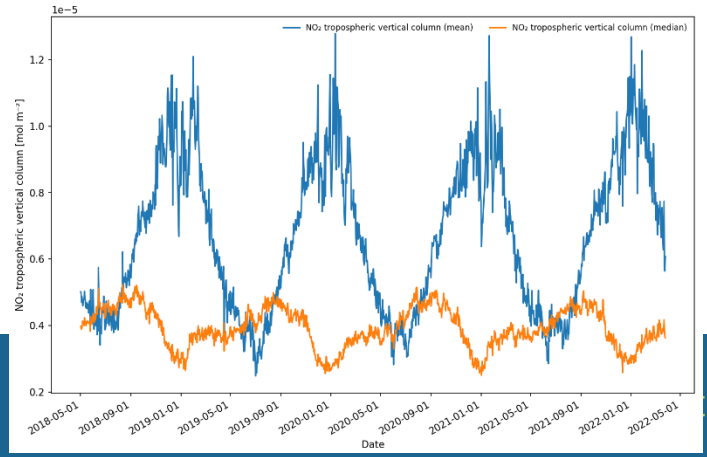
TROPOMI Data Overview:

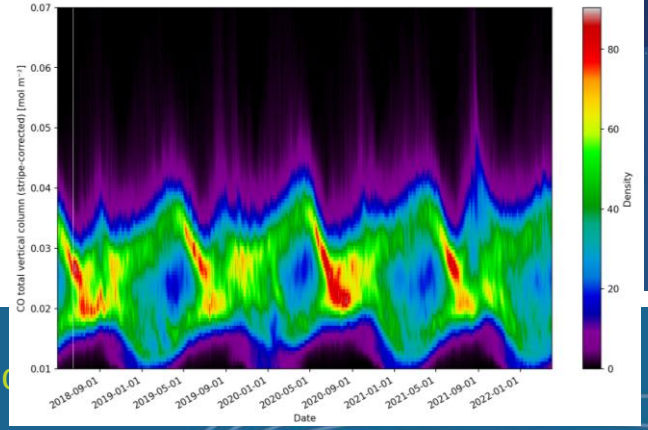


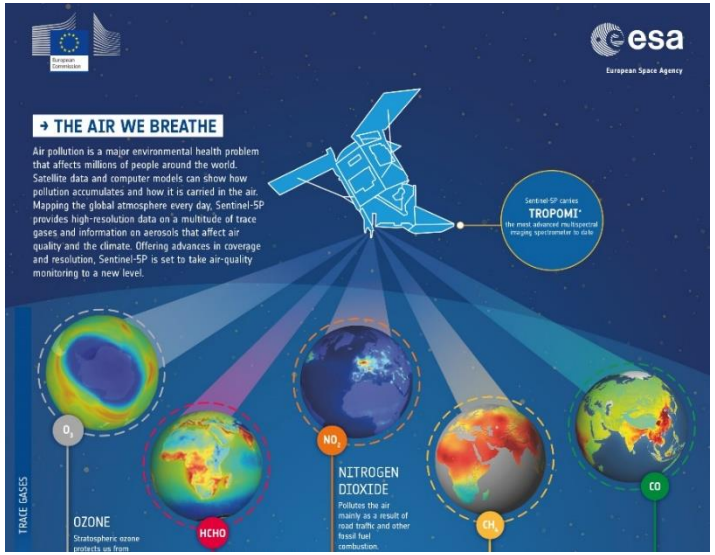
- Which air- and climate-pollutants are measured by TROPOMI?
- Use case examples of TROPOMI data applications
- How does TROPOMI data differ from emissions?
- What are data levels? Level 0, 1, 2 explained
- How can the data be mapped & analyzed?
- Where can you get the data?
- Which tools are available for your own analysis?



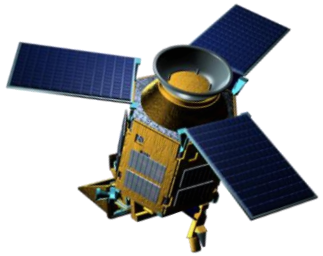




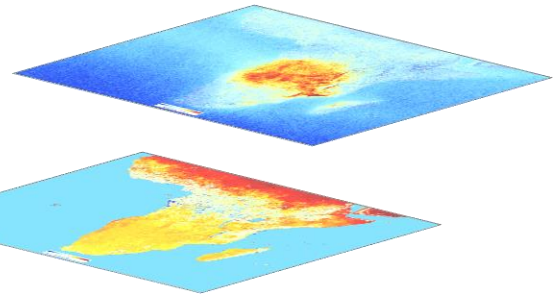




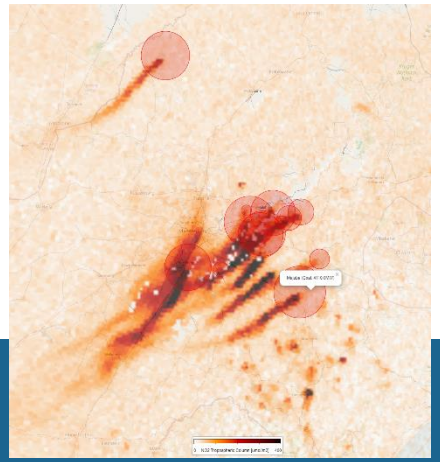
TROPOMI Data Practicum:

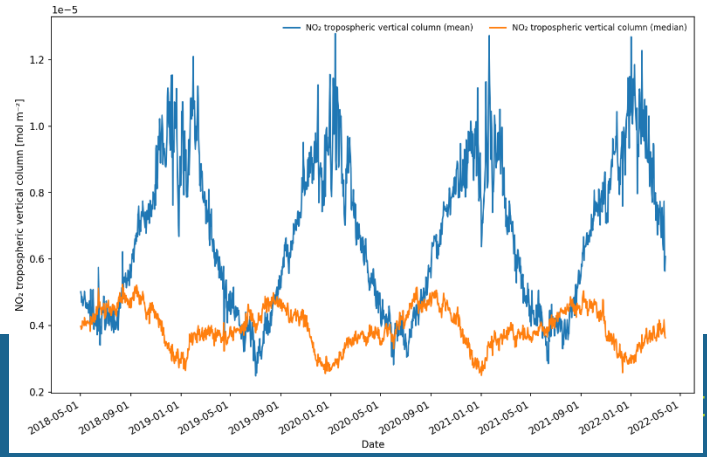


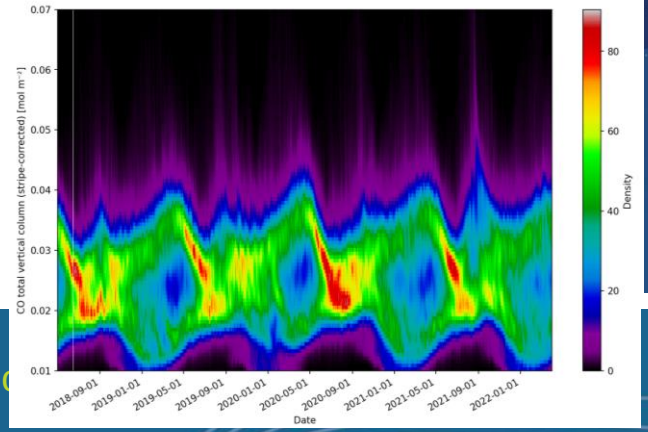
- Value of evaluating multiple species from TROPOMI
- Data timeliness – which type of data to use
- Granule, orbit, daily images & time-averaging

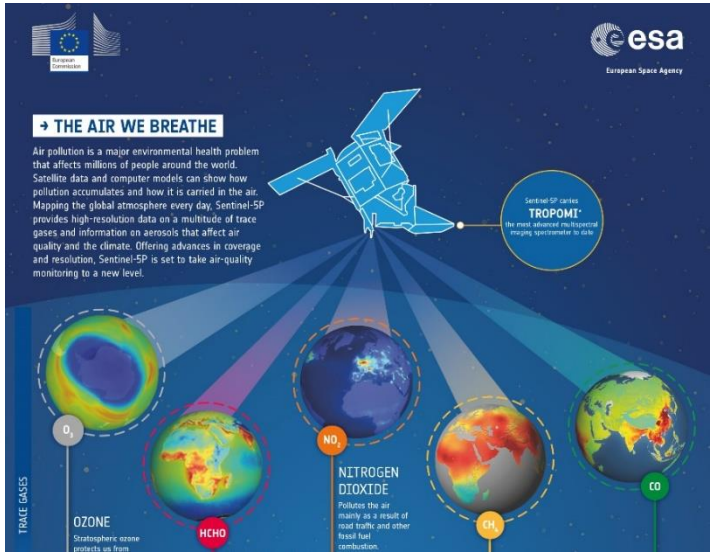


- Should I be regridding my data?
- What is an overpass file? Can I predict orbit locations?
- Where can I get emissions data?
- What about air quality forecast information?









KNMI – Royal Netherlands Meteorological Institute -- R&D Satellite Observations Department

Earth Science from Space

KNMI plays an important role in developing earth observation satellites and in processing and interpreting their data. Forecasts for weather and climate, air pollution and solar radiation are largely made with data from these satellites.

TROPOMI

Geostationary satellites, such as MSG, orbit so as to maintain a fixed point above the Earth

36.000 km

Polar satellites orbit at about 800 km from pole to pole, while the earth turns underneath

THE ATMOSPHERE

Northern lights

Thermosphere

85 km

Meteorites

Mesosphere

50 km

Weather balloon

Ozone layer, protects against UV radiation

Stratosphere

12 km

Troposphere

In this layer of the atmosphere our weather takes place

Important satellites with which KNMI works:

OMI
2004
NASA/KNMI
Measures ozone and air pollution

MetOp
2006
ESA/EUMETSAT
Ozone, wind and air pollution

MSG
2002-2021
ESA/EUMETSAT
Cloudiness, air pollution, sun and precipitation

TROPOMI
2017
ESA/KNMI
Air pollution, ozone and climate change

Aeolus
2018
ESA/KNMI
Wind profiles

EarthCARE
2019
ESA/JAXA/KNMI
Clouds, aerosols and climate change

What do our satellites measure?

Ozone layer
Ozone is monitored using UV light

Clouds
Cameras take pictures of the earth

Wind
Radar waves reflect from sea waves from which wind is calculated

Climate change
Greenhouse gases such as methane are measured using infrared light

Air pollution
Small particles and gases, such as nitrogen dioxide, particulate matter and volcanic ash, are measured using UV light

Measuring air pollution is increasingly important. NO_2 measurements show that the air in Europe is not clean:

low *high*

The biggest air pollutants are
- Nitrogen dioxide (NO_2)
- Particulate matter (PM)
- Ozone (O_3)

KNMI is involved in the entire process from inception to use of satellite data.

Formulating requirements

Planning

Design

Calibration

Launch

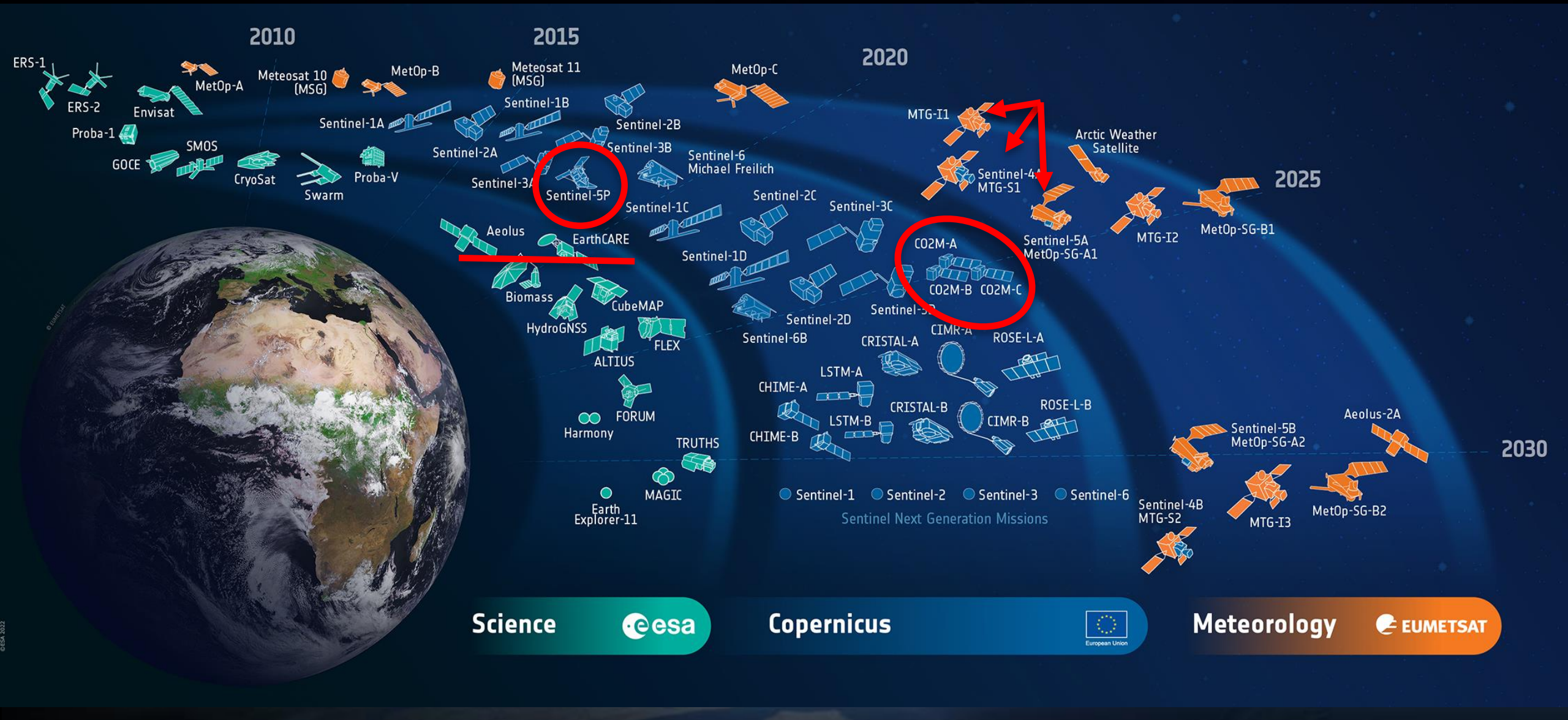
Data processing

Data interpretation

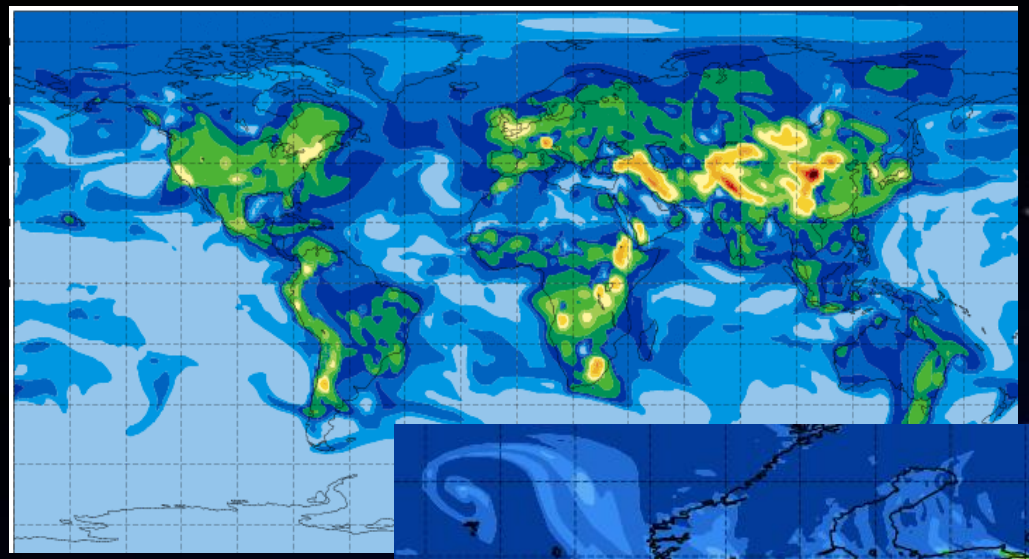
To customers
Univer-sities
Aviation
Government
Meteoro-logists
Citizens

ESA & the EU are currently our primary customers

TROPOMI

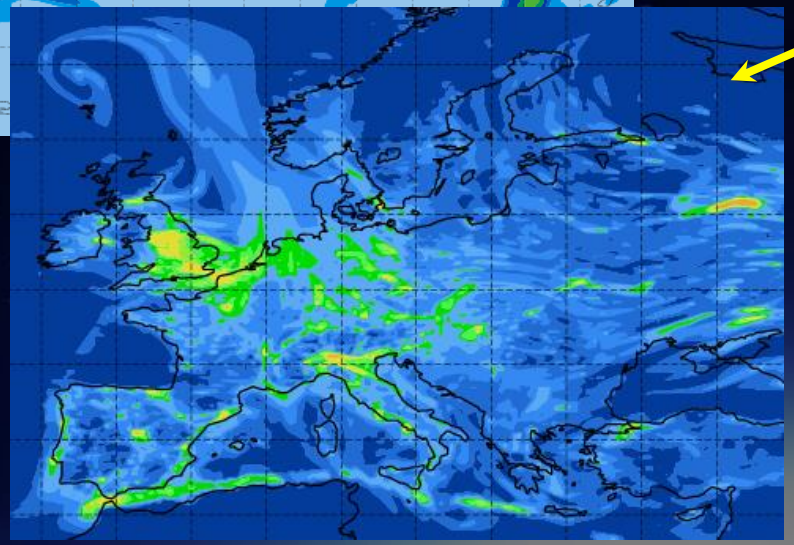


CAMS as main user of the Copernicus Sentinel 5P, 4, 5 composition observations



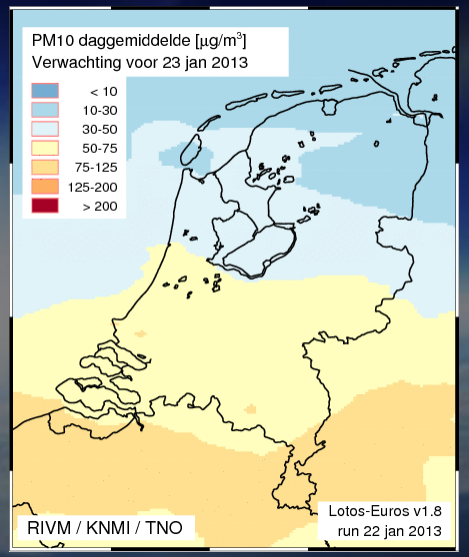
Assimilation
TROPOMI
observations

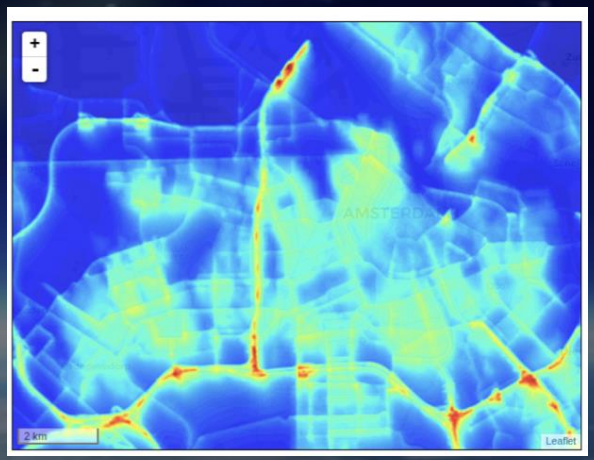
TROPOMI



CAMS-Europe as boundary condition for countries and city regions

Amsterdam



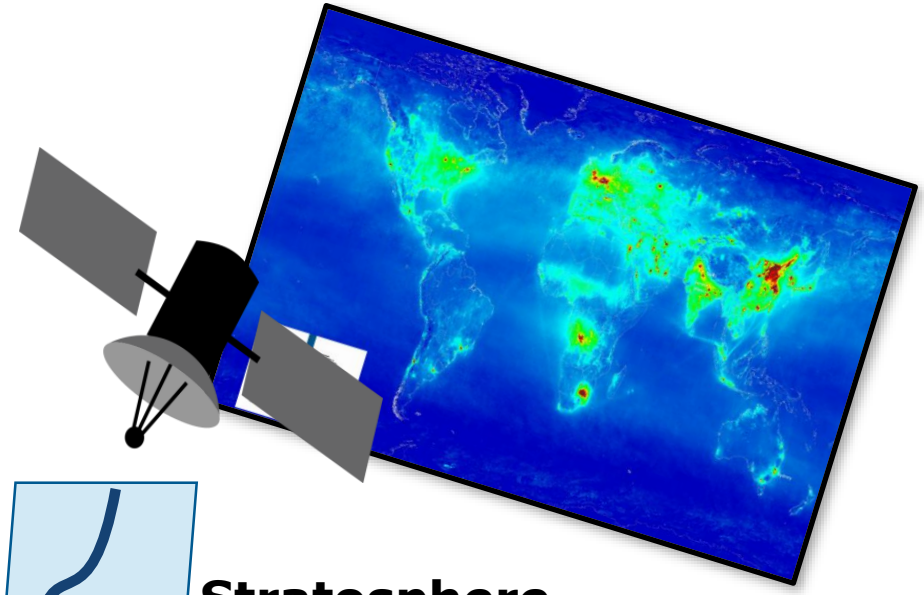


Analyses of CAMS-global as
boundary condition for CAMS-Europe

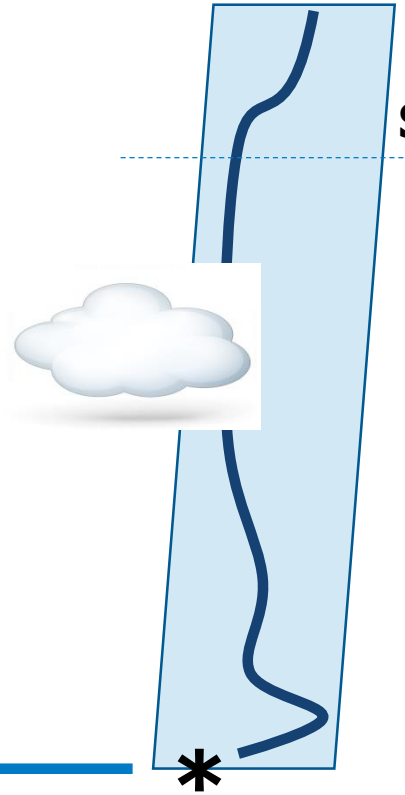
atmosphere.copernicus.eu

How does satellite data fit in global air quality monitoring?

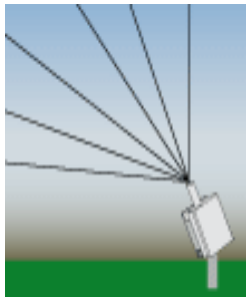
Vertical profile information



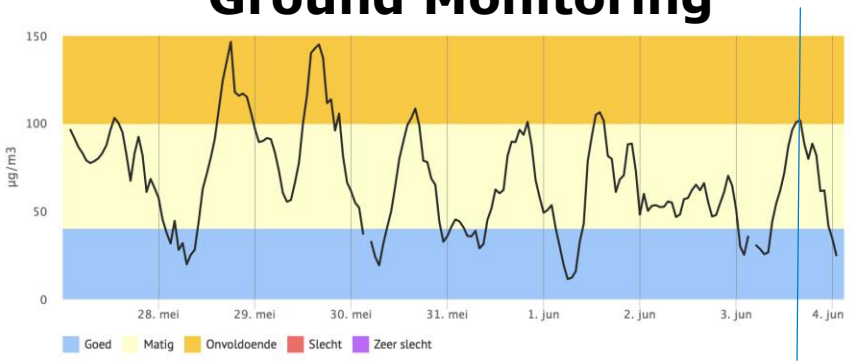
Stratosphere



MAX-DOAS, PANDORA



Ground Monitoring

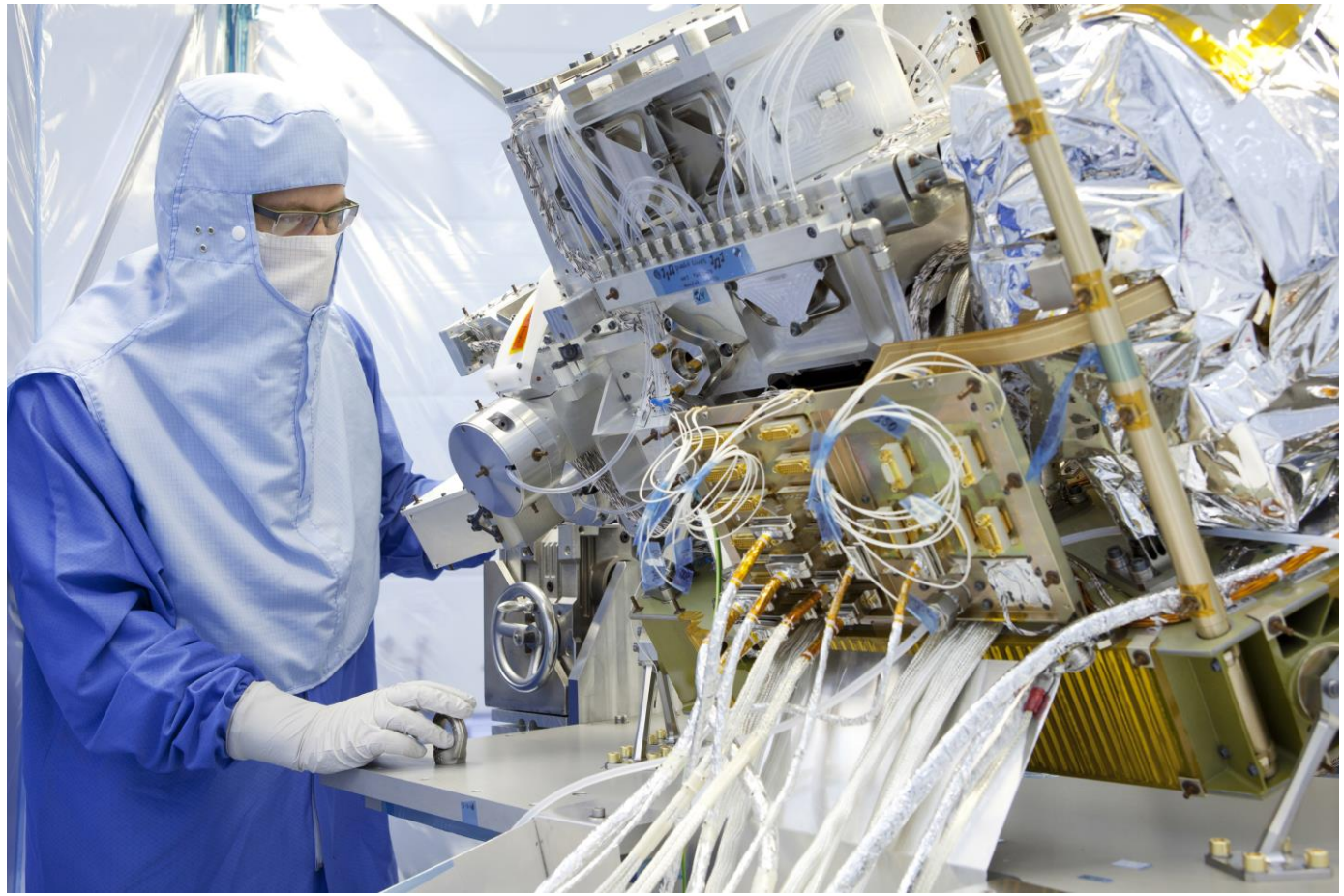



Global revisit time
0
24h

Focus on TROPOMI:
TROPOspheric Monitoring Instrument

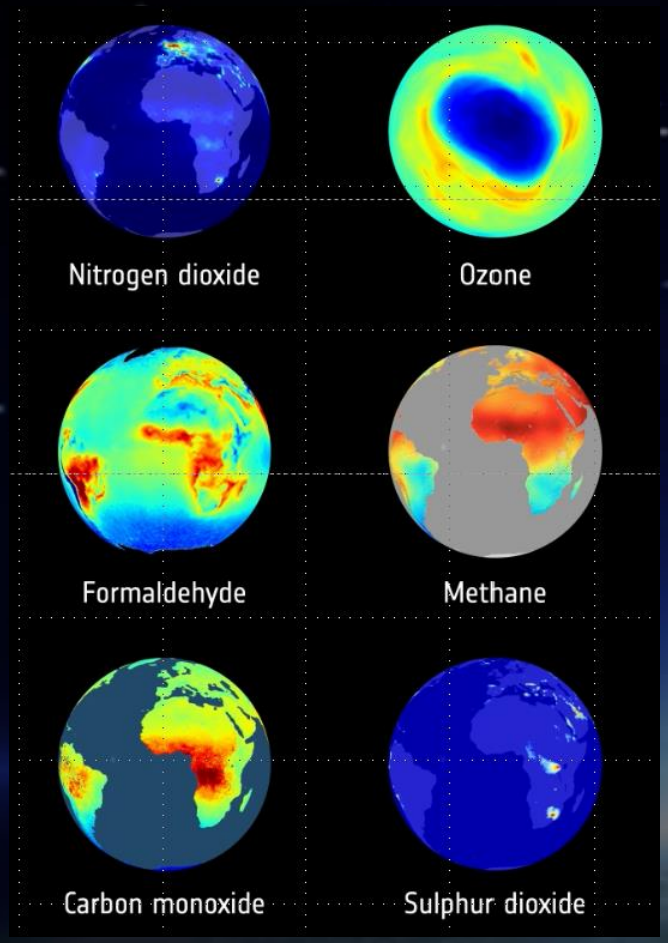
- Monitoring atmospheric composition, for:
  - Air quality
  - Climate change
  - Ozone layer

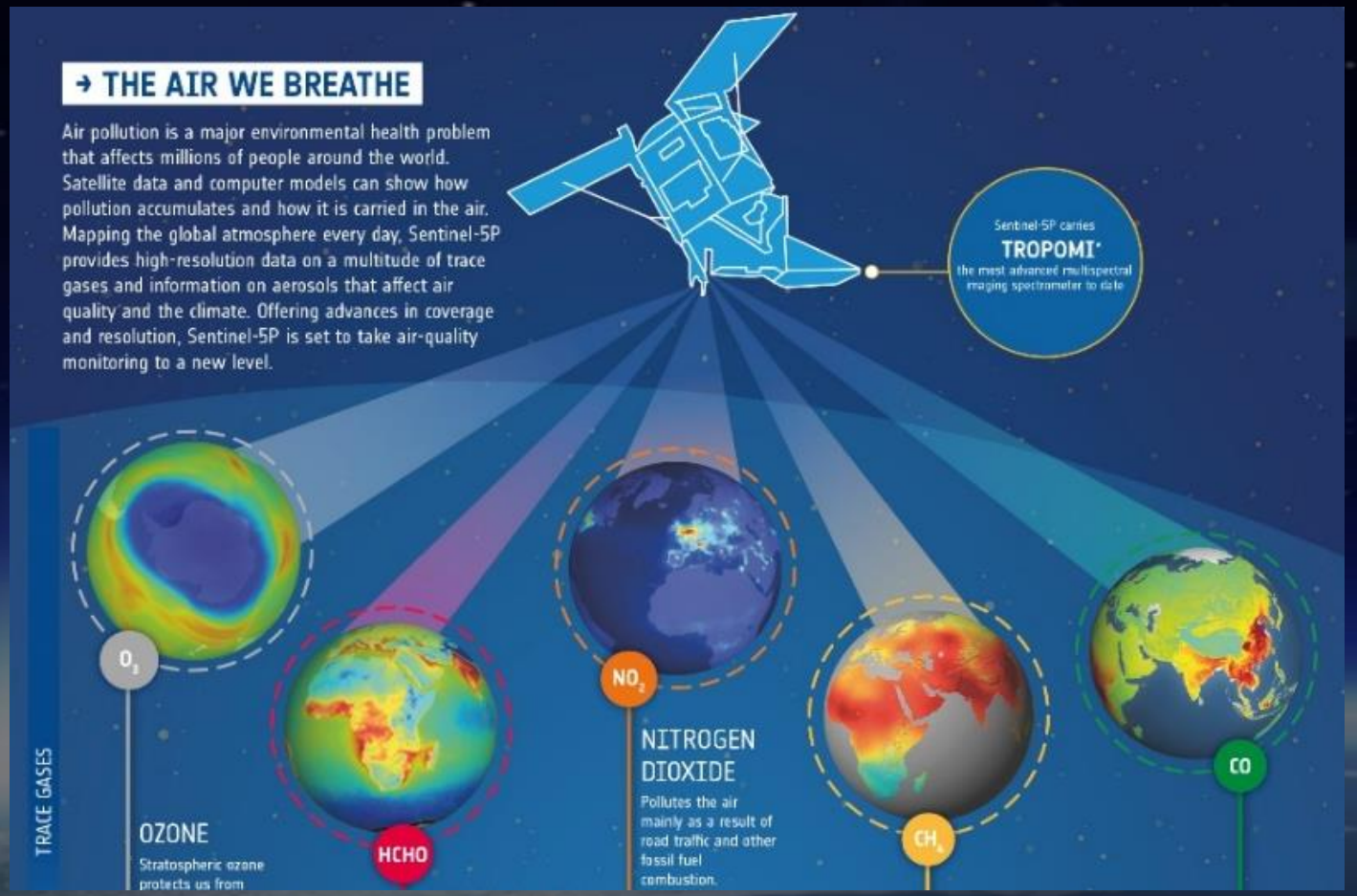
- TROPOMI details:
  - On Sentinel 5-Precursor Satellite (S5P)
  - Launched 13 October 2017
  - Polar-orbiting satellite
  - Overpass time ~13:30 LT
  - Data are free and open
  - www.tropomi.eu &
  - https://scihub.copernicus.eu/



TROPOMI: more than just air quality

Links to understanding climate, health, & biosphere dynamics





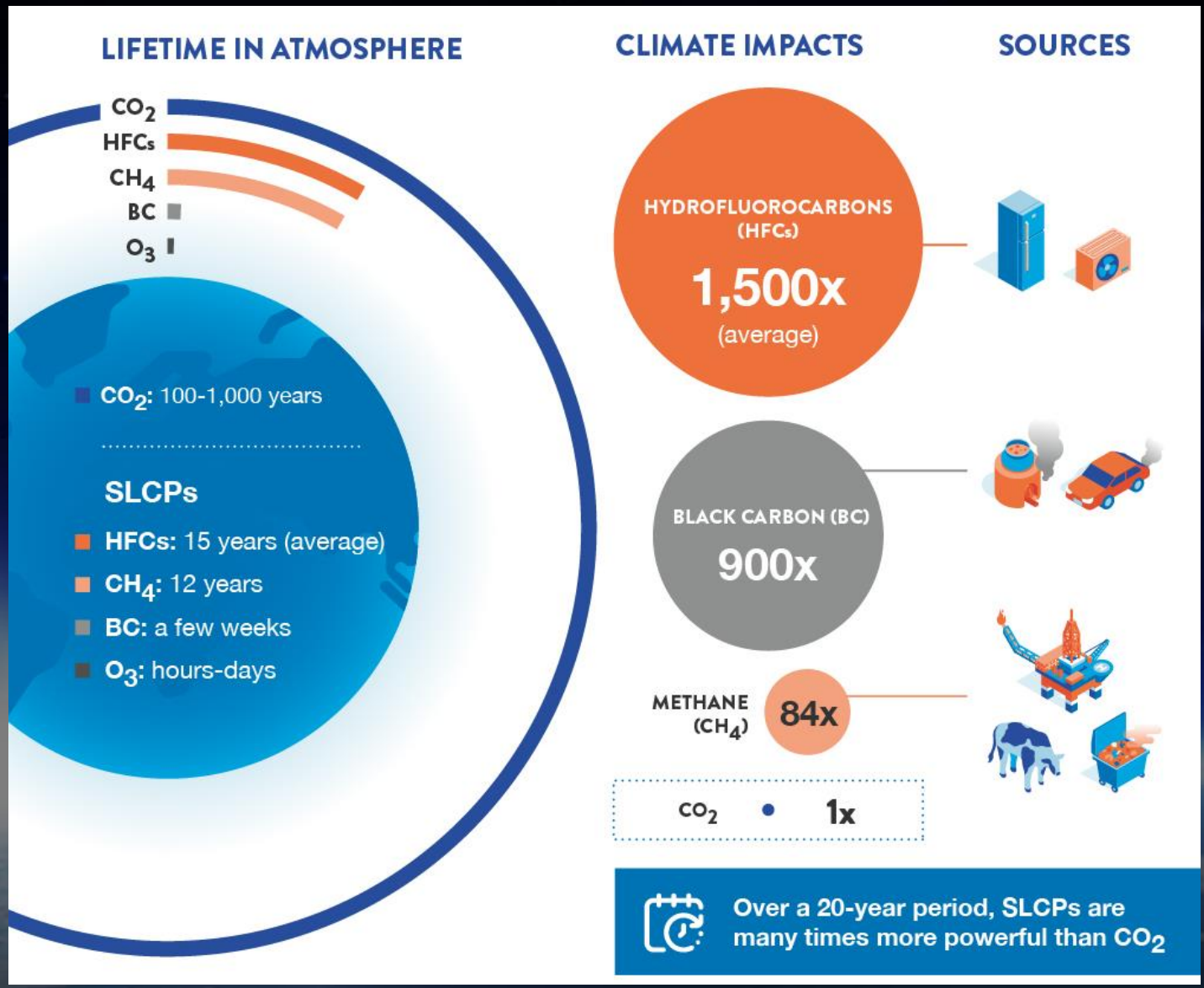
Making Links: AQ-relevant Short-Lived Climate Pollutants (SLCP)

TROPOMI

Some species have a large AQ ***and*** Climate Impact

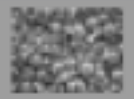
- Tropospheric Ozone
- Black Carbon Aerosol (soot & smoke)
- Methane (CH_4)

From: Climate & Clean Air Coalition



Operational TROPOMI data products include total column amounts of trace gases plus cloud & aerosol properties

TROPOMI

Parameter	Data Product	Vertical Resolution	Bias	Random
Ozone 	Ozone Profile	6 km	10-30%	10%
	Total Ozone	total column	3.5-5%	1.6-2.5%
	Tropospheric Ozone	trop column	25%	10%
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)
Aerosol 	Aerosol Layer Height	total column	<100hPa	<50hPa
	Aerosol Type	total column	~1 AAI	<0.1 AAI
Surface UV	Provided by FMI in frame of the Finnish Sentinel Collaborative Ground Segment			

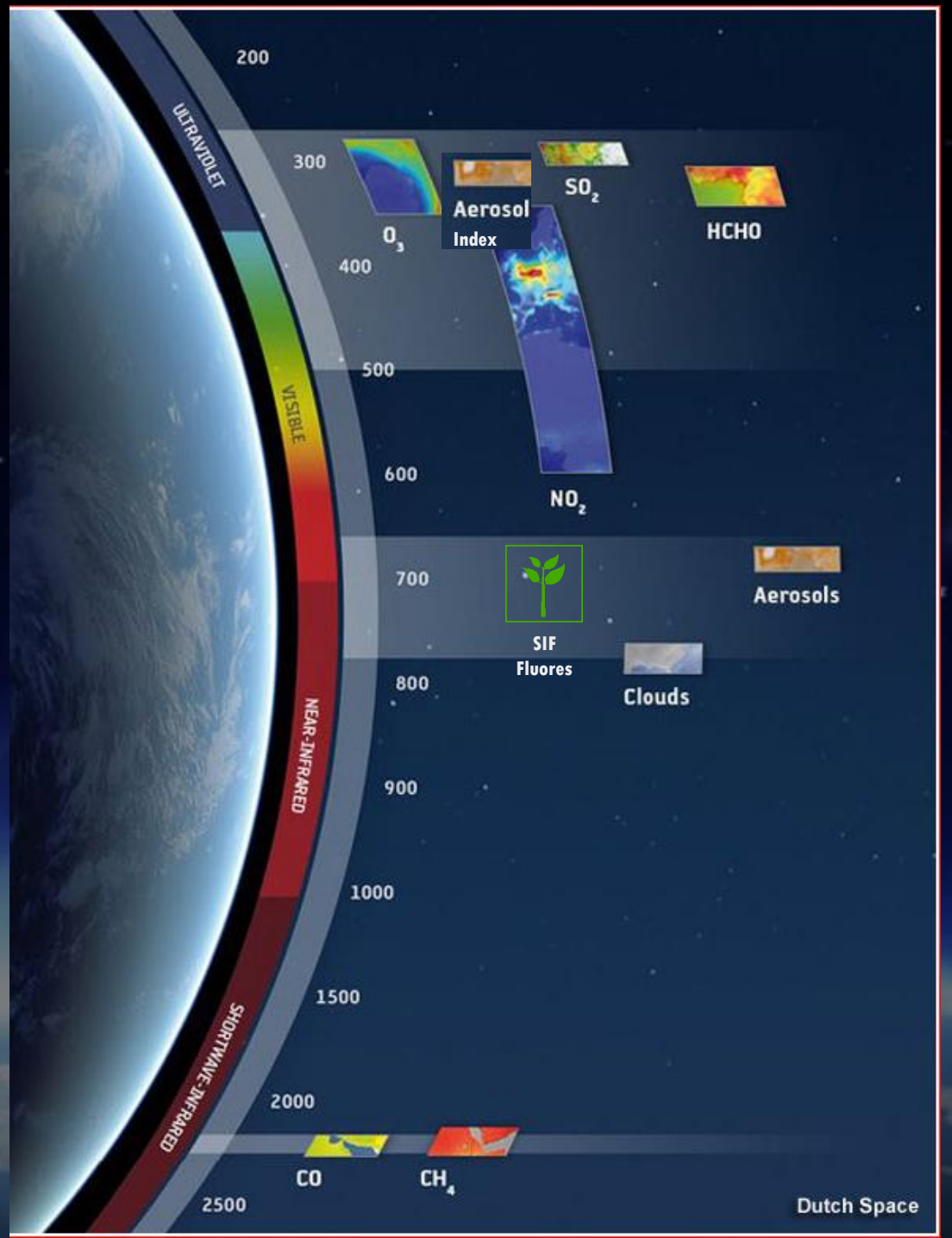
KNMI | DLR | BIRA-IASB | SRON | RAL |IUP-Bremen | MPIC | FMI

Measuring Air Quality & SLCPs Directly with TROPOMI

- Operational data May 2018 to present
- Additional prototype Data Products

- What is being measured directly:
  - **(Tropospheric) Ozone** Column & profile
  - UV Surface Radiation / Dose
  - **Aerosol Index,** *Ocean Color & properties**
  - NO_2, SO_2, HCHO, *CHOCHO**, *BrO**
  - Clouds & Aerosol Layer Height
  - *(SIF) Fluorescence**
  - CO, **CH_4**

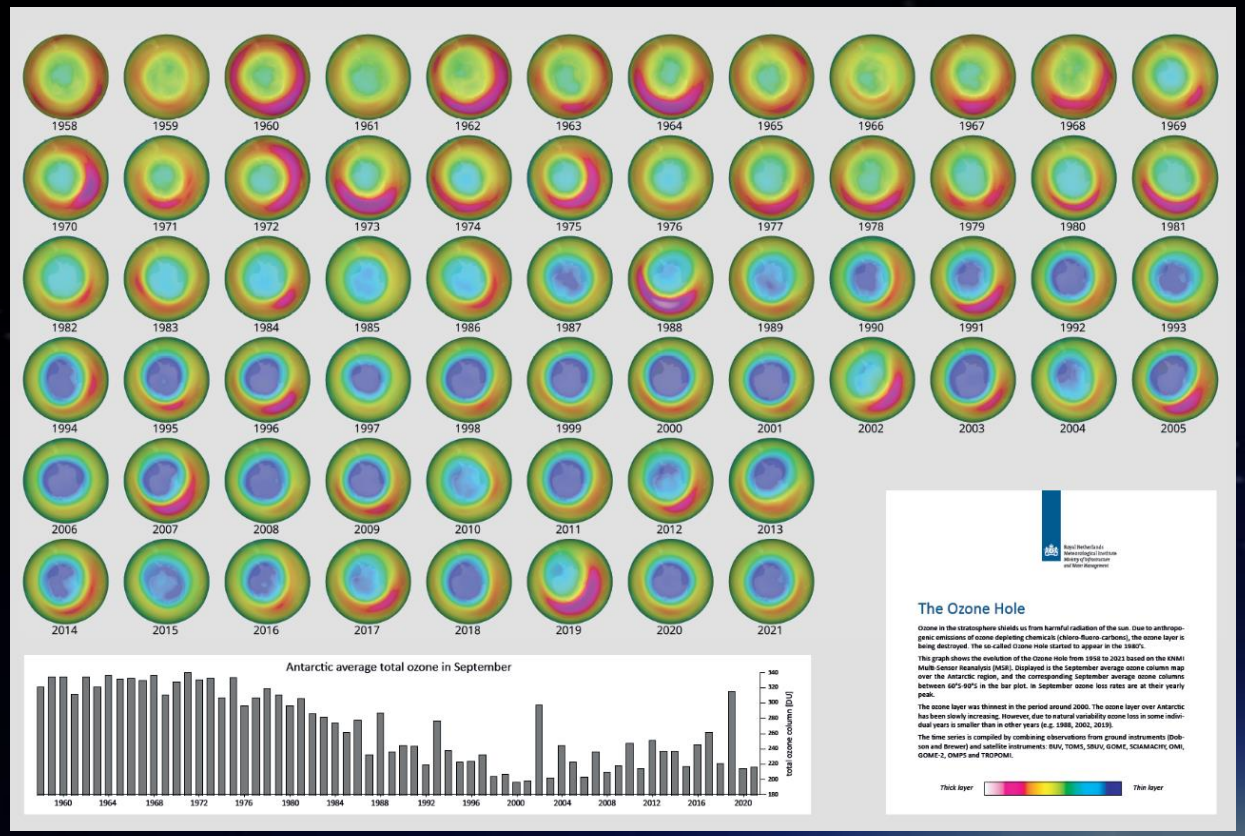
**Not yet Operational products*



Monitoring by Proxy: Links to Climate with TROPOMI

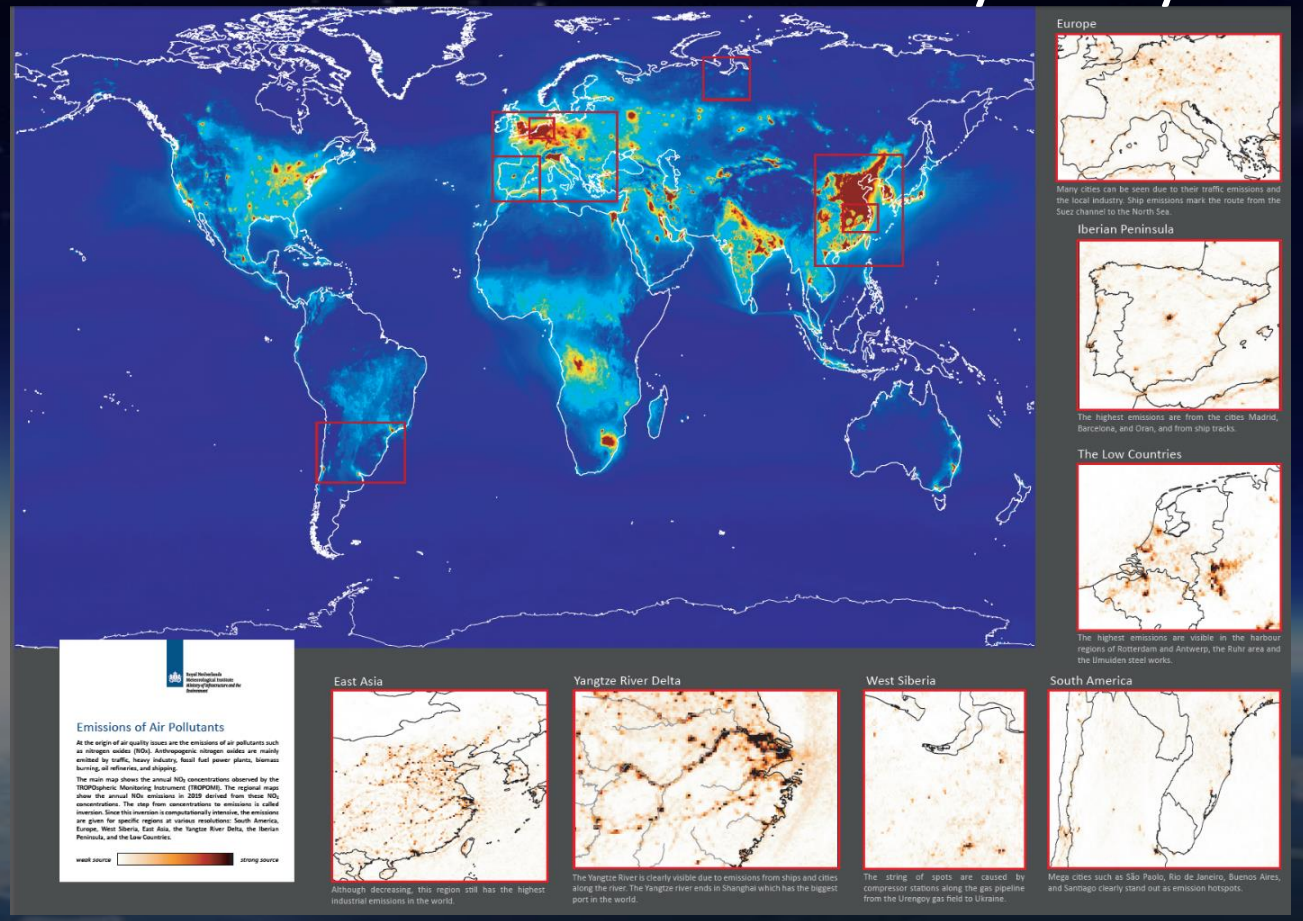
- **Point Sources:** which are Climate & Air Quality relevant
  - Industrial (ex. Power generation) plumes detailed NO_2 emissions calculations, can be used for **CO_2 emissions**
- **Biosphere:** Solar-Induced Fluorescence (SIF) measurements Clear links for monitoring biosphere changes induced by air quality, seasonal & climate changes
  - TROPOMI data can be used to compare to future FLEX mission
- **Urban Growth:** links to understanding urban growth by evaluating year-to-year differences in urban and background measurements
- **Long data record:** combine with predecessor missions like OMI extending from November 2004 to present (2023)

TROPOMI species and directions of application



Ozone Hole Monitoring

Global NOx Emission Inventory Analysis



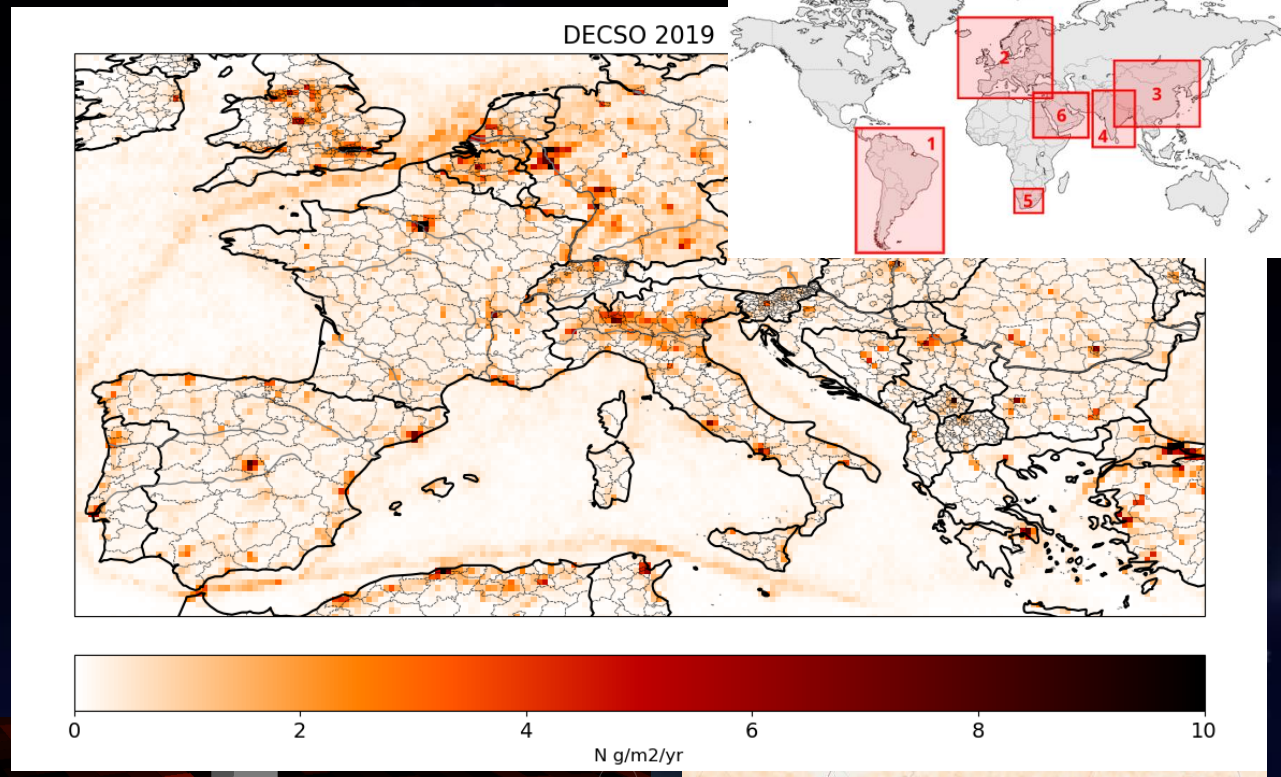
Monitoring Emissions

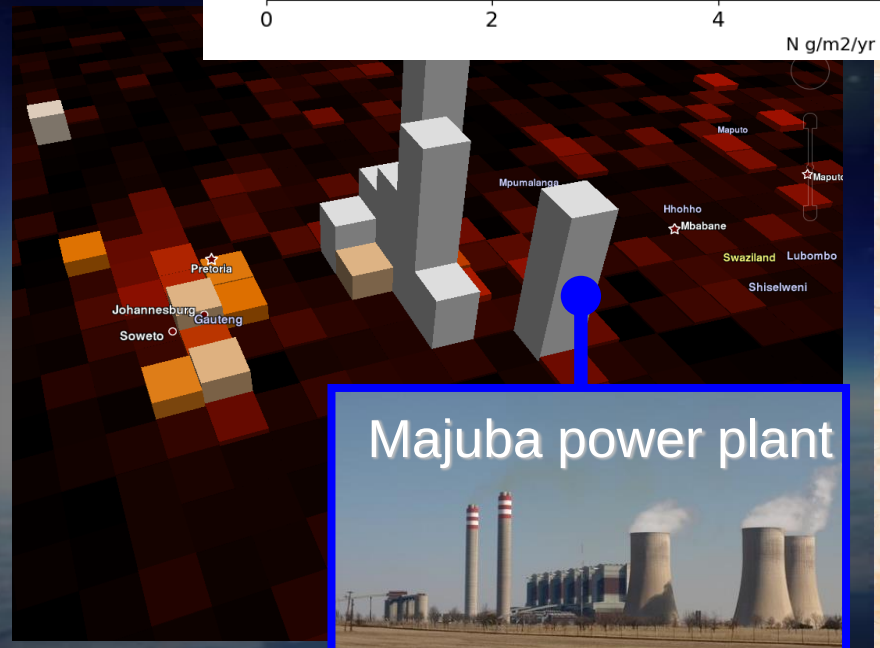
DECSO Daily Estimates Constrained by Satellite Observations

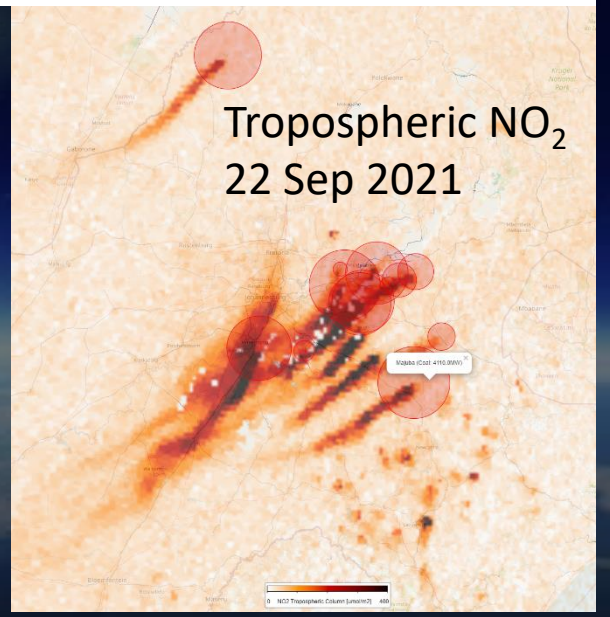
By Ronald van der A, Bas Mijling, Jieying Ding - **KNMI**

- It is fast: one model run per assimilation step of 1 day
- No *a priori* information needed: unknown sources will become visible.
- Full error estimation of new emission inventory
- Used for daily NO_x, NH_3, CH4 emissions

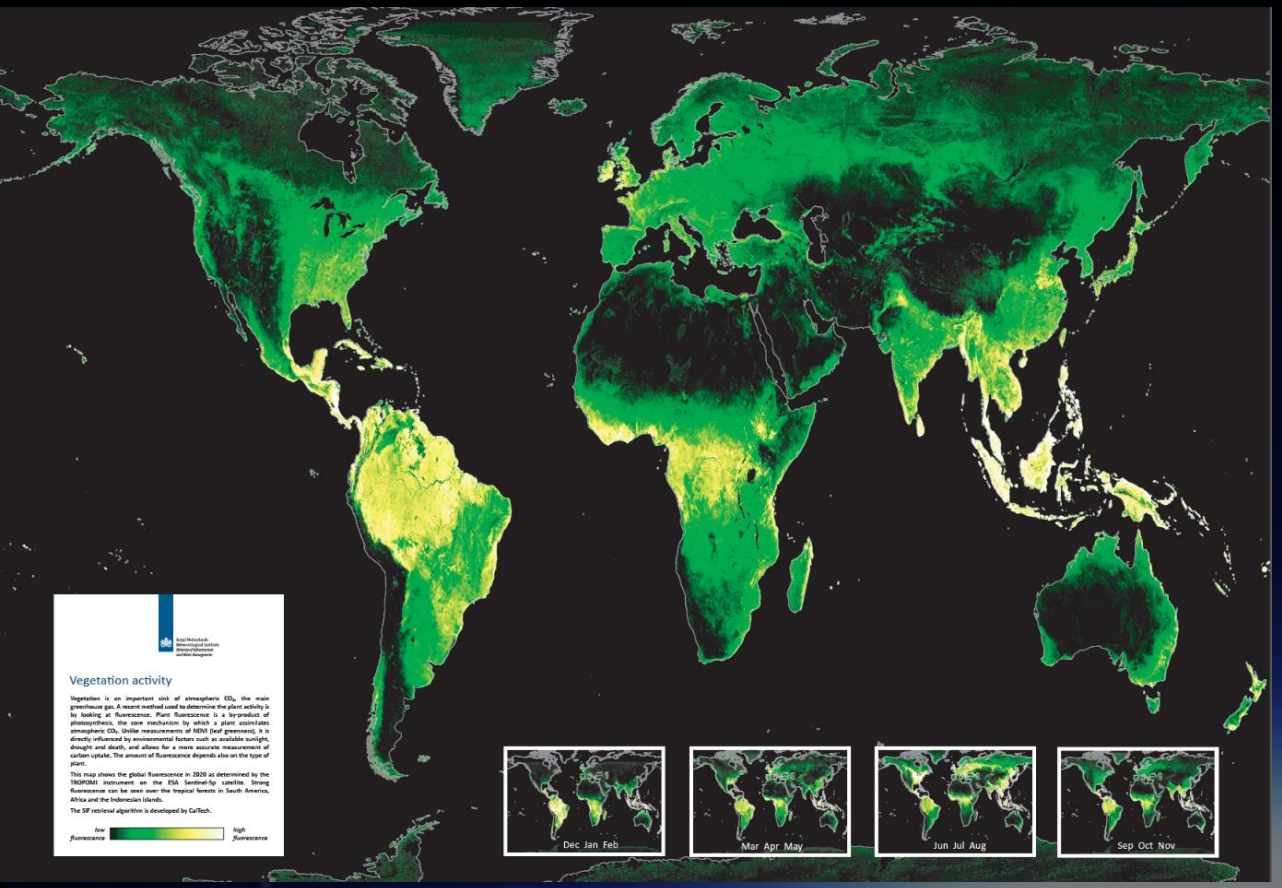
This type of emissions calculation can be linked to CO_2 emissions for known point sources (ex. Power plants)





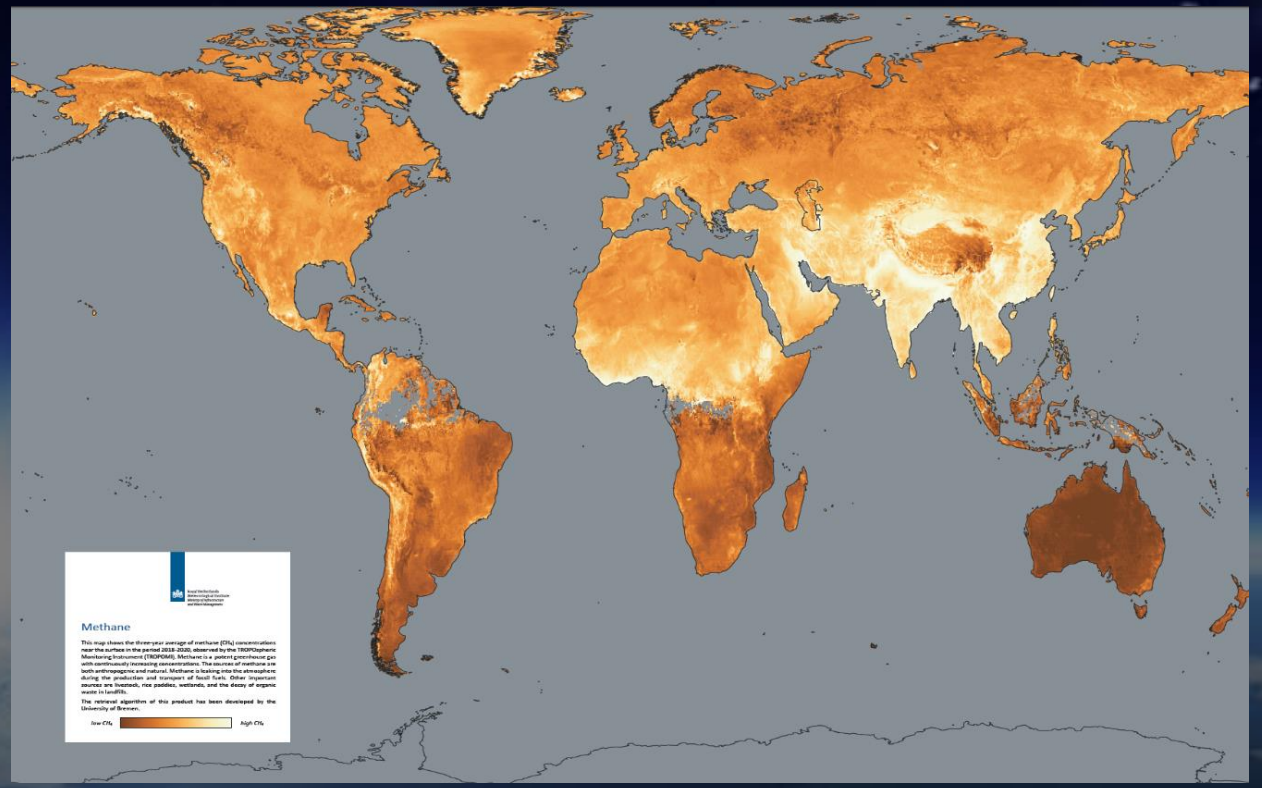


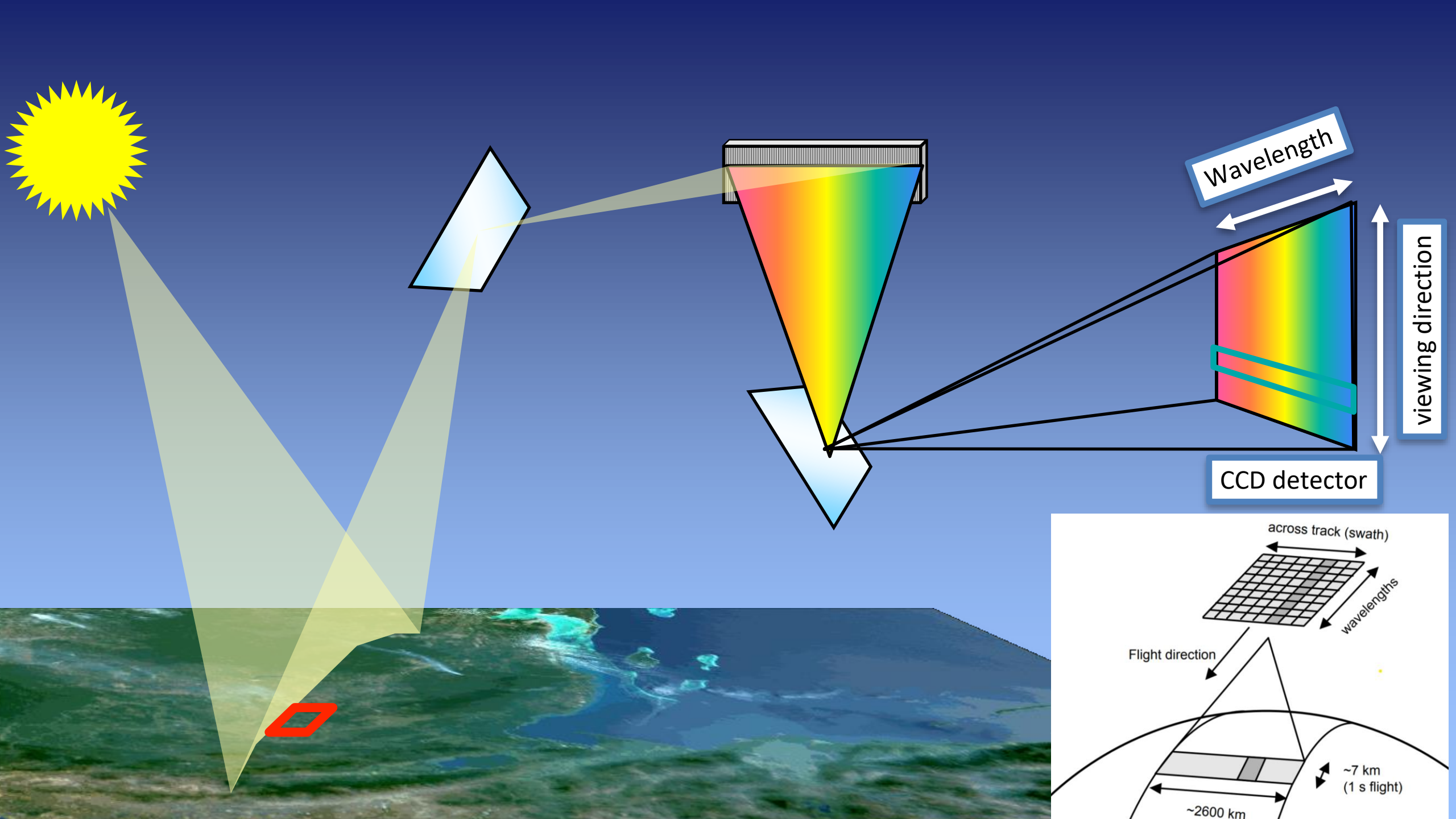
New! TROPOMI species and directions of application



Solar-Induced Fluorescence (SIF)
Monitoring of Drought, Carbon Cycling, plant productivity

Methane: Global Climate monitoring

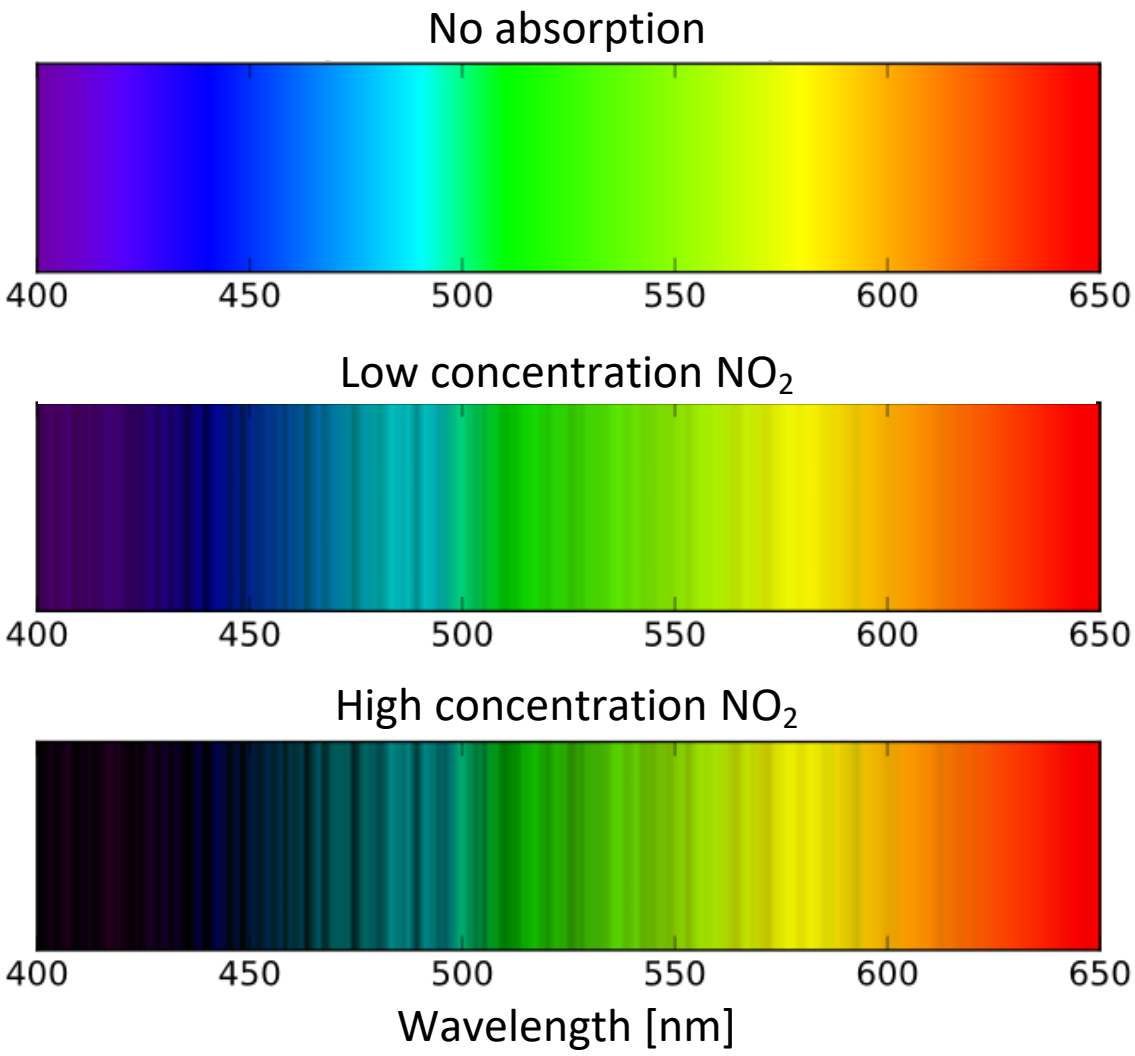



Wavelength
viewing direction
CCD detector
across track (swath)
wavelengths
Flight direction
~7 km
(1 s flight)
~2600 km

How does TROPOMI make its measurements?

- Satellite measures Sun directly and amount of light from Earth
- **Level 0** – Light enters the satellite; sensed with CCDs and is converted to digital signal → transferred to receiving stations
- **Level 1** – This raw data is processed to produce quantified amount of solar and Earth shine: irradiance & radiance
- **Level 2** – Through radiative transfer theory & absorption spectroscopy, convert radiation to a vertical column amount of the given trace gas, also aerosol & cloud properties

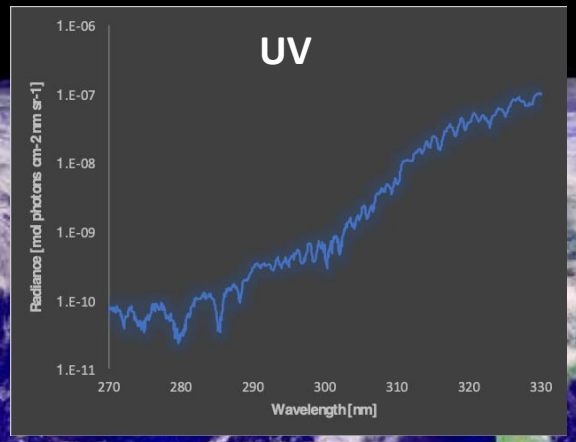
From spectra to concentrations



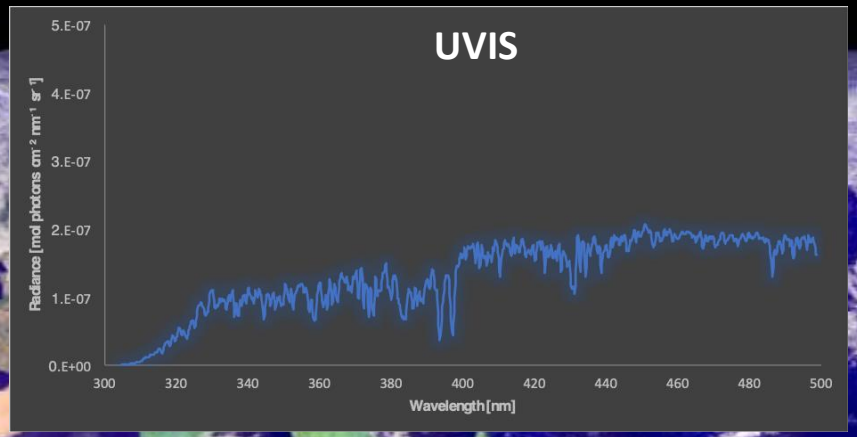
TROPOMI has 4 detectors

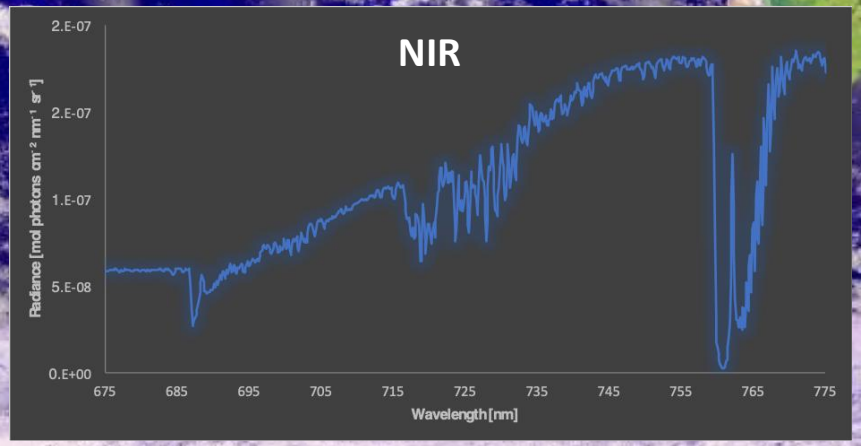
Spectral Band	Wavelength Range (nm)	Spectral Resolution (nm)	Data Products Retrieved
Ultraviolet (UV)	270–320	0.45–0.5	O_3, SO_2
Ultraviolet and Visible (UVIS)	320–490	0.45–0.65	Aerosol index, NO_2, HCHO, Cloud, Ocean Color, CHOCHO
Near-Infrared (NIR)	710–775	0.34–0.35	Cloud properties, Aerosol Height, SIF
Shortwave Infrared (SWIR)	2305–2385	0.227 | 0.225	CO, CH_4

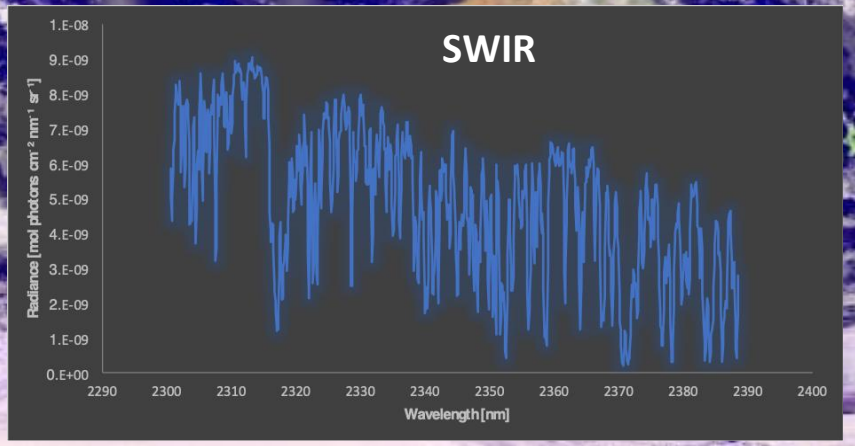
Spectra covering 4 wavelength regions



- 1 scanline per second
- 440 spectra per scanline
- 3000 scanlines per orbit
- 15 orbits per day
- 20 million groundpixels per day
- 225 Gbyte raw data per day
- 1 Tbyte L1b data per day





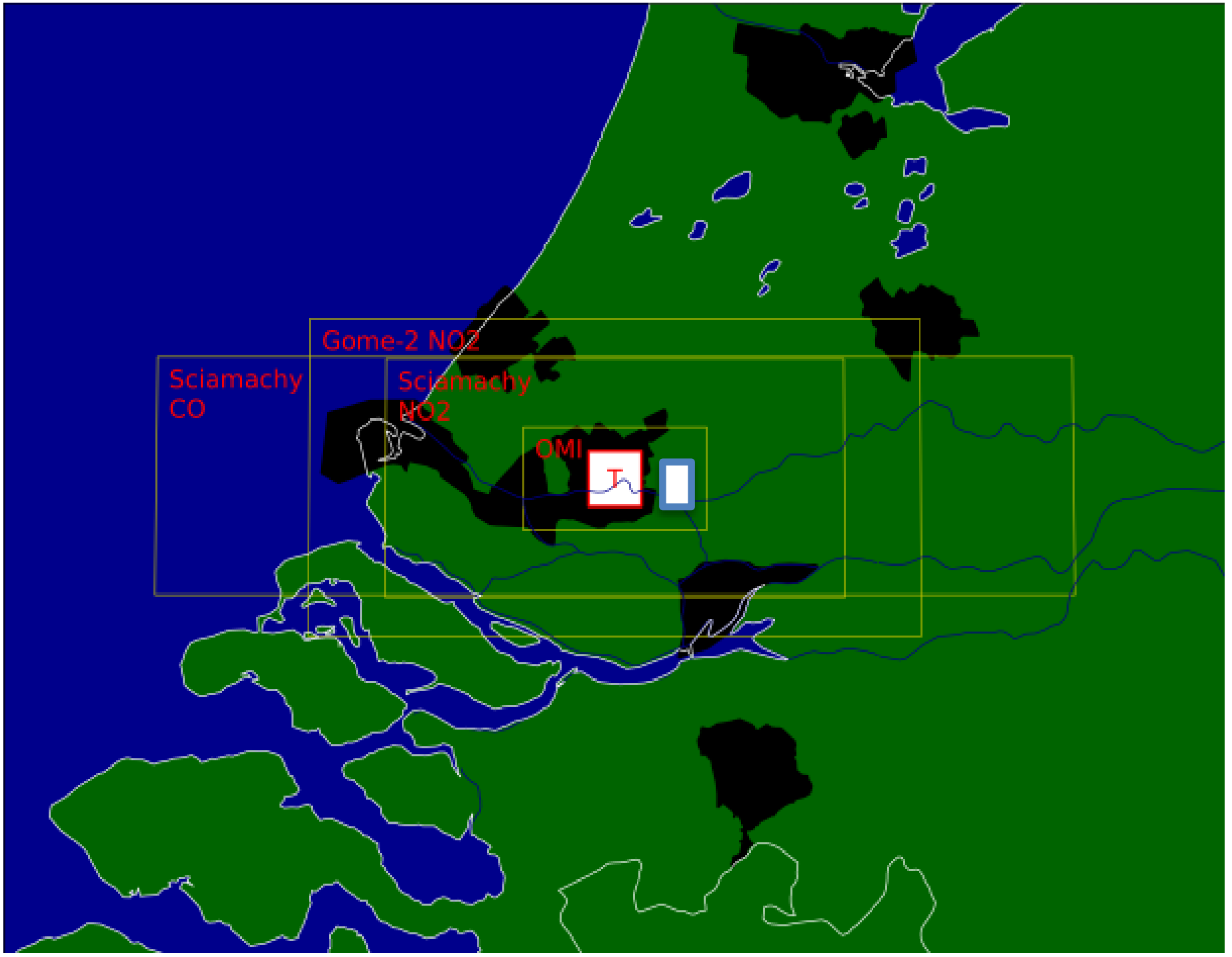


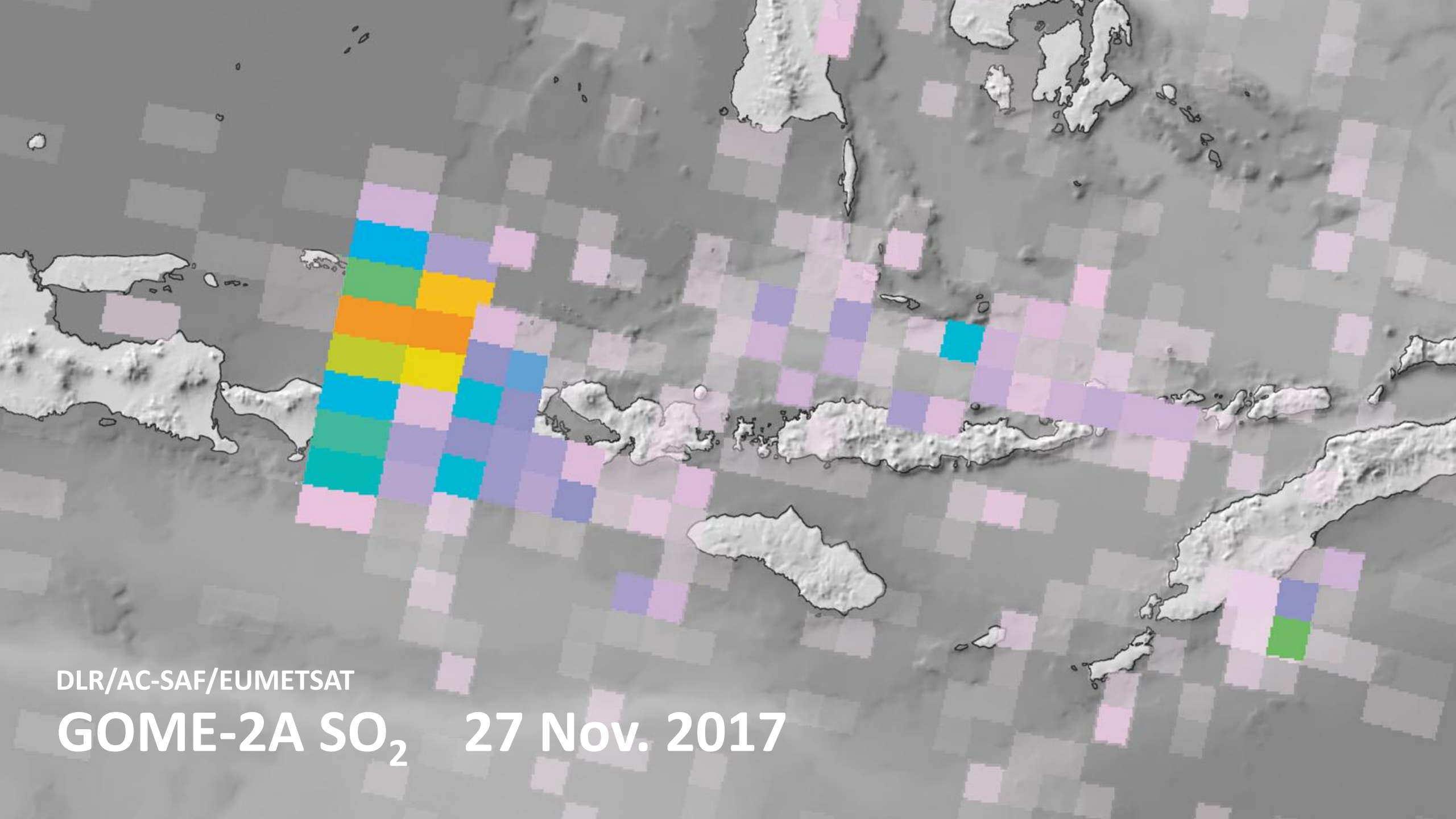
Spatial Resolution:

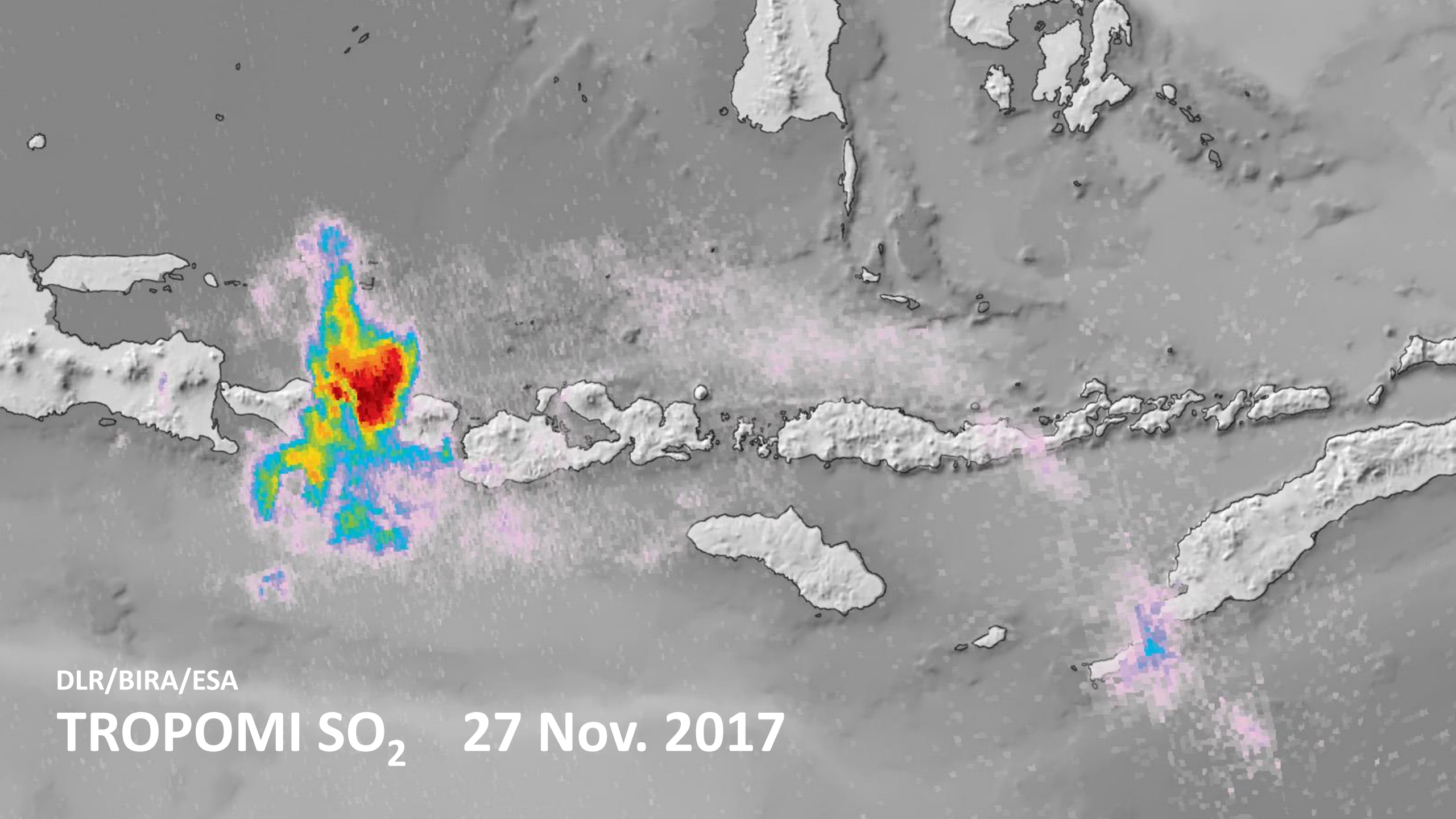
Further decreased to 3.5 x 5.5 km in August 2019

Individual source Identification, Intra-city variability

See next slides for difference in spatial resolution

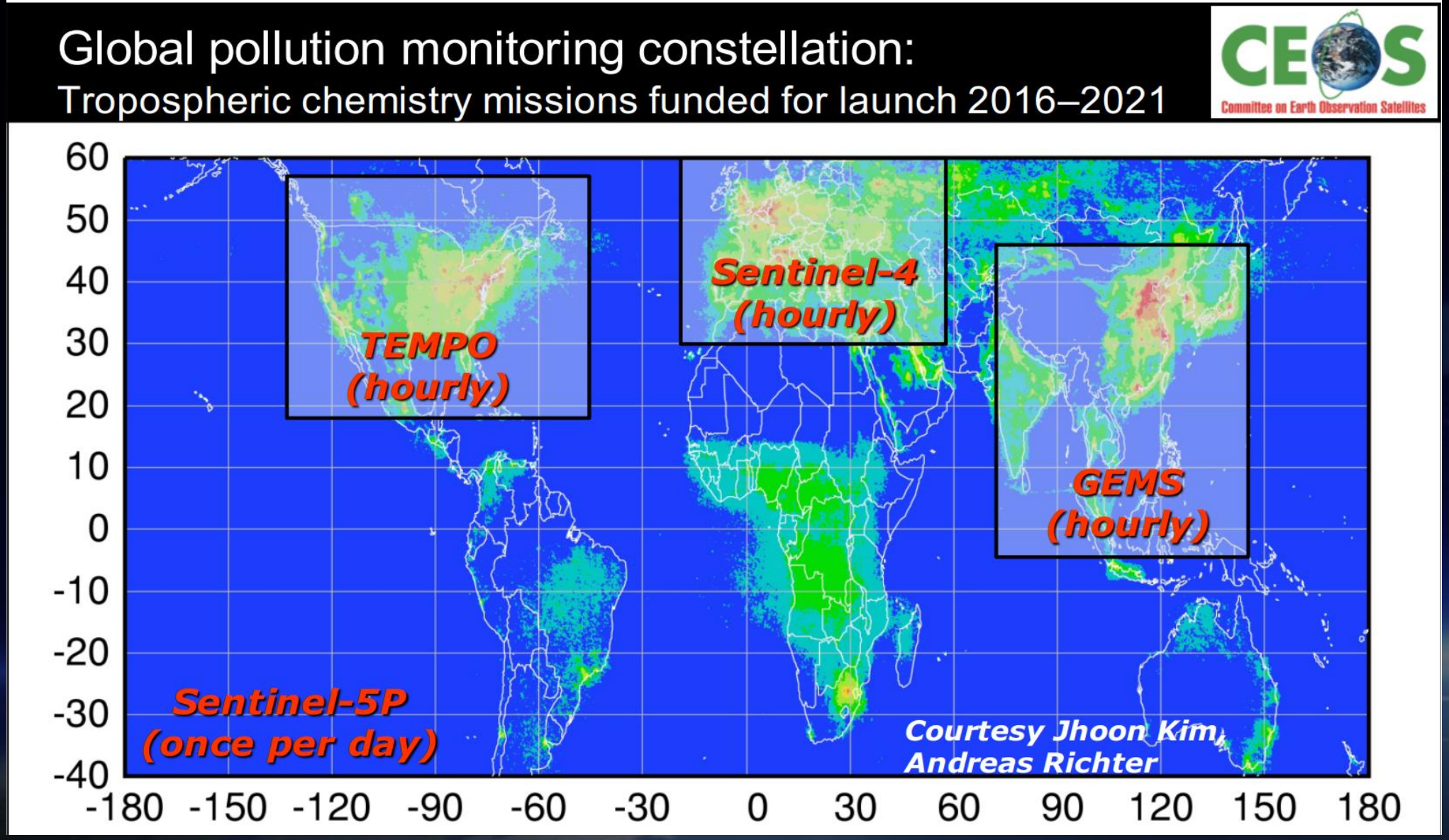



DLR/AC-SAF/EUMETSAT
GOME-2A SO_2 27 Nov. 2017


DLR/BIRA/ESA
TROPOMI SO2 27 Nov. 2017

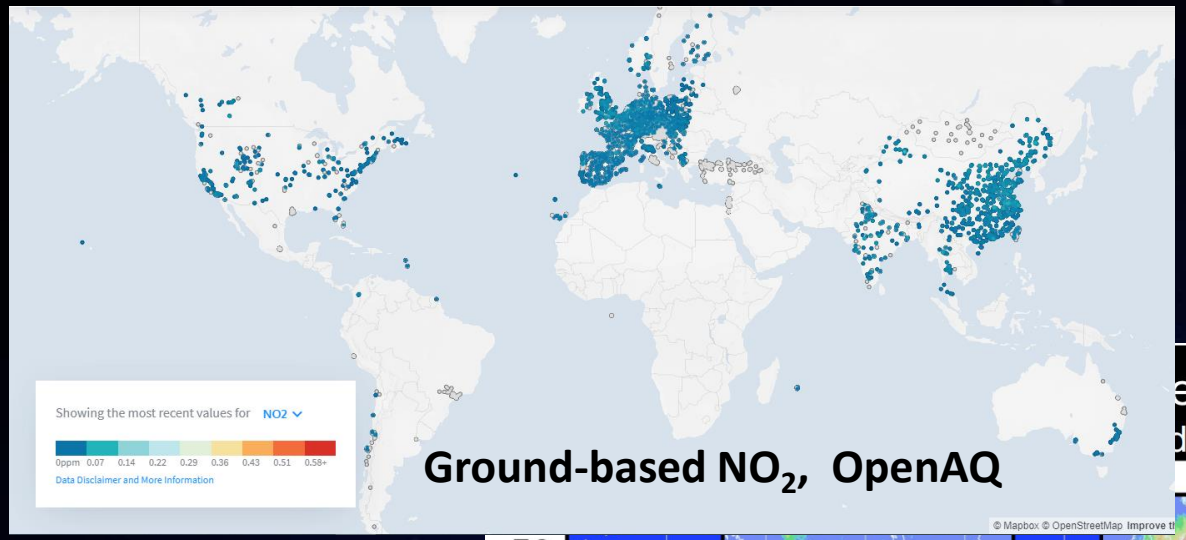
GEO + LEO Observing Strategy, *covered by Brian*

TROPOMI

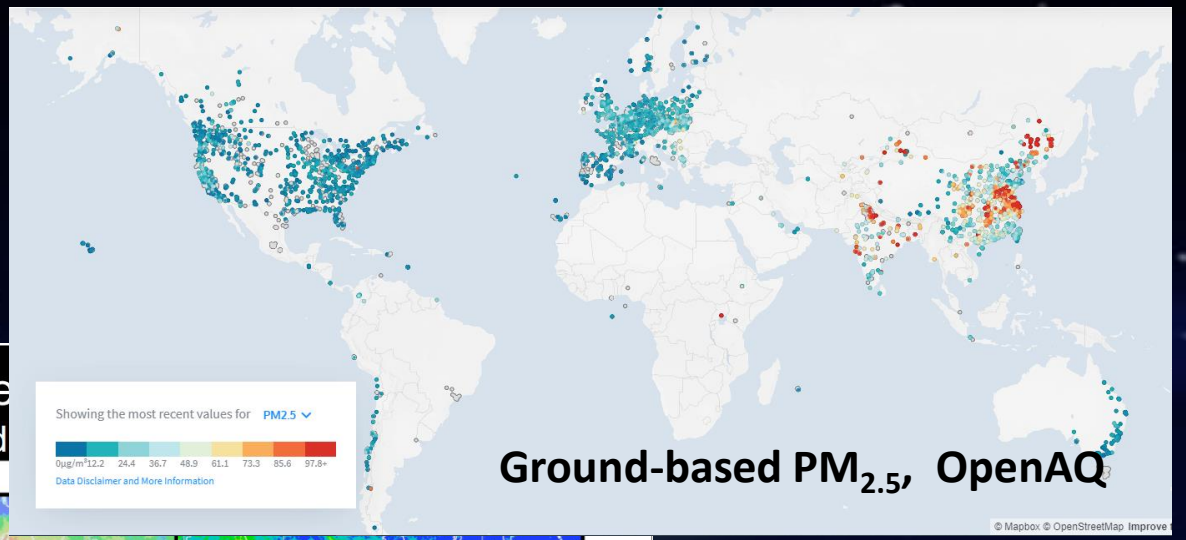


Missing out on observations of the Global South

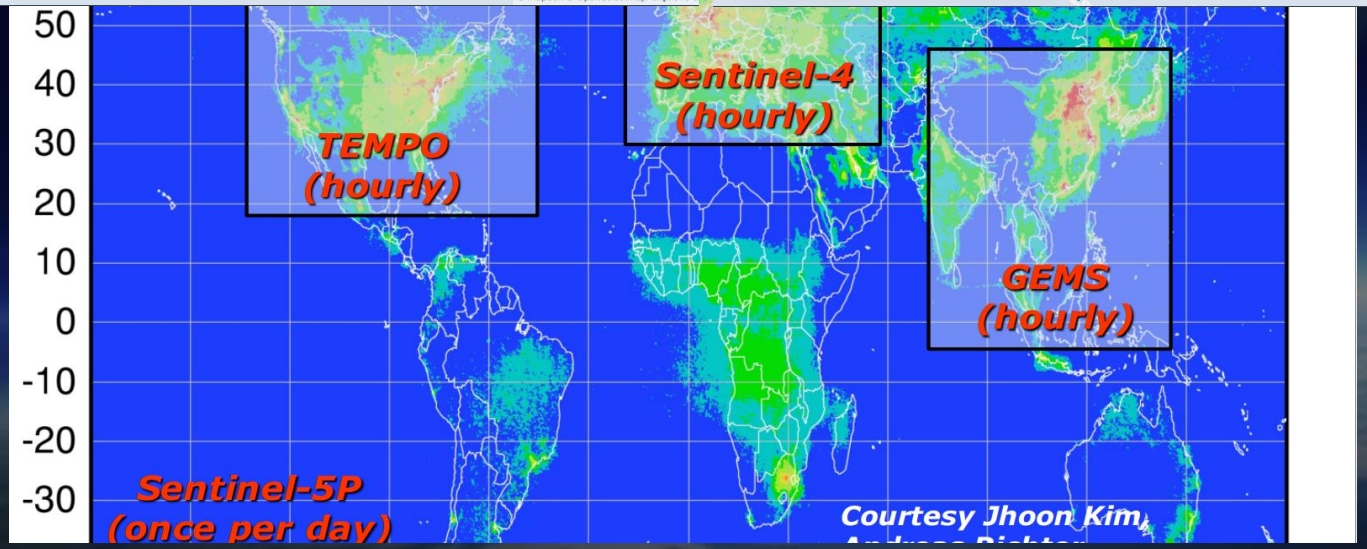
TROPOMI is a base map covering gaping holes geostationary and ground-based networks



Ground-based NO_2, OpenAQ



Ground-based $PM_{2.5}$, OpenAQ



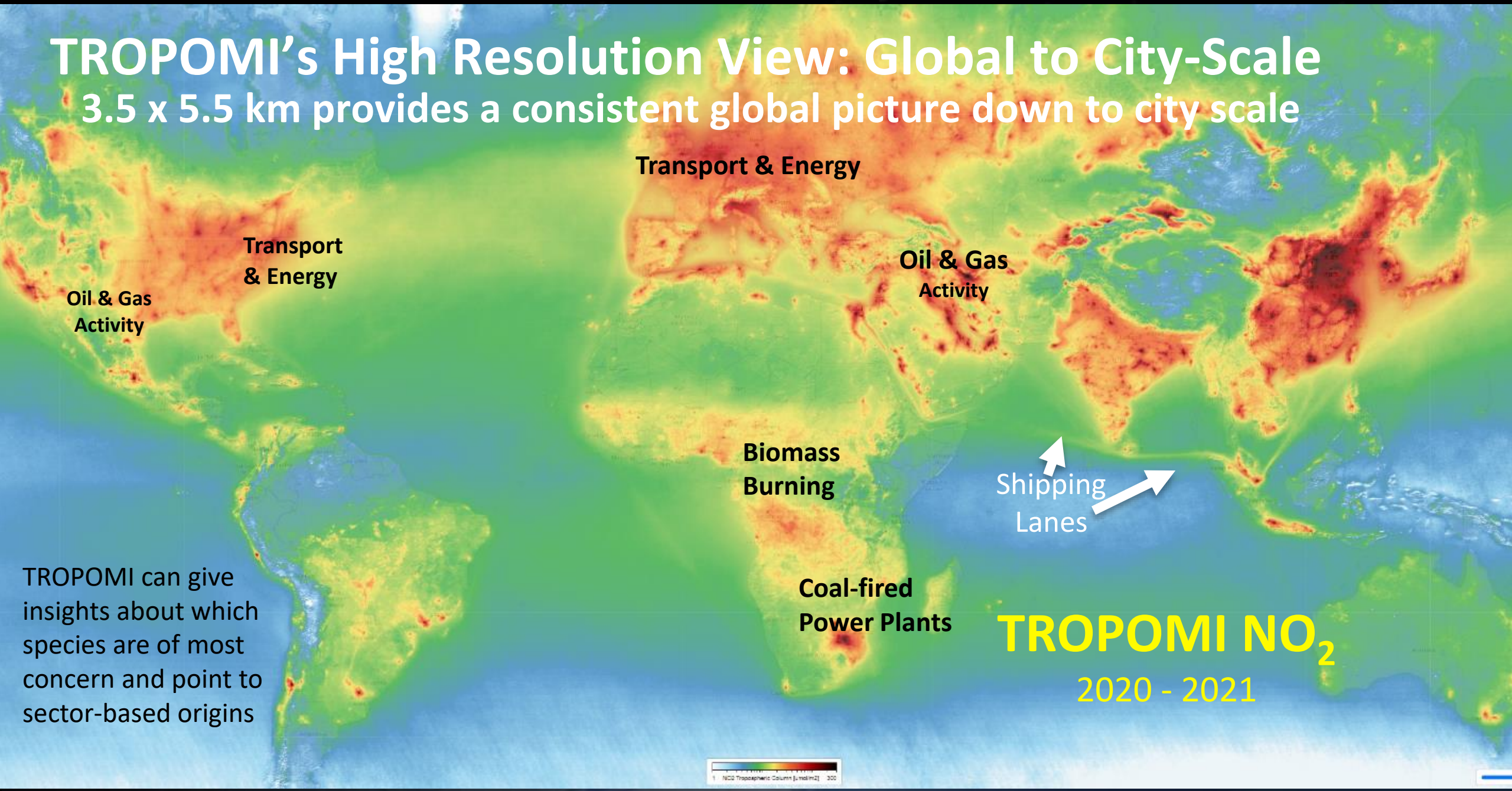
Motivation: How can you use TROPOMI stand-alone?

- ***Context:*** Satellite data is sometimes overlooked because it does not equate to surface 'nose-level' pollution quantities needed for classical exposure studies

- **TROPOMI satellite data can be starting point for identifying:**
  - Which air pollutants are most prominent for my region/city?
  - What is the seasonal cycling of these species?
  - What is my city footprint? Urban vs. Background, trends, etc.
  - Is long-range transport occurring? Dust and smoke plumes

TROPOMI's High Resolution View: Global to City-Scale

3.5 x 5.5 km provides a consistent global picture down to city scale



TROPOMI can give insights about which species are of most concern and point to sector-based origins

Motivation: What do you want to get out of TROPOMI?

Brief survey of the audience:

- How many workshop participants are using satellite data?
- Do you currently work with TROPOMI data?
- Which species?
- Have you experienced any limitations in accessing and/or when using and analyzing TROPOMI data?

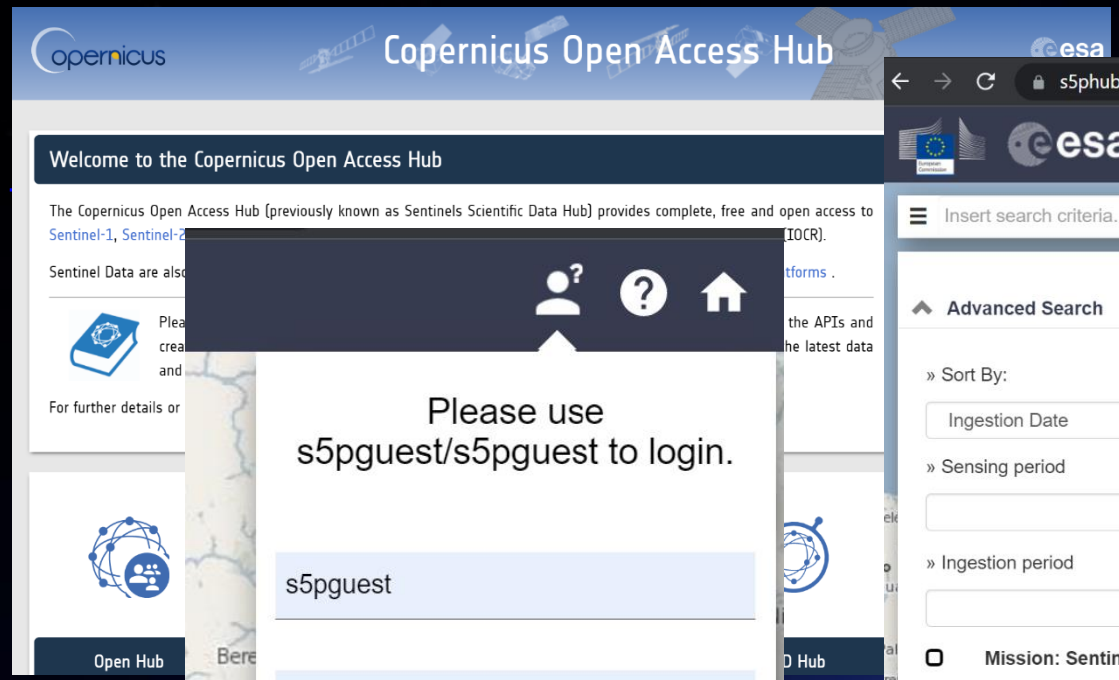
Getting Started with TROPOMI data

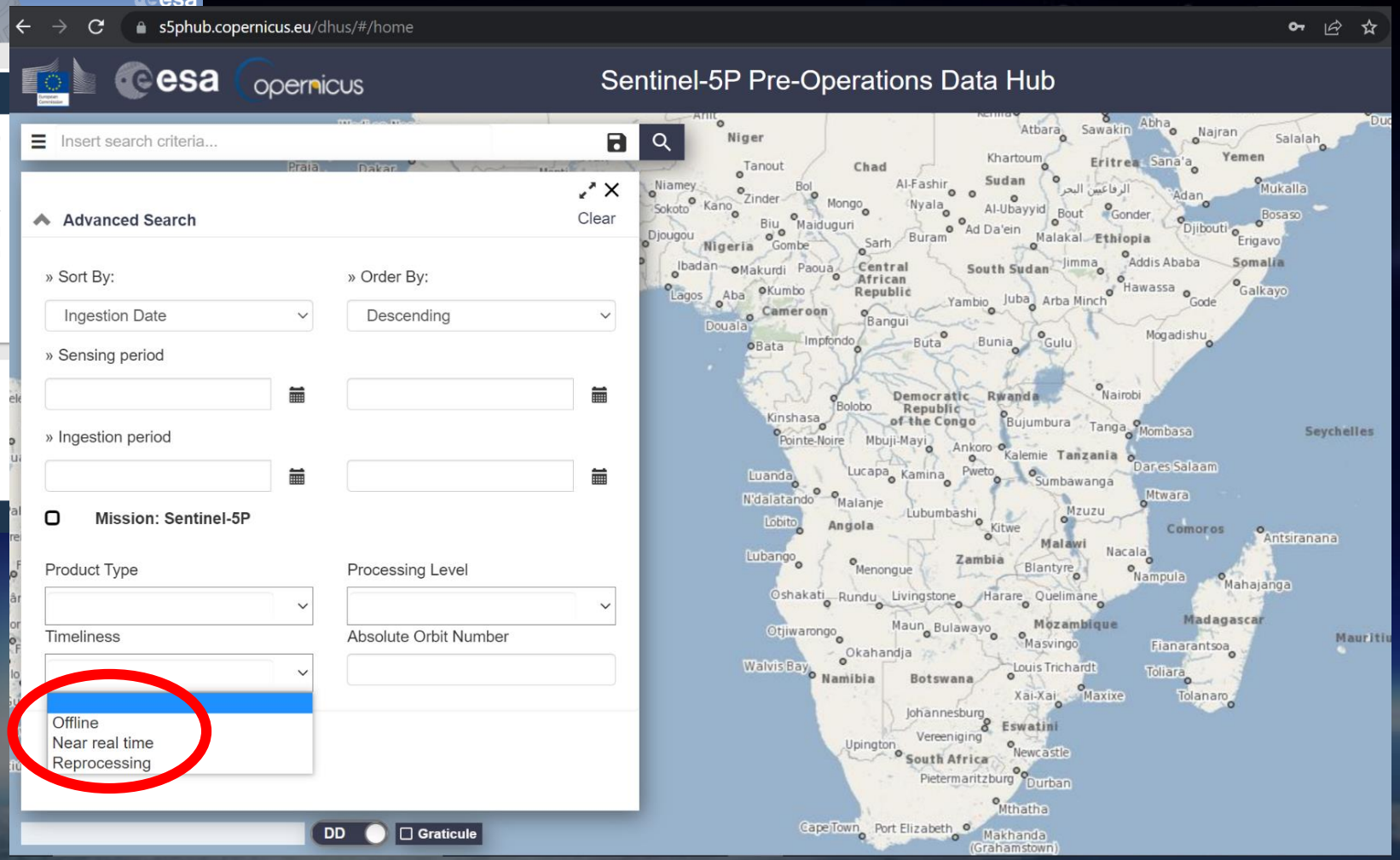
- Which data product / species do you want to use?
  - **https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-5p/products-algorithms**
- Choose an operational data product
- Download some files from the **Open Access Data Hub**
- Look at file structure with hdfview or Panoply
- Read the supporting documentation
- List of tools for mapping & analysis
- Look to the future & overview of in-cloud analysis solutions
- Feedback & Questions

NEW!! Copernicus Data Ecosystem

https://dataspace.copernicus.eu/ → Create a personal login

Download files from the Data Hub → *Select timeliness*
https://s5phub.copernicus.eu/dhus/#/home





TROPOMI Data Timeliness

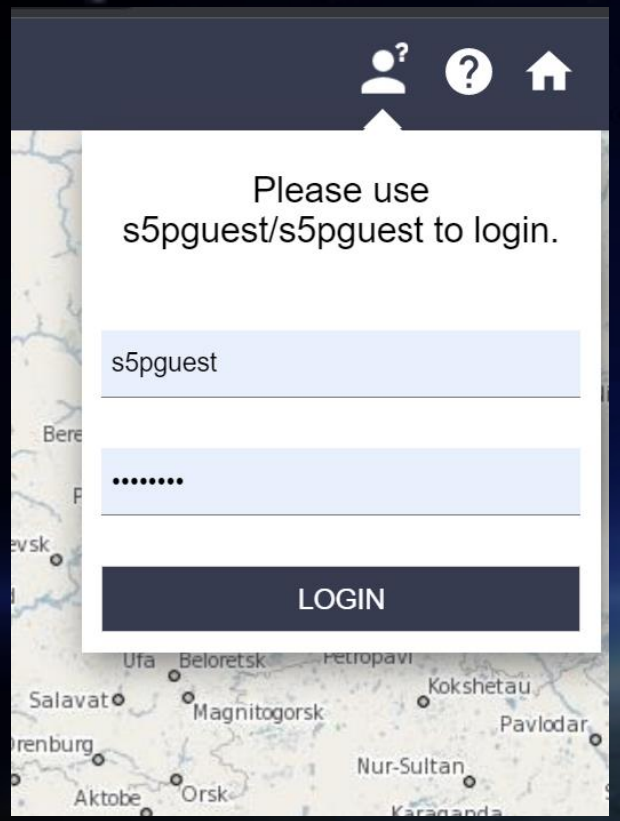
- **Near-real-time (NRTI)** stream, in data granules (part of an orbit)
  - NRTI is available within 3 hours after data acquisition and intended for quick access & rapid use operational processing. However,
  - NRTI data may sometimes be incomplete and has a slightly lower data quality as compared to the other data streams.

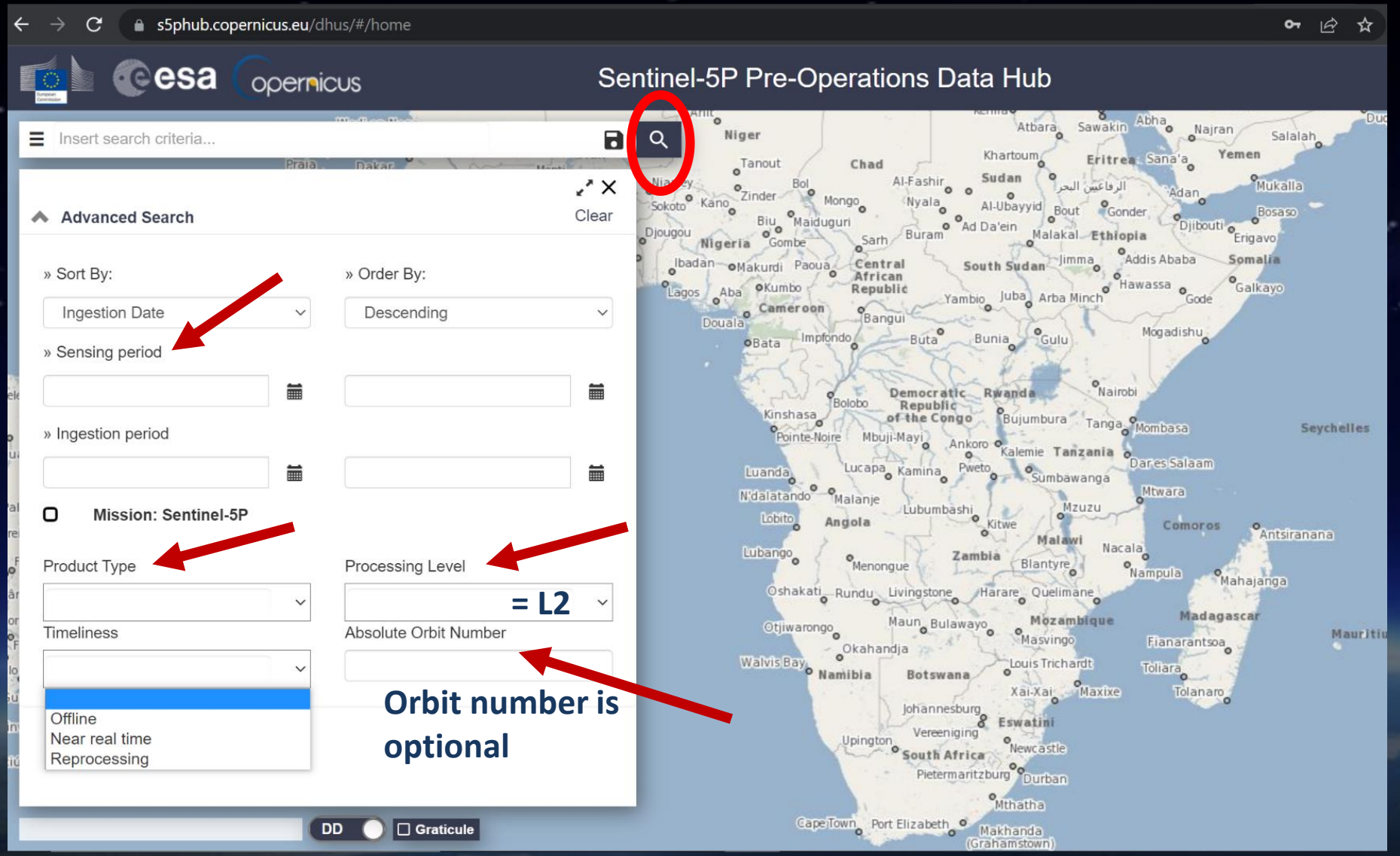
- **Offline (OFFL) or Non-Time Critical (NTC)** stream, in orbits
  - Most data users should use the offline data, available within a few days after acquisition, or the latest version of reprocessed data.

- **Reprocessing stream (RPRO),** in orbits
  - For longer term trend analysis, the latest version of the reprocessed data should be used to avoid shifts due to data version updates.
  - All of the RPRO data from May 2018 – July 2022
  - Can be combined with OFFL data from July 2022 to the present

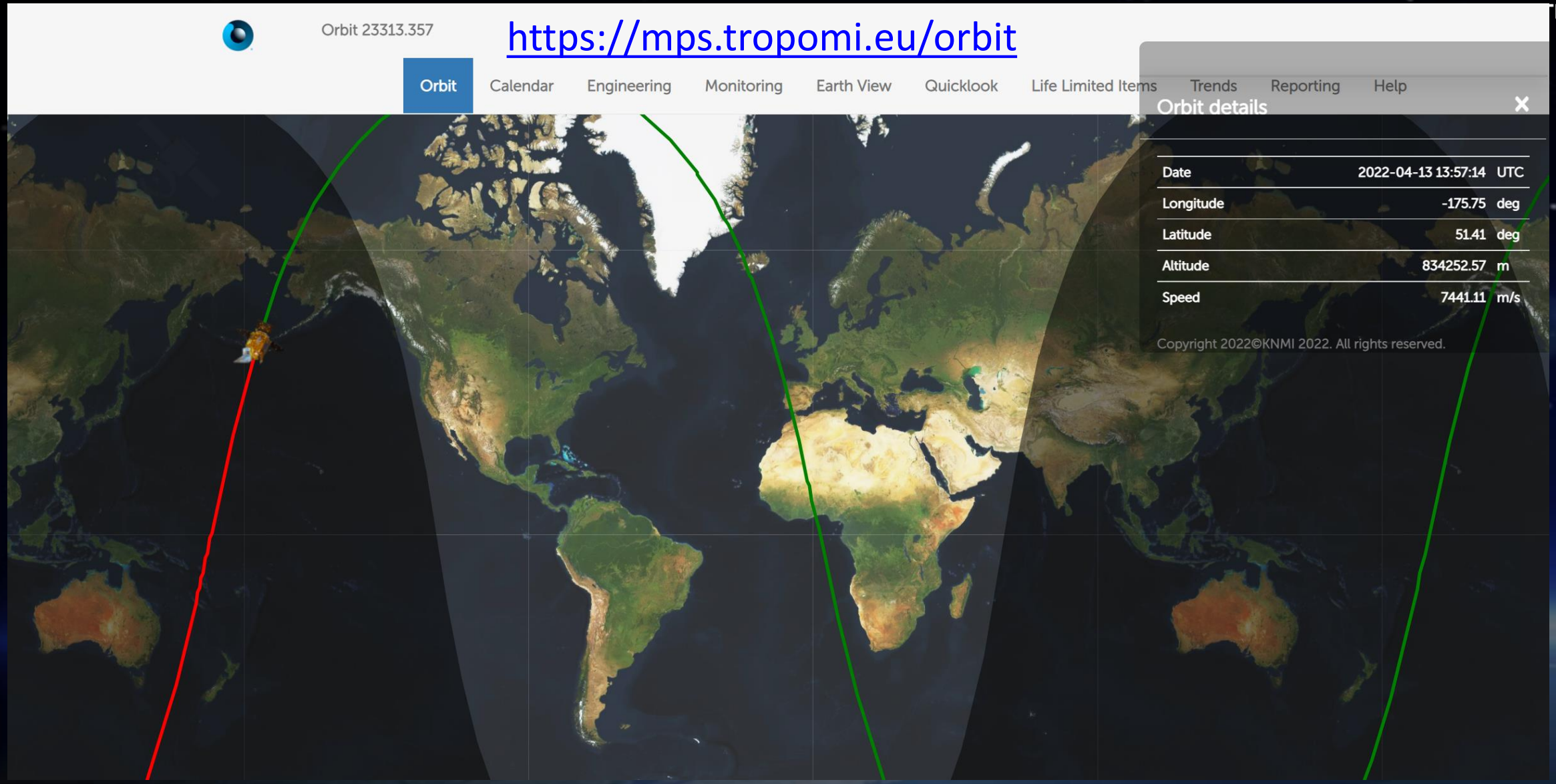
NEW!!

Searching for files → *Select L1 or L2*
https://s5phub.copernicus.eu/dhus/#/home



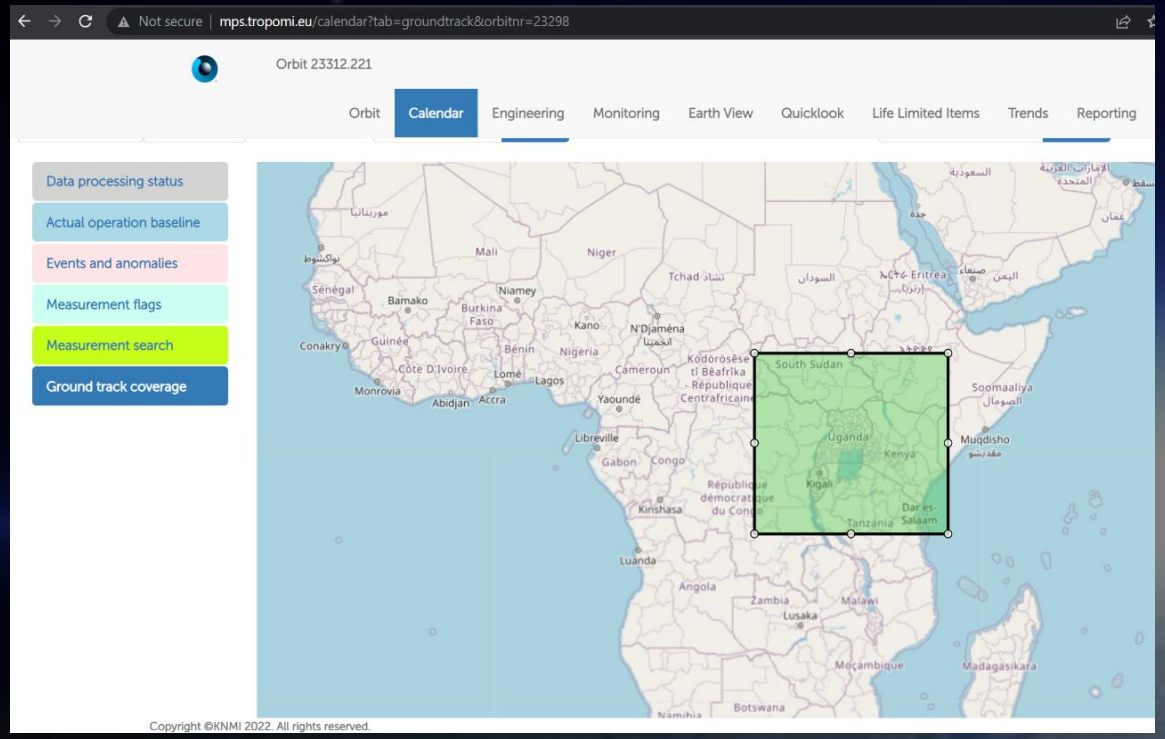


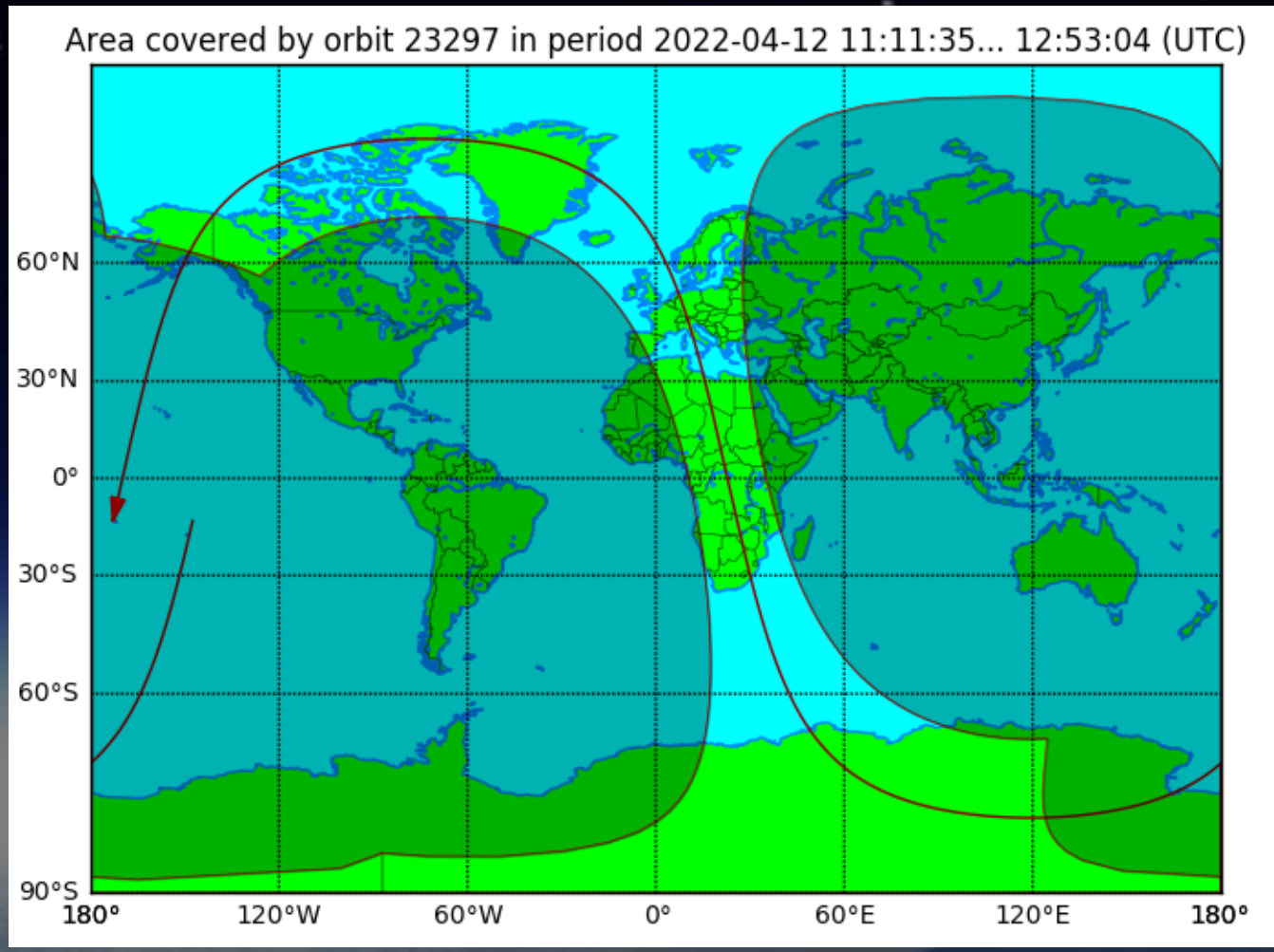
Choosing an orbit number, Where is TROPOMI now?



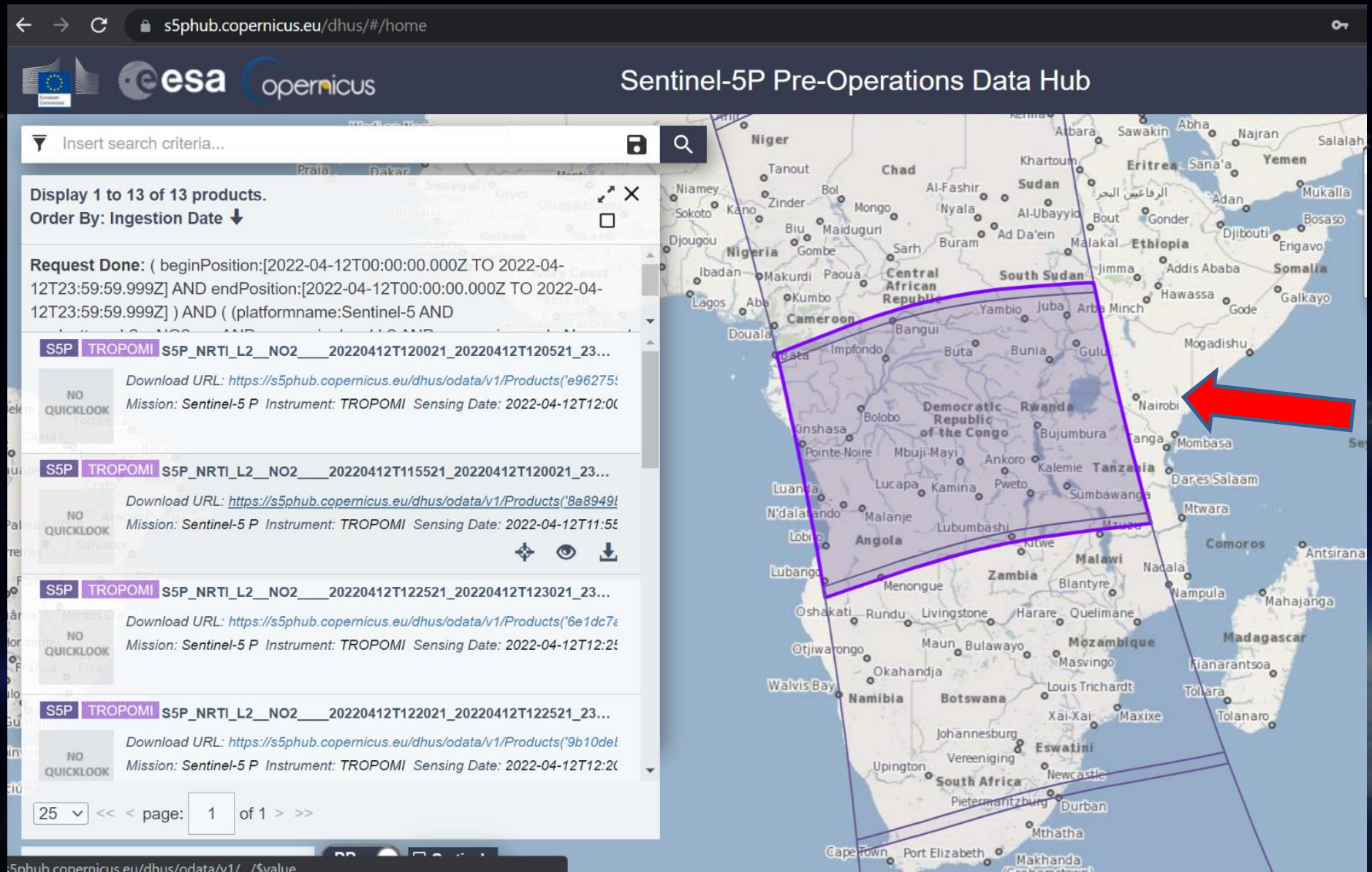
Which Swath, Track, Orbits, or Granule …?

- Where on Earth is my data??
- Orbit-based calendar:
  https://mps.tropomi.eu/calendar
  click on “Ground Track Coverage”





Interacting with the Data Hub



A granule is one part of an orbit

Sentinel 5P/TROPOMI Technical Library

https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-5p/products-algorithms

Documents needed to understand the data

README / PRF

- File structure
- Data Quality filtering
- Known Features
- Version History

ATBD: Technical Algorithm Explanation

PUM: Detailed file structure user manual

Level 2 – User technical documentation

The information needed to properly use the Level 2 data can be found on Table 2:

- **PUM** (Product User Information): information on the technical characteristics of the S5P/TROPOMI Level 2 products
- **ATBD** (Algorithm Theoretical Basis Document): detailed information on the retrieval algorithms
- **IODD** (Input Output Data definition): description of the input and output data of the S5P/TROPOMI Level 2 products
- **PRF** - description of changes between different products versions and overall quality information

More documents are available on the S5P document library.

Table 2: TROPOMI Level 2 geophysical products and user documentation

Product type	Parameter	User Documents
L2__O3___	Ozone (O_3) total column	PRF-O3-NRTI, PRF-03-OF… O3, ATBD-O3, IODD…
L2__O3_TCL	Ozone (O_3) tropospheric column	PRF-03-T, PUM-O… T, IO… D-UPA
L2__O3__PR	Ozone (O_3) profile	PRF…3_PR, IODF… O3_PR, ATB…
L2__NO2___	Nitrogen Dioxide (NO_2), total and tropospheric columns	PRF-NO2, PUM-N… IOD…
L2__SO2___	Sulfur Dioxide (SO_2) total column	PRF-SO2, PUM-SO…, IODD-UPAS
L2__CO___	Carbon Monoxide (CO) total column	PRF-CO, PUM-CO, ATBD-CO, IODD-NL

Sentinel 5P/TROPOMI Technical Library

https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-5p/products-algorithms

1 Summary

This is the Product Readme File (PRF) of the Copernicus Sentinel 5 Precursor Tropospheric Monitoring Instrument (S5P/TROPOMI) nitrogen dioxide (NO_2) Level 2 data product and is applicable for the Near Real Time (NRTI) and Offline (OFFL) timeliness products.

Product Identifier: **L2__NO2___**

Example filename:

S5P_NRTI_L2__NO2____20201007T202447_20201007T220617_15471_01_020200_20210515T213556
S5P_OFFL_L2__NO2____20201007T202447_20201007T220617_15471_01_020200_20210515T213556

The OFFL data product has the following DOI: **http://doi.org/10.5270/S5P-9bnp8q8**

The Readme file describes the current processing baseline, product and quality limitations, and data availability status. More information on this data product is available from the Sentinel product web

https://sentinels.copernicus.eu/web/sentinel/technical-guides/sentinel-5p/products-algorithms,

and from the TROPOMI product webpage http://www.tropomi.eu/data-products.

The data file contains the `nitrogendioxide_tropospheric_column` which gives the atmospheric NO_2 column between the surface and the top of the troposphere. The respective estimate originating from the spectral fit and other retrieval aspects is given in the data `nitrogendioxide_tropospheric_column_precision`. As a user guideline for the data quality, a `qa_value` is provided with the data. In order to avoid misinterpretation of the data quality, it is recommended at the current stage to only use those pixels with a `qa_value` above 0.75 (or above 0.5 in case cloud covered scenes are also of interest).

Note that the NO_2 data product may be used in different ways, and depending on the application, different data fields in the file are relevant. For details on NO_2 data usage, we refer to the product user manual [RD03]. The averaging kernels are provided in the data product file and should be used, e.g., for comparisons with models or profile measurements. Stratospheric NO_2 columns (`nitrogendioxide_stratospheric_column`) and total as well as summed NO_2 columns (`nitrogendioxide_total_column` / `nitrogendioxide_summed_total_column`) are provided. For the stratospheric column, it is recommended at the current stage to use those pixels with a `qa_value` above 0.5. For the total and summed columns, the same recommendation as for the tropospheric column applies.

Note: Starting from processor version 02.02.00, new improved Level 1b version 2.0 data products are used as input [RD05].

2 Processing baseline description

Table 2 contains the history of the NO_2 processor versions. Note that the processor version for NO_2 is changing when there is a change to any of the products belonging to the NL-L2 processor suite (NO2, CO, CH4, AI, ALH, O3 PR) even if the change is not affecting the NO_2 product.

Processor Version	In operation from	In operation until	Relevant improvements
02.04.00	NRTI: orbit 24697, 2022-07-20 OFFL: orbit 24655, 2022-07-17	Current version	– This version makes use of a Directional Lambe climatology derived from TROPOMI observatio OMI and GOME-2 datasets used in versions 1 **Note**: Starting from processor version 2.4.0, new i products are used as input [RD05].
02.03.01	NRTI: orbit 21223, 2021-11-17 OFFL: orbit 21188, 2021-11-14	Orbit 24697, 2022-07-20 Orbit 24654, 2022-07-17	– Few bugs fixed (see section 4.2) – Minor format changes (see section 6.1)
02.02.00	NRTI: orbit 19308, 2021-07-05 OFFL: orbit 19258, 2021-07-01	Orbit 21222, 2021-11-17 Orbit 21187, 2021-11-14	– New O2-O2 cloud algorithm integrated (this is O_2 collision induced absorption around 47 retrieved and stored in the output NO2 produc NO2 slant column to vertical column (AMF ca versions. – The regridded FRESCO cloud parameters are – In the NO_2 window the surface albedo is n fractions while maintaining radiance closure. **T tropospheric NO2 for cloud-free scenes** c cover pixels in version 01.04.00 related to t Similarly, for fully clouded scenes with bright rather than allowing over-unity cloud fraction. – Cloud parameters used for the AMF calculatio NO_2 vertical columns): for every ground pixel, to the 'old' cloud variables. In this version, ve copy of the FRESCO parameters. In the futur FRESCO cloud parameters depending on un best. – Implementation of a 'spike removal' algorithm that are not flagged for saturation or blooming influenced, and on pixels over the South Atlan – Correct the unit of the ghost column in the NR – OFFL only: metadata fix (in Chemistry Transp

Recommendations for how to use the data

3 Product Quality

3.1 Recommendations for data usage

The quality of the individual observations depends on many factors, including cloud cover, surface albedo, presence of snow-ice, saturation, geometry etc. These aspects are taken into account in the definition of the "quality assurance value" (`qa_value`), available for each individual observation, which provides the users of the data with an easy filter to remove less accurate observations. The `qa_value` is a continuous variable, ranging from 0 (error) to 1 (all is well). The main flag for data usage is as follows:

For the variables `nitrogendioxide_tropospheric_column`, `nitrogendioxide_total_column`, `nitrogendioxide_summed_total_column`:

- `qa_value` > 0.75

  This is the recommended pixel filter. It removes cloud-covered scenes (cloud radiance fraction > 0.5), partially snow/ice covered scenes, errors, and problematic retrievals.

- `qa_value` > 0.50

  Compared to the stricter filter, this adds the good quality retrievals over clouds and over scenes covered by snow/ice. Errors and problematic retrievals are still filtered out. In particular, this filter may be useful for assimilation and model comparison studies.

For variable `nitrogendioxide_stratospheric_column`:

- `qa_value` > 0.50

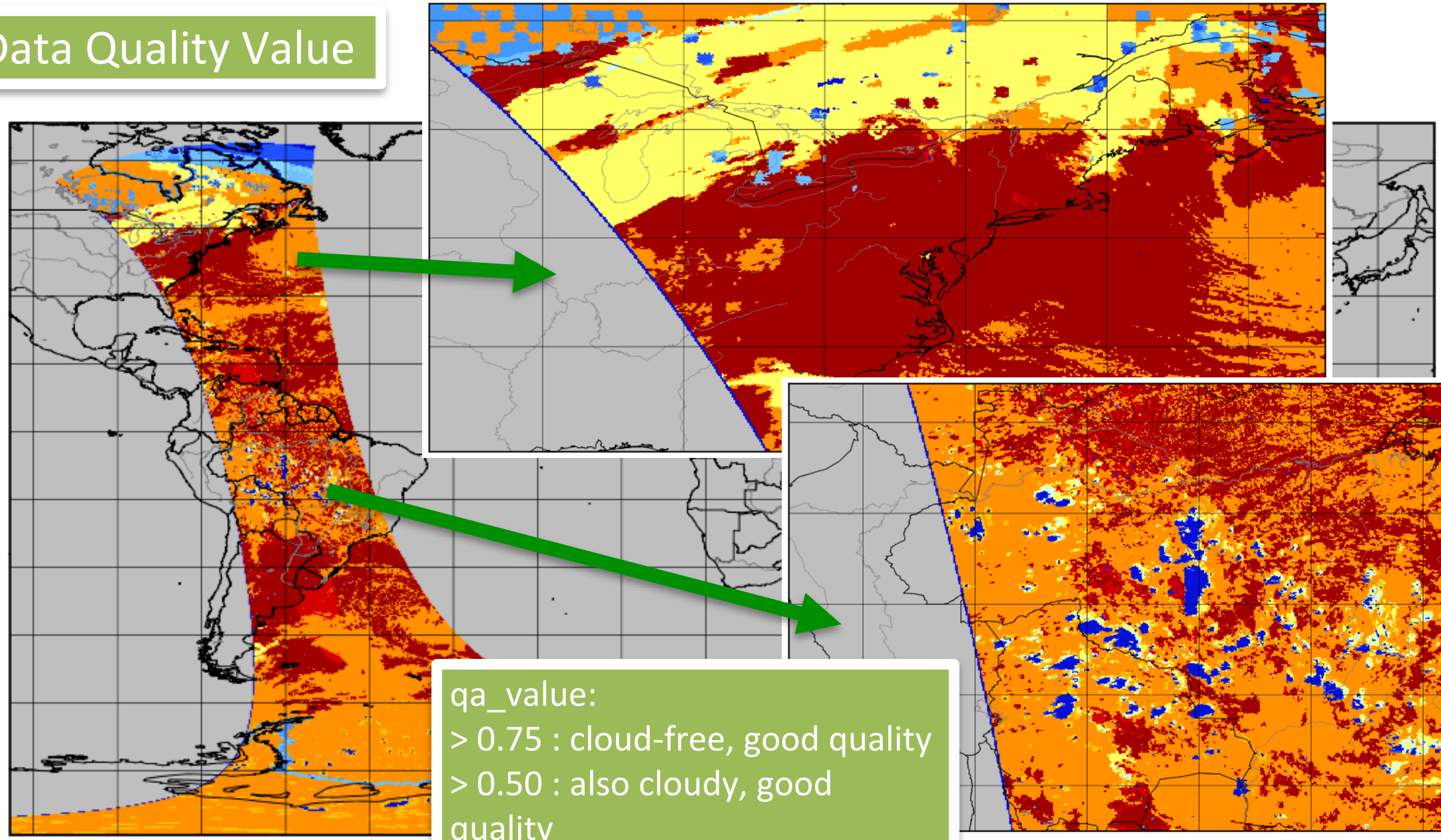
For further details, data users are encouraged to read the Product User Manual (PUM) and Algorithm Theoretical Basis Document (ATBD) associated with this data product, available on https://sentinels.copernicus.eu/web/sentinel/technical-guides/sentinel-5p/products-algorithms.

3.2 Validation results

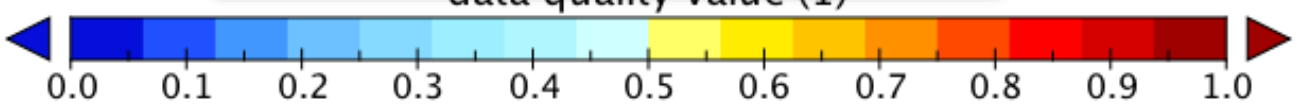
3.2.1 Status of product validation

Independent preliminary validation by S5p MPC Cal/Val experts and the S5PVT concludes that NRTI / OFFL NO_2 data is in overall agreement with (i) reference measurements collected from global ground-based networks, (ii) the corresponding satellite data products from OMI, and (iii) is compliant with the requirements as defined in S5p Calibration and Validation Plan [RD01], see Table 1.

Data Quality Value



qa_value:
> 0.75 : cloud-free, good quality
> 0.50 : also cloudy, good quality



Quality Overview, Quicklooks, and Summary Stats for TROPOMI data on a Daily basis

S5P - Mission Performance Centre - Level 2 Quality Control Portal

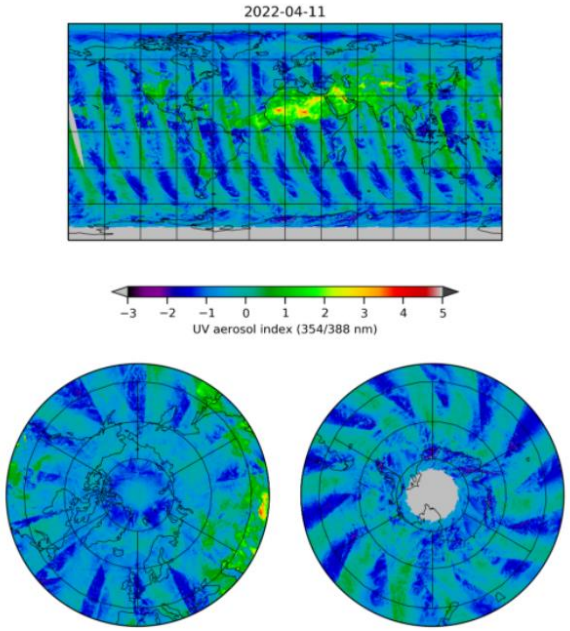
Help

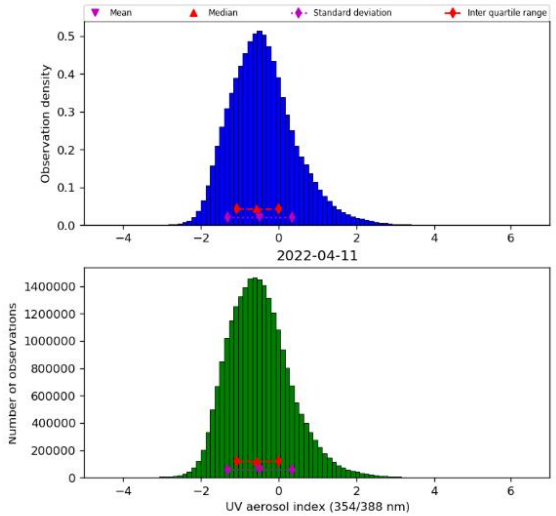
Previous day | Next day | Month | Week | Day | 2022-04-11 | Submit | OFFL | NRTI

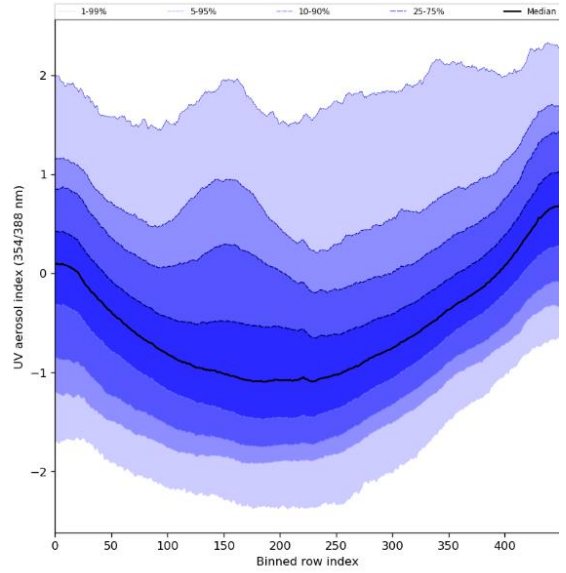
- AER_AI
- AER_LH
- CH4___
- CLOUD_
- CO____
- FRESCO
- HCHO__
- NO2___
- O3____
- O3__PR
- O3_TCL

Extracted QC data
Daily report

https://mpc-l2.tropomi.eu/#aer_ai







Quality Overview, Quicklooks, and Summary Stats for TROPOMI data on a Daily basis

S5P - Mission Performance Centre - Level 2 Quality Control Portal

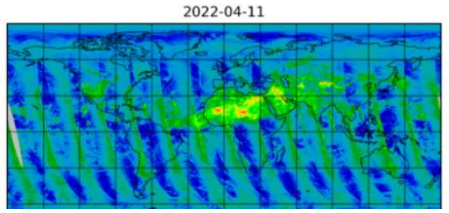
Help

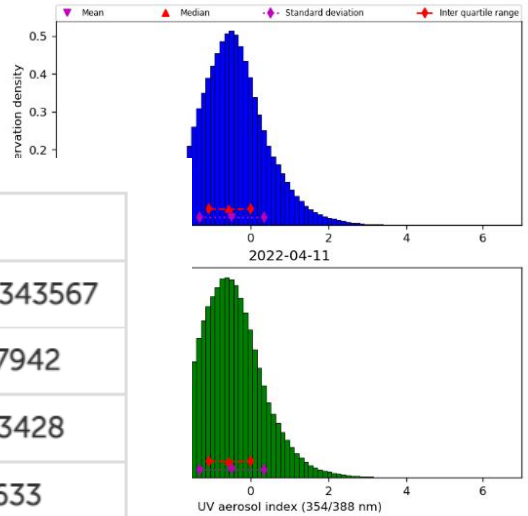
Previous day | Next day | Month | Week | Day | 2022-04-11 | Submit | OFFL | NRTI

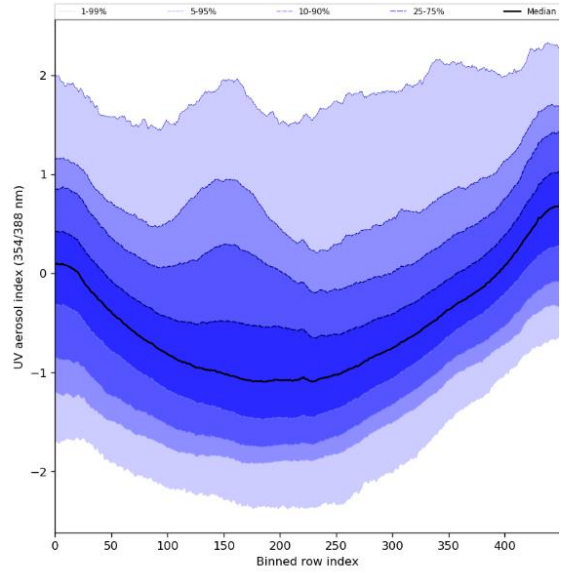
AER_AI
AER_LH
CH4___
CLOUD_
CO____
FRESCO
HCHO__
NO2___
O3____
O3__PR
O3_TCL

Extracted QC data
Daily report

https://mpc-l2.tropomi.eu/#aer_ai







aerosol_index_354_388_count	24014867
aerosol_index_354_388_mean	-0.48804953694343567
aerosol_index_354_388_standard_deviation	0.8271353840827942
aerosol_index_354_388_min	-6.030690670013428
aerosol_index_354_388_max	34.72804641723633
aerosol_index_354_388_median	-0.5554167628288269
aerosol_index_354_388_inter_quartile_range	1.062771845376119
aerosol_index_354_388_mode	-0.6200000047683716

More TROPOMI Tools & Resources via tropomi.eu

https://www.tropomi.eu/tools

https://www.giss.nasa.gov/tools/panoply/

Tools

HOME | MISSION STATUS

DOCUMENTATION
TOOLS
PUBLICATIONS
GALLERY
OUTREACH
LINKS

S5P-PAL - Visualization & mapping website for T

Atmospheric Toolbox - This site aims to provide analyzing atmospheric remote sensing data. Som 5P), Aeolus, GOME-2 (MetOp), and OMI (Aura). T such as provided by EVDC. The user forum also p

Panoply - Visualization tool designed to plot geo be used to view the TROPOMI data file structure.

Working with netCDF data - TROPOMI data uses for manipulating or displaying netCDF data and i used with netCDF data. Note: not all netCDF too

PyCAMA - A python-based tool designed to anal (Correlate Everything with Everything). The PyCA of the output from level 2 retrieval algorithms. It between all given parameters are calculated (her data processing facility to extract key data quality

HARP - Software designed to serve as a data har tranform TROPOMI data into so-called Level 3 d example, QGIS.

ADAGUC - Another visualization tool design curr
Datasets from different instruments are converted to the ADAGUC data product standard format and are made available to other users by using the OGC Web Services. Satellite swath data can be retrieved using the Web Feature Service. Using the Web Services it is possible to reproject, resample and make selections in space and time.

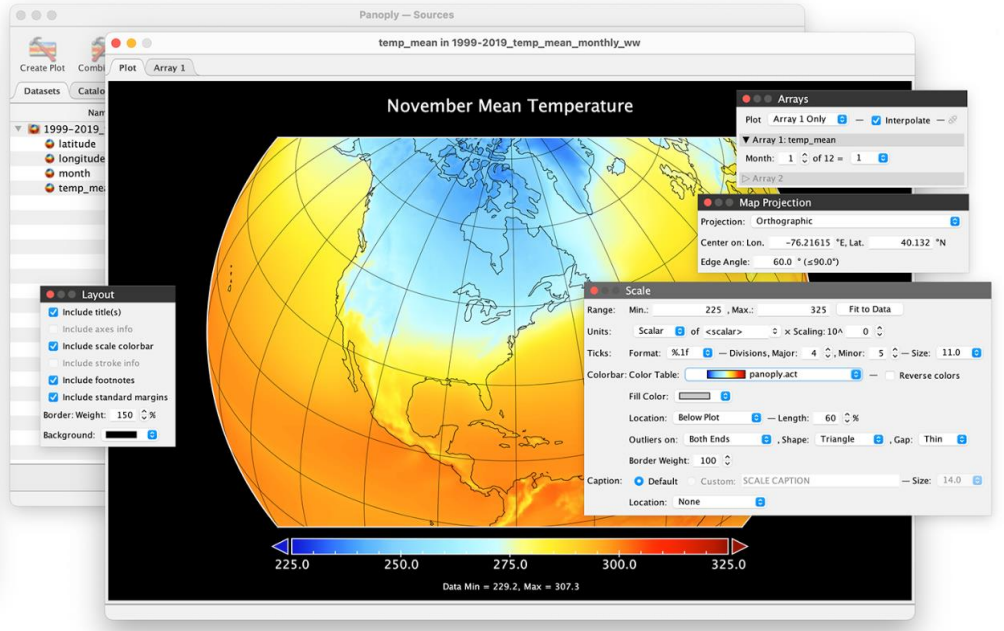
National Aeronautics and Space Administration
Goddard Institute for Space Studies

Goddard Space Flight Center
Sciences and Exploration Directorate
Earth Sciences Division

GISS Home
News & Features
Projects & Groups
Datasets
Publications
Software
Education
Events
About GISS

Panoply netCDF, HDF and GRIB Data Viewer

panoply \PAN-uh-plee\, noun: 1. A splendid or impressive array. ...



List of TROPOMI-relevant online resources:

- **Data Download Hub(s)**: https://dataspace.copernicus.eu/ (new) or https://s5phub.copernicus.eu
- Level 1 TROPOMI portal for satellite location, RGB images and much more

  -- Orbit visualization: https://mps.tropomi.eu/orbit; Quicklooks for RGB and more: https://mps.tropomi.eu/earthview

  -- Ground Track coverage maps of each orbit: https://mps.tropomi.eu/calendar
- Level 2 data quality site for quicklooks on a global scale, also for advanced statistics

  – Daily global maps and statistics per L2 data product https://mpc-l2.tropomi.eu/
- TROPOMI Validation visualization & analysis site (VDAF) - https://mpc-vdaf.tropomi.eu/

  – Comparison of TROPOMI data with reference ground sites around the world
- EVDC for orbit prediction, overpass information etc. for support of site-based studies https://evdc.esa.int/ → Campaign-based validation data sets also available here

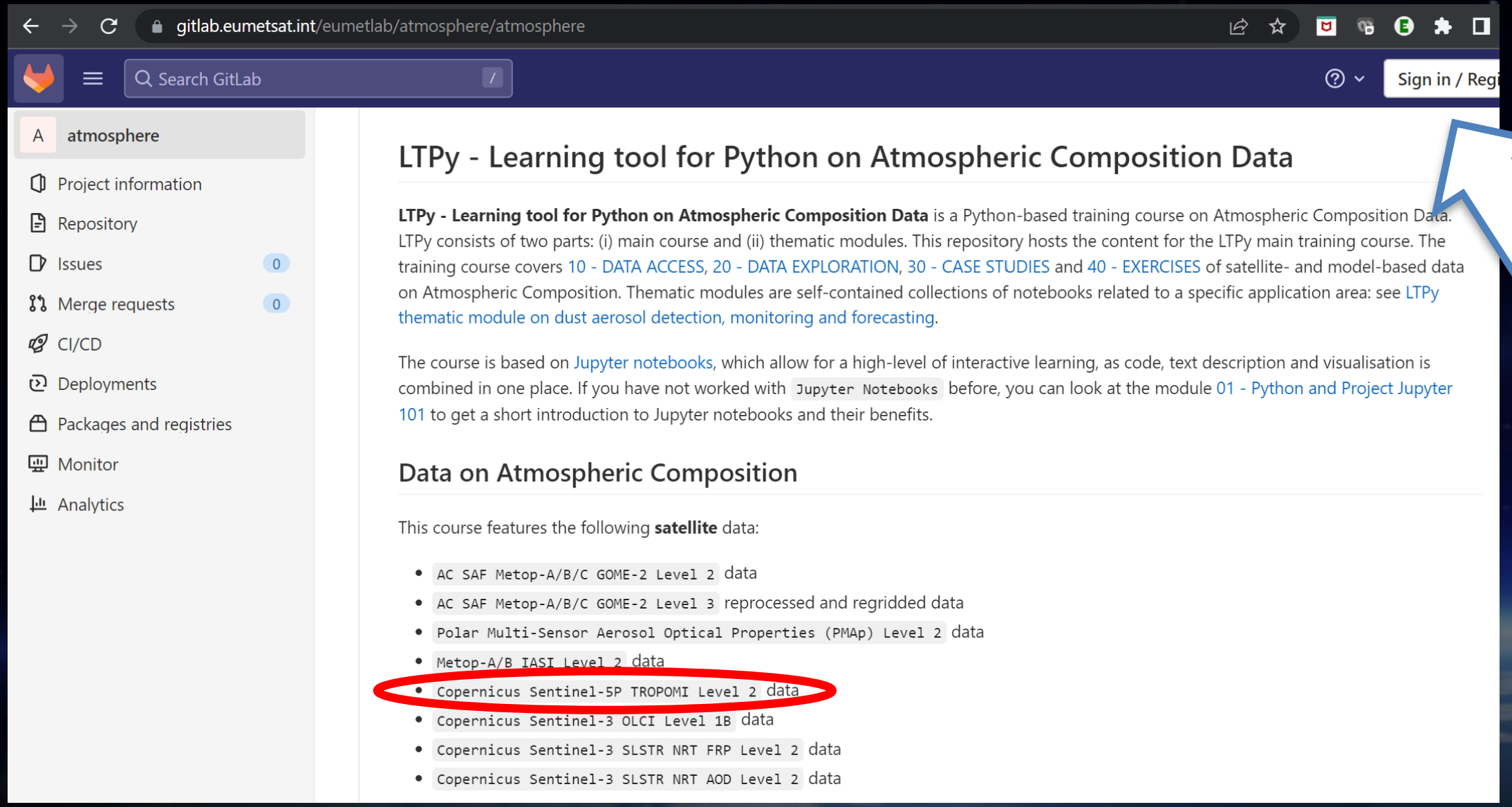
Additional Visualization Sites

- S5P-PAL visualization site features 2-week averages to take meteorological variability into account so that the user can better compare time periods: https://maps.s5p-pal.com/
- Sentinel EO browser: https://www.sentinel-hub.com/explore/eobrowser/ ; ACOM Worldview - https://worldview.acom.ucar.edu/
- Terrascope.be – Visualization Tool and Mapping Site

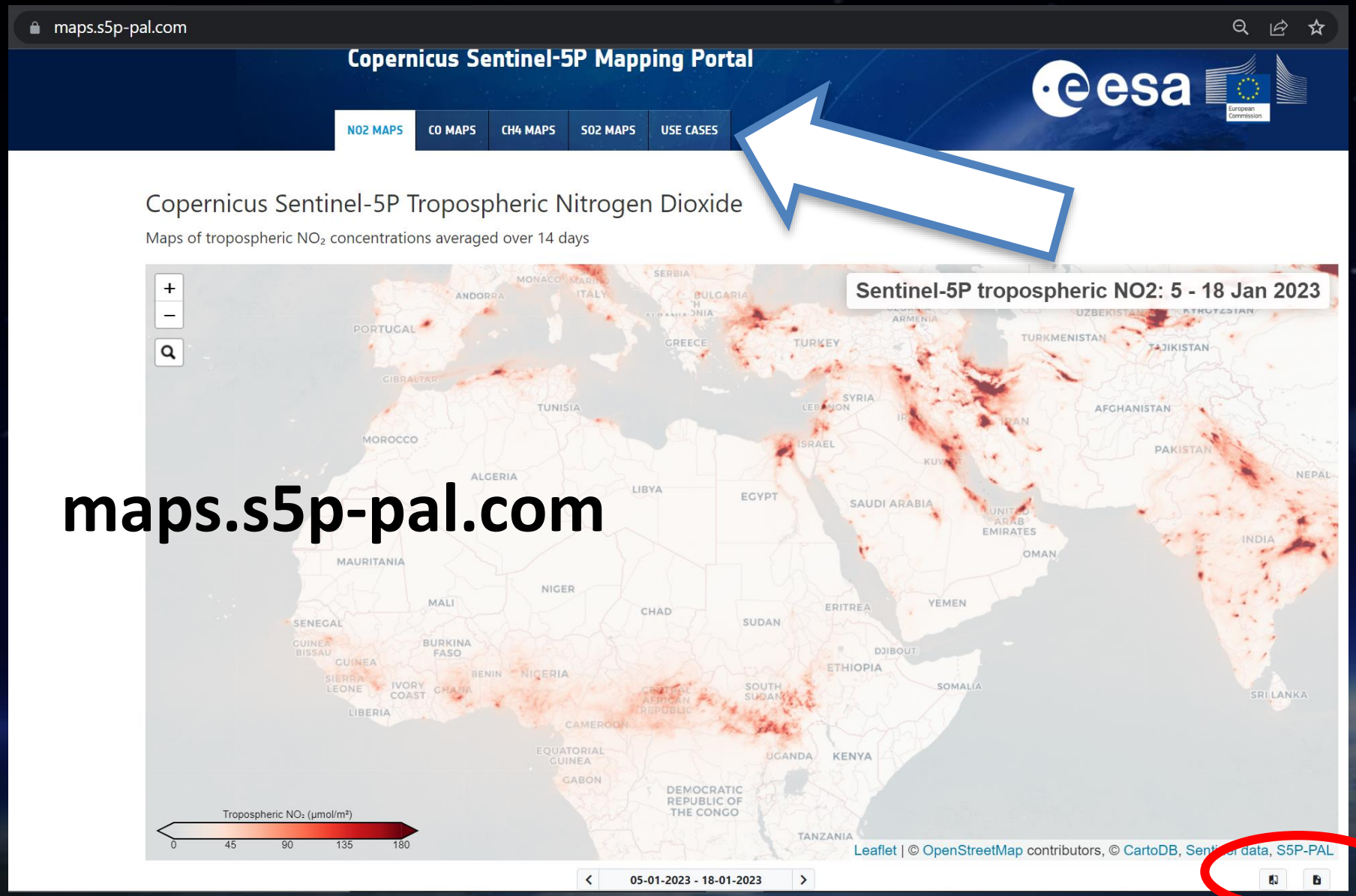
TRAINING Modules, including Jupyter Notebooks:

- EUMETSAT https://gitlab.eumetsat.int/eumetlab/atmosphere/atmosphere
- Copernicus Atmospheric Visualization Toolbox available via https://dataspace.copernicus.eu/ or https://s5phub.copernicus.eu

EUMETSAT Training Resources including Jupyter notebooks



S5P-PAL system – TROPOMI mapping & data



maps.s5p-pal.com

S5P-PAL Data Portal – access to prototype algorithms

TROPOMI

Root / Sentinel-5P

Sentinel-5P (sentinel-5p)

https://data-portal.s5p-pal.com/cat/sentinel-5p/catalog.json

Sentinel-5P products generated by the S5P-PAL service

Collections | Catalogs | Items | Links

Title
S5P_L2__NO2___
S5P_L2__AER_OT
S5P_L2__BRO___
S5P_L2__TCWV__
S5P_L2__CHOCHO
S5P_L2__SO2CBR
S5P_L2__SIF___
S5P_L2B_SIF___

S5P PAL

S5P-PAL Data Portal

This is the dissemination site for data products generated by Sentinel 5P processors running in S5P-PAL.

Products

The following products are currently made available publicly via this portal:

product	description
NO2	reprocessed NO2 data from April 2018 - September 2021 using a consistent version of the official L2 processor
AOT	pre-operational AOT data, starting from July 2018, new products updated daily
BrO	pre-operational BrO data, starting from May 2018, new products updated daily
TCWV	pre-operational TCWV data, starting from May 2018, new products updated daily
CHOCHO	pre-operational CHOCHO data, starting from July 2022, new products updated daily
SO2 COBRA	pre-operational SO2 COBRA data, starting from July 2022, new products updated daily

Browse S5P-PAL products

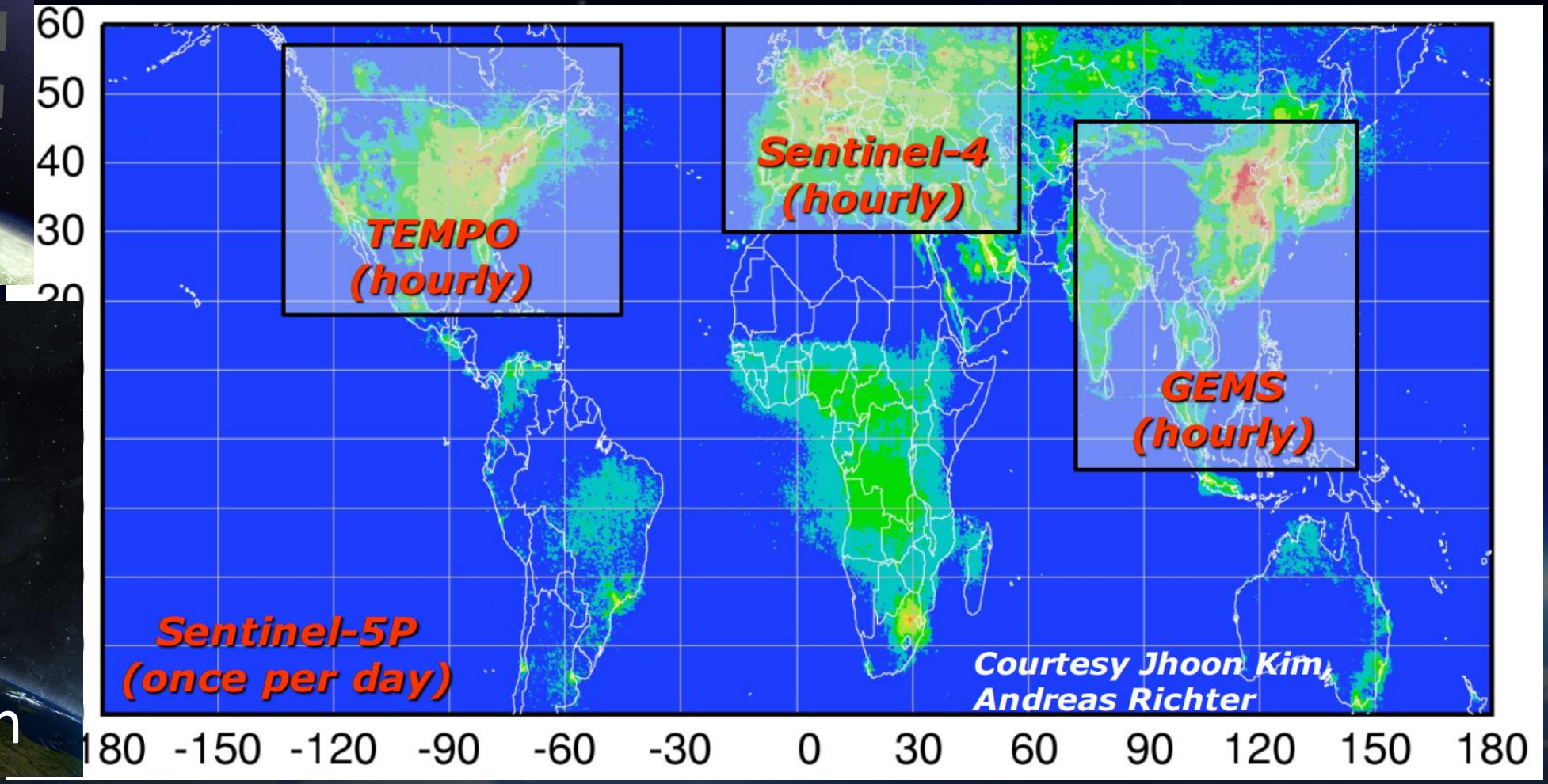
API info

TROPOMI acts as a base map to a host of missions

Constellation of current and future GEO, LEO, & small satellites

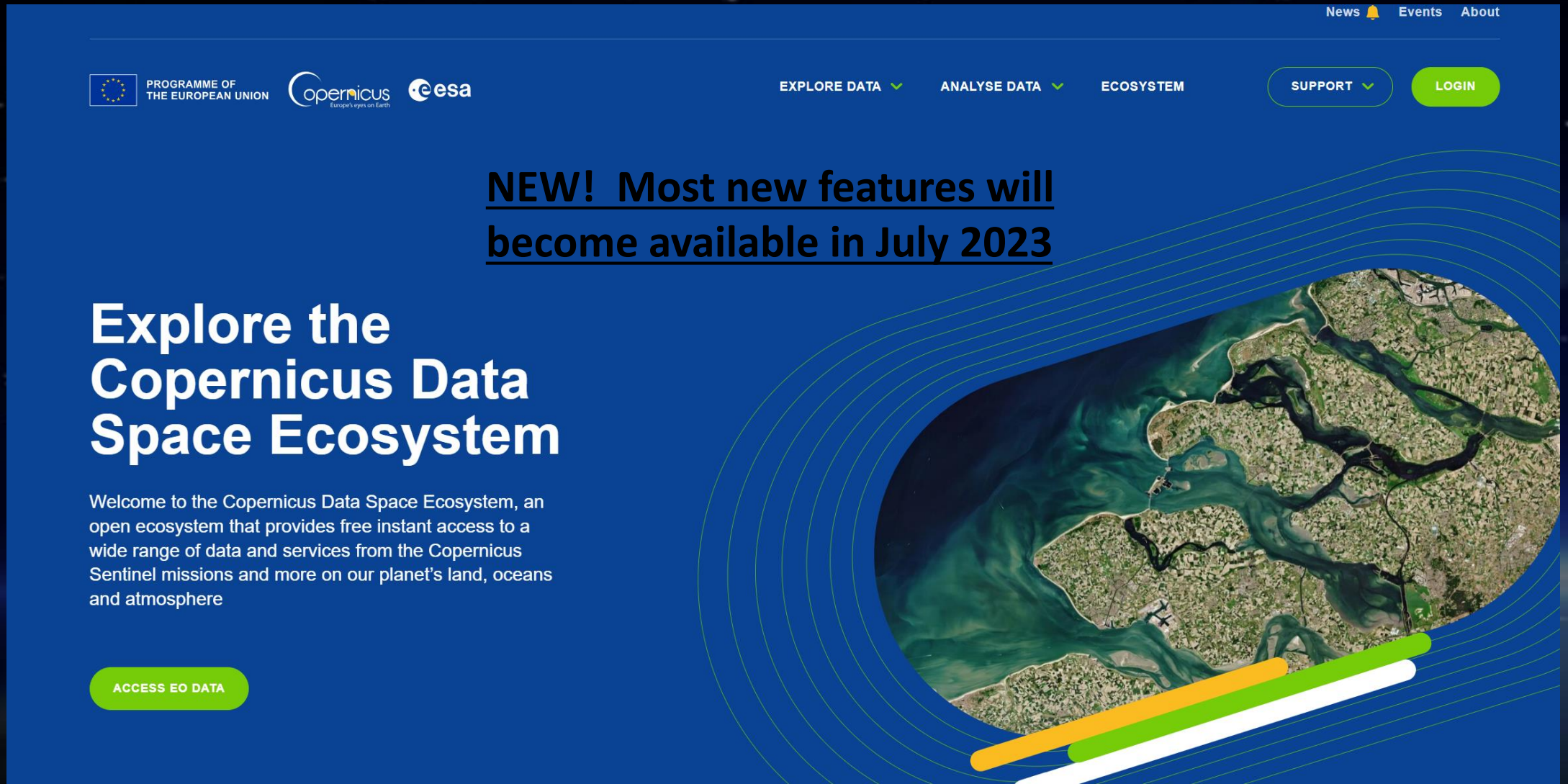
FLEX - Mission

CO2M - Mission



NEW!! Copernicus Data Ecosystem – *Feedback welcome!!!*

https://dataspace.copernicus.eu/ → Create a personal login



Thanks for your attention!!

deborah.steinzweers@knmi.nl

- Feel free to reach out with your questions for the TROPOMI teams

- American-Dutch satellite scientist using TROPOMI for air quality monitoring, validation, & outreach
- ***Main Role:*** Technical Manager of the TROPOMI Mission Performance Center (**ATM-MPC**)
- ***Interest:*** How can we make open TROPOMI data better a to global users?

Background:

- Meteorology, B.S., Environmental Sciences, PhD.
- Worked at KNMI and NASA-Goddard

Acknowledgements

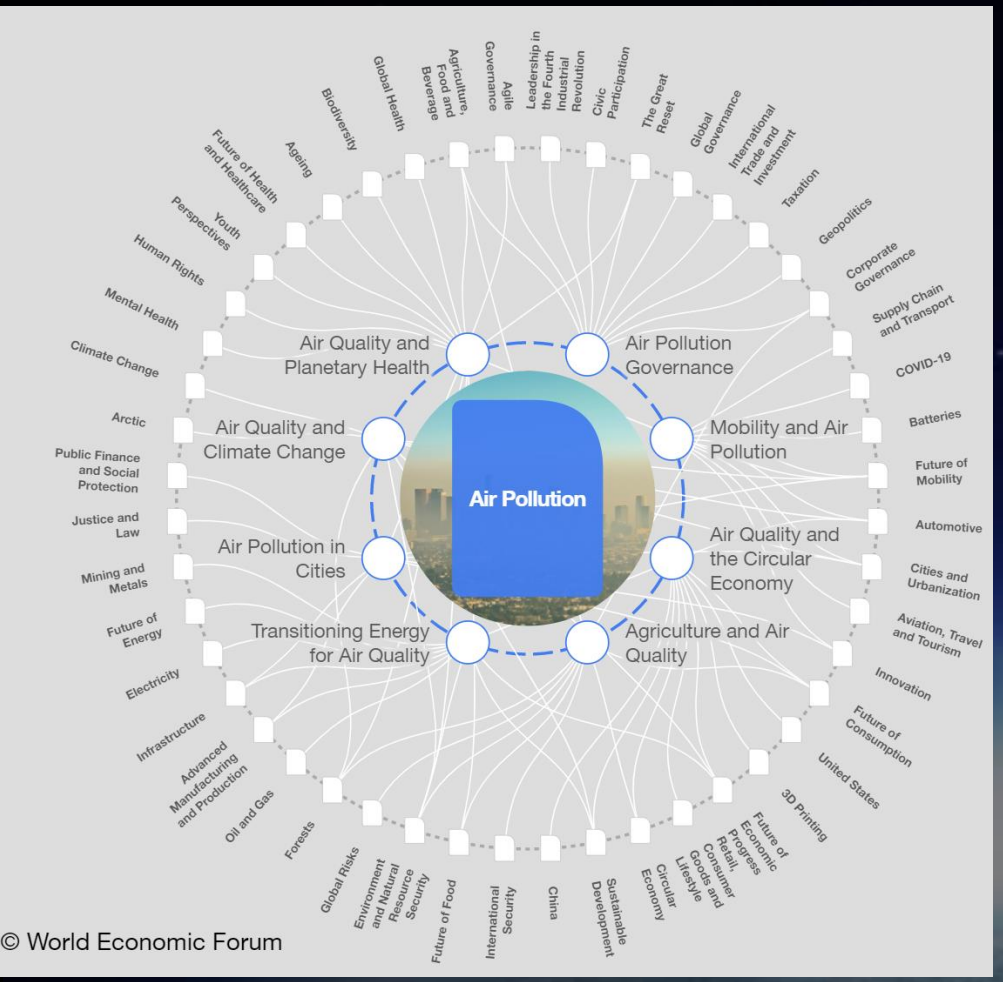
- TROPOMI efforts funded by:
  - Netherlands Space Office (NSO)
  - European Space Agency (ESA)

- https://www.tropomi.eu
- **Instagram**: knmi_nl
- **Twitter**: @tropomi

Ministry of Infrastructure and Water Management

EXTRA SLIDES

Air Quality is just the beginning…



What can TROPOMI do?

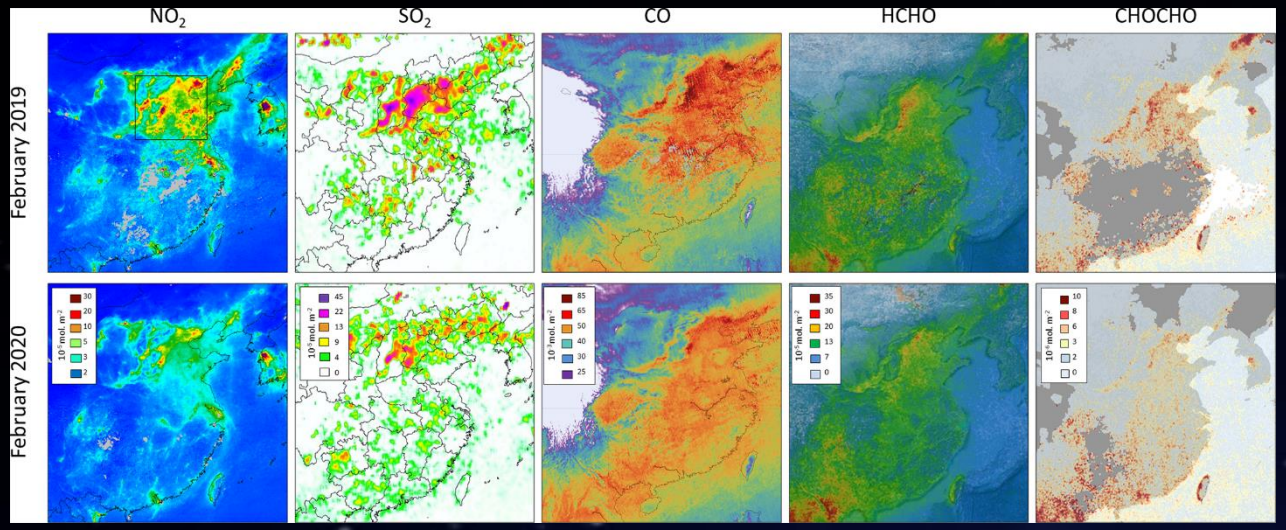
- **Compelling visuals:** Describe AQ changes over time and in space, from global to city-level for a variety of trace gas species relevant for understanding health impacts
  - Demonstrate policy-driven AQ improvements, ex. Before/after scrubber installation, effects of car-free days;
  - Pinpoint structural & incidental **Hotspots**, ex. CH4 gas leaks
- Can be used to **calculate satellite-based emissions** with additional model and source information
  - Emissions help to better enter the realm of policy & AQ standards
- **Complement & Contextualize** ground-based measurements including low-cost sensor networks
- **Climate Change** pieces of the puzzle: Methane (CH_4), and NO_2 data can be use as a proxy for CO_2
- Further insights about **carbon cycling** and link to the biosphere with measurements of Solar-Induced Fluorescence (**SIF**) indicative of vegetative productivity, Anteneh tomorrow

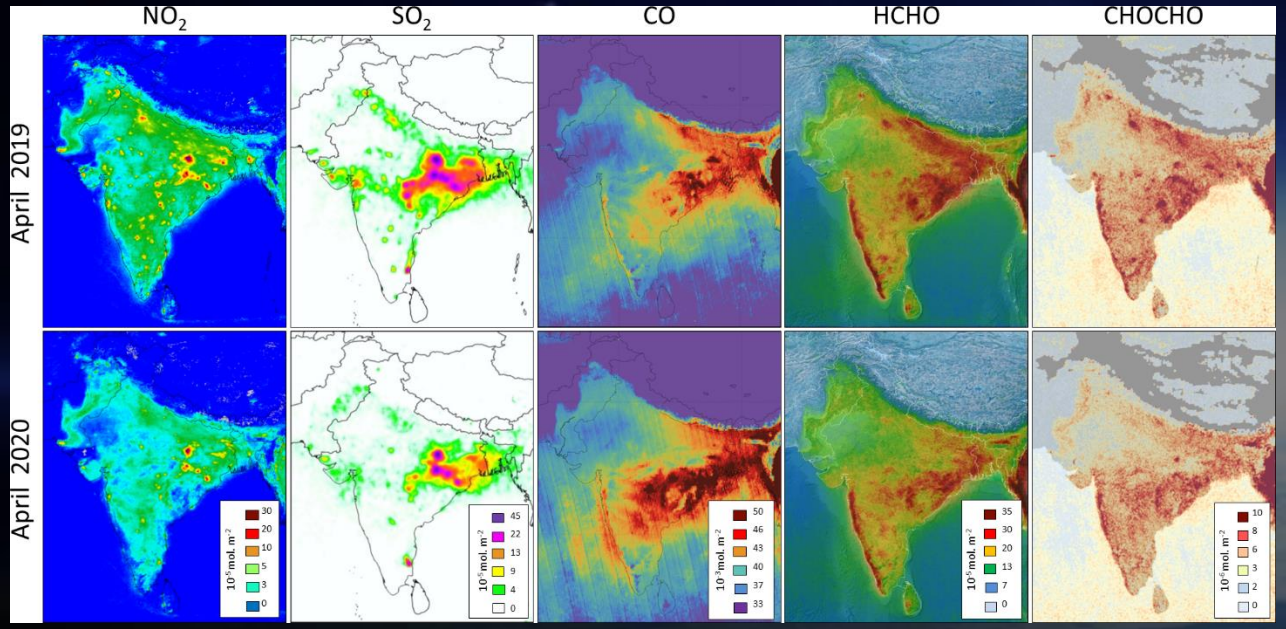
Mapping and Creating Time Series

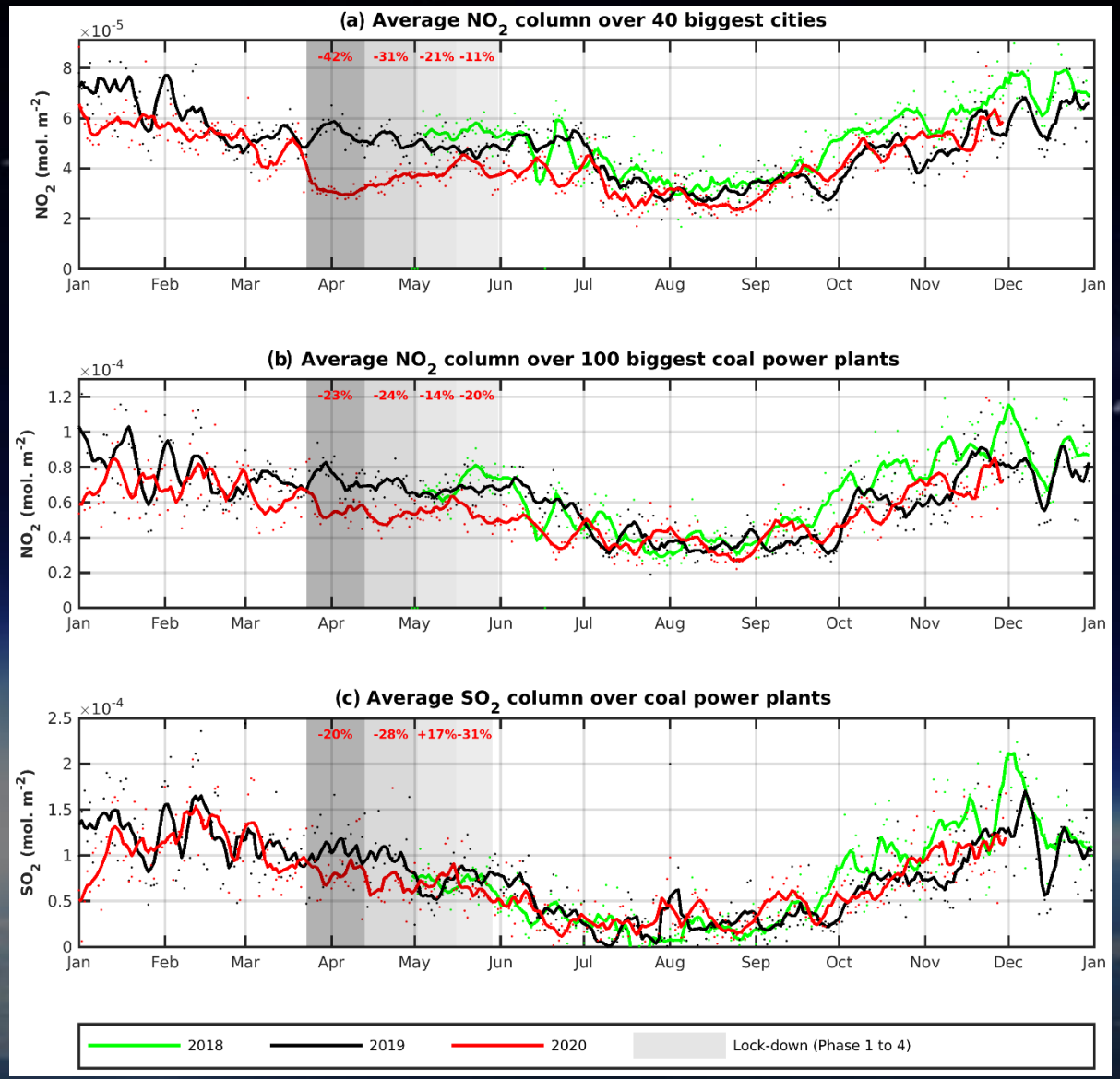
- Example of simultaneous evaluation of multiple species

COVID-19 Lockdown Periods: Rapid impact on AQ

TROPOMI

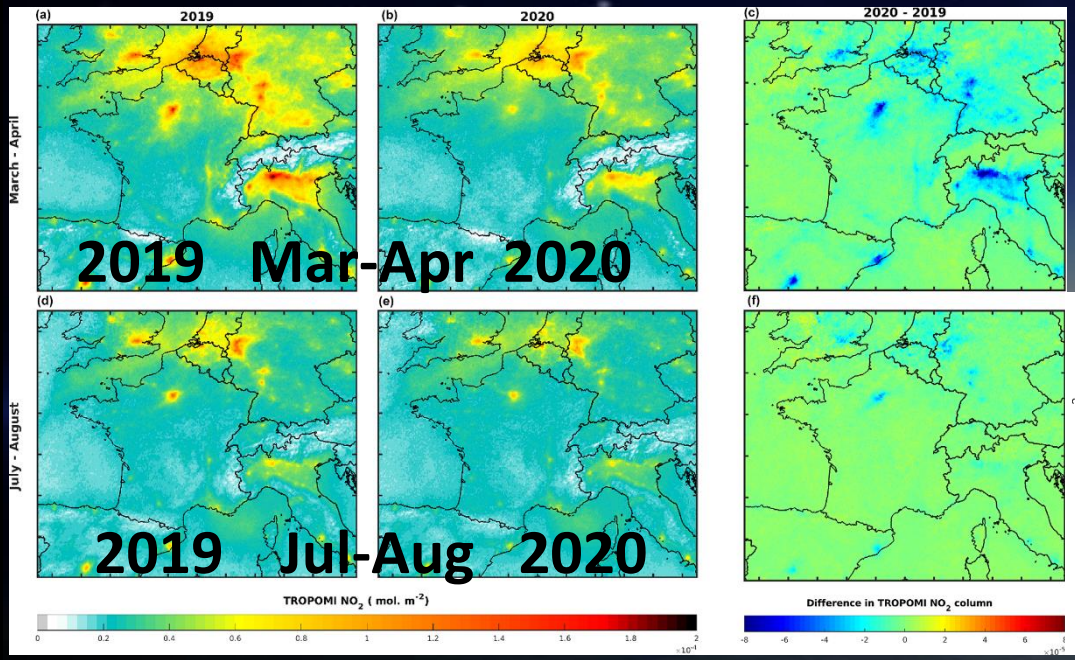


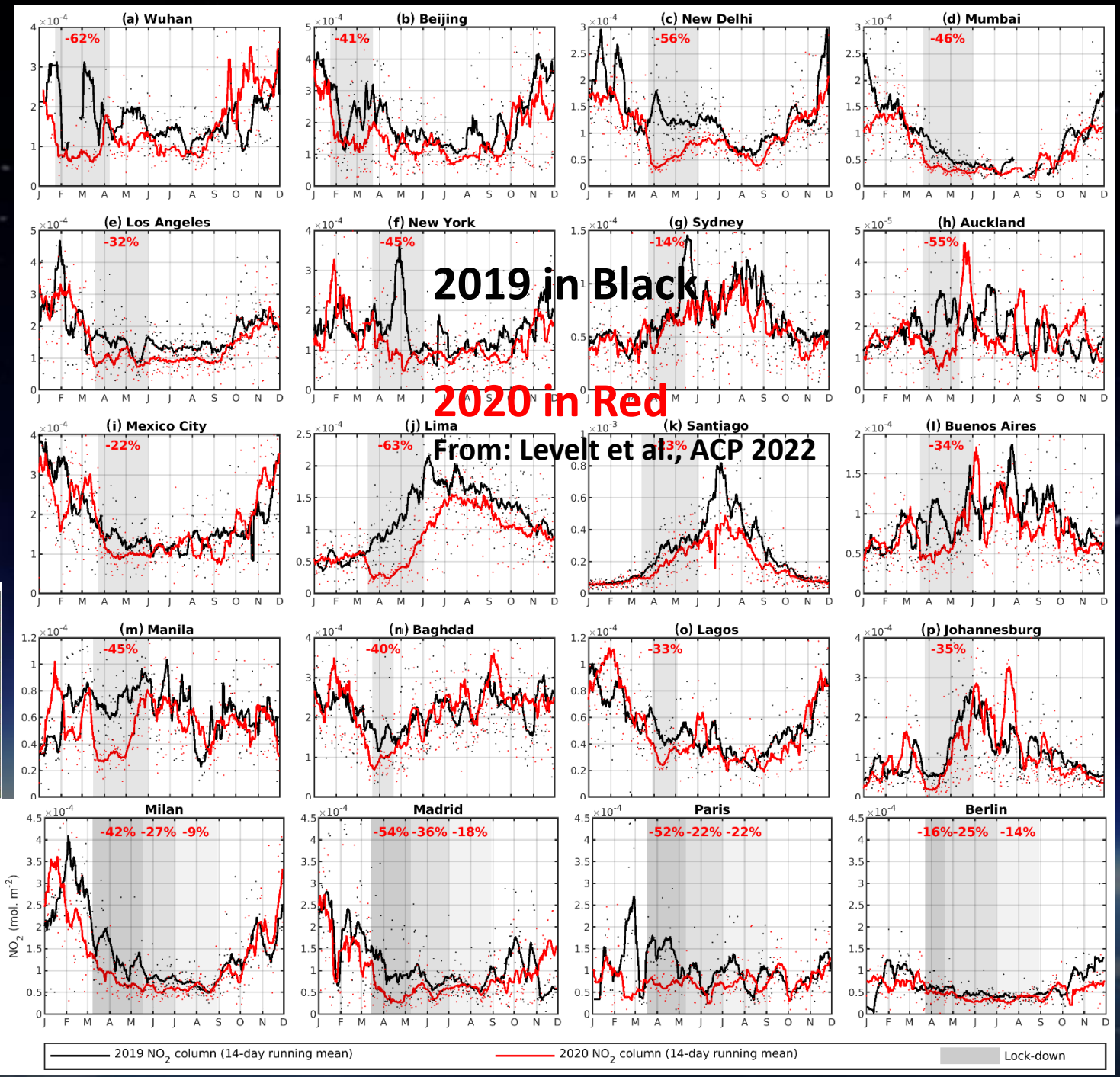




COVID-19 Lockdowns: Rapid AQ Impacts measured by TROPOMI

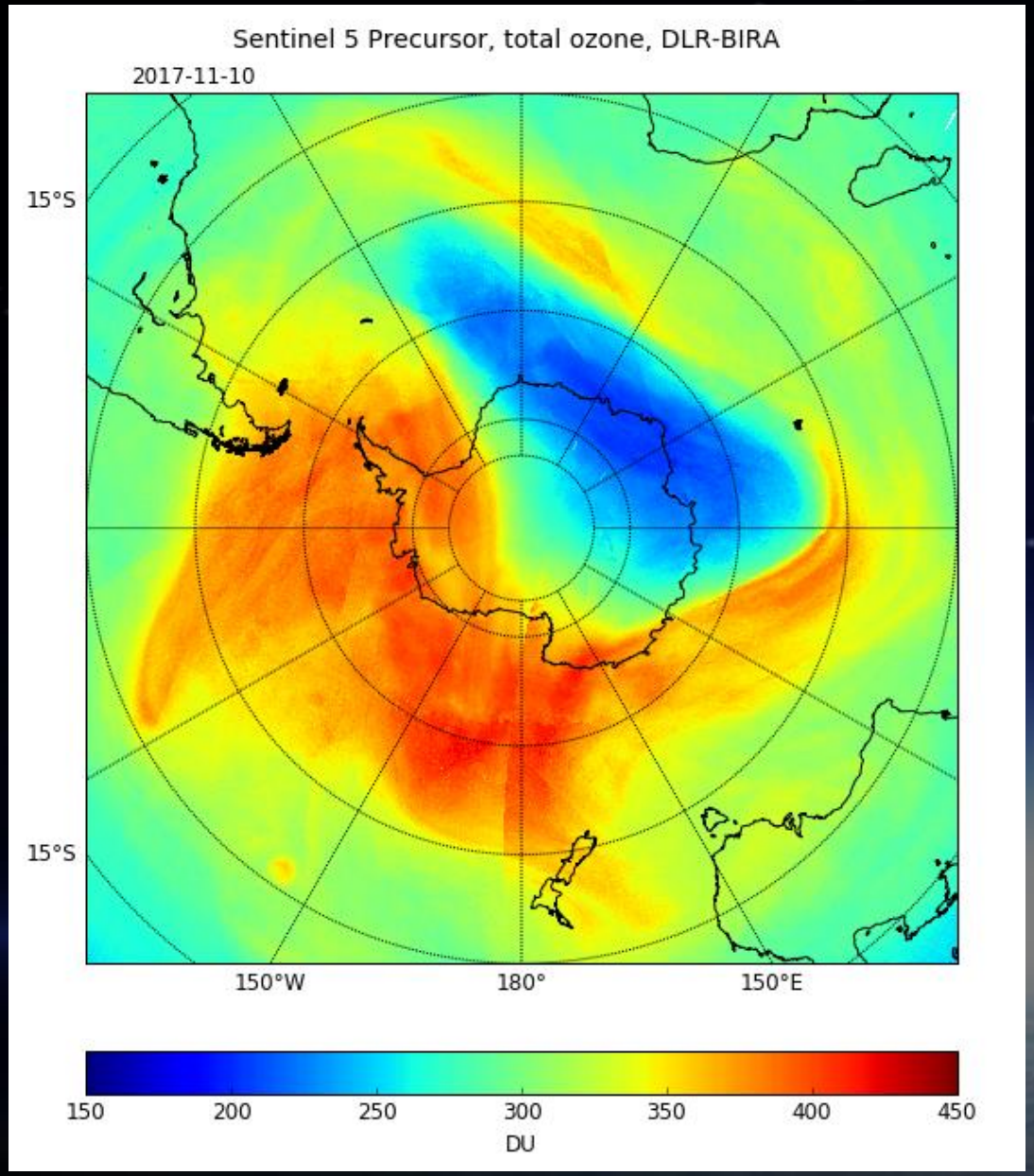
The short lifetime of NO_2 is ideal capturing quick changes in emissions from industry, transport & power generation (all sectors heavily impacted by lockdowns)

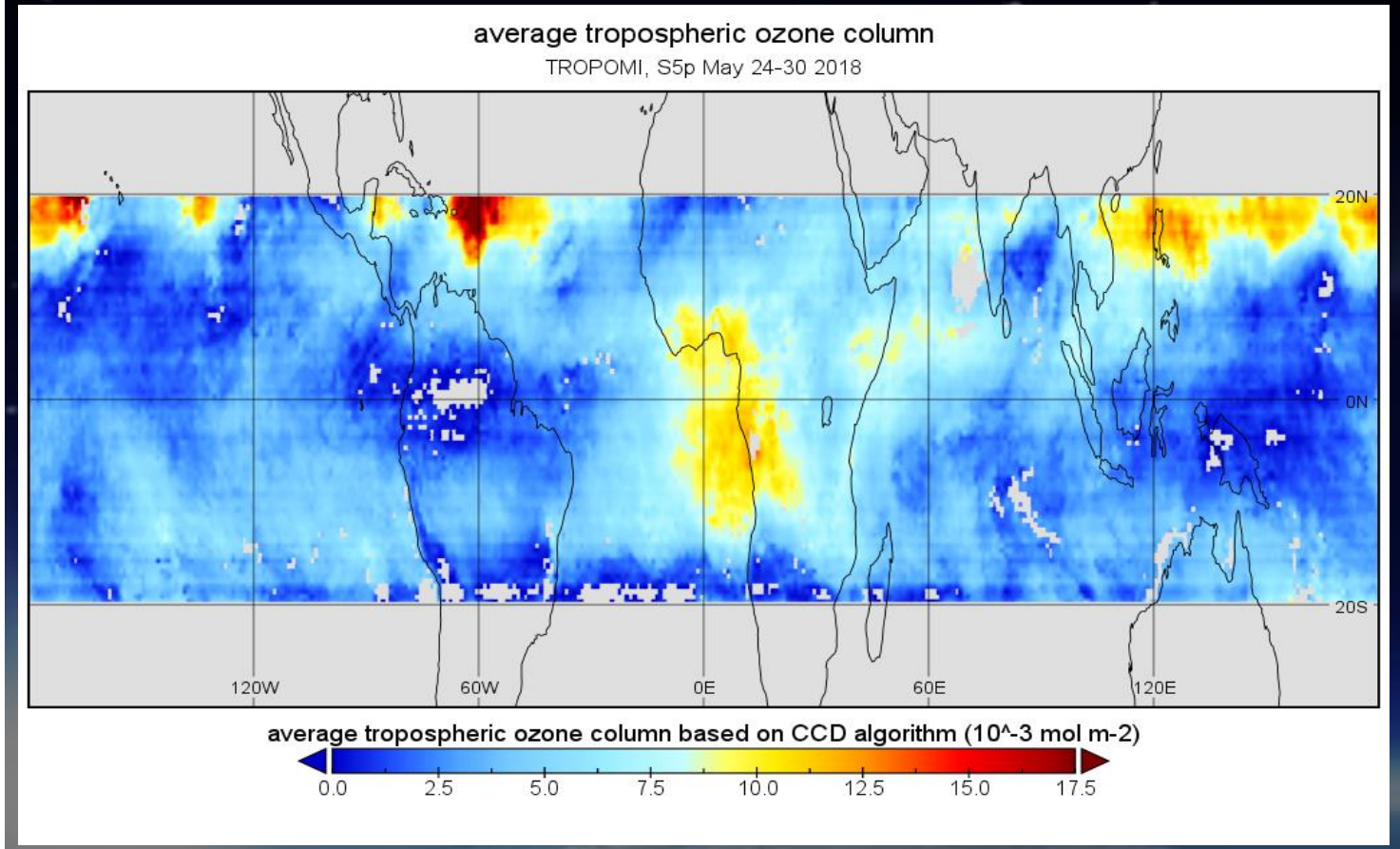




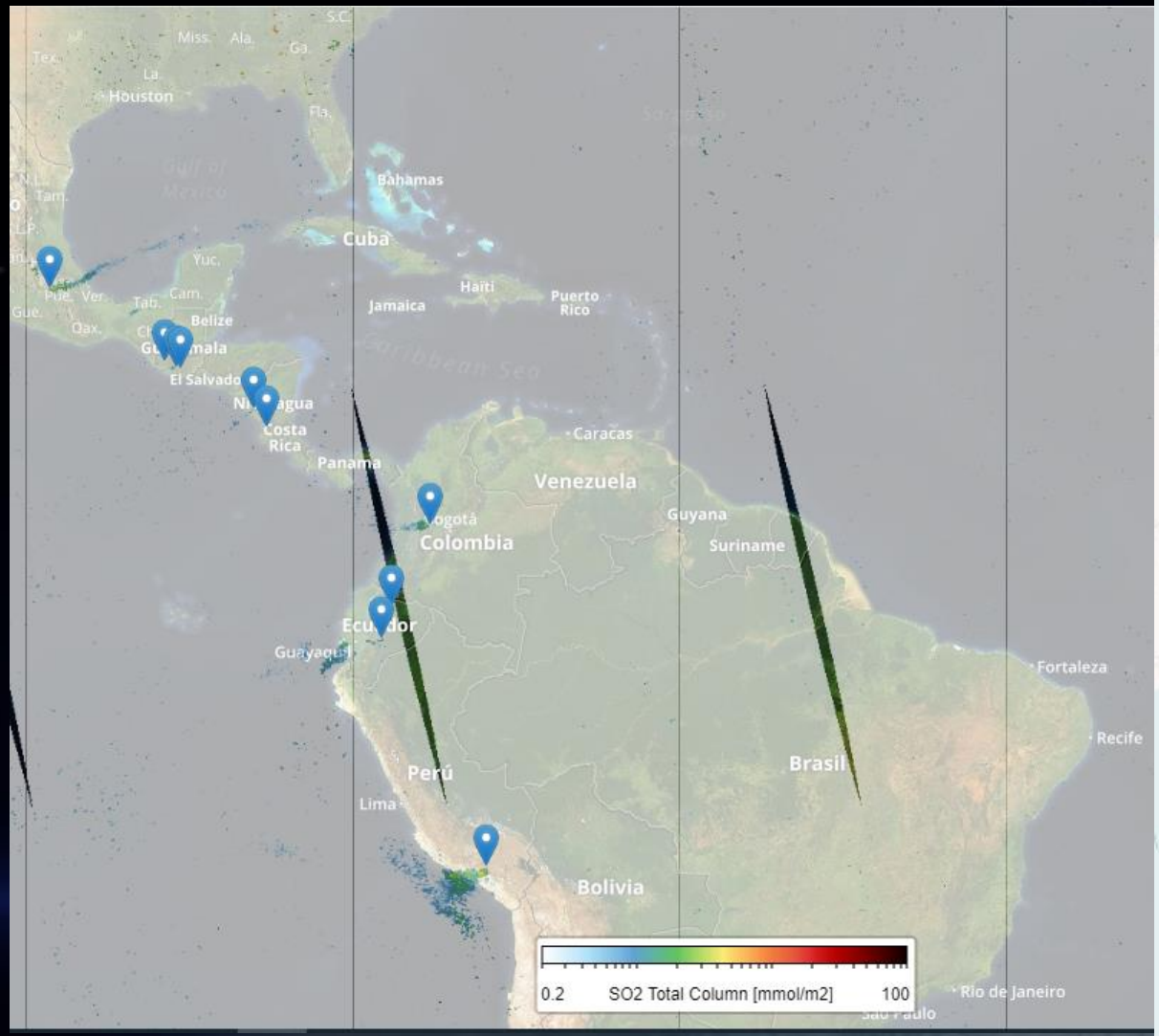
OVERVIEW OF TROPOMI L2 DATA PRODUCTS

TROPOMI Ozone data products: stratosphere & troposphere

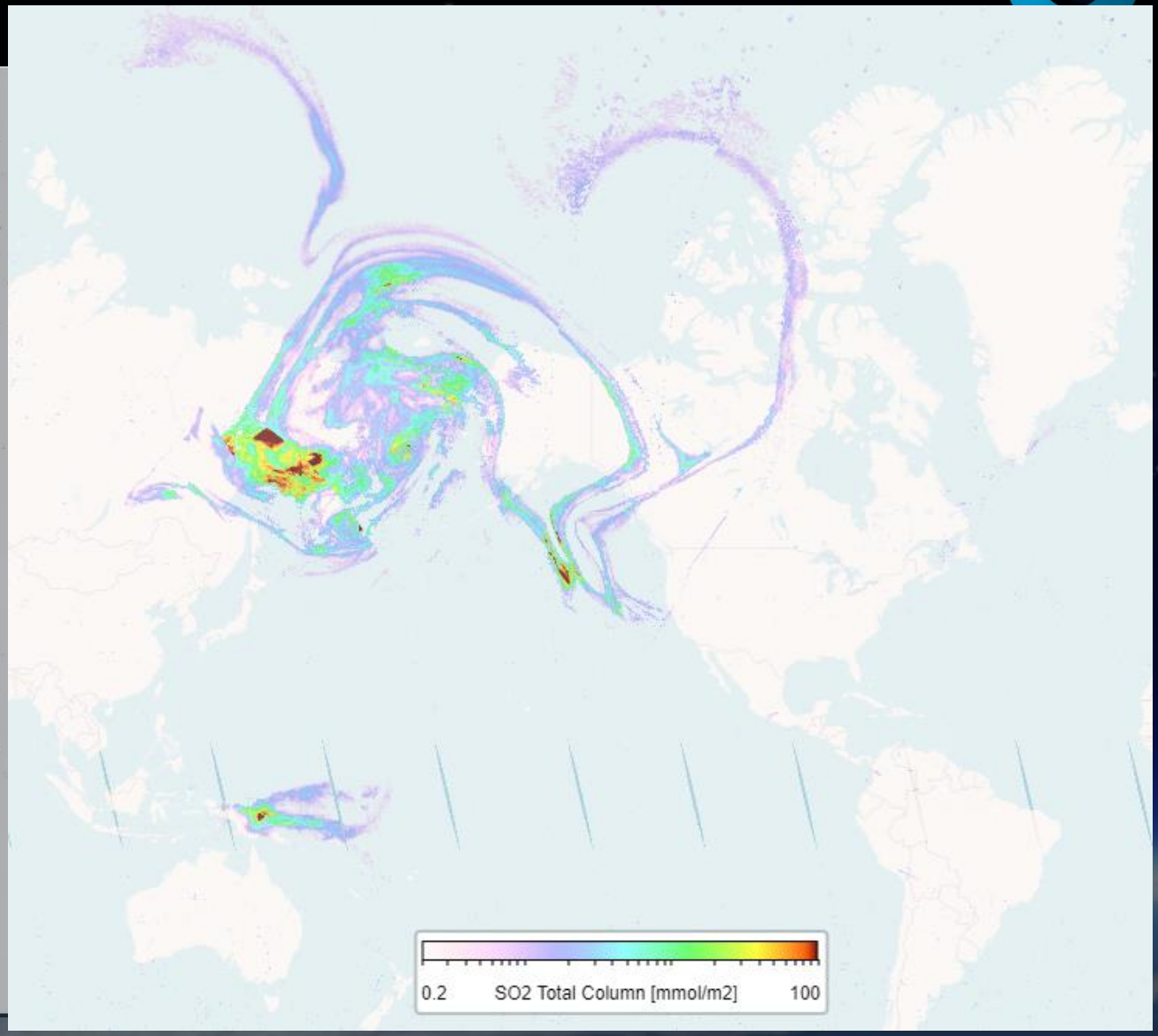




Sulfur Dioxide (SO2): 2019 Volcanic Emissions, Small & Large sources

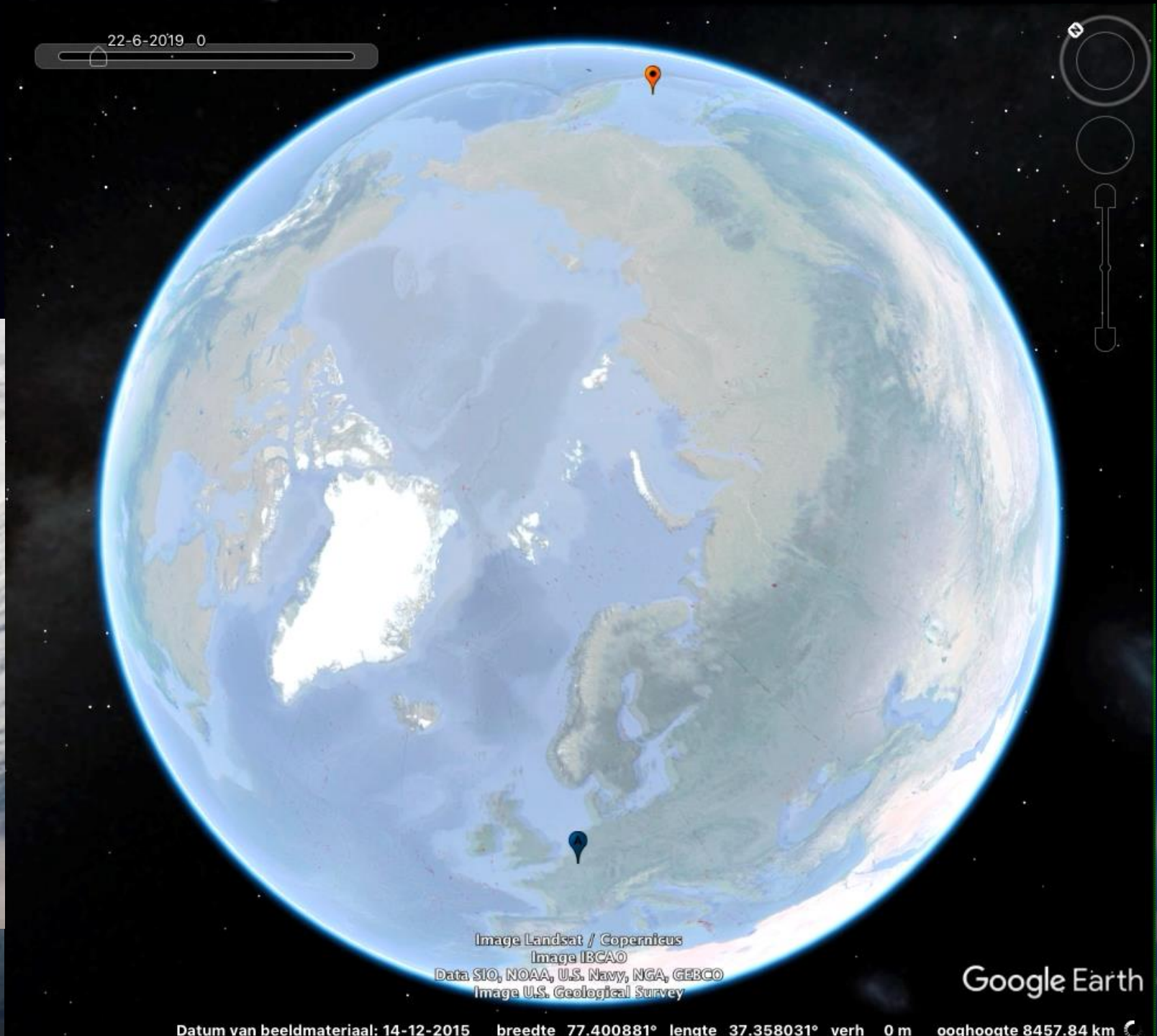


Popocatepetl & Sabancava, 19 Dec 2019



Raikoke 28 June 2019

Raikoke Volcano
SO_2 in the stratosphere observed by TROPOMI

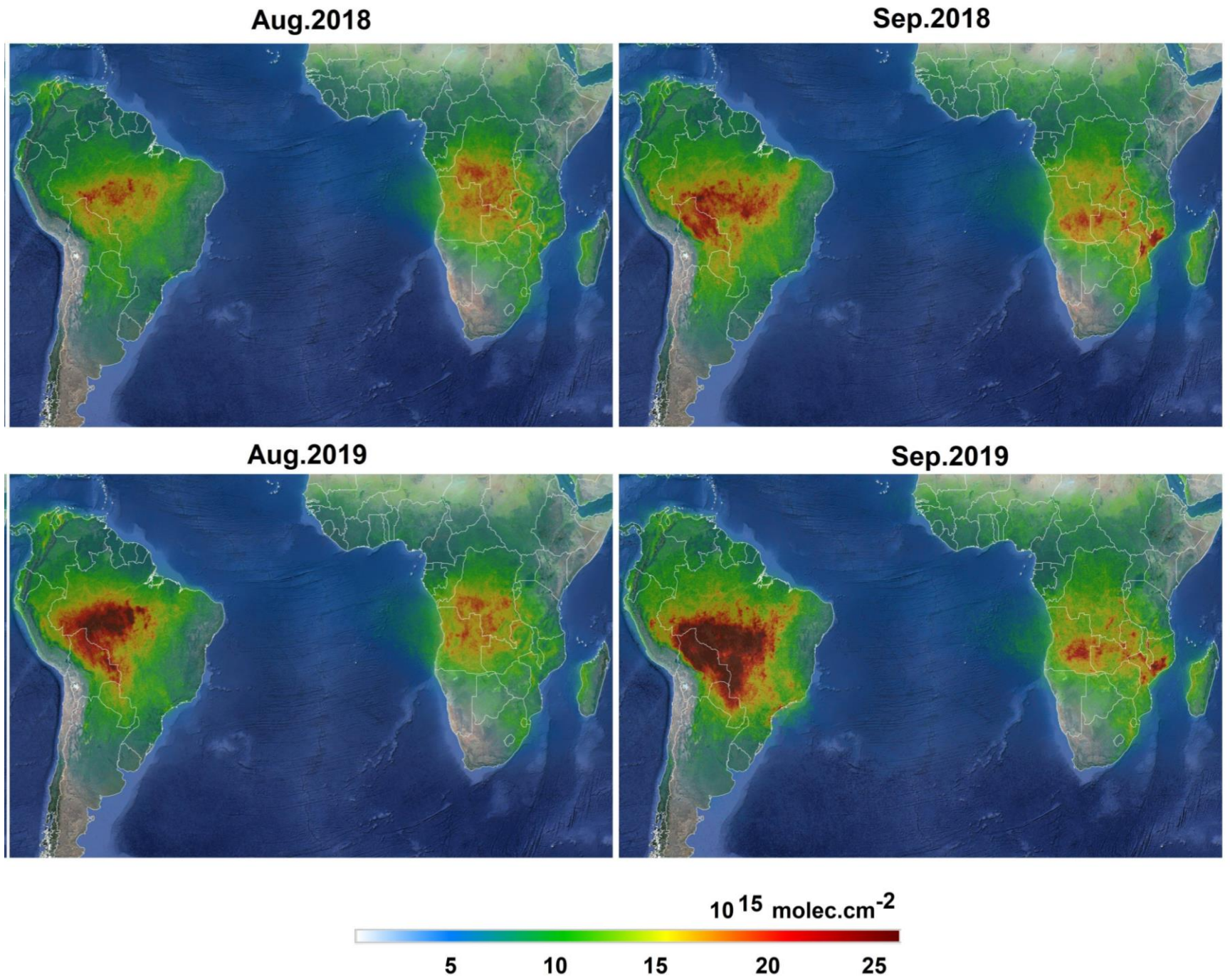


Formaldehyde:

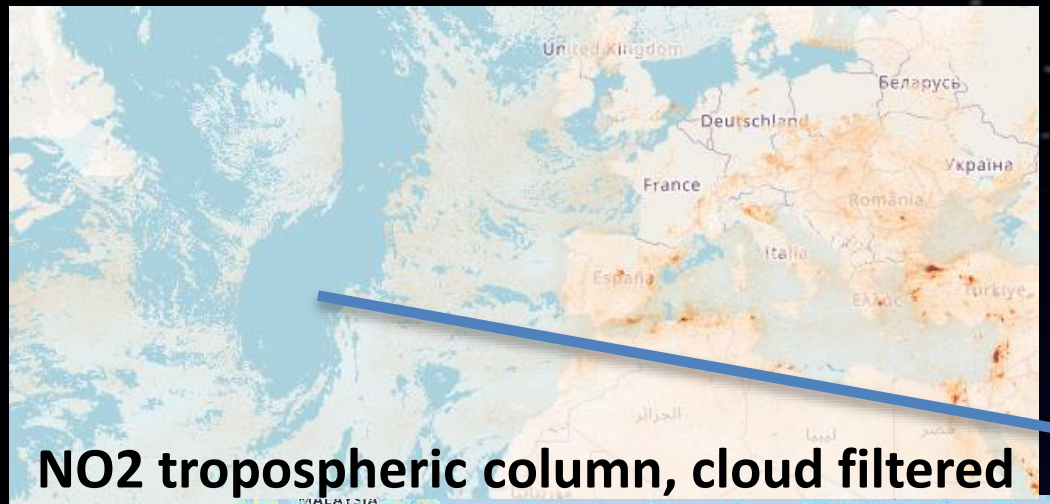
Temperature-dependent emission

Primarily Biogenic & Combustion sources

Lends clues about complex chemical cycling relevant to O3, VOCs

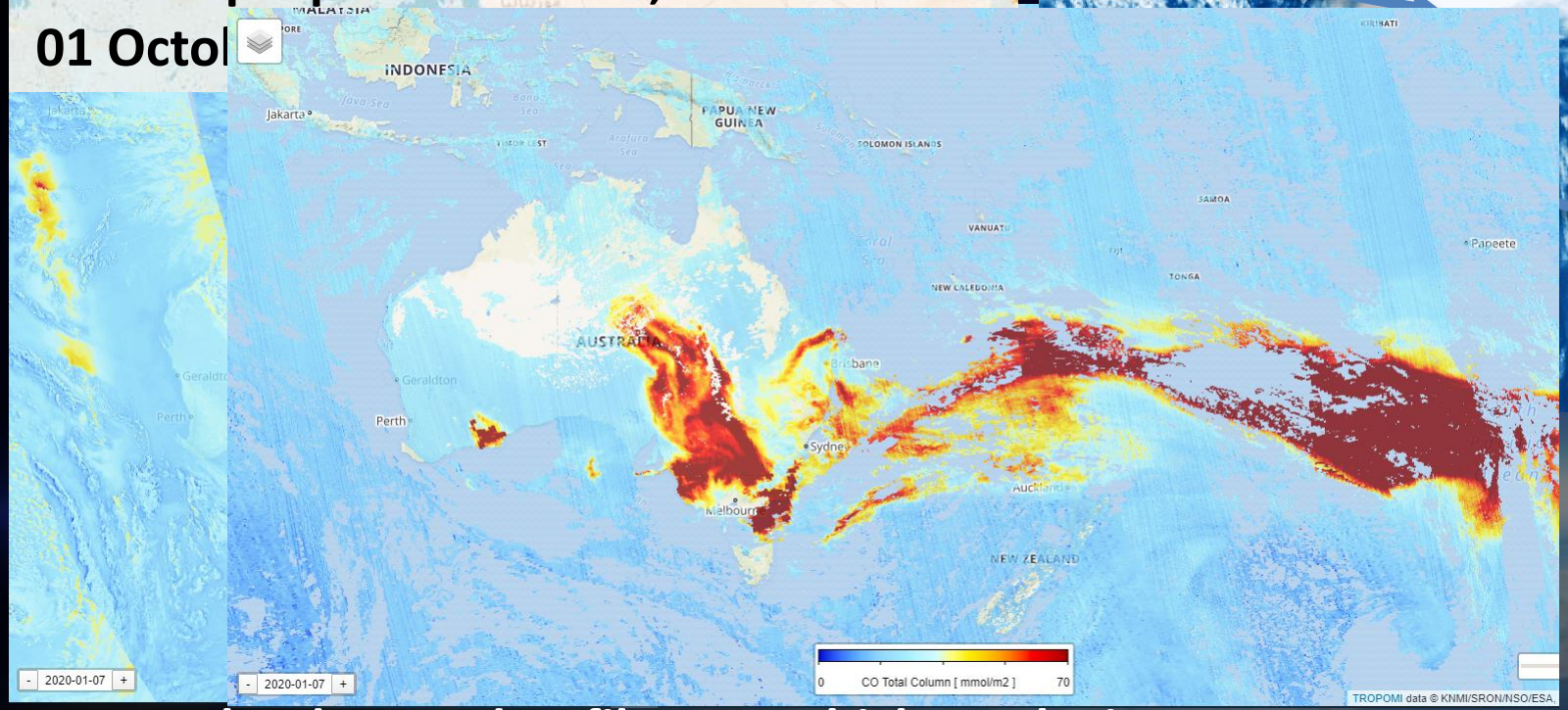


Aerosol & Cloud: Key for correcting trace gas retrievals

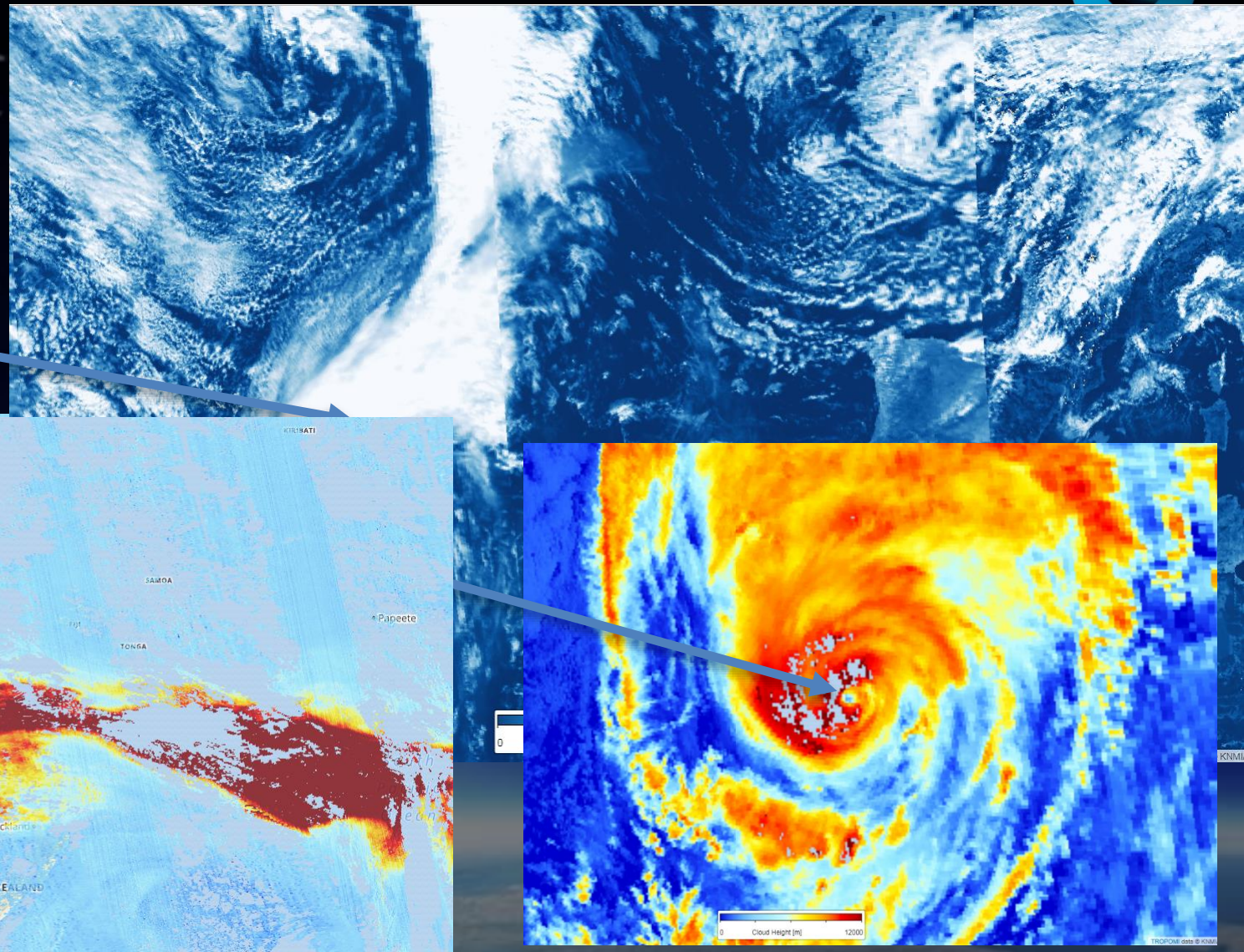


NO2 tropospheric column, cloud filtered

01 Octol

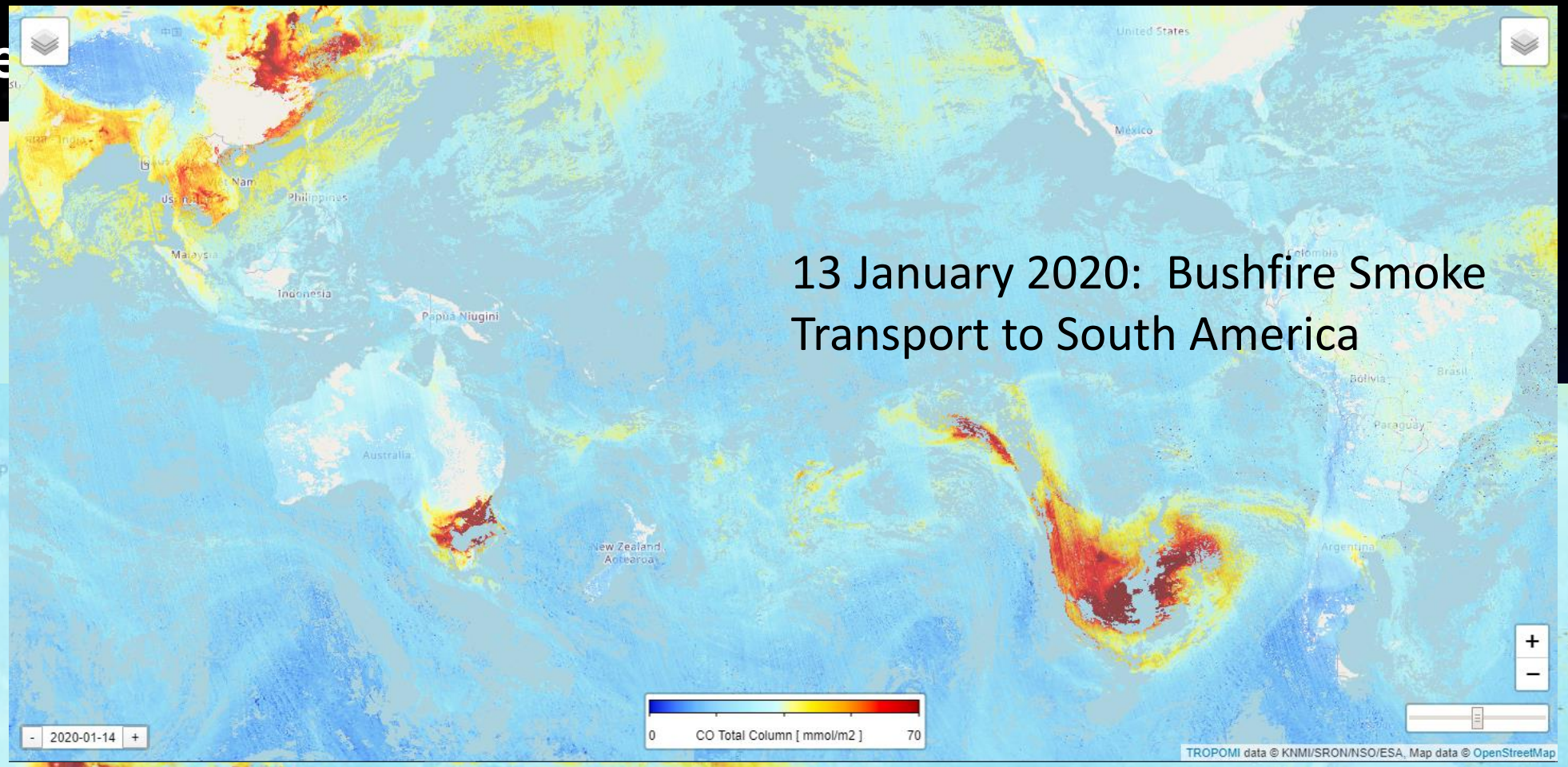


Aerosol Index used to filter out thick smoke in CO, 7 Jan 2020



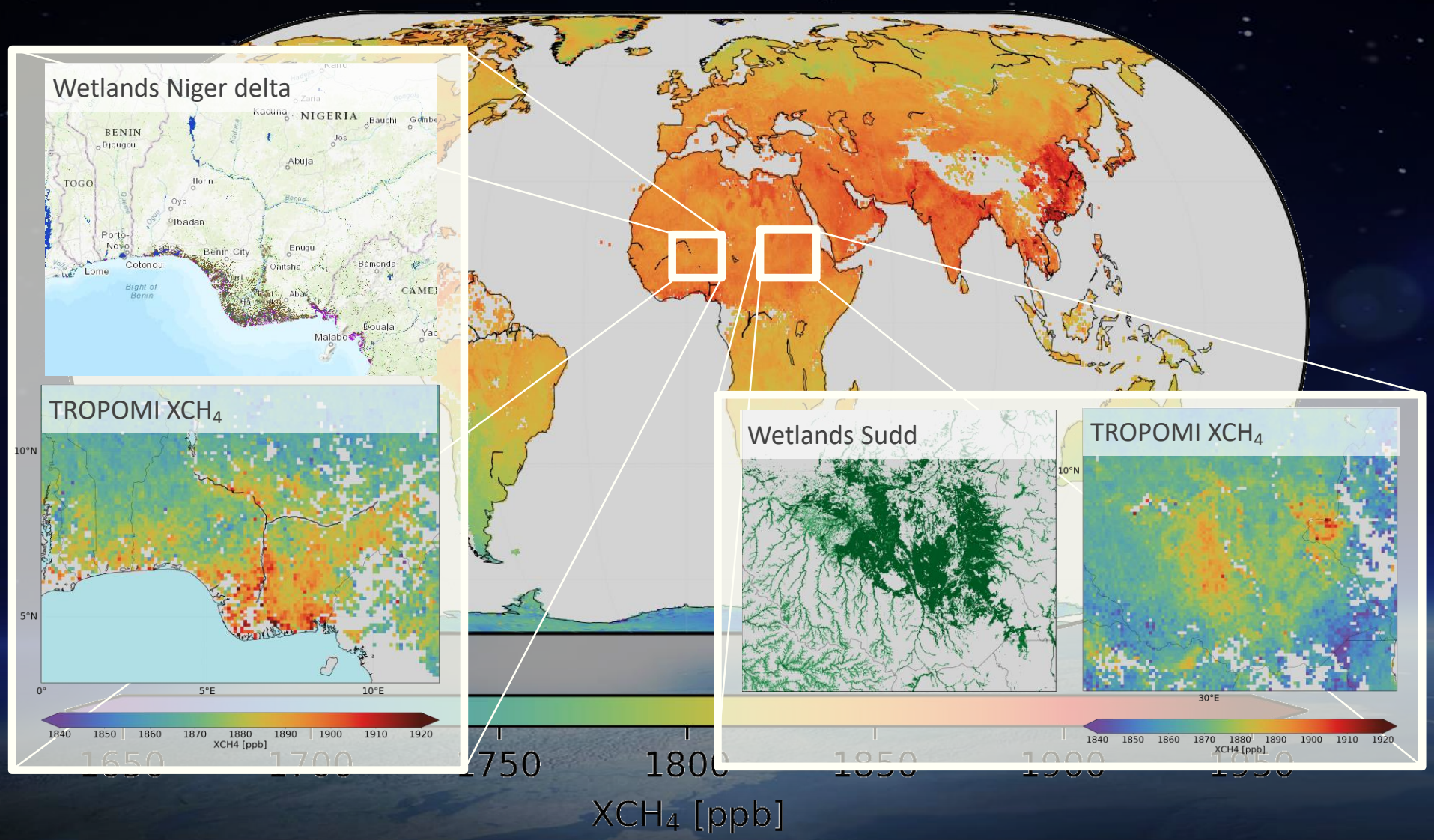
Cloud Fraction & Cloud Height

Carbon Monoxide

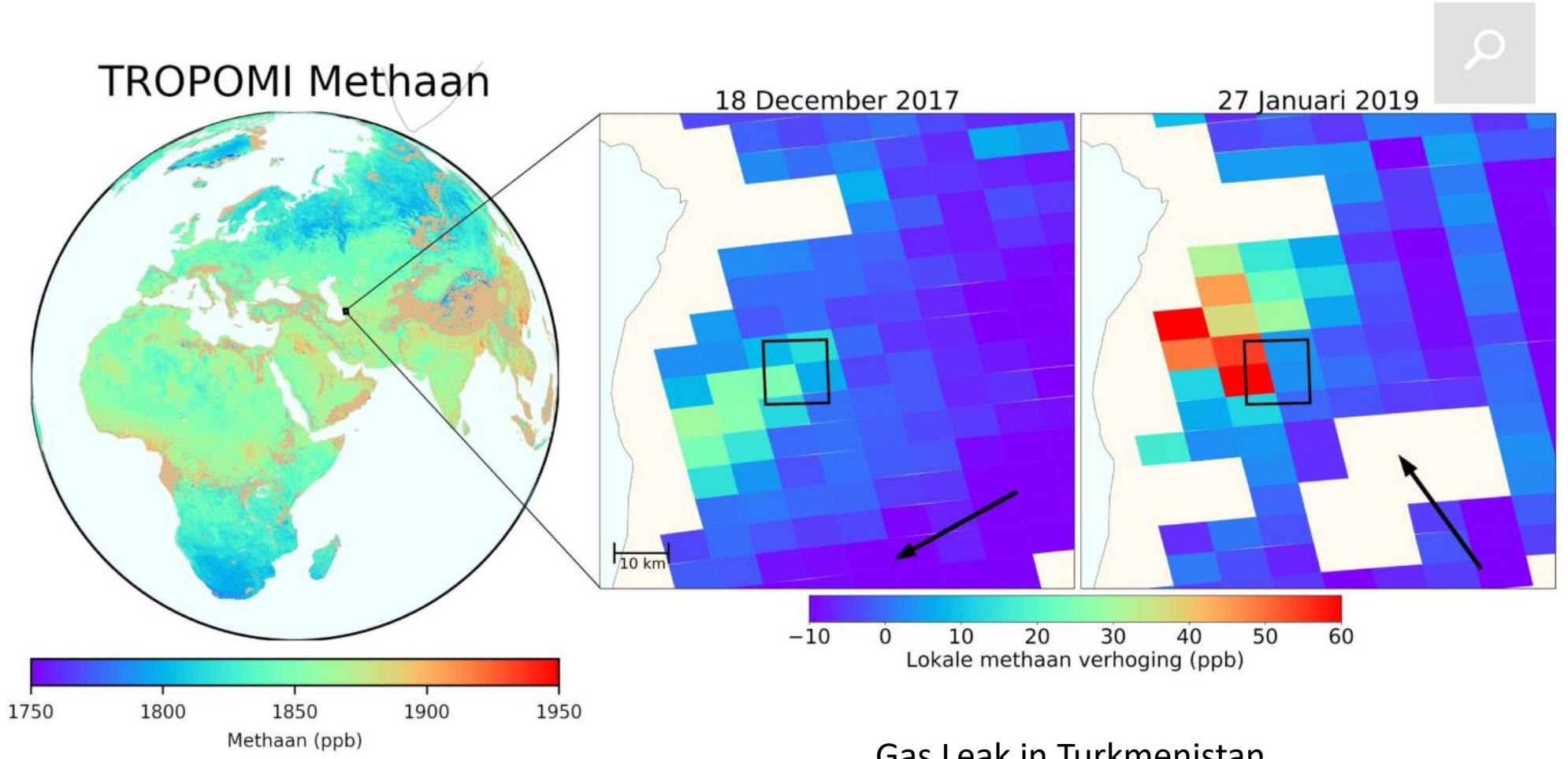


0 CO Total Column [mmol/m2] 70
TROPOMI data © KNMI/SRON/NSO/ESA, Map data © OpenStreetMap

Methane (CH4): Wetland emission seen by TROPOMI



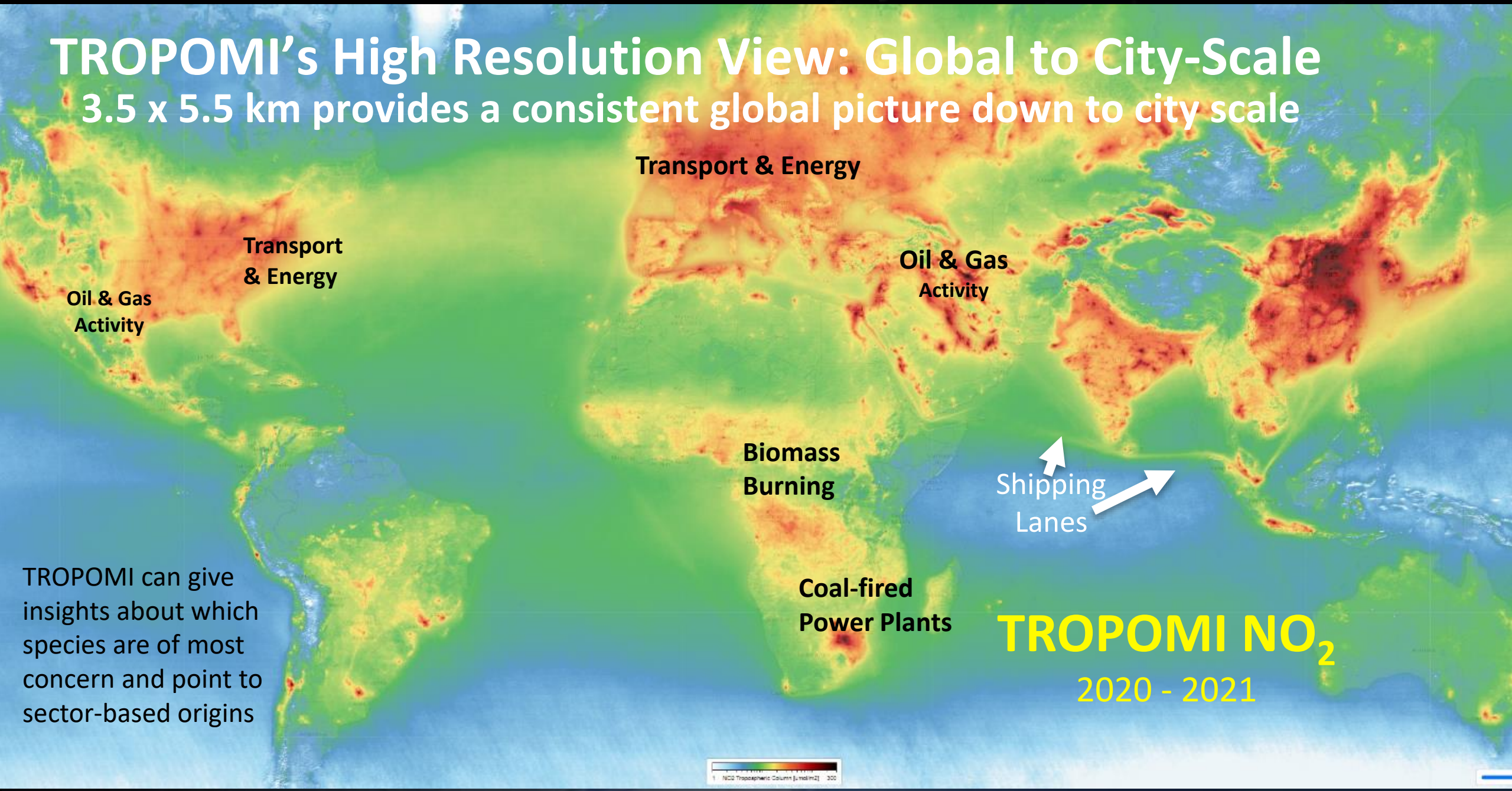
Methane (CH4): Gas leak as seen by TROPOMI



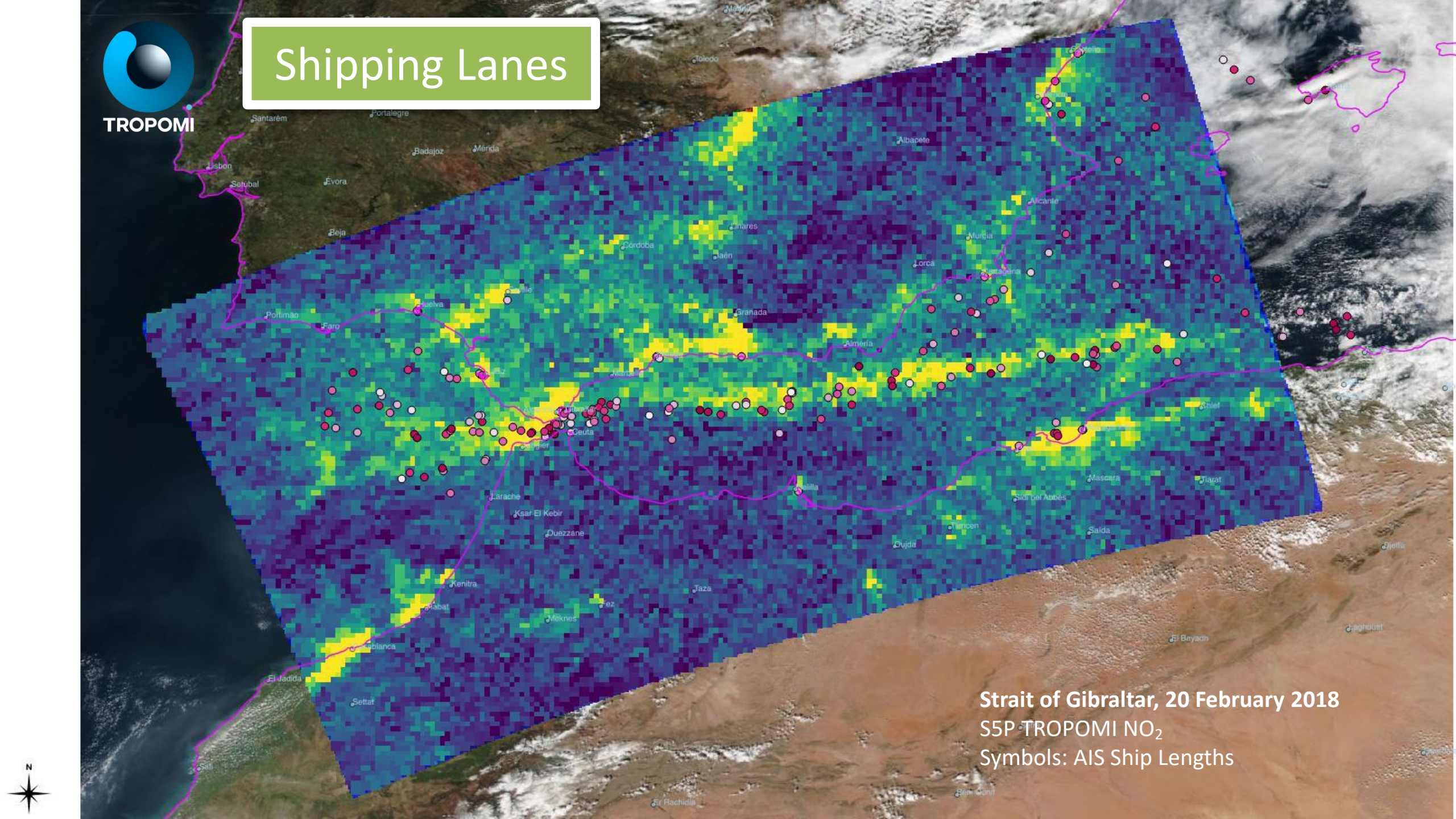
Gas Leak in Turkmenistan

TROPOMI's High Resolution View: Global to City-Scale

3.5 x 5.5 km provides a consistent global picture down to city scale

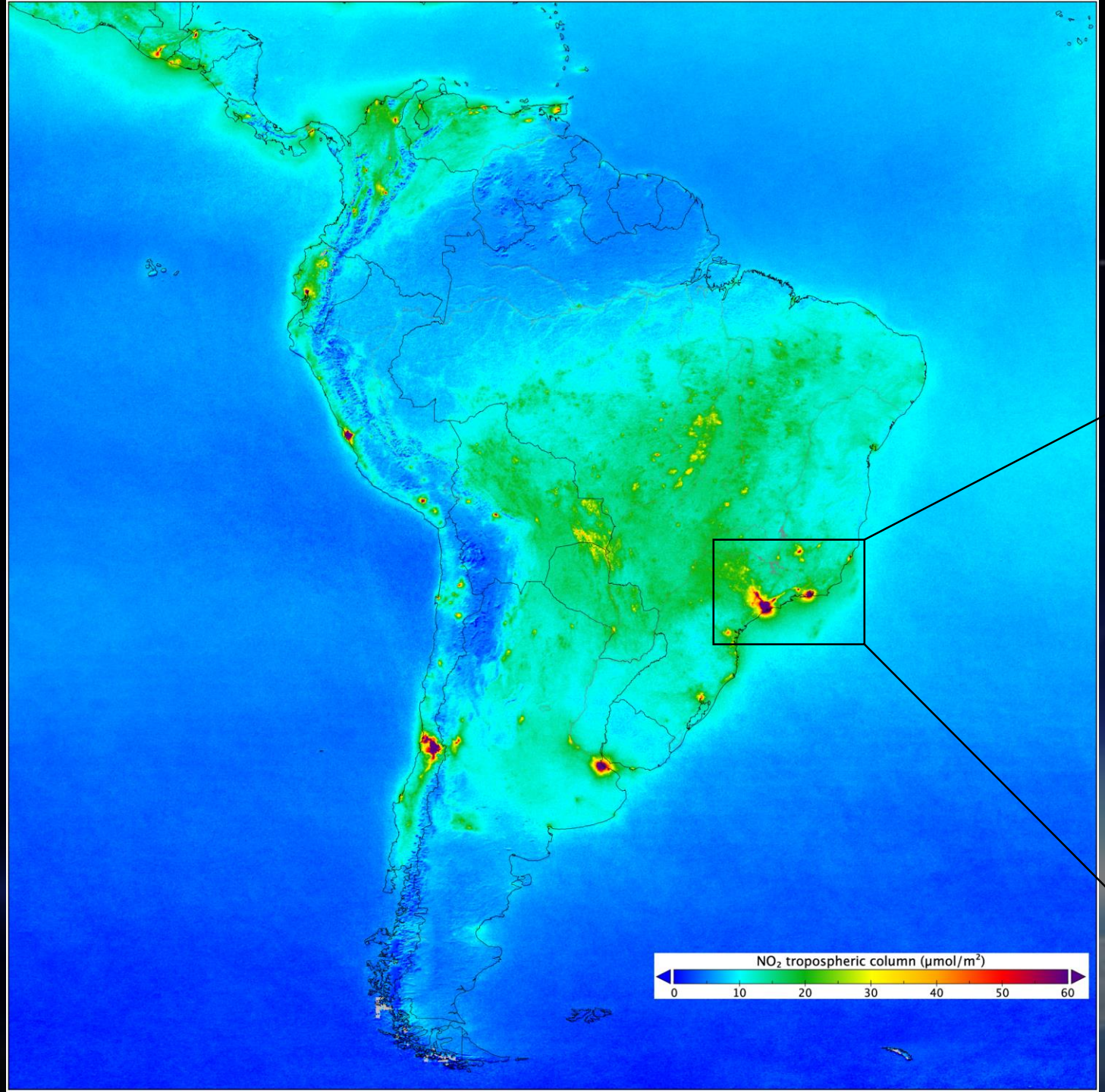


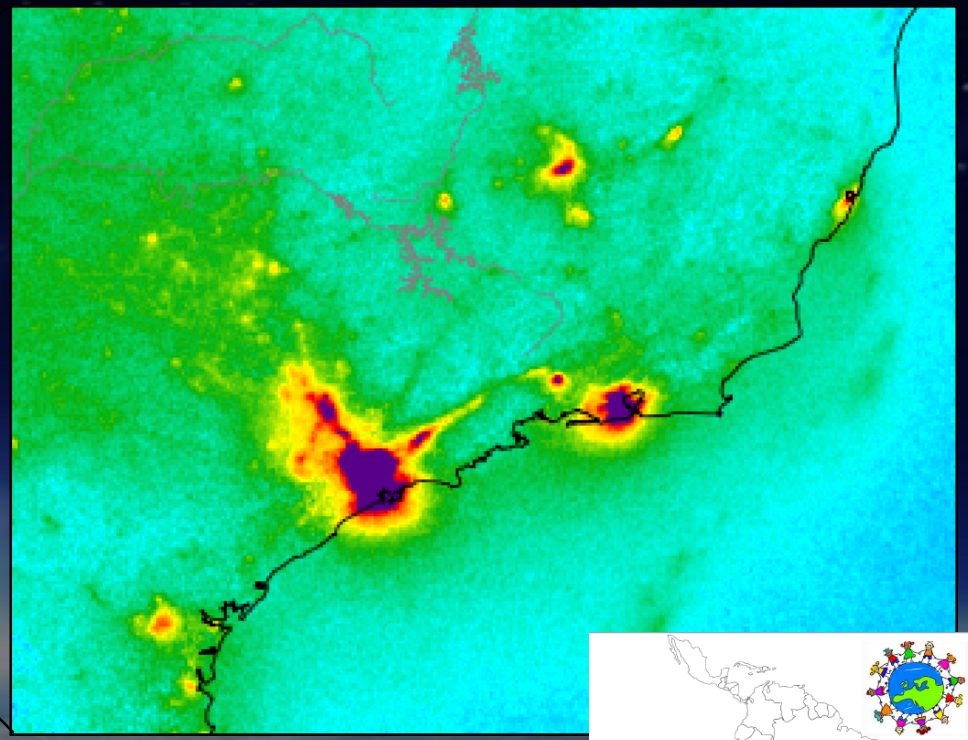
TROPOMI can give insights about which species are of most concern and point to sector-based origins


TROPOMI
Shipping Lanes
Strait of Gibraltar, 20 February 2018
S5P TROPOMI NO_2
Symbols: AIS Ship Lengths
N

NO_2 tropospheric column

Annual Average 2019

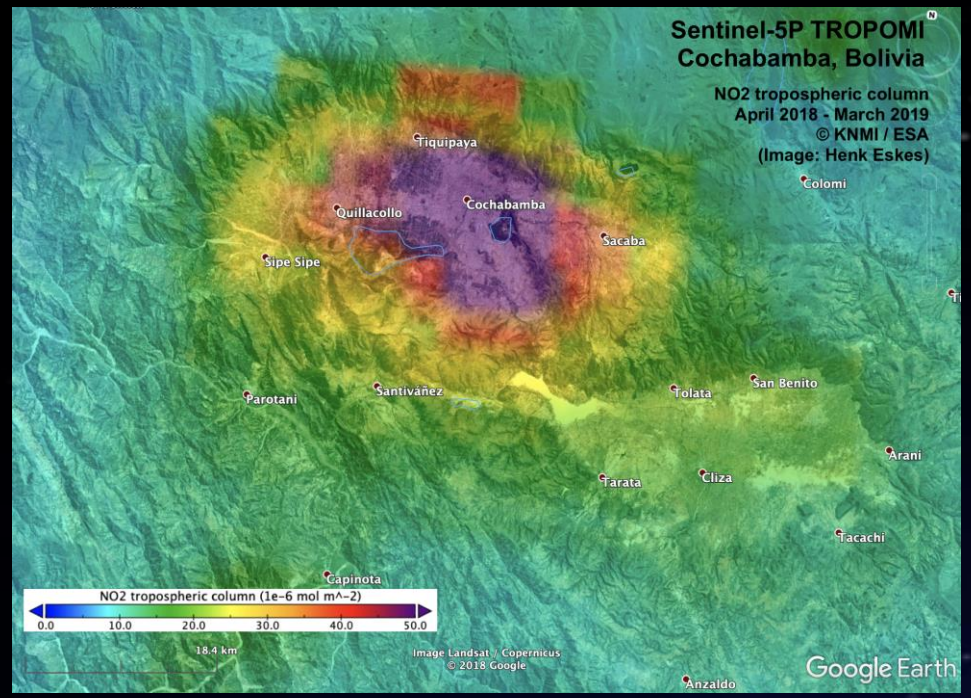




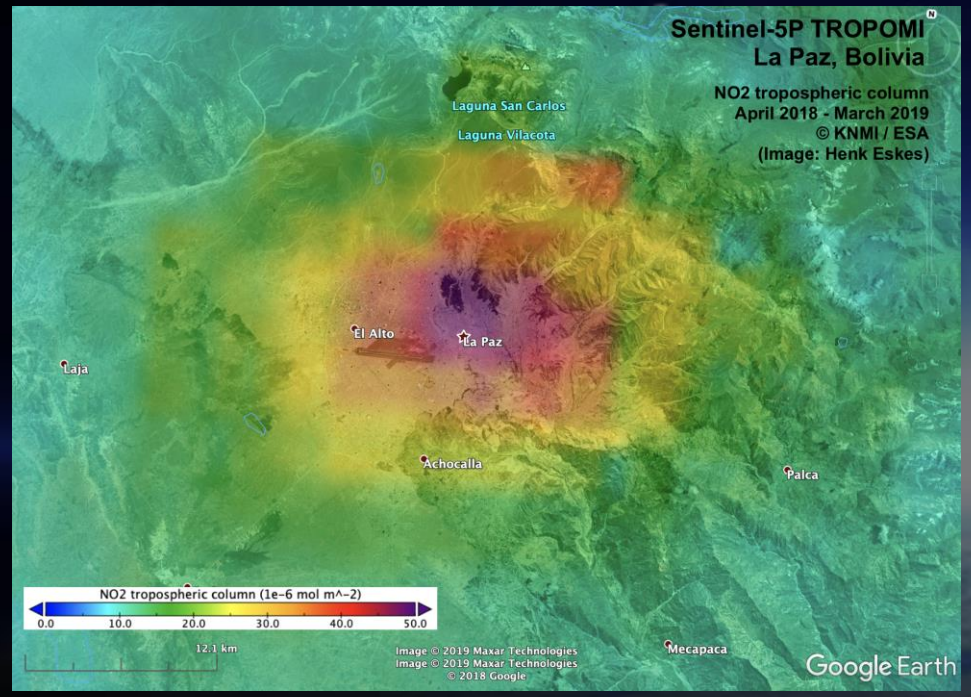
PAPILA

Prediction of Air Pollution in Latin America and the Caribbean

City footprints, Annual average

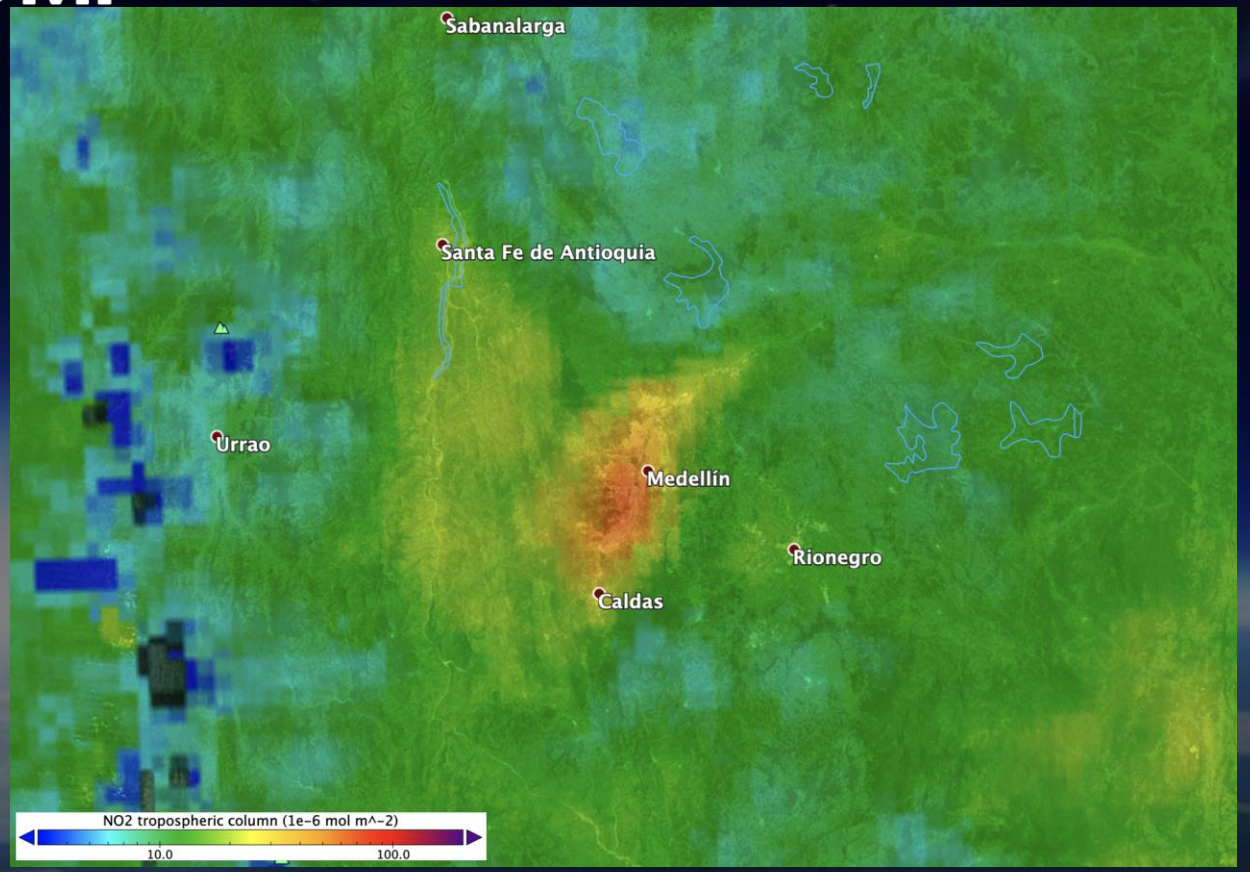


Cochabamba, Bolivia



La Paz, Bolivia

Medellín, Colombia

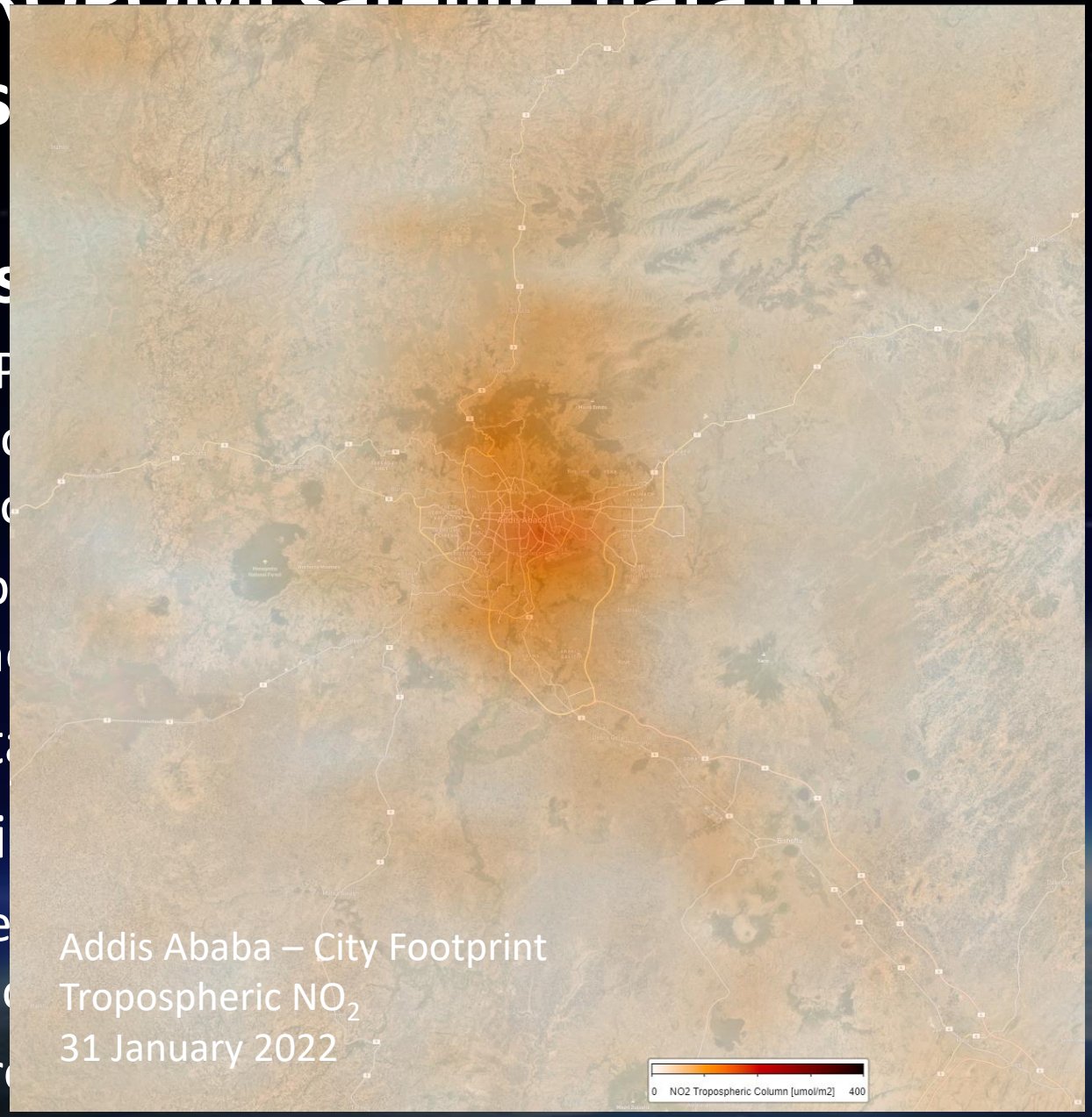


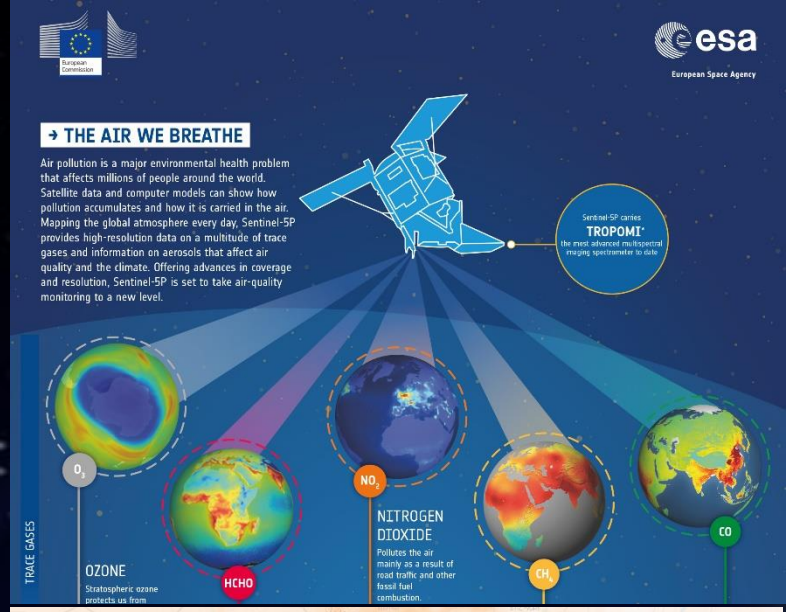
How can TR… used to ans…

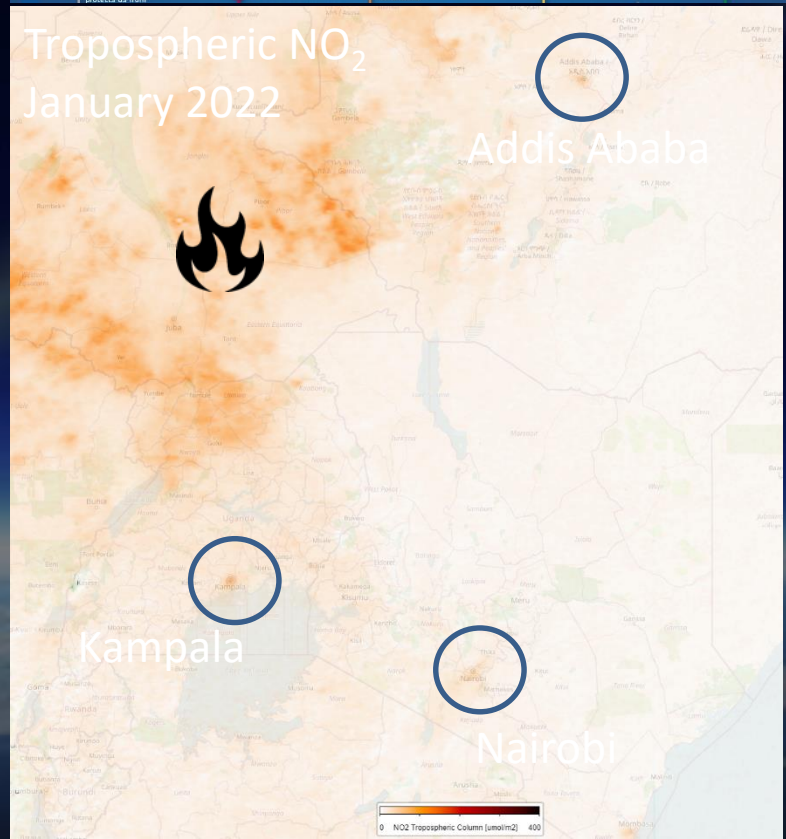
How Clean is…

Once a day, TROP… in the lower atmo… surrounding regio…

- This daily glob… space and time…
  - Air Pollut…
  - Informati…
- TROPOMI offe… allowing to zoo…
- Most Pixels ar…







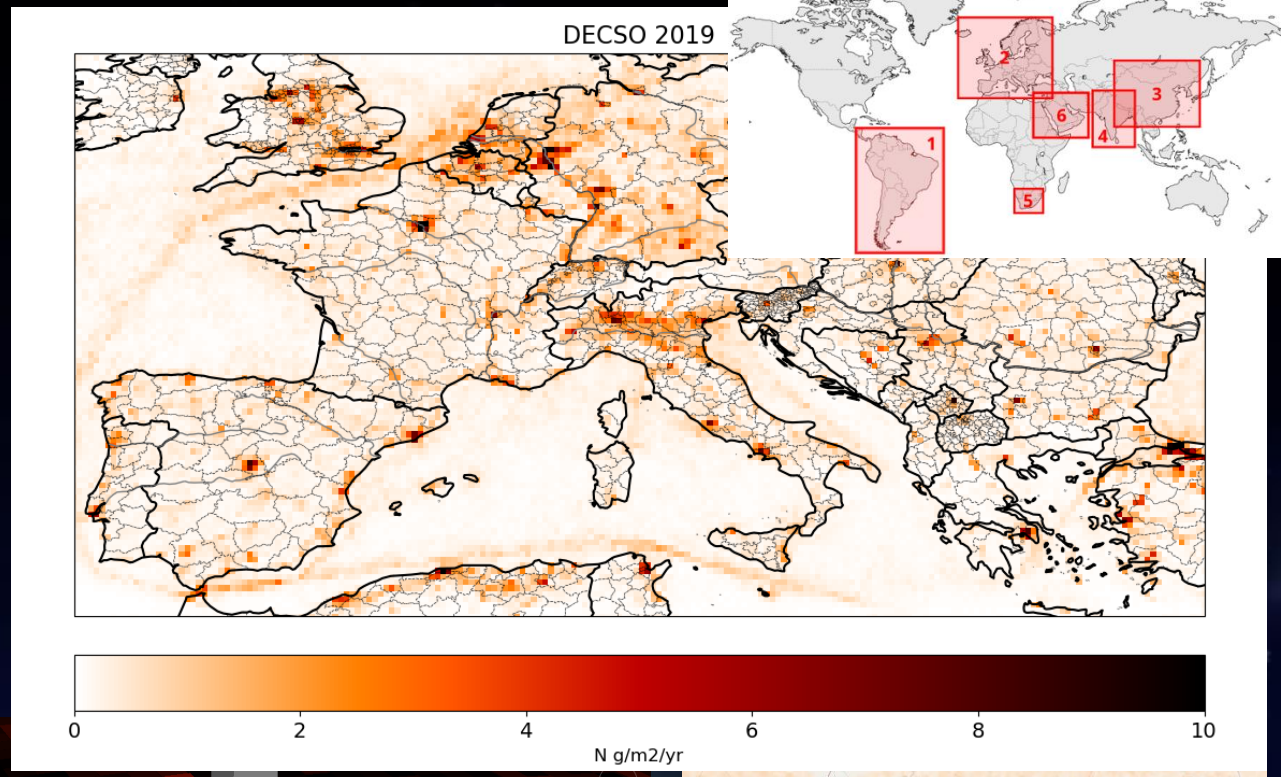
Monitoring Emissions

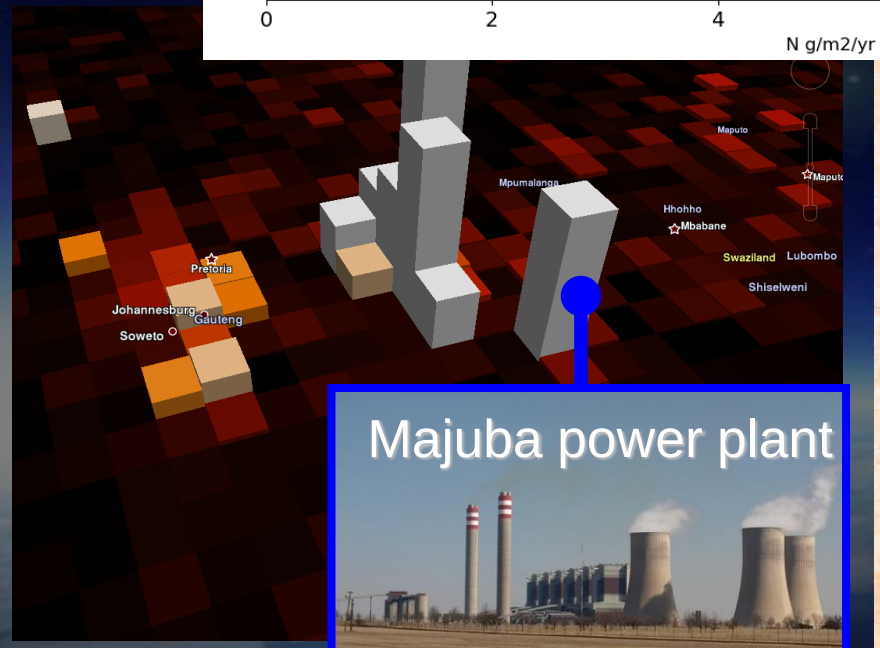
DECSO Daily Estimates Constrained by Satellite Observations

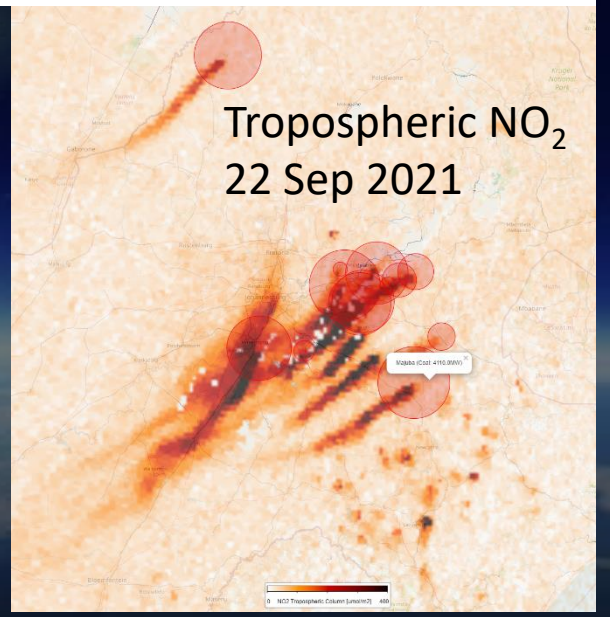
By Ronald van der A, Bas Mijling, Jieying Ding - **KNMI**

- It is fast: one model run per assimilation step of 1 day
- No *a priori* information needed: unknown sources will become visible.
- Full error estimation of new emission inventory
- Used for daily NO_x and NH_3 emissions

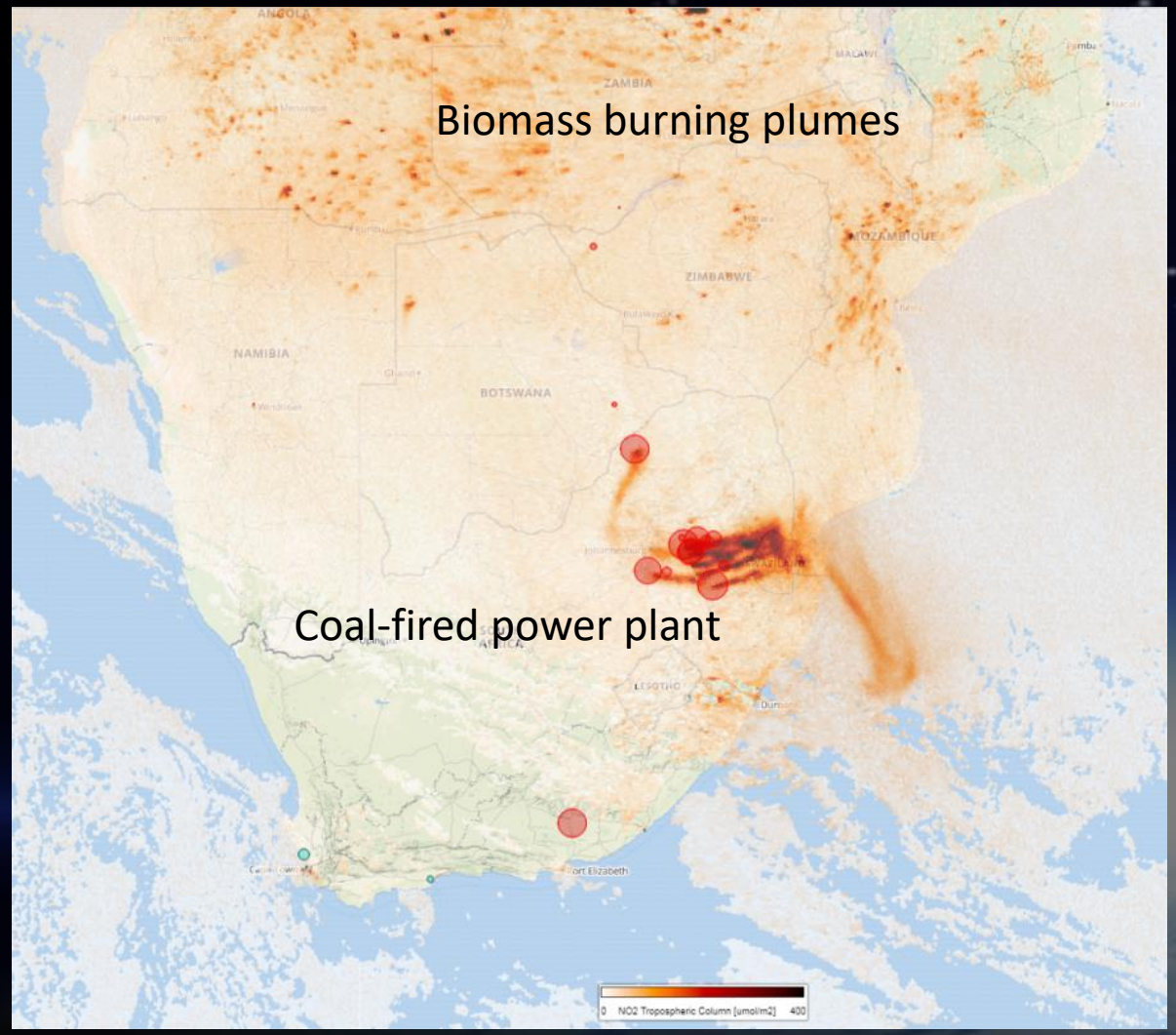
This type of emissions calculation can be linked to CO_2 emissions for known point sources (ex. Power plants)



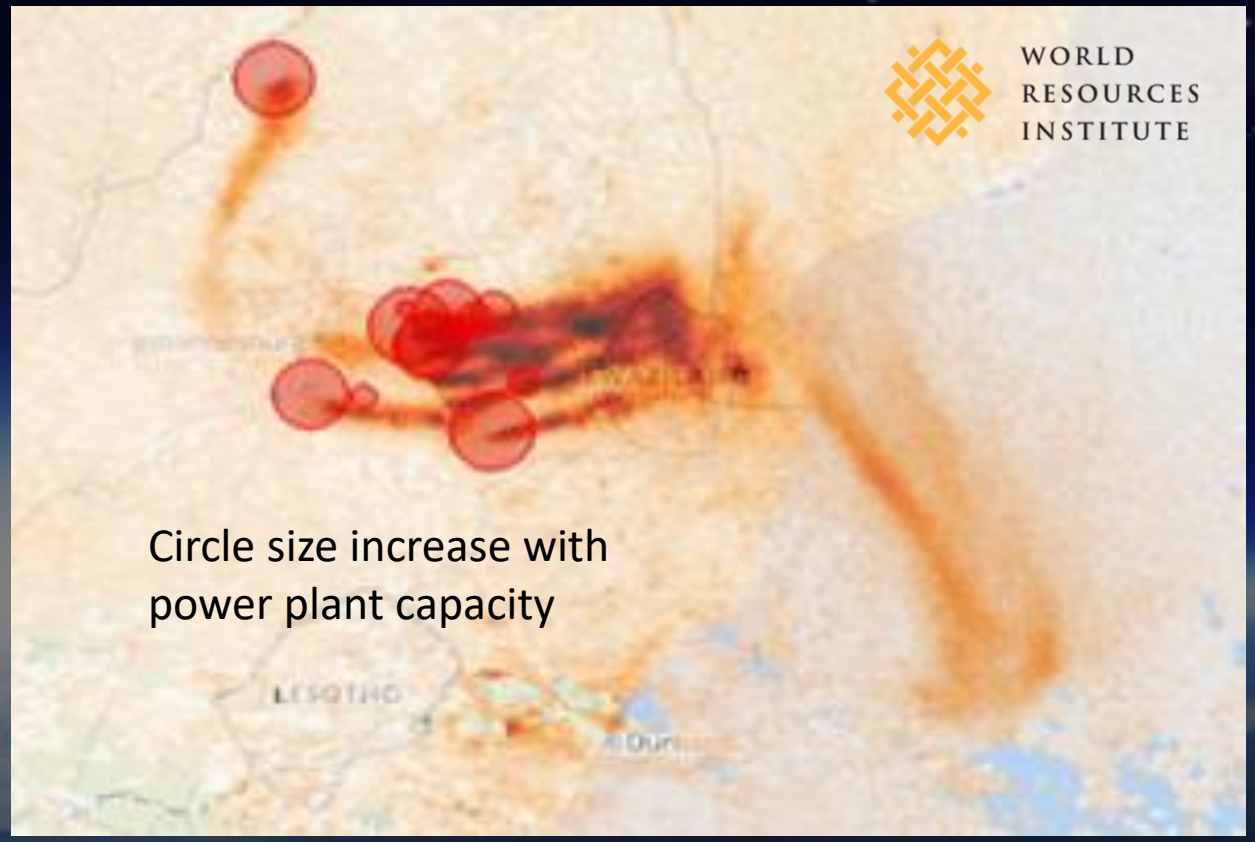




Power generation: plume monitoring and emission calculations

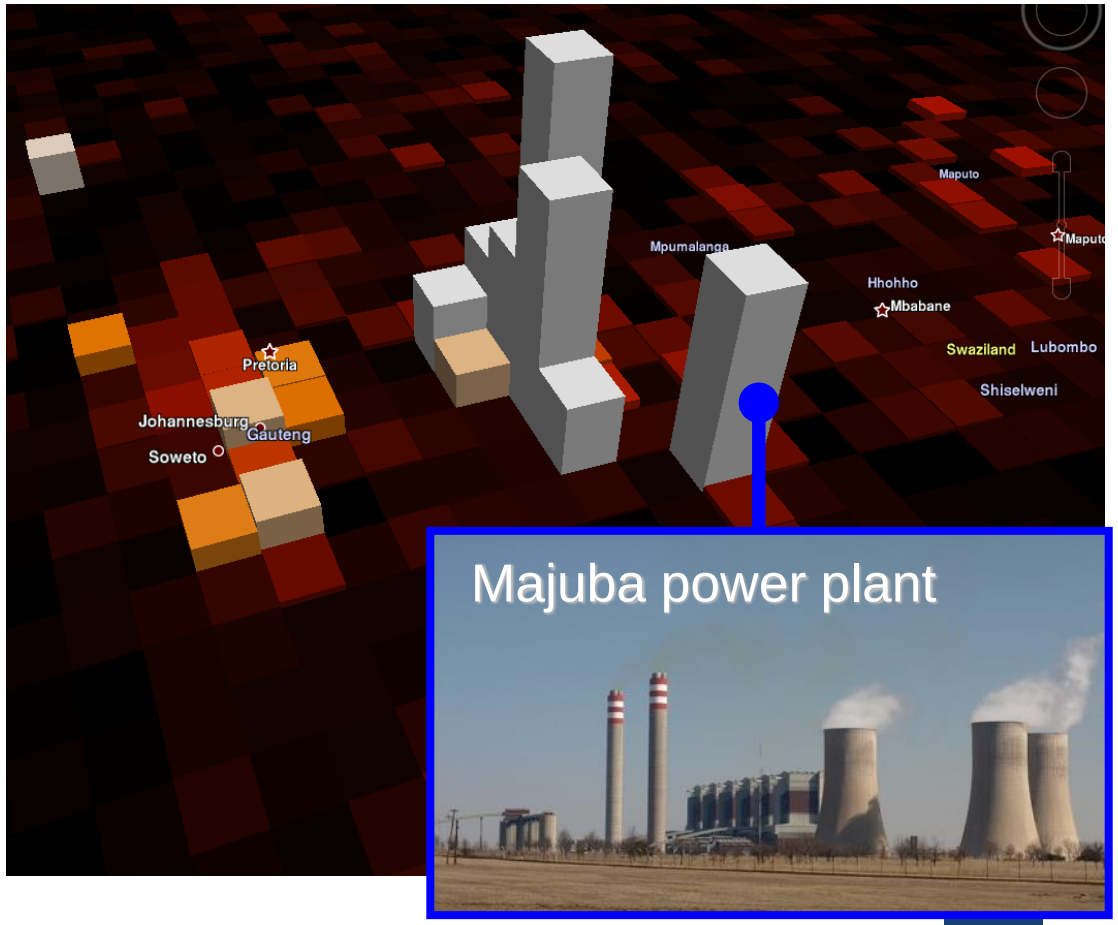


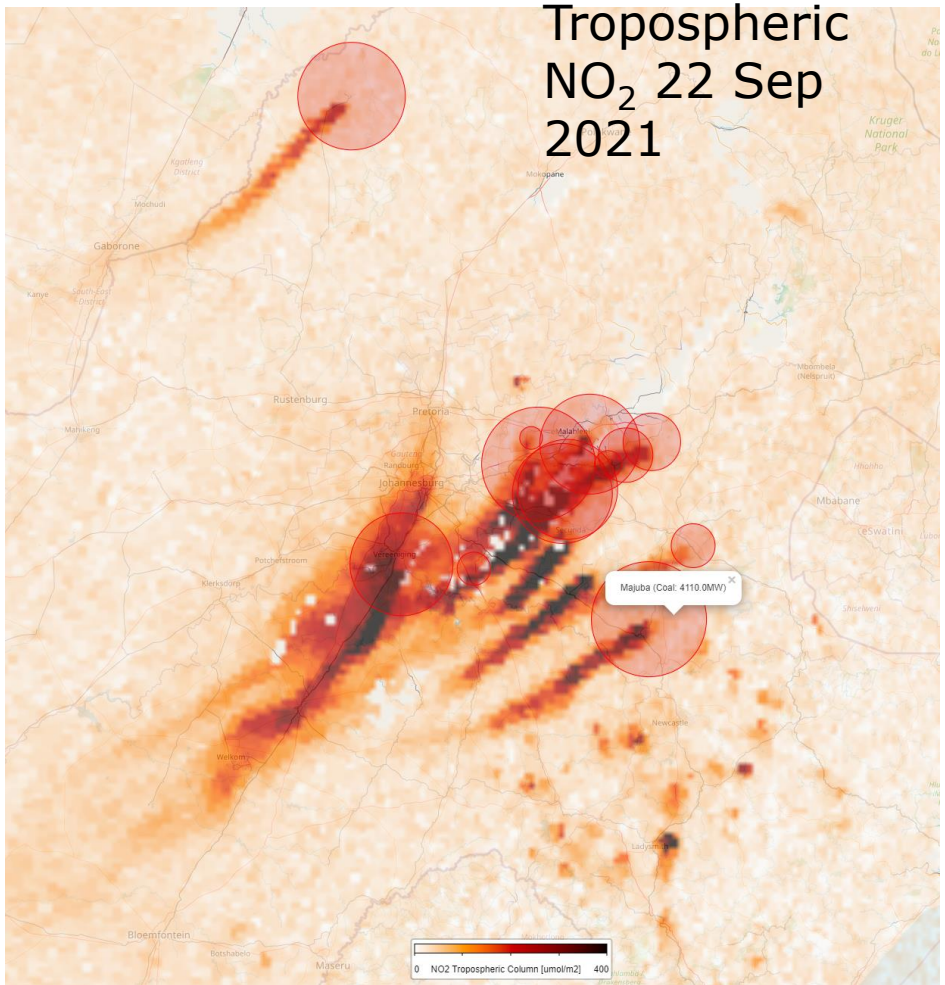
Next steps: Monthly and Daily emissions inversions combined with daily generation information from WRI Power Explorer Team



Common metrics of emissions, exposure

Power of combining satellite data with atmospheric models, ground-measurements, demographics, point source locations, vehicular usage, health, etc. we can create common metrics

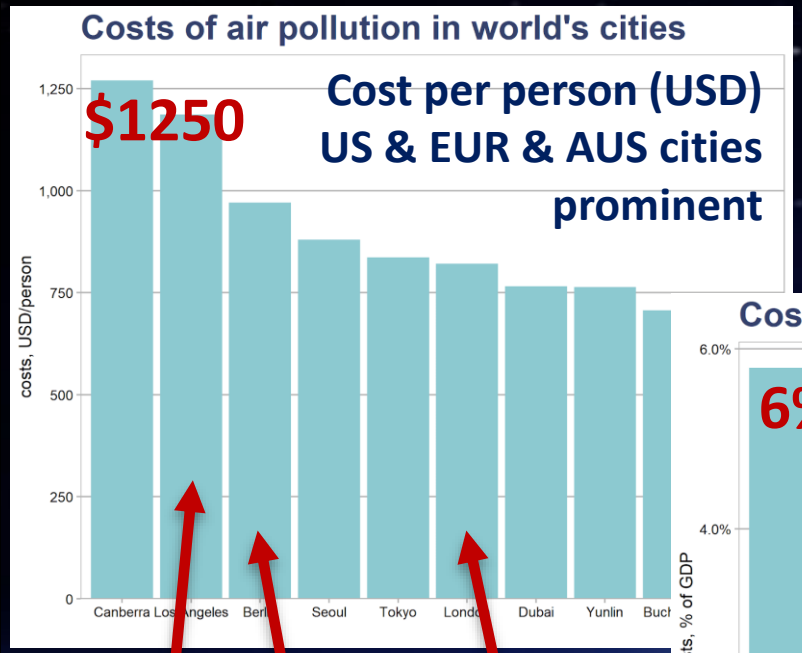




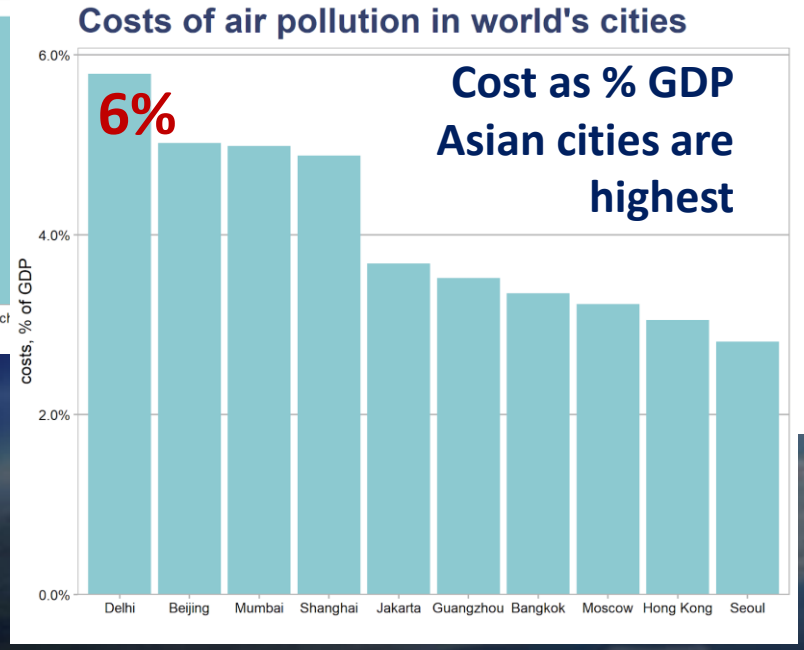
WHY Measure Air Quality (AQ)?: to motivate mitigation of human health impacts

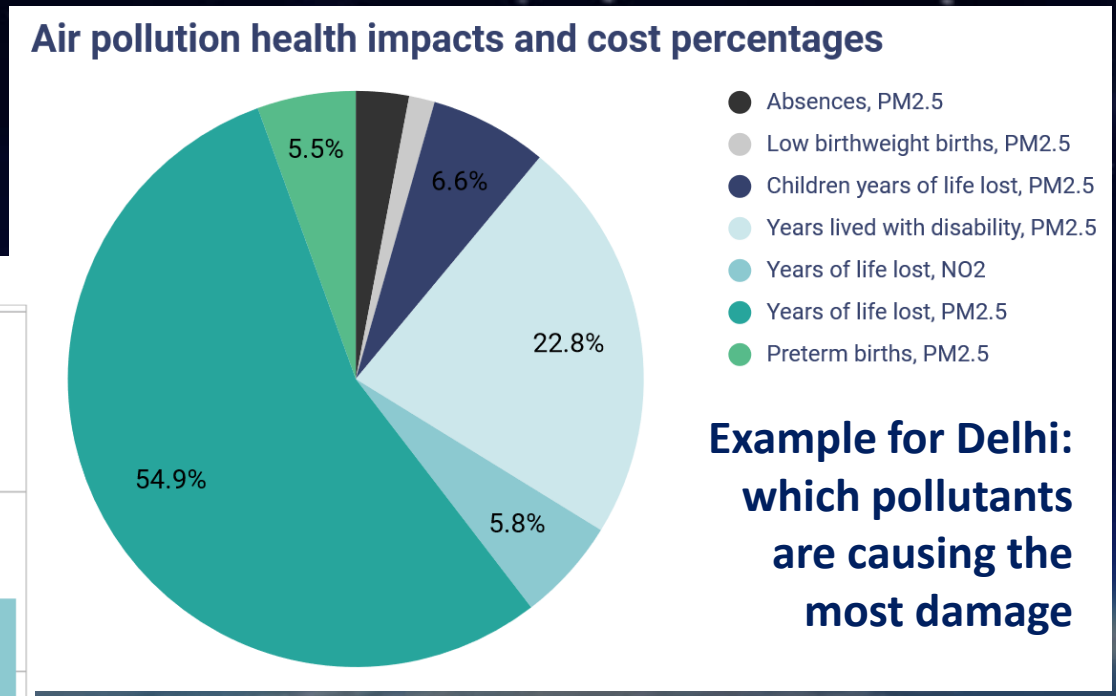
TROPOMI

- Improving air quality is a gateway to tackling climate change
- Staggering global costs & health impacts of air quality



LA, Berlin, London





Example for Delhi: which pollutants are causing the most damage

From: Center of Research on Clean Air & Energy
https://energyandcleanair.org/revealing-the-cost-of-air-pollution-in-real-time/

What kind of data do users want?

- Satellite retrieval community: L1, L2 data orbit or granule-based with lots of metadata and flag information, customizable for analyzing & visualizing in their own way
- Broader science(-interested) community: L3 data & visualization, on a consistent geolocation grid, preferably time averaged for a least a day, and for longer time periods like months, years
- Policy, changemakers, stakeholders and interested public: Nice visualizations and easy-to-understand (trend) analyses of regions/sources already on their 'radar', will rarely use data files
- Data dissementators: Best quality, most-documented data files in formats that can be manipulated to fit their own platforms

(Mis)information

- Example of how TROPOMI data was used in a Greenpeace report to make the following conclusion:
- Mpumalanga (African highveld) is the most polluted hotspot on the planet.

The world's biggest hotspot is Mpumalanga in South Africa, home to a cluster of a dozen coal fired power plants with a total capacity of over 32 gigawatts owned and operated by Eskom.

- With this conclusion, no context given about when or how often (seasonality), certainly no nuance regarding vertical distribution, impacts of cloud cover, etc.

GREENPEACE

New satellite data reveals world's largest NO2 air pollution emission hotspots - Greenpeace Media Briefing

The global air pollution crisis and the role of NO2

Air pollution is a global public health crisis, with up to 95% of people across the world breathing unsafe air, and several million deaths per year attributable to it.

Power Plant Hotspots

For the power plant hotspots, the main source of emissions is also readily visible from images generated from daily snapshots of NO2 levels in the atmosphere – these images show plumes originating from specific power plants.

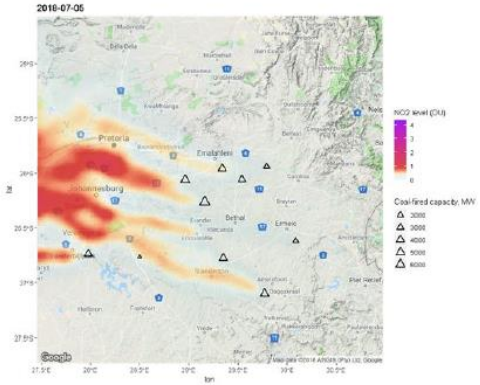
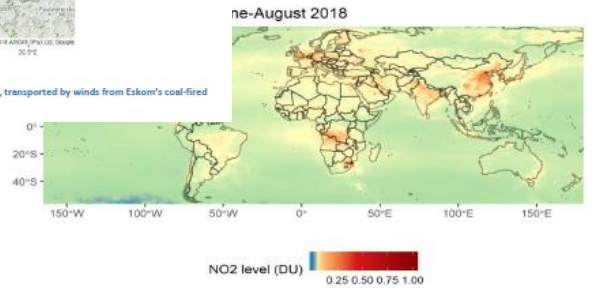


Figure 3. Power plant pollution plumes detected by Sentinel 5P on Jul 5, 2018, transported by winds from Eskom's coal-fired power plants in South Africa to Johannesburg.



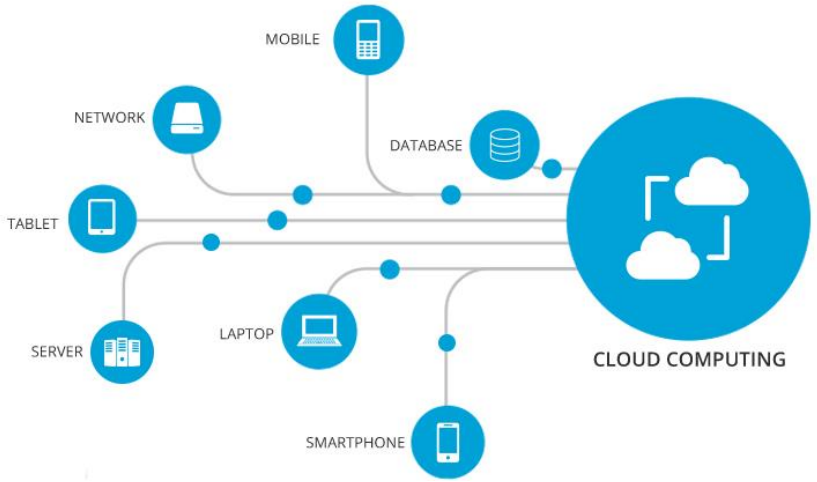
The list of the largest emissions hotspots includes several coal-fired power plants in India, South Africa and Germany, 10 power plant and industrial clusters in China, 14 megacities with very high transport-related emissions, including Santiago de Chile, Tehran, Dubai, London and Paris; as well as agricultural burning in Congo and Angola. Some hotspots, such as Seoul, Jakarta and New Delhi, have a mix of contributing sources, including transport, coal power plants and manufacturing.

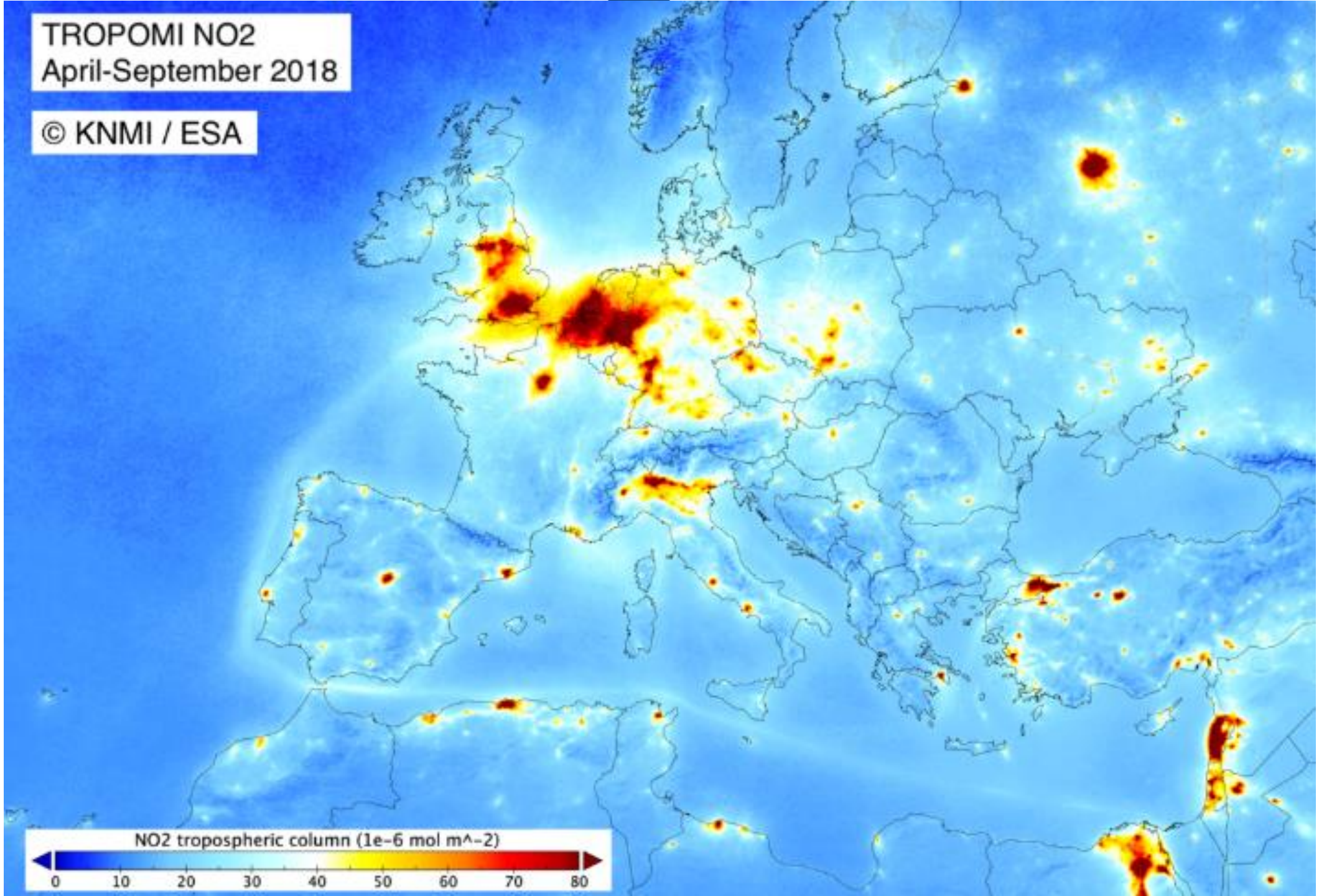
The world's biggest hotspot is Mpumalanga in South Africa, home to a cluster of a dozen coal fired power plants with a total capacity of over 32 gigawatts owned and operated by Eskom.

The data covers the period from 1 June to 31 August 2018.

Better accessbility via the cloud

- As TROPOMI dataset grows it is increasingly prohibitive for anyone except the largest data warehouses to ‘download’ the data and work with it, need to be selective for local data use
- With cloud computing environments, the data and the analysis no longer has to be on your own machine in principle this means that a whole new group of users can access, learn about, and analyze the data with out in-house computative limitations




TROPOMI NO2
April-September 2018
© KNMI / ESA
NO2 tropospheric column (1e-6 mol m^-2)
0
10
20
30
40
50
60
70
80

Who makes up the TROPOMI community?

- People who do work similar to ours typically in Europe, US and Asia
  - Includes training of the next generation of scientists via student opportunities
- People in different branches of science
  - Often instrumental in making valuable operational applications, ex. risk management, aviation safety etc.
- People in policy sometimes with background / interest in science
- Stakeholders, like funding agencies
- Data disseminators: commericial & non-commercial
- Communicators (media outlets) & Changemakers (NGOs)
- Industry / Commercial entities

Who's missing?

- Underrepresented regions, links to knowledge 'on-the-ground'
  - Satellite data can help greatly in regions with little or no ground measurements
- Potential users with limited access / bandwidth
  - New solutions for 'remote', online data access & analysis, mapping services
- Policy & changemakers without knowledge of the value of satellite data for setting agenda for improving air quality & addressing climate change
  - Awareness of satellite data as tool for understanding AQ & climate change is steadily increasing with powerful imagery
- Potenital users who don't know how to use the data
  - Simple (in-cloud) tutorials can facilitate better use of the data

S5P-PAL site: ESA is interested in L3

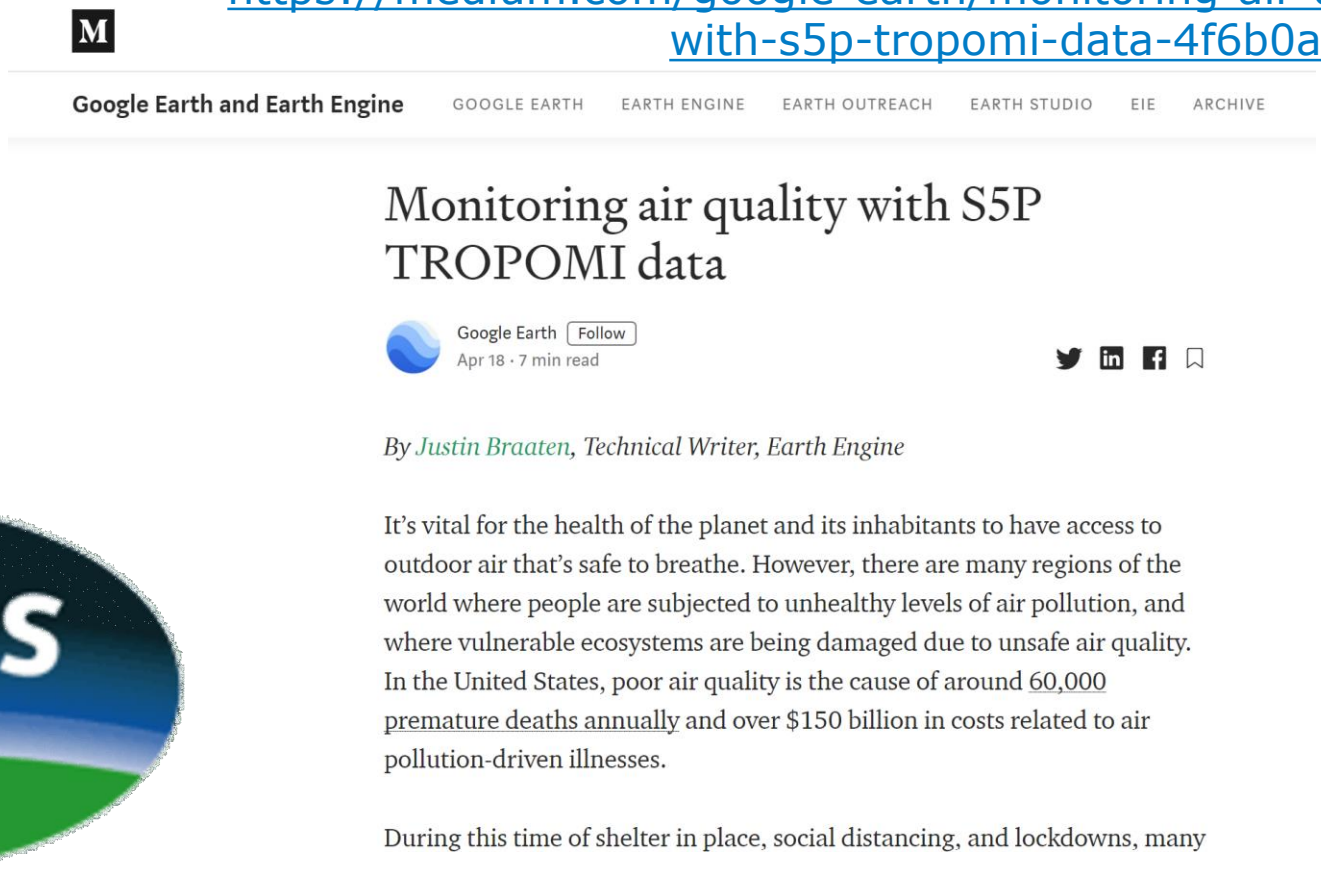
Copernicus Sentinel-5P Tropospheric Nitrogen Dioxide › https://maps.s5p-pal.com/

Maps of tropospheric NO_2 concentrations averaged over 14 days

From TEMIS to Google

- Importance of L3 data
- For rapid case studies
- For trend analysis,
- We need L3, gridded
- QC-filtered data

https://medium.com/google-earth/monitoring-air-quality-with-s5p-tropomi-data-4f6b0aebe1c0



Google Earth and Earth Engine GOOGLE EARTH EARTH ENGINE EARTH OUTREACH EARTH STUDIO EIE ARCHIVE

Monitoring air quality with S5P TROPOMI data

Google Earth Follow
Apr 18 · 7 min read

By Justin Braaten, Technical Writer, Earth Engine

It's vital for the health of the planet and its inhabitants to have access to outdoor air that's safe to breathe. However, there are many regions of the world where people are subjected to unhealthy levels of air pollution, and where vulnerable ecosystems are being damaged due to unsafe air quality. In the United States, poor air quality is the cause of around 60,000 premature deaths annually and over $150 billion in costs related to air pollution-driven illnesses.

During this time of shelter in place, social distancing, and lockdowns, many

TROPOMI user forum: work starting soon

- Together with SRON via NSO / EU leveraging our NGO & national networks to reach out, spread awareness and gather feedback
- August 2023 will be setting up the project
- Work planned to start in Dec 2020
- Deliverables
  - Building a network of changemaker users
  - Survey them and their networks to culminate themes of (un)met needs
  - Work with accessible (data) platforms to keep these new users visible

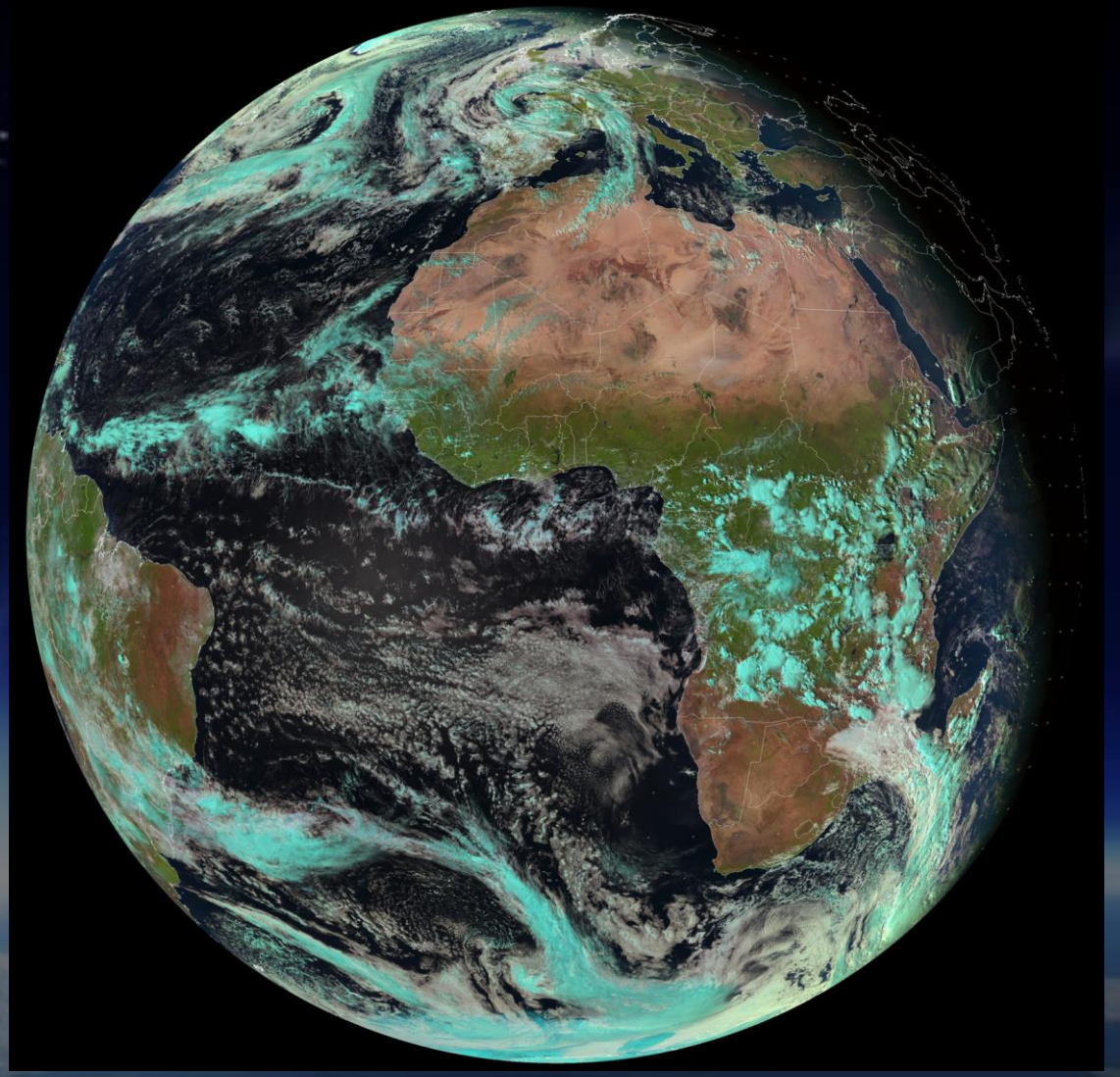
Why Satellites?

Meteorological satellites have revolutionized our understanding of dynamics and dramatically improved forecast skill

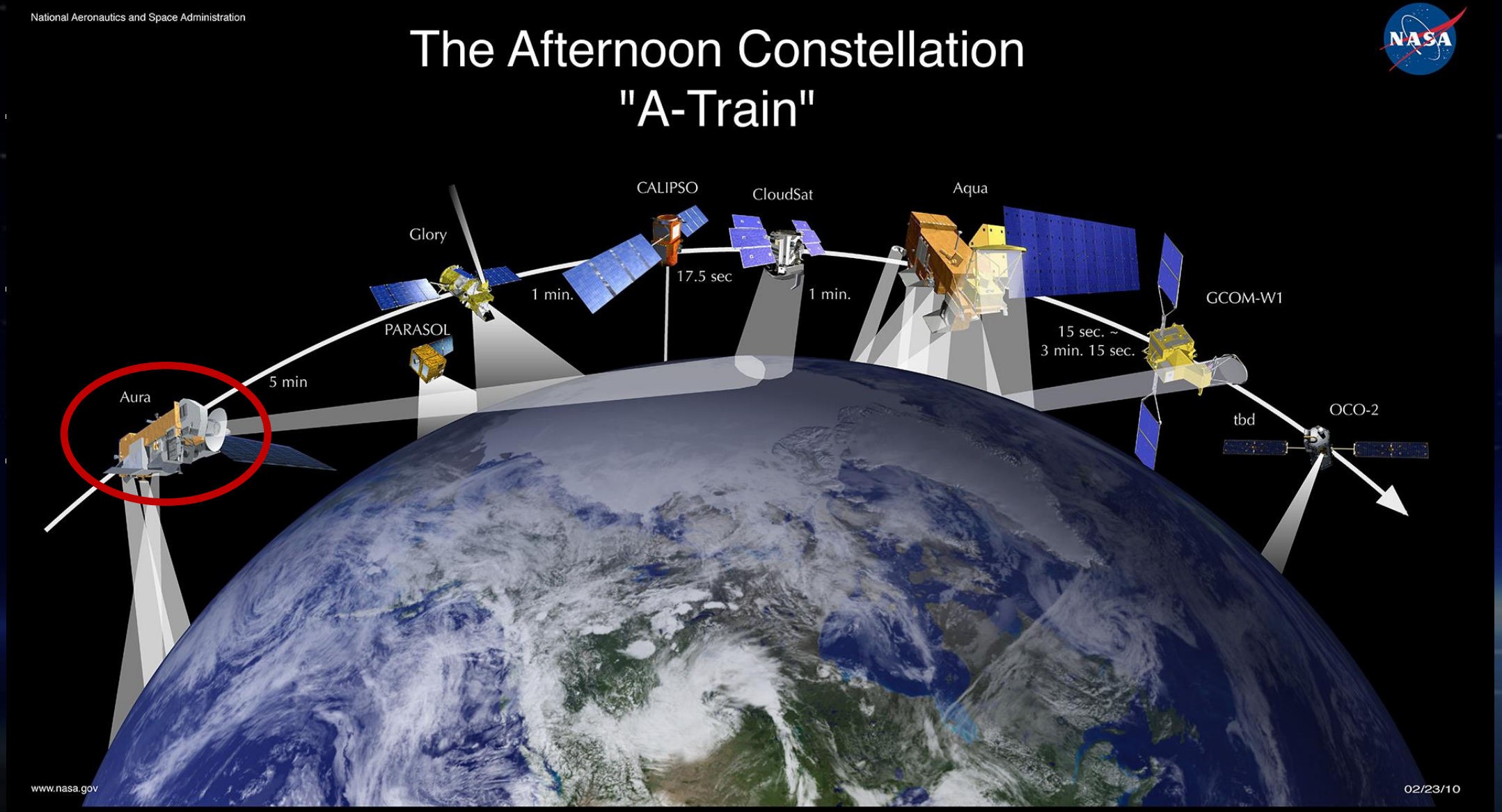
- Now, > 90% of data used in weather forecasting comes from satellites!

What can a space borne perspective offer as compared to other atmospheric chemical datasets?

- “Honest judge”: uniform methods for daily, global snapshots at a specific time
- Global, consistent input for Assimilation
- Copernicus Atmospheric Monitoring Service (CAMS) uses satellite data for global/regional air quality forecasts
- Assimilation/Forecast framework advances our understanding of global atmospheric chemical cycling – which in turn informs mission prio’s



Flavors of Satellite Instruments



Using OMI & TROPOMI to monitor CO_2

- CO2 is a difficult measurement for many reasons
  - Long atmospheric lifetime of CO2 complicates separation of local emissions, background concentration, and
  - Vertical distribution of NO2 is better understood and more easily modeled
- However, NO2 is useful proxy for CO2 in many situations
- KNMI produced a press release regarding this work
- https://www.knmi.nl/over-het-knmi/nieuws/CO2-uitstoot-in-beeld-dankzij-tropomi

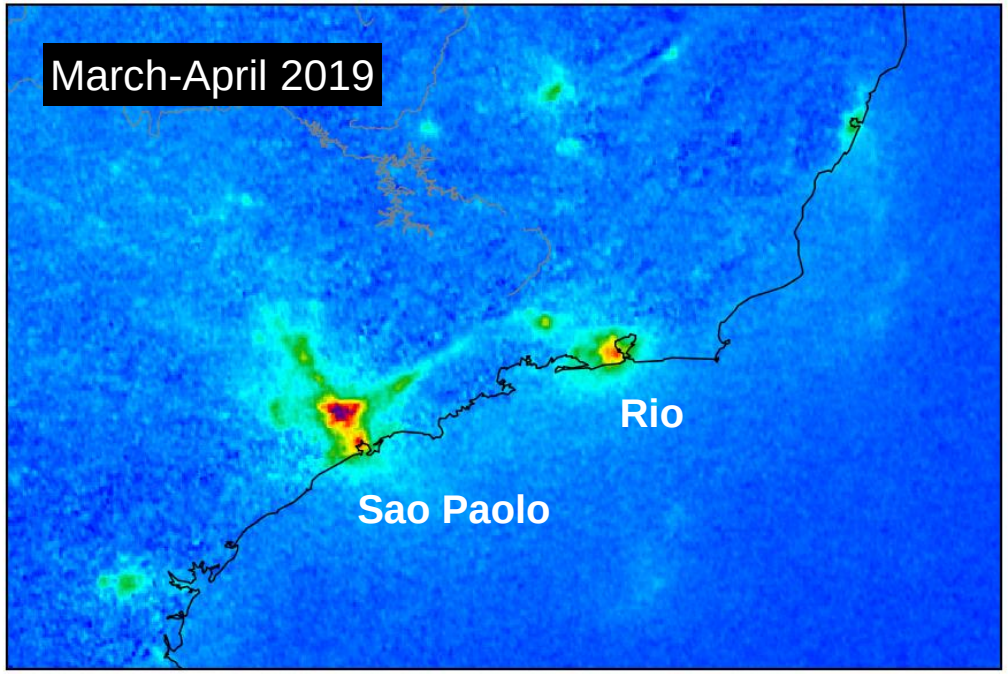
Nieuwsbericht

CO2-uitstoot in beeld dankzij Tropomi

11 december 2018

Satellietinstrument Tropomi meet stikstofdioxide (NO2) over de hele wereld. Via NO2 kunnen de hotspots van CO2 door verbranding van fossiele brandstoffen worden getraceerd. Dankzij Tropomi krijgen we dus ruimtelijk inzicht waar veel CO2 wordt uitgestoten. Zo kunnen de komende jaren wereldwijd de belangrijkste veranderingen in CO2 hotspots worden bijgehouden.

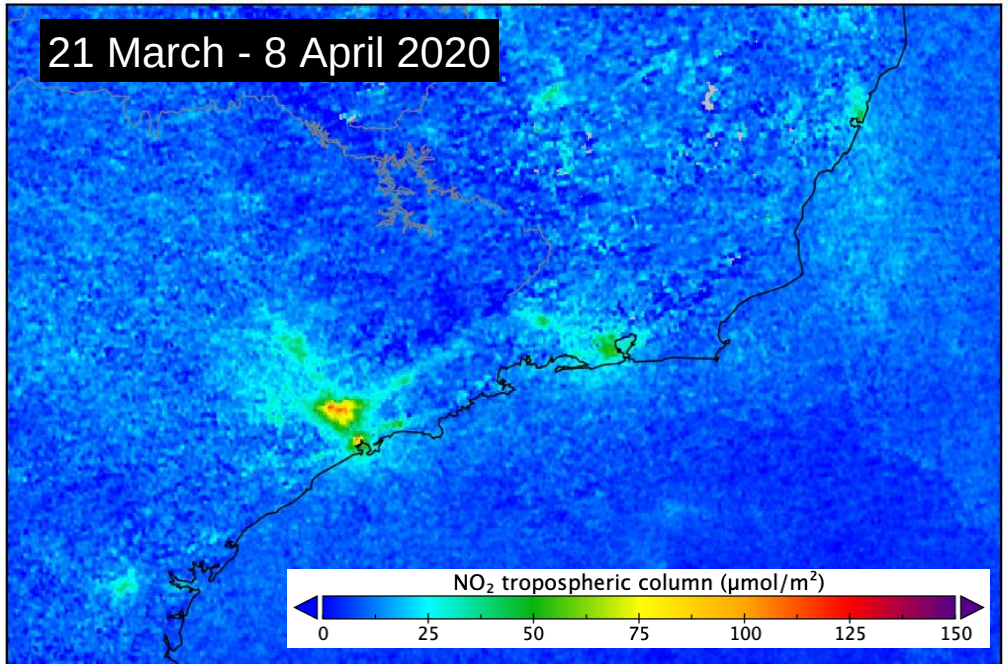
CO_2 hotspots traceren via NO_2

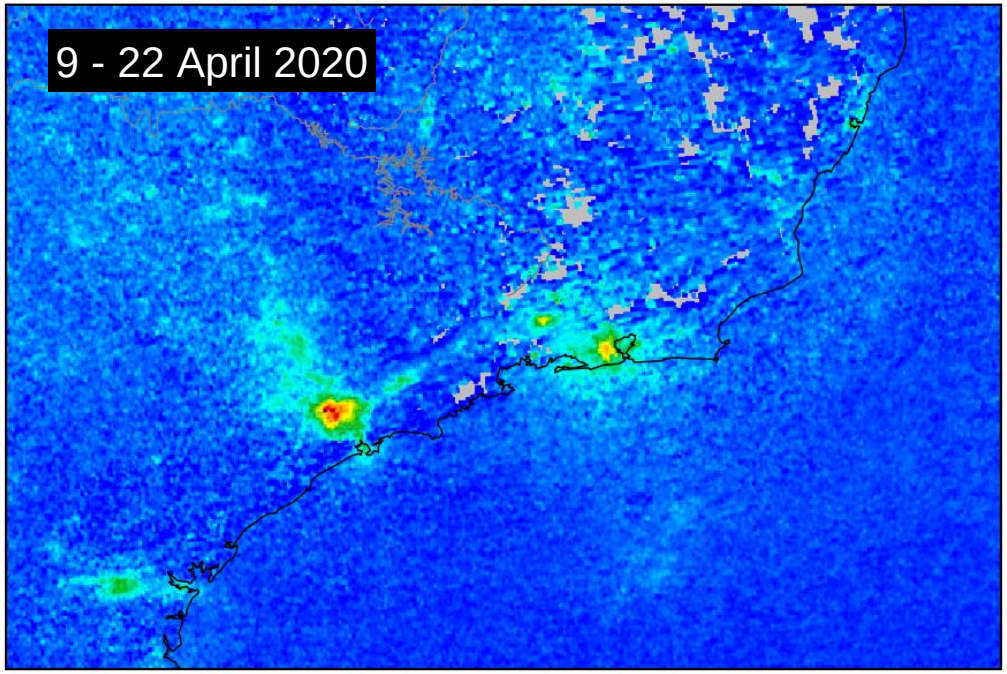


2019

First weeks after lockdown

The two weeks after that:
Indication of increasing emissions.
Traffic?





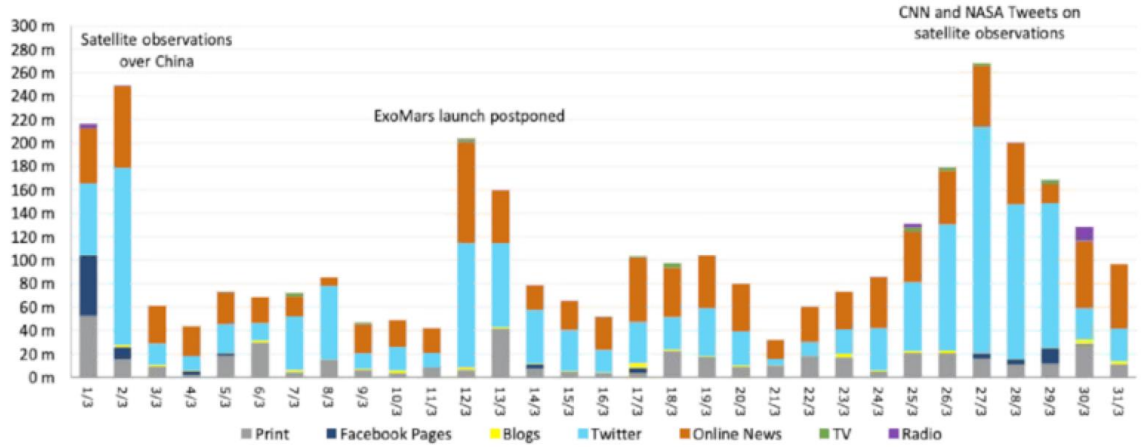
COVID-19 impact as 'seen' by Sentinel-5P (March 2020 - ESA internal Statistics)

European Union

esa

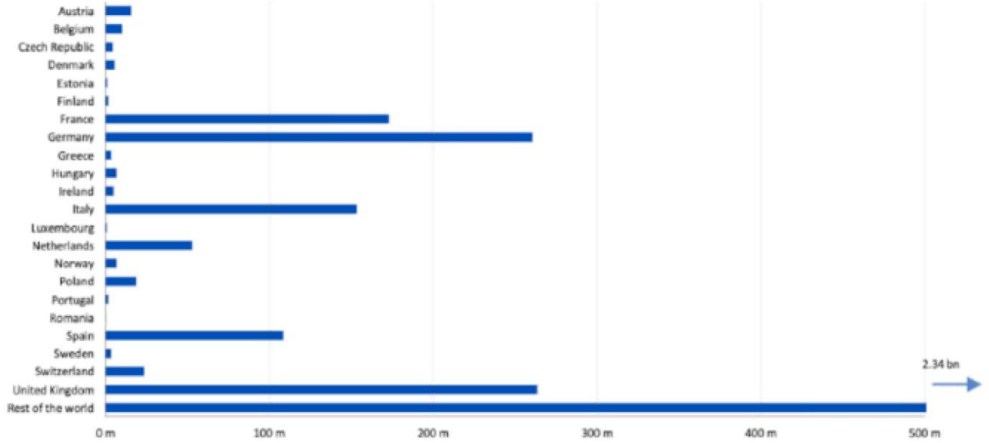
ExoMars and Sentinel-5P drive the media visibility

Visibility by date and by channel (Gross Reach)



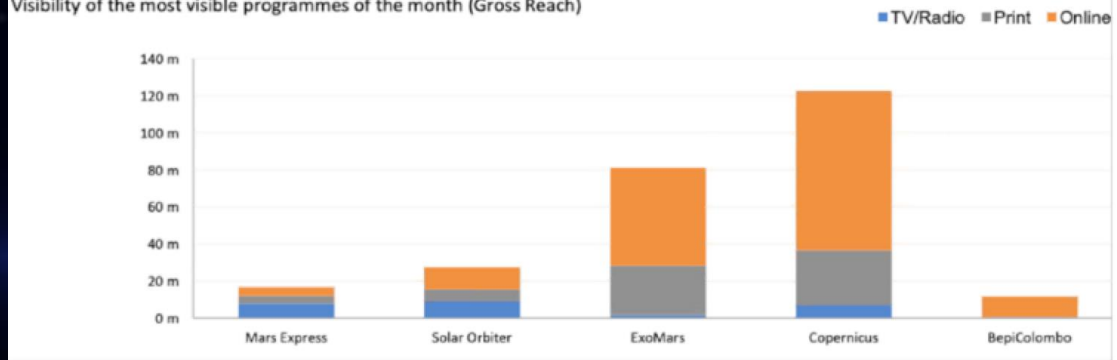
32 % of the visibility generated by ESA member states media

Visibility by country (Gross Reach)



Programmes

Visibility of the most visible programmes of the month (Gross Reach)



	Mars Express	Solar Orbiter	ExoMars	Copernicus	BepiColombo
Gross Reach	16.6 M	27.4 M	81 M	122.5 M	11.8 M
Frequency % out of total 912 M	1.8 %	3 %	8.9 %	13.4 %	1.3 %

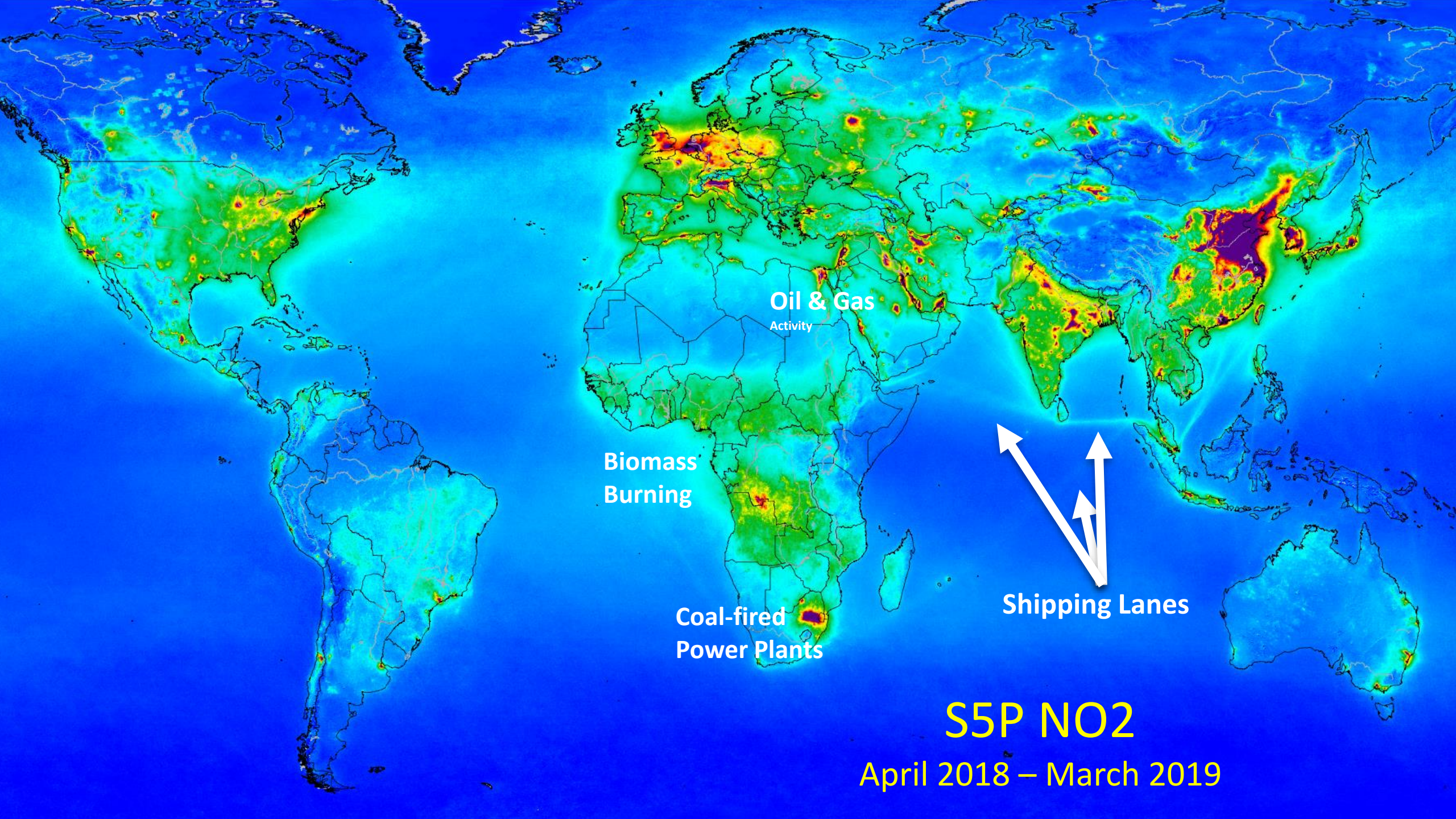
Key messages

Italy

- Italy was overwhelmingly the story which gained most traction in March. 53% of all Facebook posts were focused on NO2 drops in Northern Italy.

China

- China also featured prominently, though the posts looked at increasing emissions after the lockdown was relaxed. 12% of all Facebook posts focused on China.


Oil & Gas
Activity
Biomass
Burning
Coal-fired
Power Plants
Shipping Lanes
S5P NO2
April 2018 – March 2019

But first, a thought exercise…

Motivation: Confronting our Meme Culture

TROPOMI

meme *noun*

ˈmēm

1 : an amusing or interesting item (such as a captioned picture or video) or genre of items that is spread widely online especially through social media

- Memes as a Metaphor: make a nice picture, add a caption or soundbite
- Reductionism to deal with Complexity

Example of Meme-Style TROPOMI Data Usage

GREENPEACE

New satellite data reveals world's largest NO2 air pollution emission hotspots - Greenpeace Media Briefing

The global air pollution crisis and the role of NO2

Air pollution is a global public health crisis, with up to 95% of people across the world breathing unsafe air, and several million deaths per year attributable to it.

Unprecedentedly detailed satellite data generated by the European Space Agency's new satellite and analyzed by Greenpeace reveals the location of the globes worst NO2 emissions sources.

NO2, and NOx[1] more generally, are dangerous air pollutants, causing respiratory symptoms and lung damage on acute exposure, increasing the risk of chronic diseases in long-term exposure.

Long-term exposure to NO2 is associated with increased mortality rates world-wide[2]. In the European Union, exposure to NO2 is linked to an estimated 75,000 premature deaths per year[3]. In China, there is growing scientific evidence that indicates significant increases in respiratory and cardiovascular mortality as a result of exposure to NO2[4 5 6].

Furth
most

The list of the largest emissions hotspots includes several coal-fired power plants in India, South Africa and Germany, 10 power plant and industrial clusters in China, 14 megacities with very high transport-related emissions, including Santiago de Chile, Tehran, Dubai, London and Paris; as well as agricultural burning in Congo and Angola. Some hotspots, such as Seoul, Jakarta and New Delhi, have a mix of contributing sources, including transport, coal power plants and manufacturing.

The world's biggest hotspot is Mpumalanga in South Africa, home to a cluster of a dozen coal fired power plants with a total capacity of over 32 gigawatts owned and operated by Eskom.

The data covers the period from 1 June to 31 August 2018.

Power Plant Hotspots

For the power plant hotspots, the main source of emissions is also readily visible from images generated from daily snapshots of NO2 levels in the atmosphere – these images show plumes originating from specific power plants.

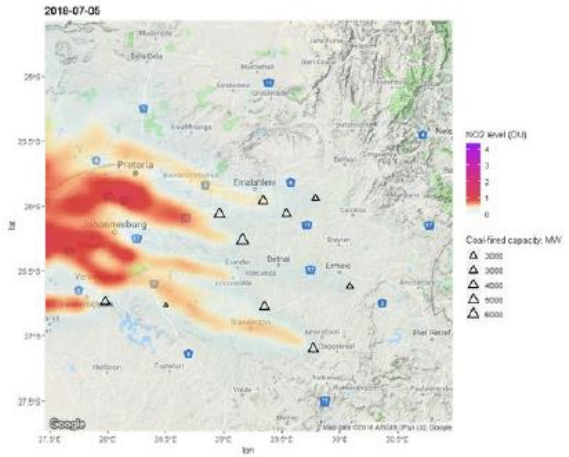
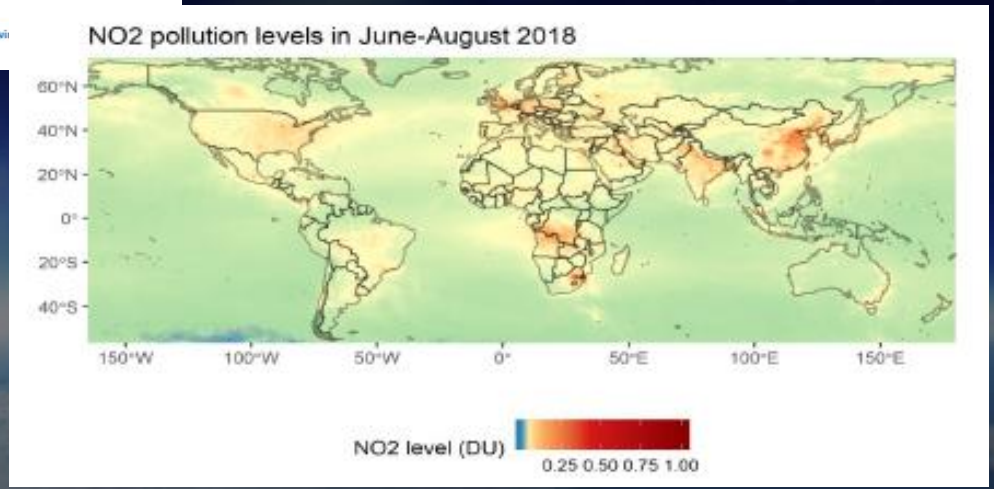
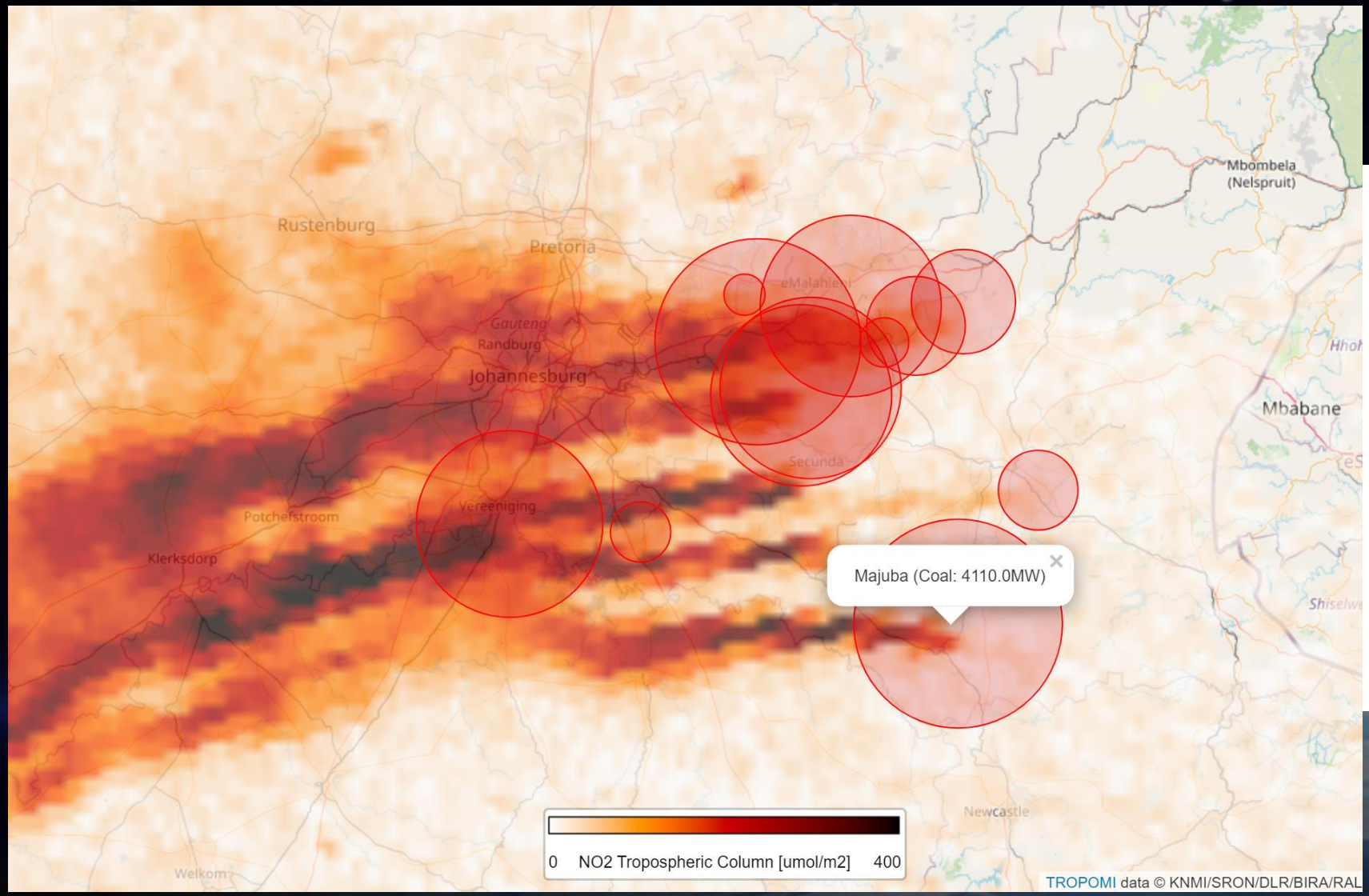


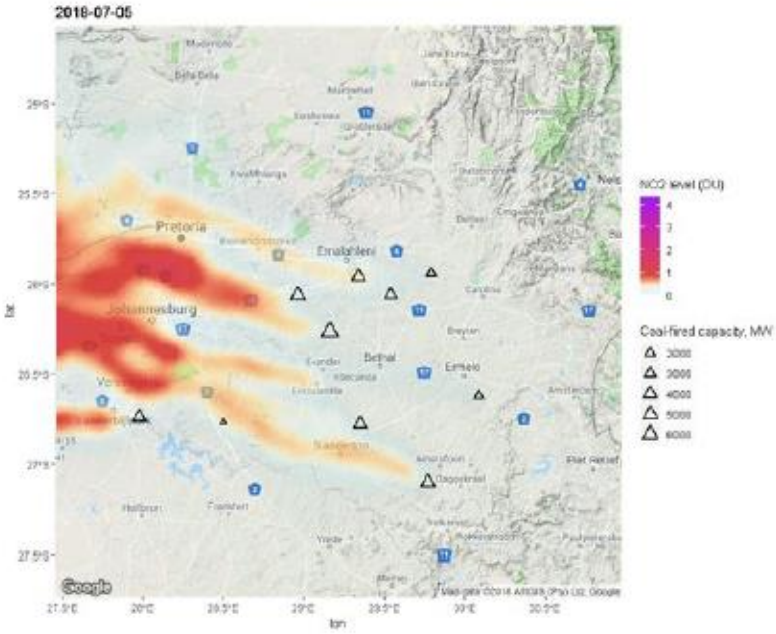
Figure 3. Power plant pollution plumes detected by Sentinel 5P on Jul 5, 2018, transported by wi
power plants in South Africa to Johannesburg.

- Climatological and seasonal context was ignored
- Mix of data streams and versions
- No information about data quality (filtering)
- Color scale matters

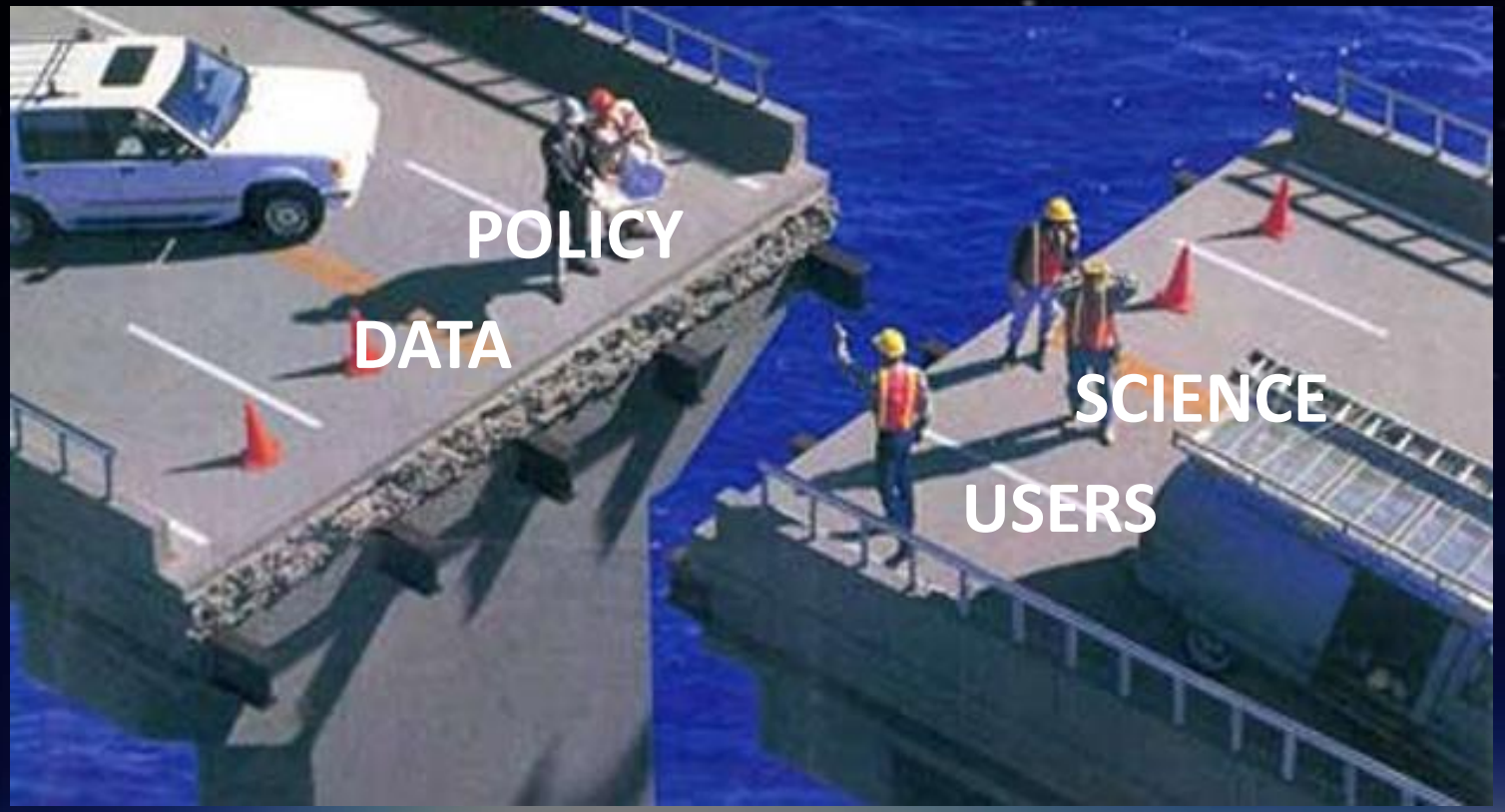


Combining TROPOMI NO_2 with WRI Power Explorer





Motivation: Bridging the Gap(s)



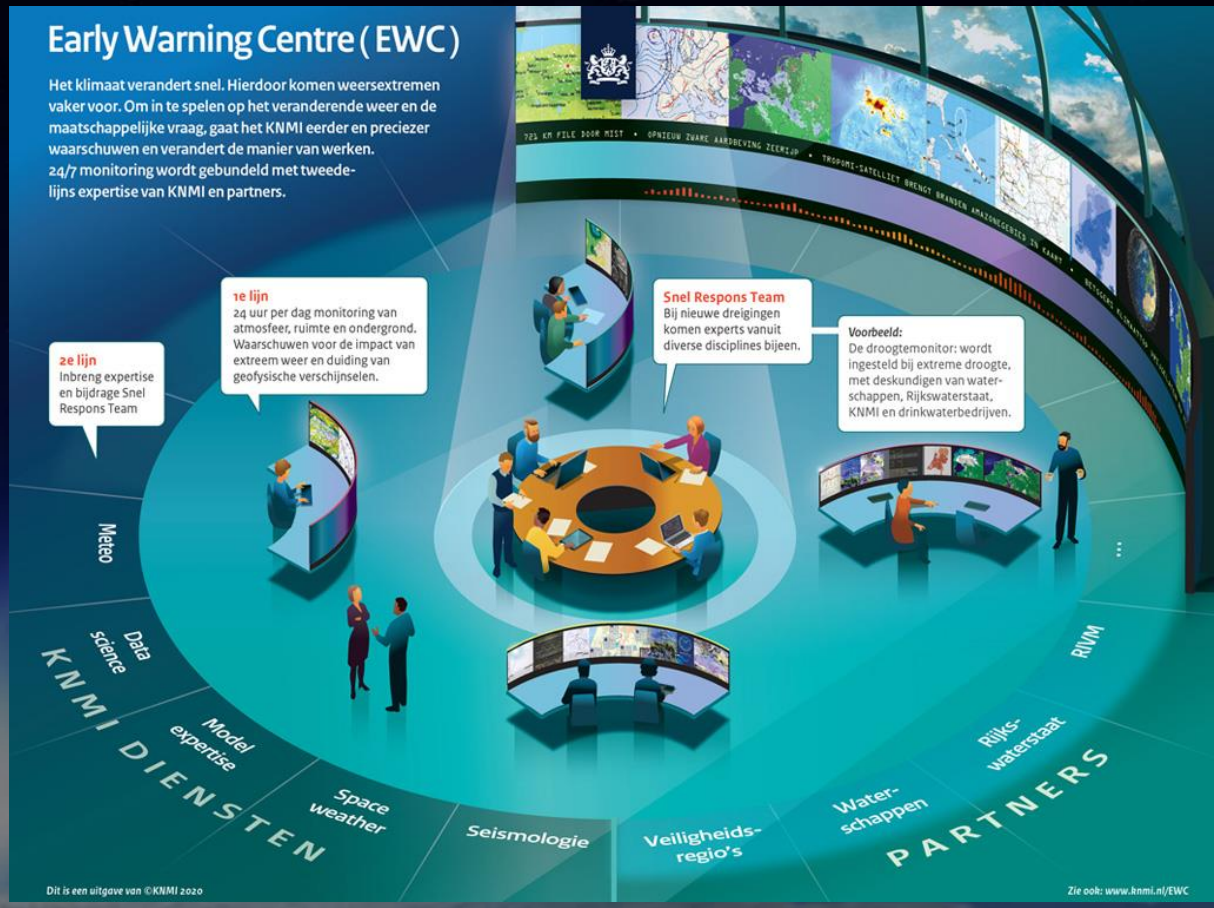
Goal today: Identify which gaps are present between the data creators & data provider and the (non-technical) data user

With which types of non-scientific users are you interacting?

- Policy makers,
- City council members,
- Concerned citizen groups,
- Local, regional environmental agencies
- …

KNMI: who are we & what do we do?

- **New Director & New Directions**
- Maarten van Aalst: former director International Red Cross/Red Crescent **Climate Risk Management** research background
- KNMI is reframed and reorganized to act as an **Early Warning Center**
- **KNMI Global** is driven by WMO initiatives to facilitate international partnerships to expand services beyond the Netherlands



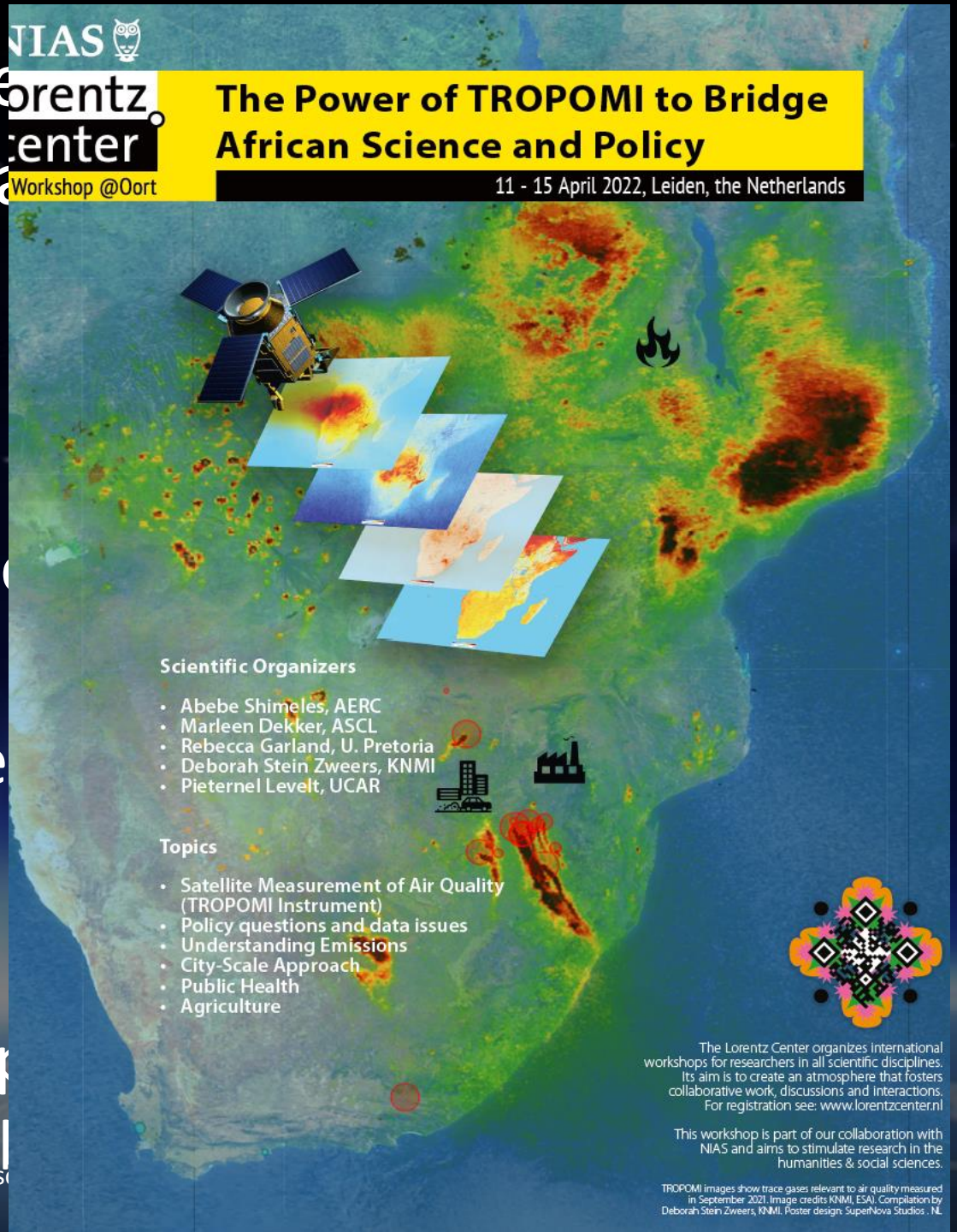
KNMI: Engaging African Researchers

- **Motivation to act as facilitators to** engage & learn regarding
- **Operationalization of Early Warning Systems**
- **Climate Attribution & Communication**
- **Utilization of Satellite datasets for Monitoring and services**
  - Meteorology & Climate
  - Air Quality & Emissions
  - Agriculture & Public Health
- **Innovations for sensor networks city-scale field measurements**
- **What data, services, insights related to the development can we share with you to learn from you?**

KNMI: Rece
African-focused a

- Workshop about Bridging African S
  TROPOMI
- 11-15 April, 2022 in Leiden, The Ne

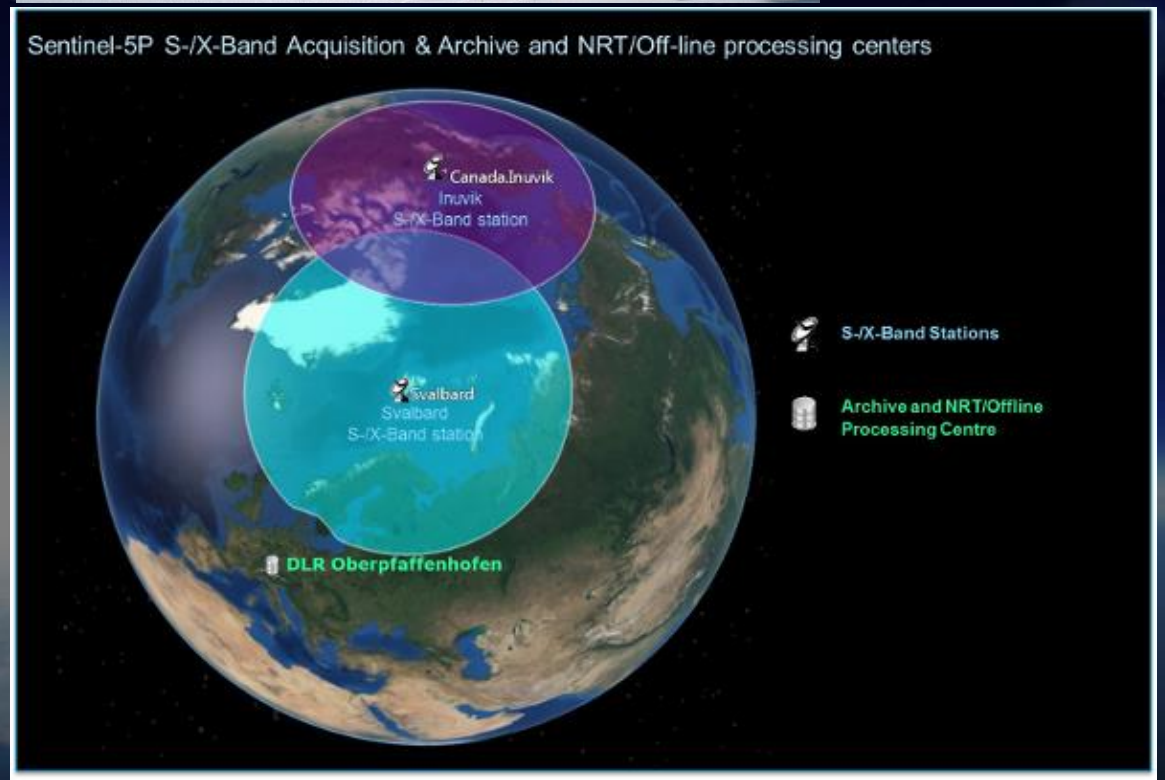
- Invited a mix of Natural Sciences &
  researchers from Africa, US & Europ
  establish needs & partnerships for l
  worlds together for green growth



What are data levels? From satellite to ground

- **LEVEL ZERO (L0):** This electronic information is the so-called L0 data and is transmitted to receivers (satellite dishes) at high-latitude
- Using electronic L0 data from both direct sunlight and Earth plus lots of information about the satellite itself the L0 is translated into L1 data
- **LEVEL ONE (L1):** is a description of the exact amount of light for many spectral wavelengths as detected by TROPOMI for a given ground location (or pixel);

Kiruna, Sweden: Station for sending commands to TROPOMI



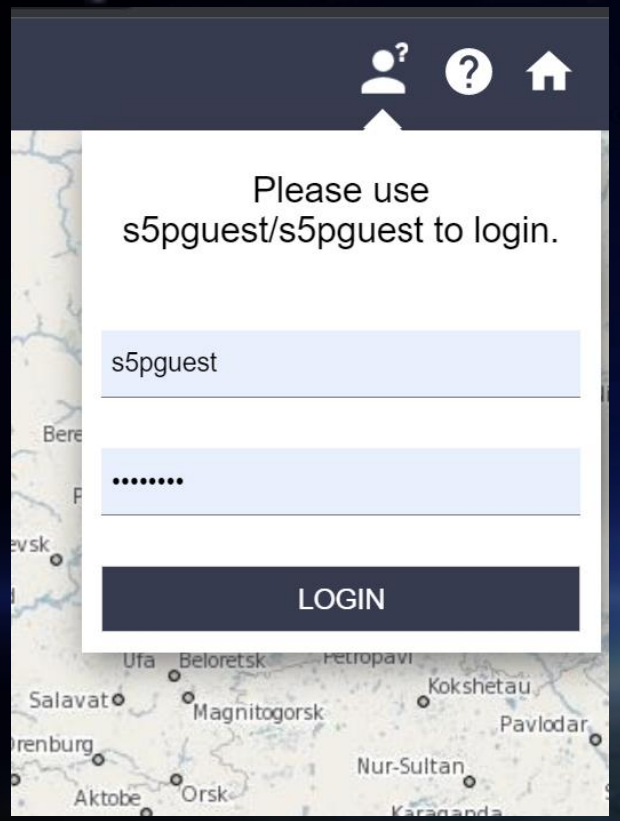
What are data levels? spectral bar codes

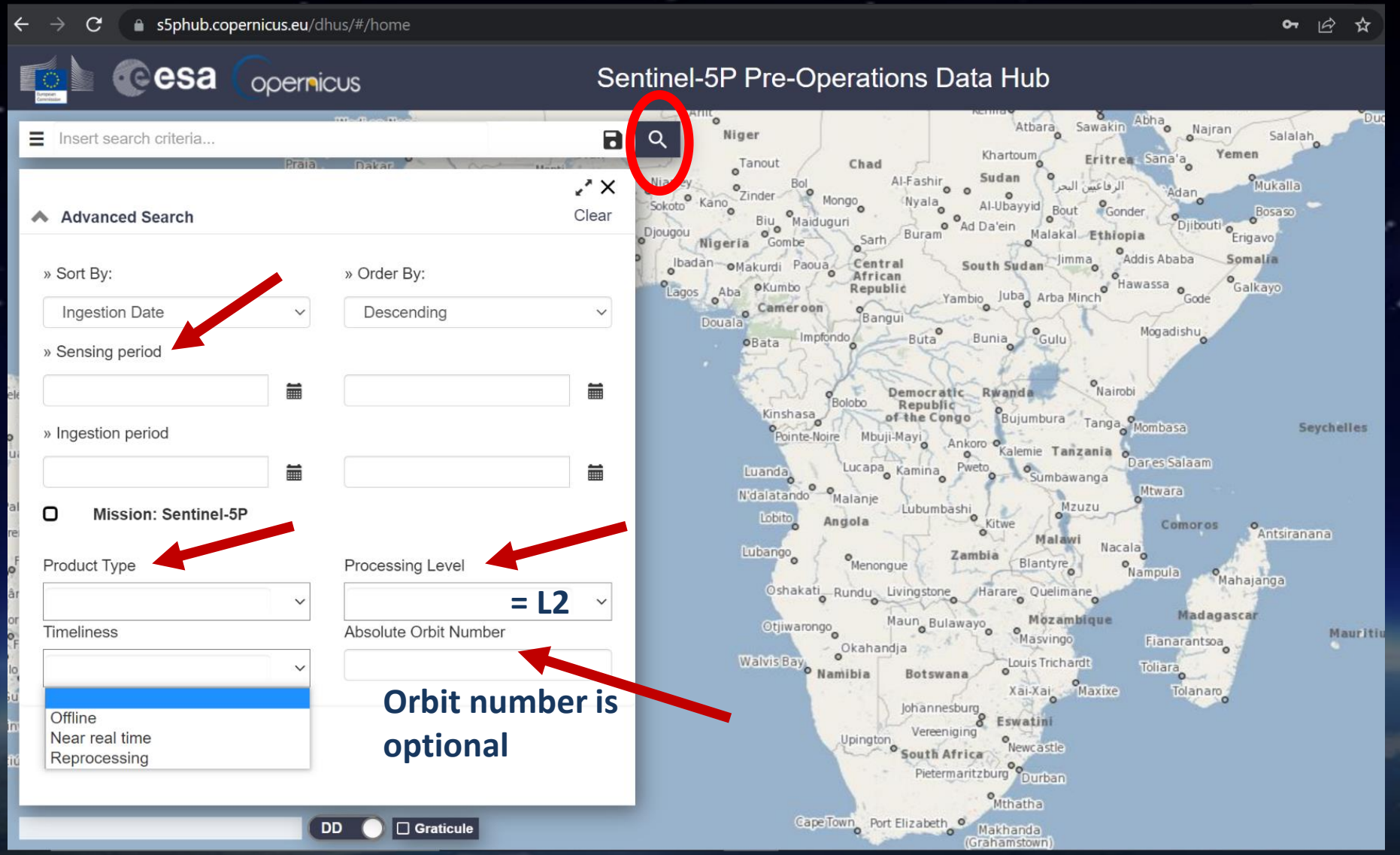
Each trace gas species, aerosol type, or cloud has a unique spectral signature which acts like a kind of barcode telling us how much light absorption is taking place in the atmosphere due to that specific species

- **LEVEL TWO (L2):** the spectrum is transformed into an amount of the trace gas spread over the atmospheric vertical column for a given pixel (ground location); The pixels in an orbit are not all the same size across an orbit (larger on the extreme edges) and orbits don't fall over the same place
- **LEVEL THREE (L3), GEE is an example:** To more easily compare the day-to-day variability for a specific location the all of the orbit-based data needs to be averaged and redistributed on a fixed grid; L3 data can be used to make time-series analyses for a specific site

Searching for files
https://s5phub.copernicus.eu/dhus/#/home

TROPOMI





Sentinels Website – TROPOMI

- **https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-5p/products-algorithms**
- L1, L2 and supporting documentation per product

- **Product Readme Files (PRF)** – Start with this Document
  - Compact overview of how to use TROPOMI data products
  - Short descriptions of data fields, version, quality & validation status
- Product User Manual (PUM)
- Algorithm Theoretical Basis Document (ATBD)