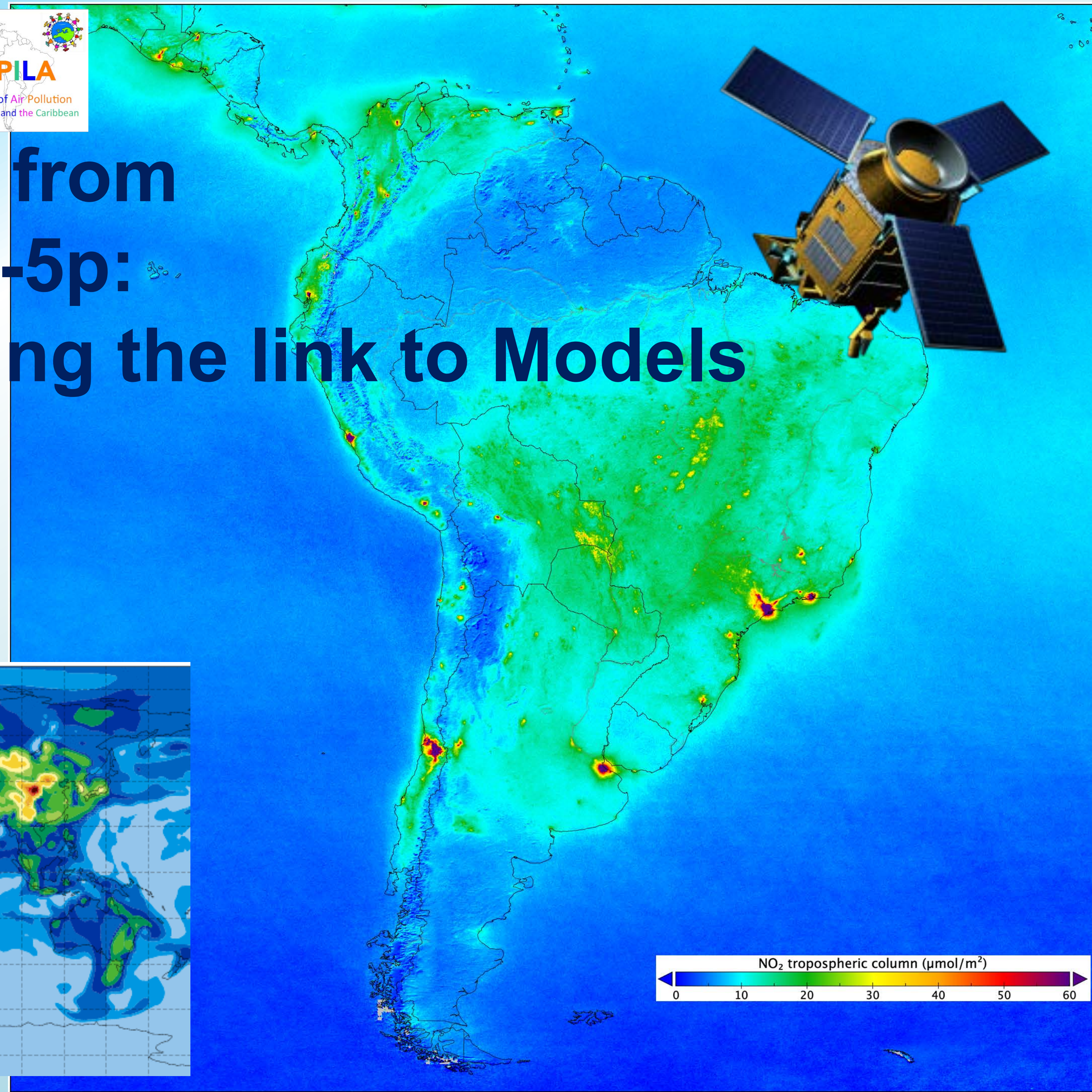
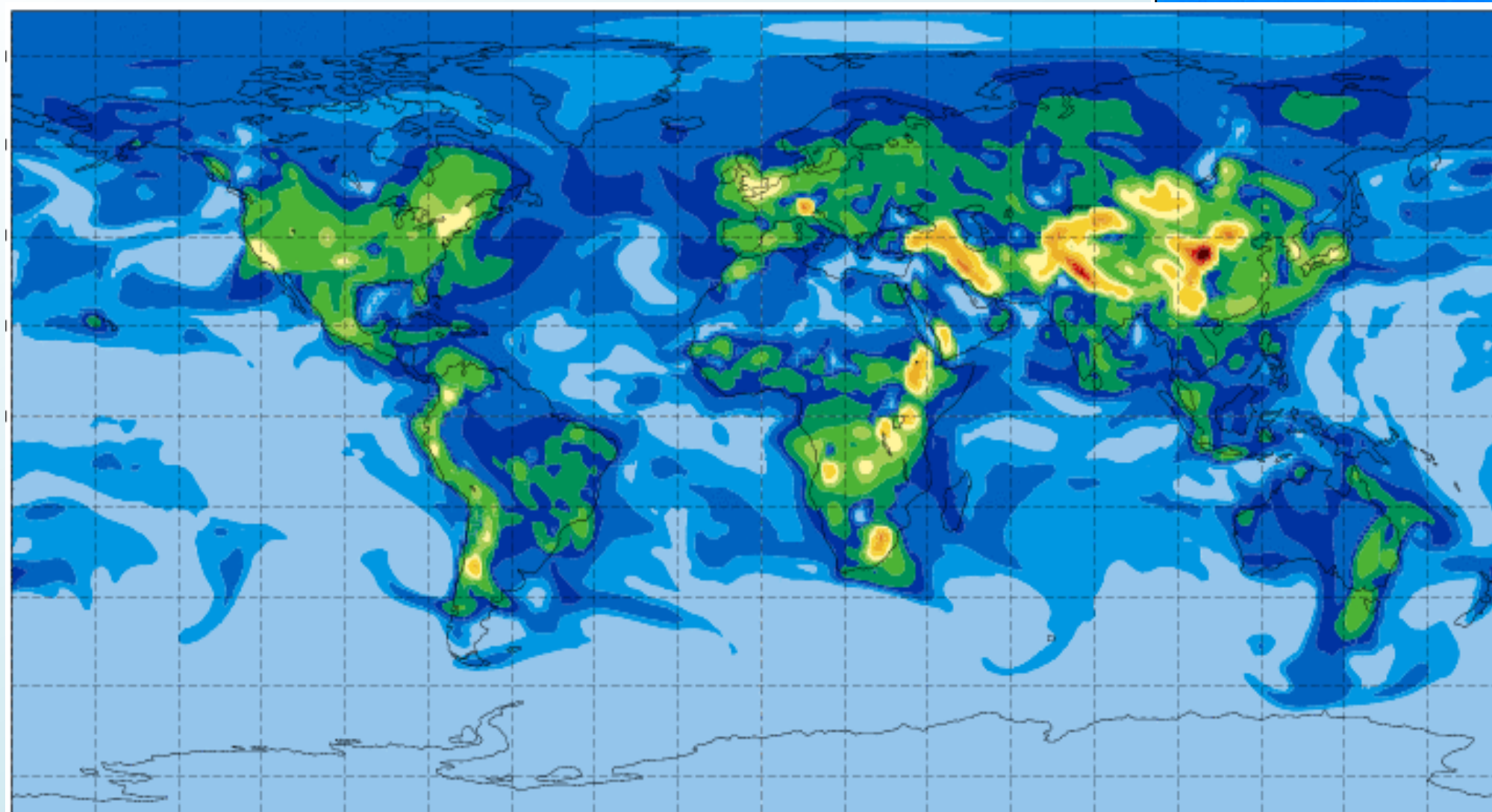


Satellite observations from TROPOMI on Sentinel-5p: Measurements & Making the link to Models

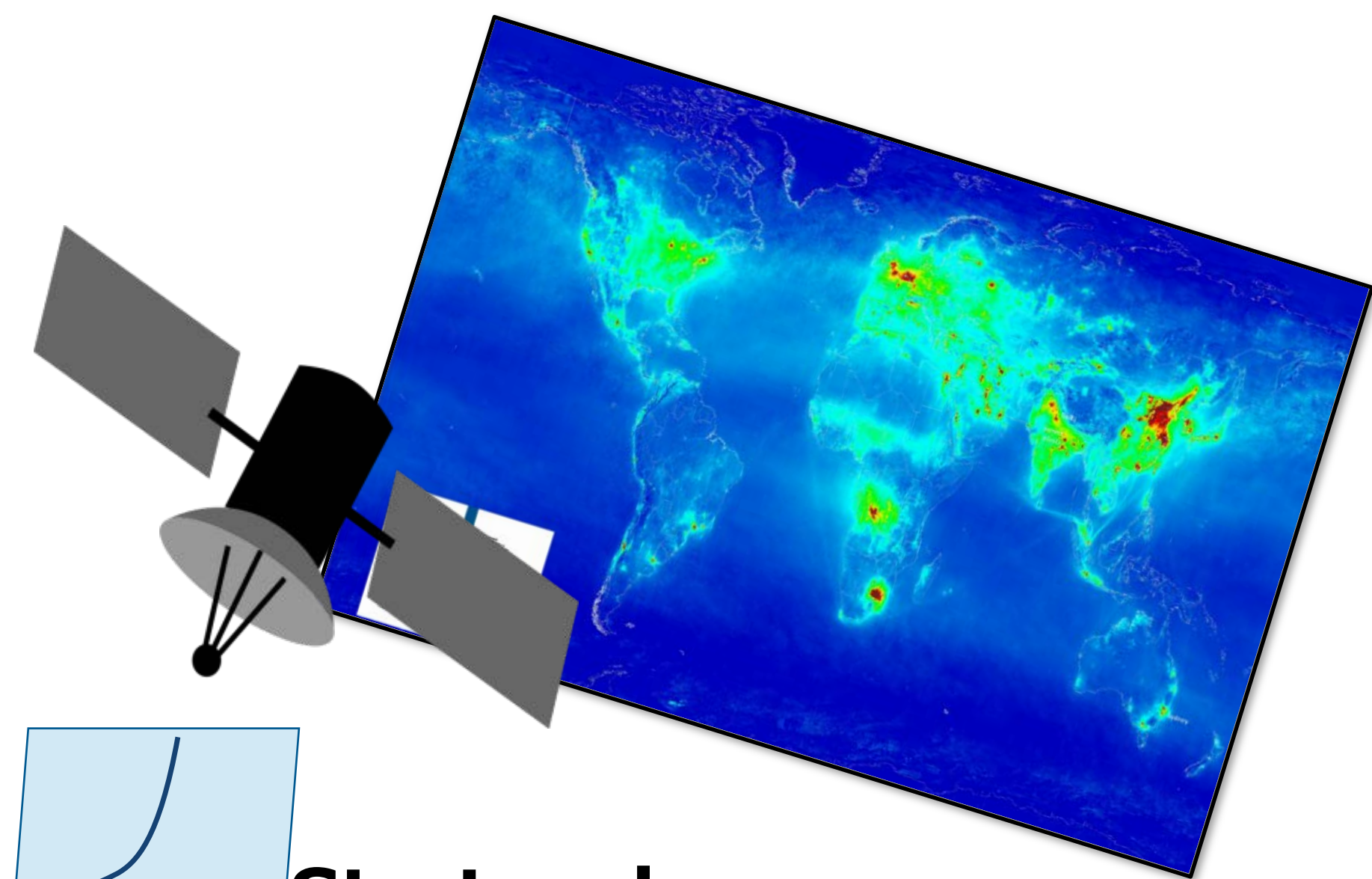
Henk Eskes, Deborah Stein Zweers
R&D Satellite Observation, KNMI

PAPILA summer school, 24 April 2020





How does satellite data fit in global air quality monitoring?



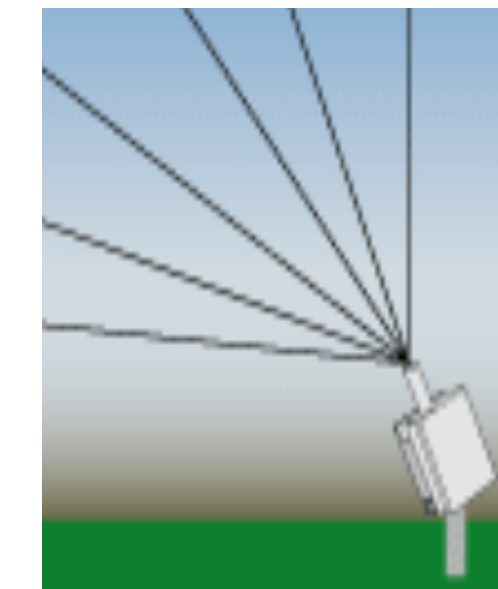
Vertical profile information



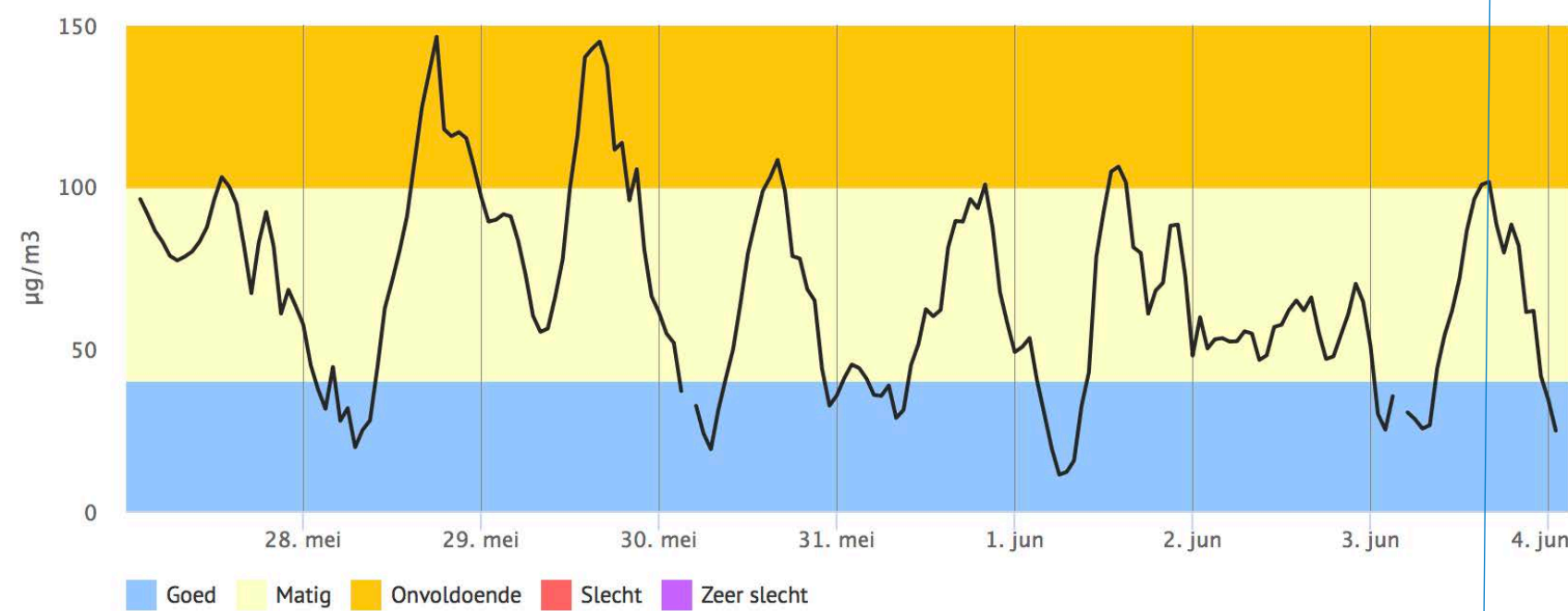
Stratosphere



MAX-DOAS, PANDORA



Ground Monitoring





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.



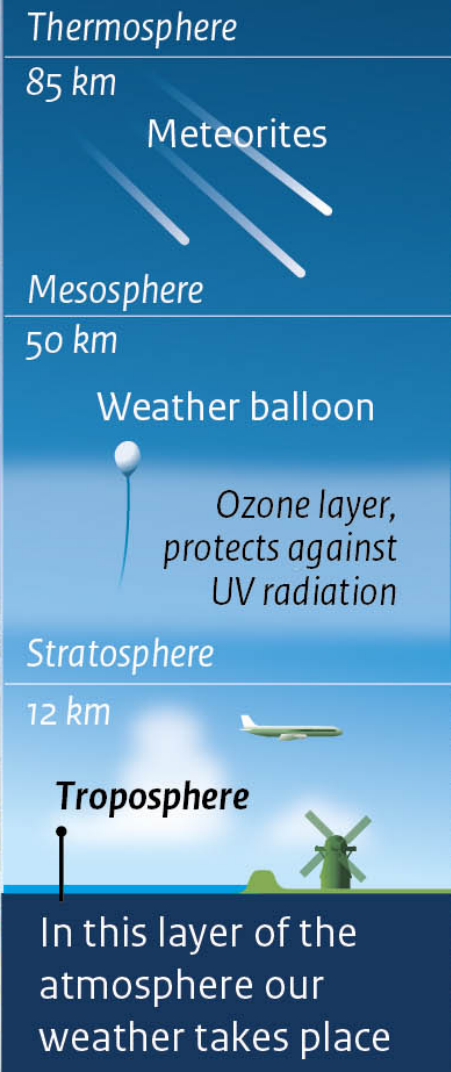
Geostationary satellites, such as MSG, orbit so as to maintain a fixed point above the Earth



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



THE ATMOSPHERE



Important satellites with which KNMI works:

OMI
2004
NASA/KNMI
Measures ozone and air pollution

MetOp
2006
ESA/EUMETSAT
Ozone, wind and air pollution

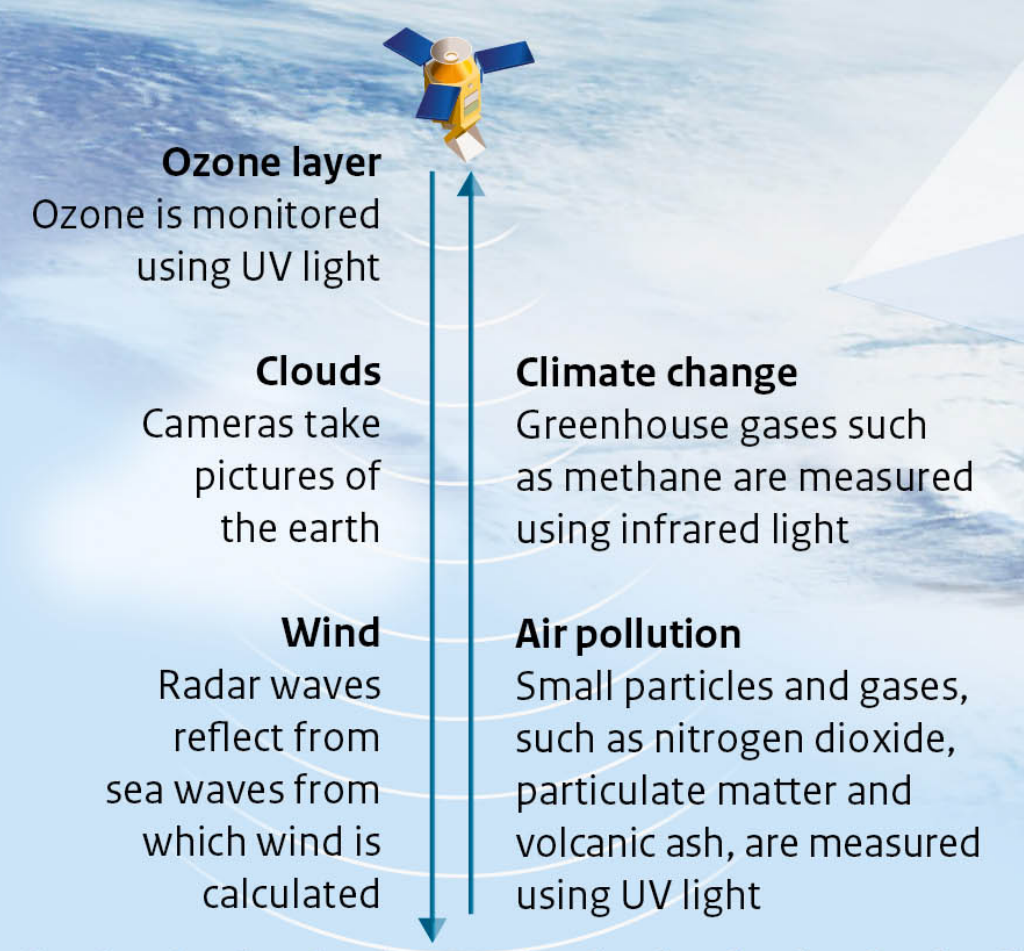
MSG
2002-2021
ESA/EUMETSAT
Cloudiness, air pollution, sun and precipitation

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

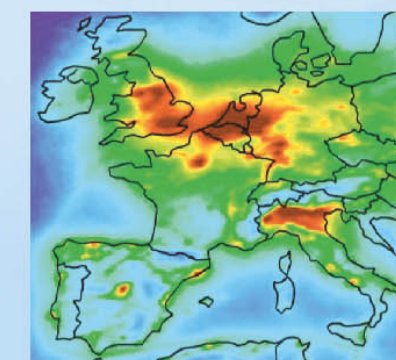
Aeolus
2018
ESA/KNMI
Wind profiles

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

What do our satellites measure?



Measuring air pollution is increasingly important. NO₂ measurements show that the air in Europe is not clean:

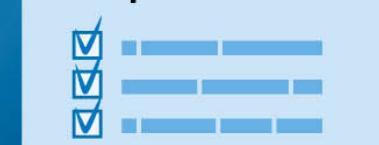


The biggest air pollutants are

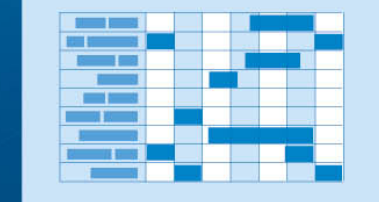
- Nitrogen dioxide (NO₂)
- Particulate matter (PM)
- Ozone (O₃)

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

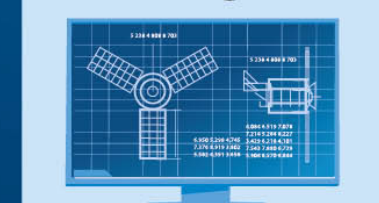
Formulating requirements



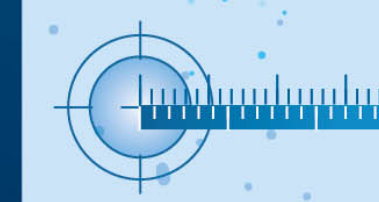
Planning



Design



Calibration



Launch



Data processing



Data interpretation

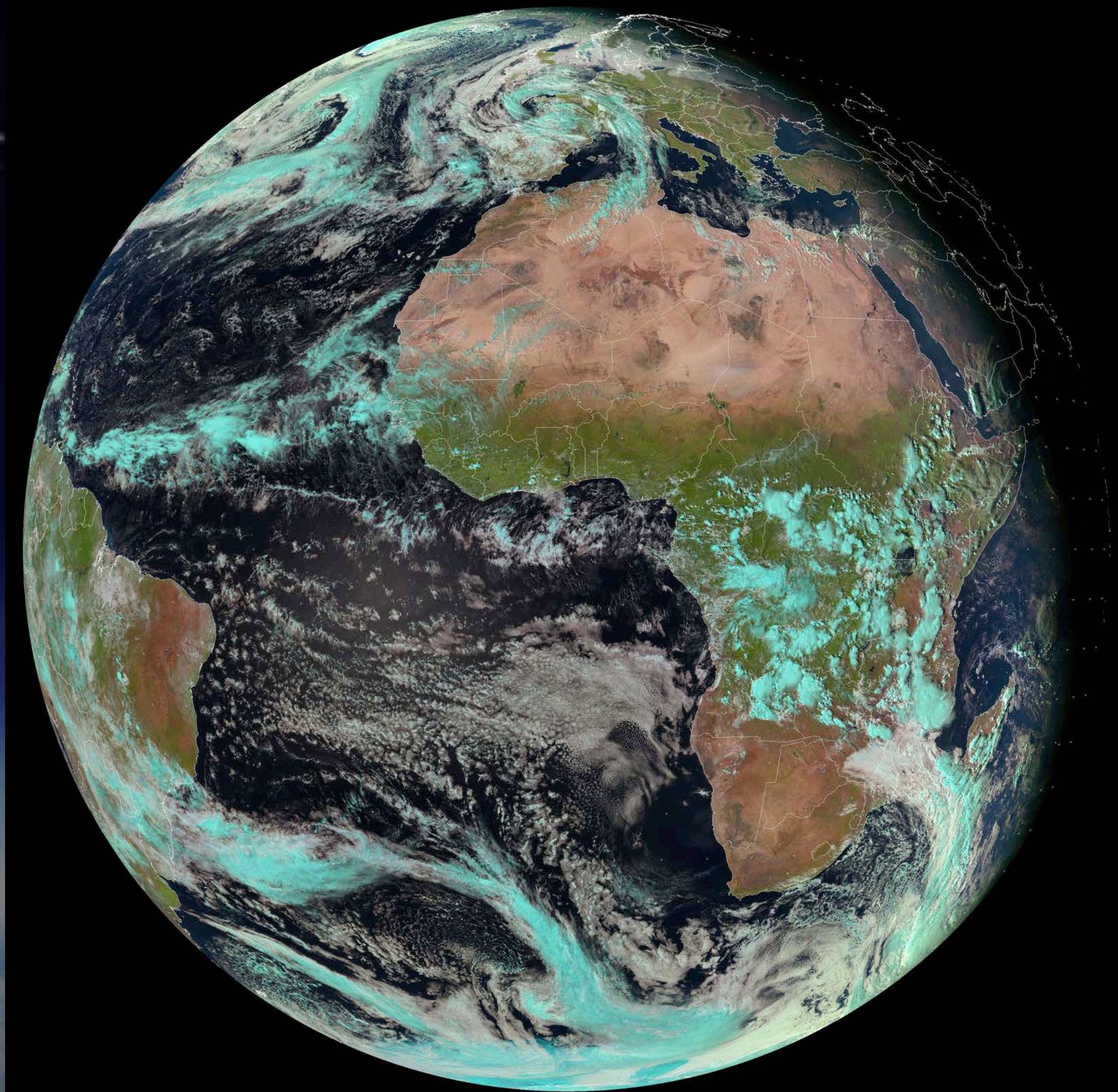


To customers

- Universities
- Aviation
- Meteorologists
- Government
- Citizens

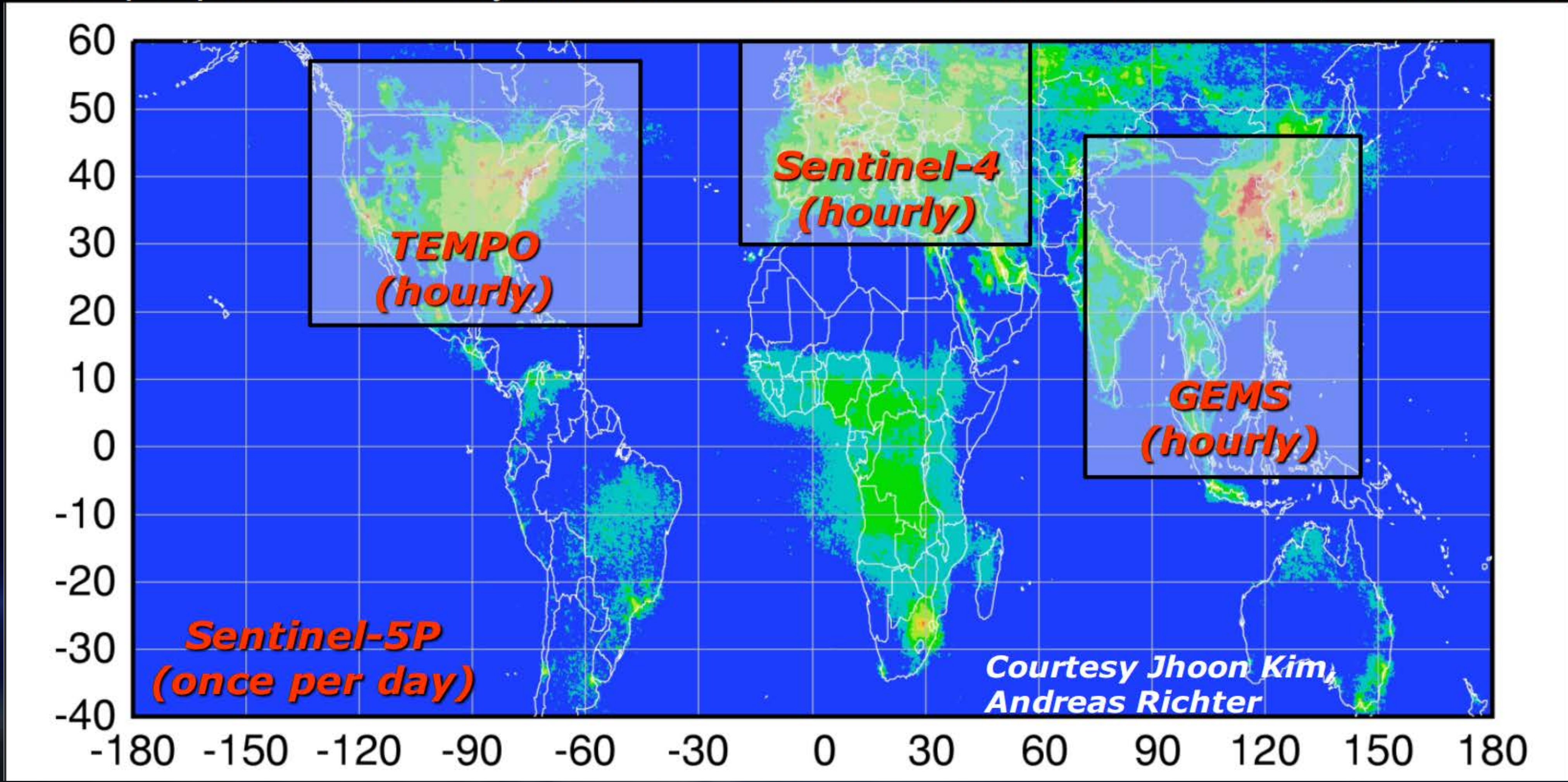
Why Satellites?

- Meteorological satellites revolutionized our understanding of dynamics
 - 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
 - Copernicus Atmospheric Monitoring Service (CAMS) uses satellite data for global/regional air quality forecasts



GEO + LEO Observing Strategy

Global pollution monitoring constellation:
Tropospheric chemistry missions funded for launch 2016–2021



Focus on TROPOMI: TROPospheric Monitoring Instrument

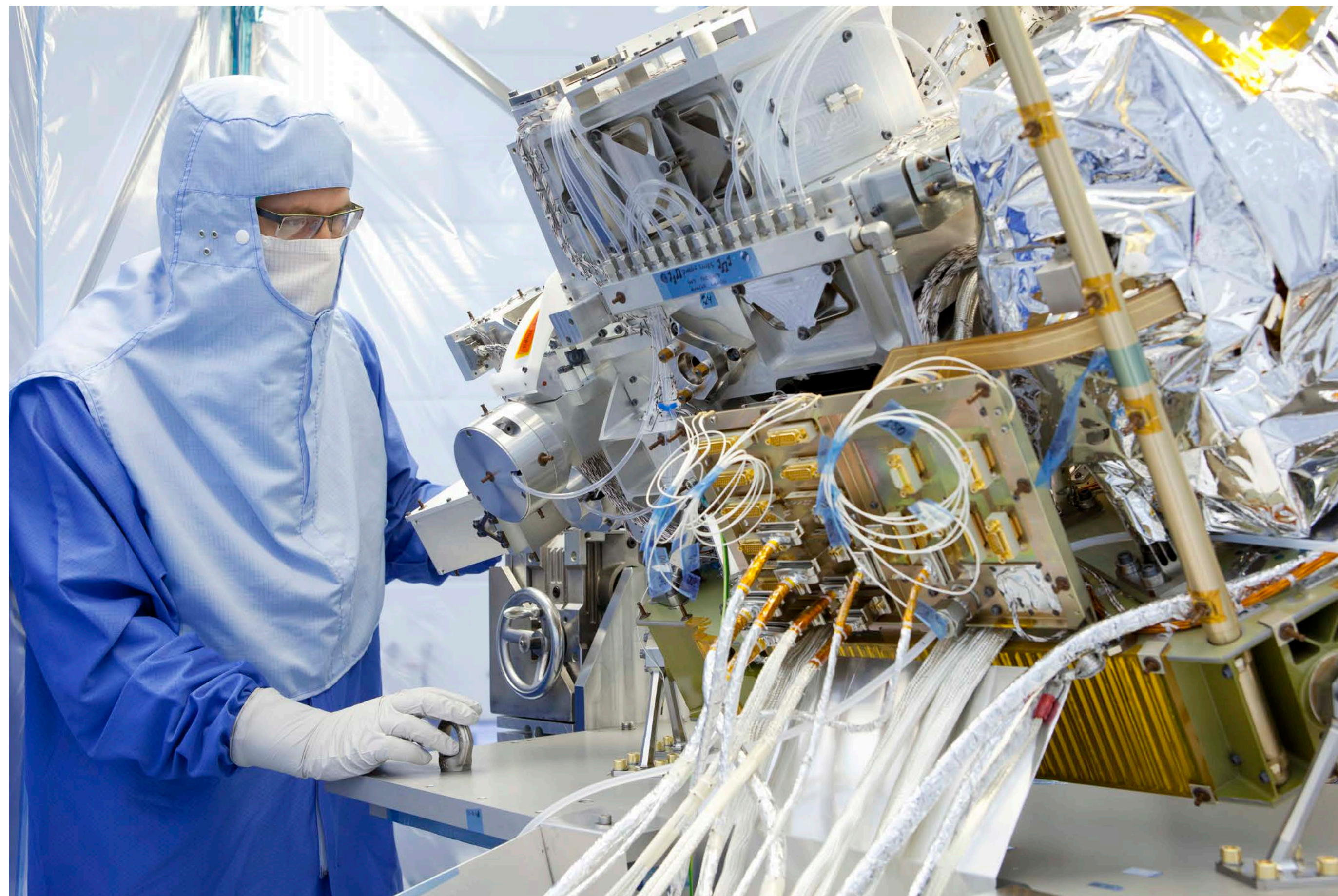


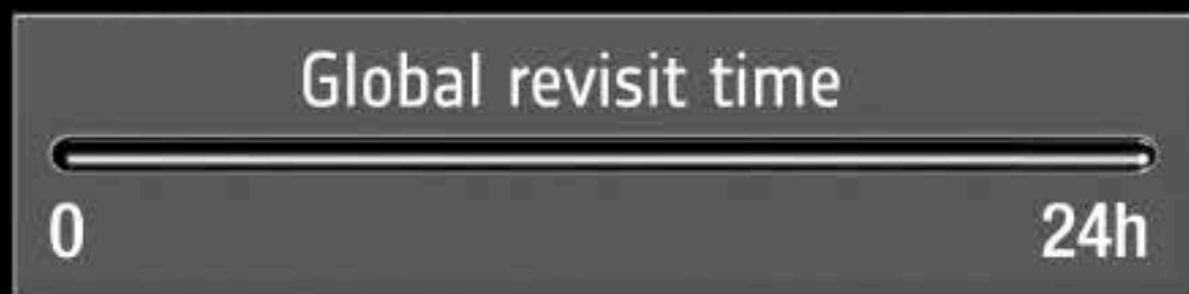
> Monitoring atmospheric composition, for:

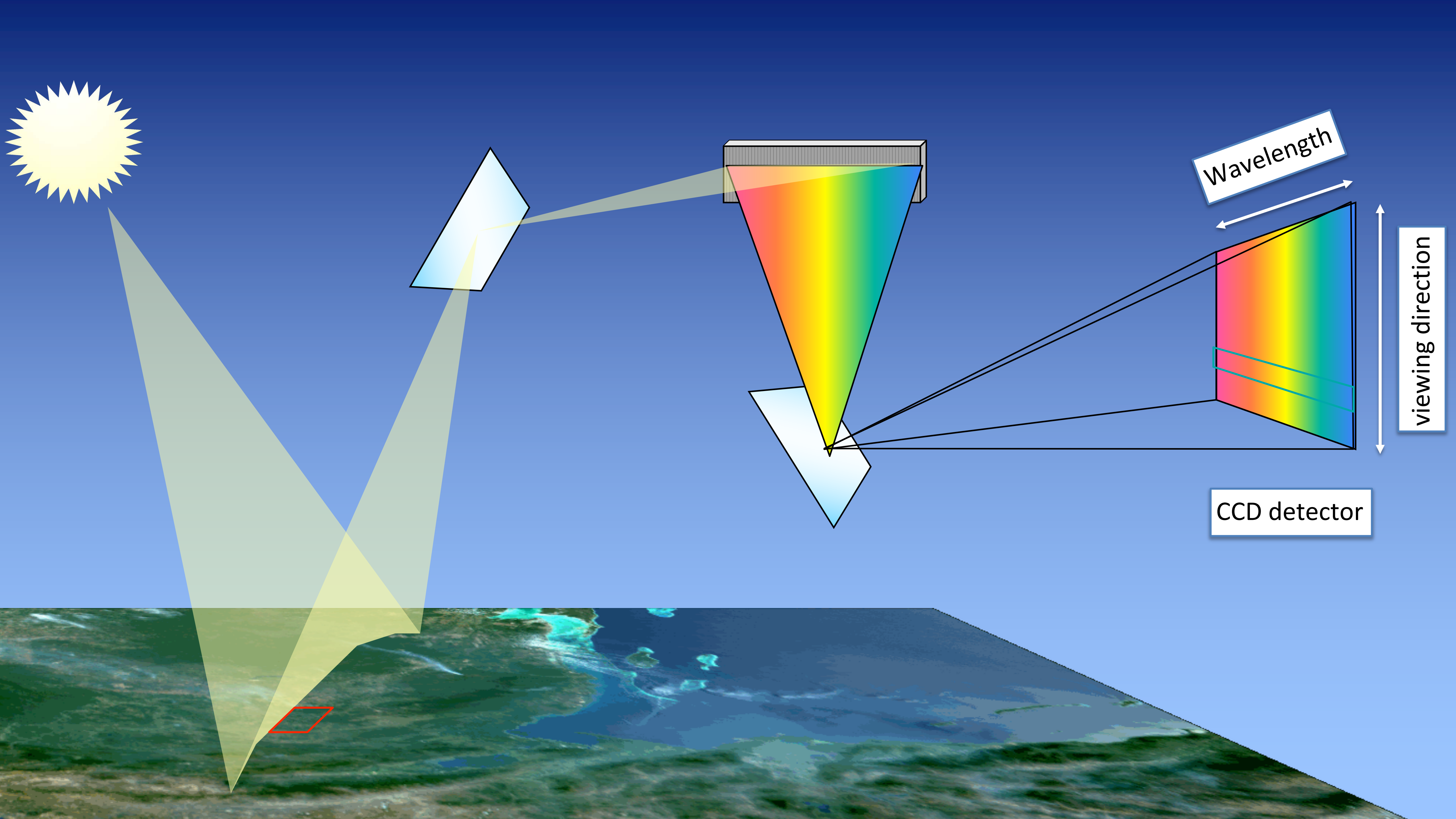
- Air quality
- Climate change
- Ozone layer

> TROPOMI details:

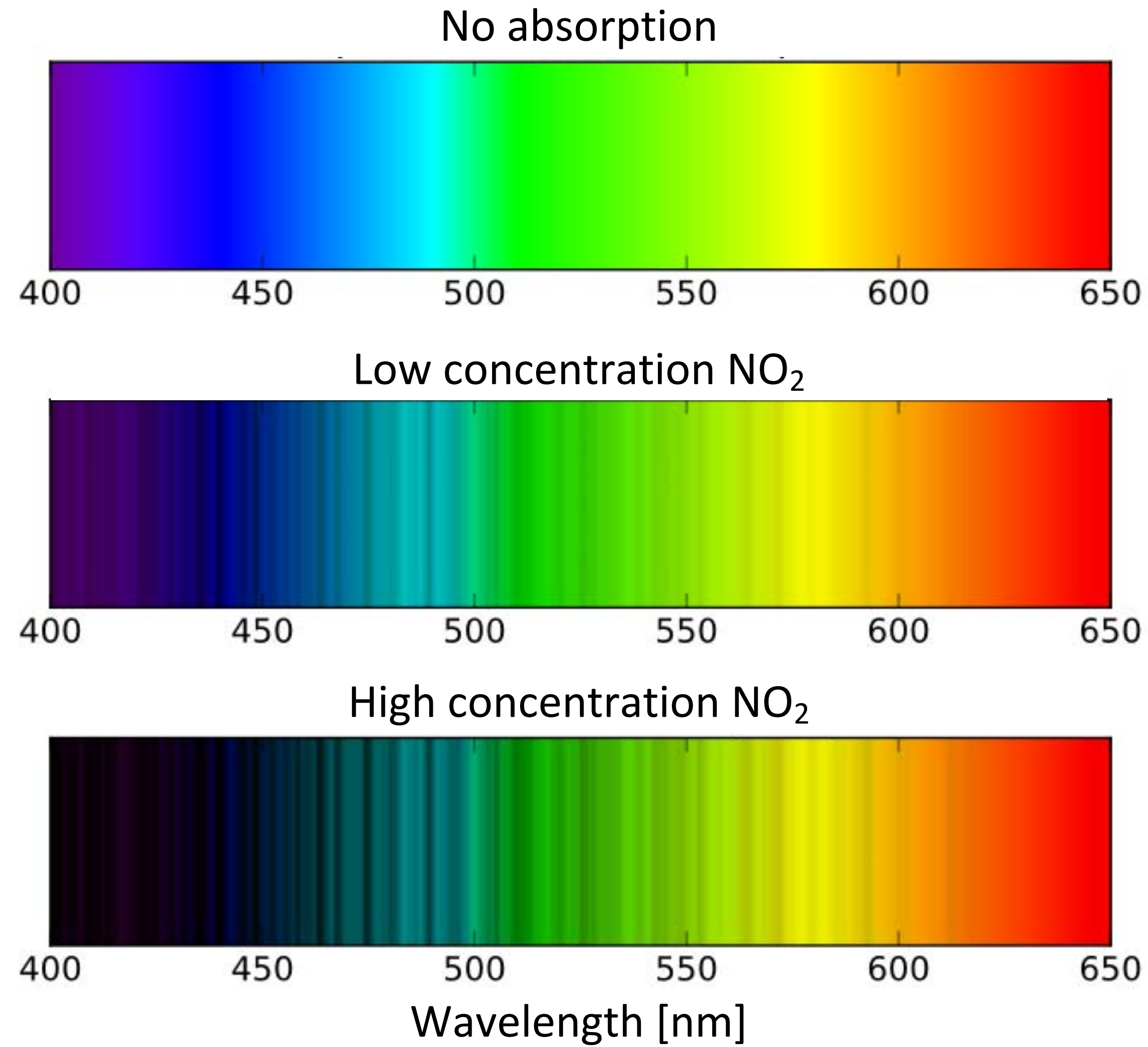
- On Sentinel 5-Precursor Satellite (S5P)
- Launched 13 October 2017
- Polar-orbiting satellite
- Overpass time ~13:30 LT
- Data are free and open
- www.tropomi.eu &
- <https://scihub.copernicus.eu/>

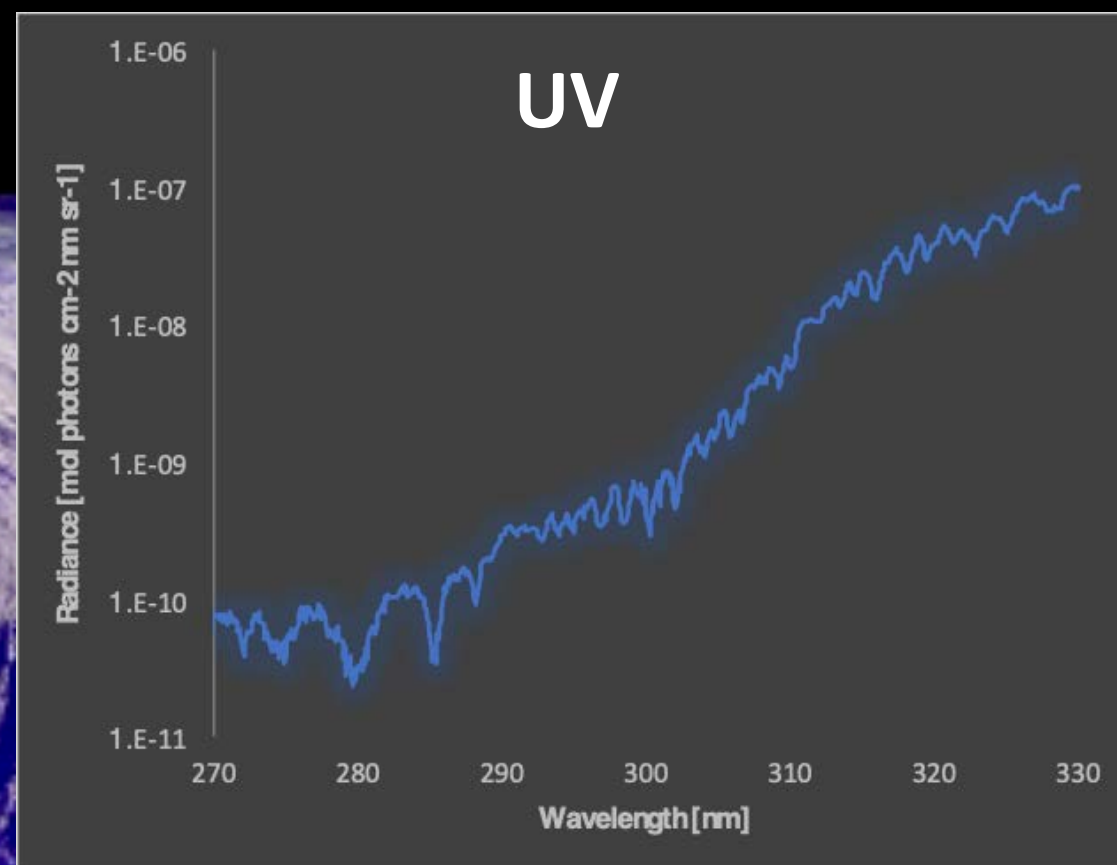




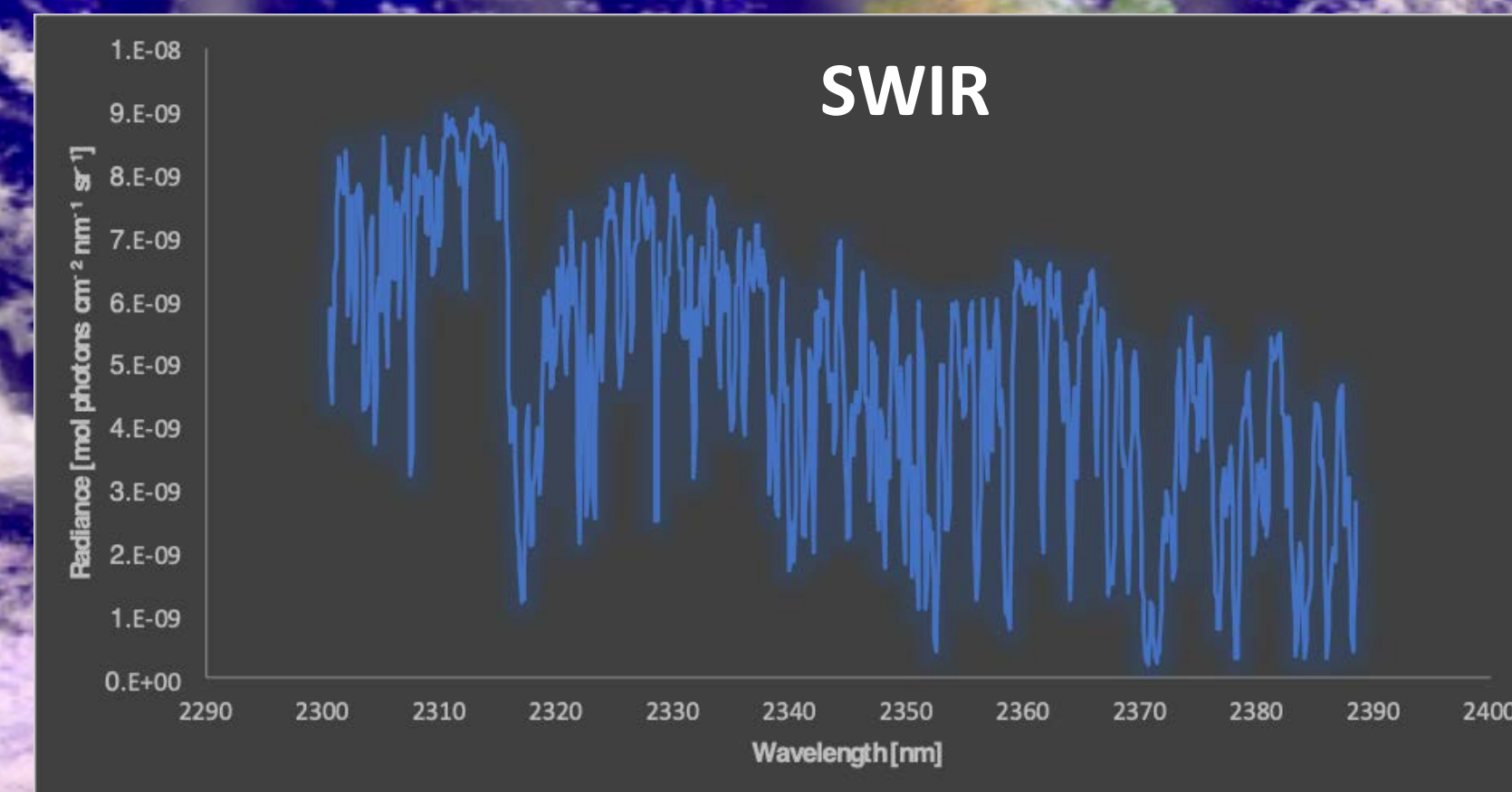
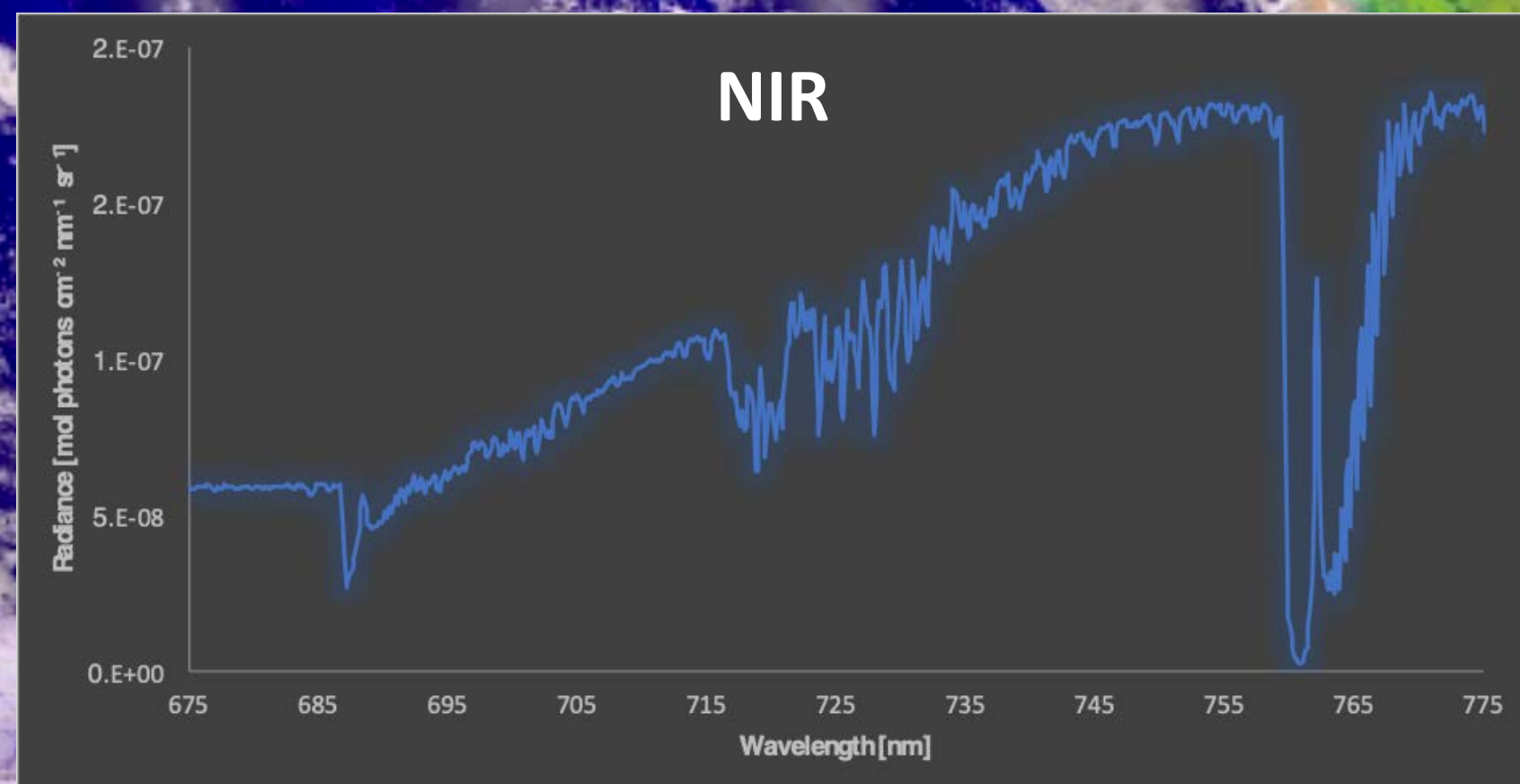
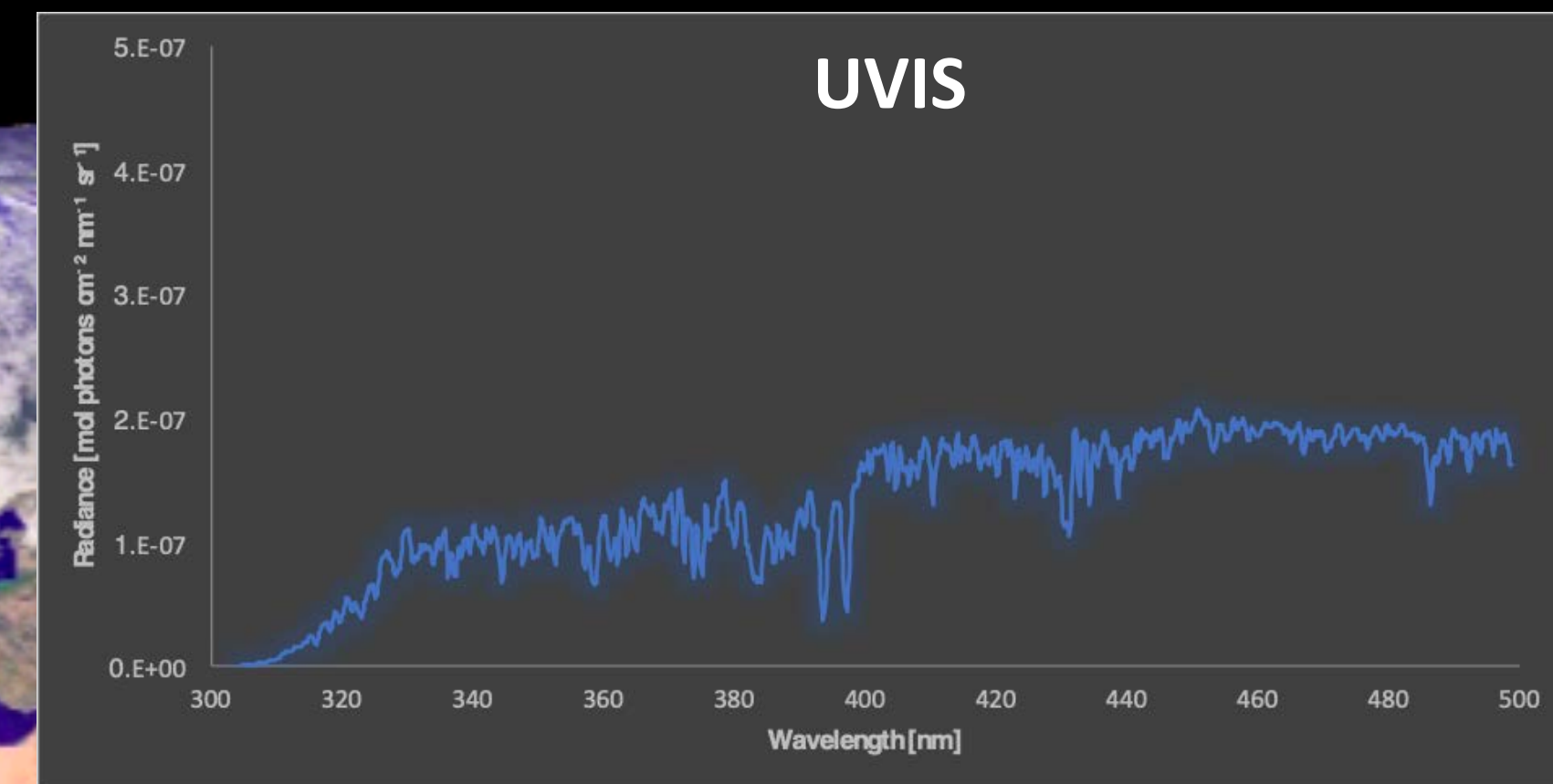


From spectra to concentrations


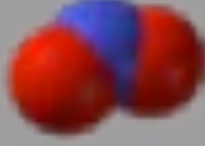

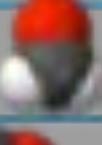
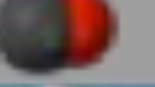
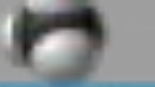




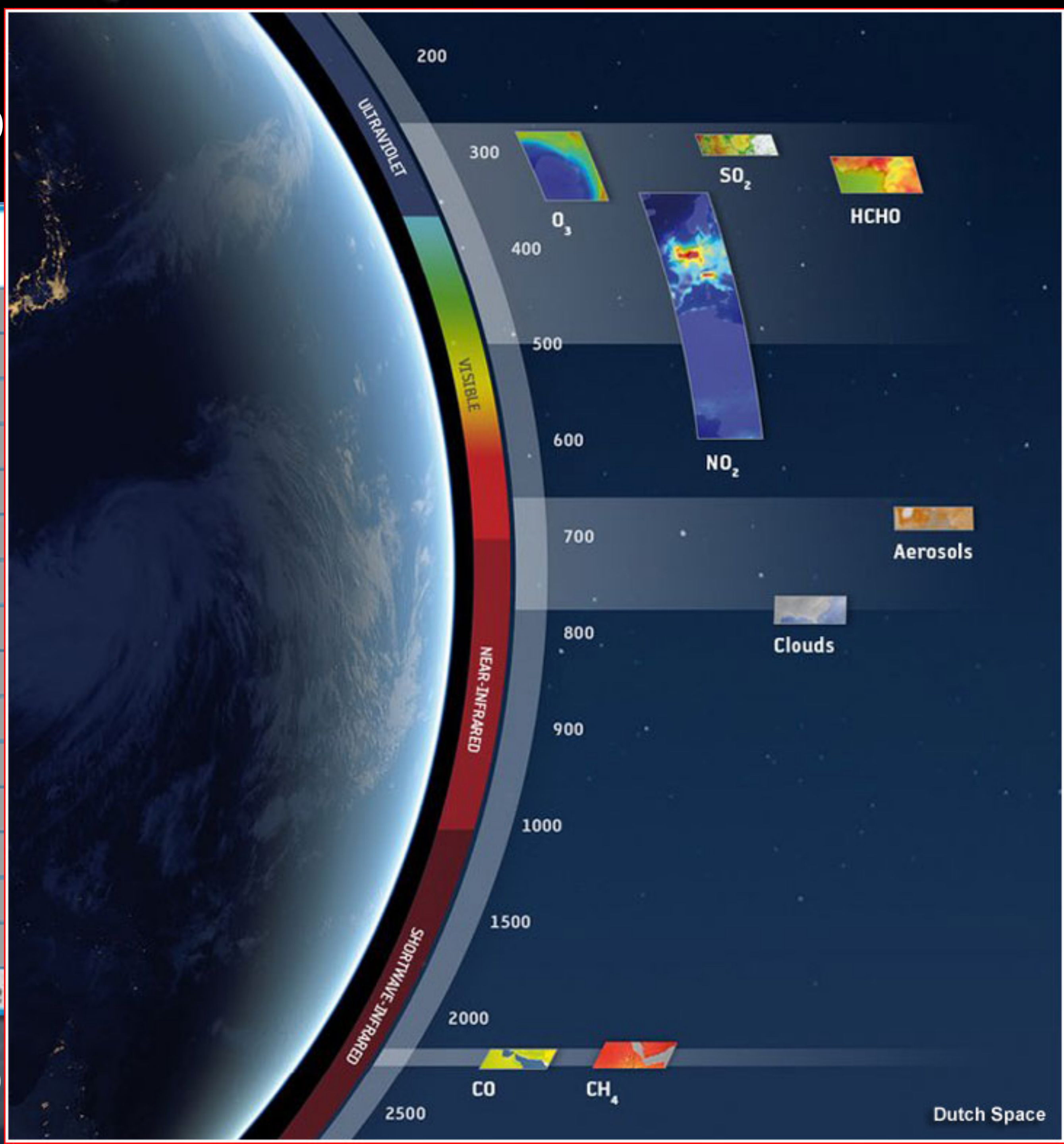


- 1 scanline per second
- 440 spectra per scanline
- 3000 scanlines per orbit
- 15 orbits per day
- 20 million groundpixels per day
- 225 Gbyte raw data per day
- 1 Tbyte L1b data per day



TROPOMI Level 2 Data Pro

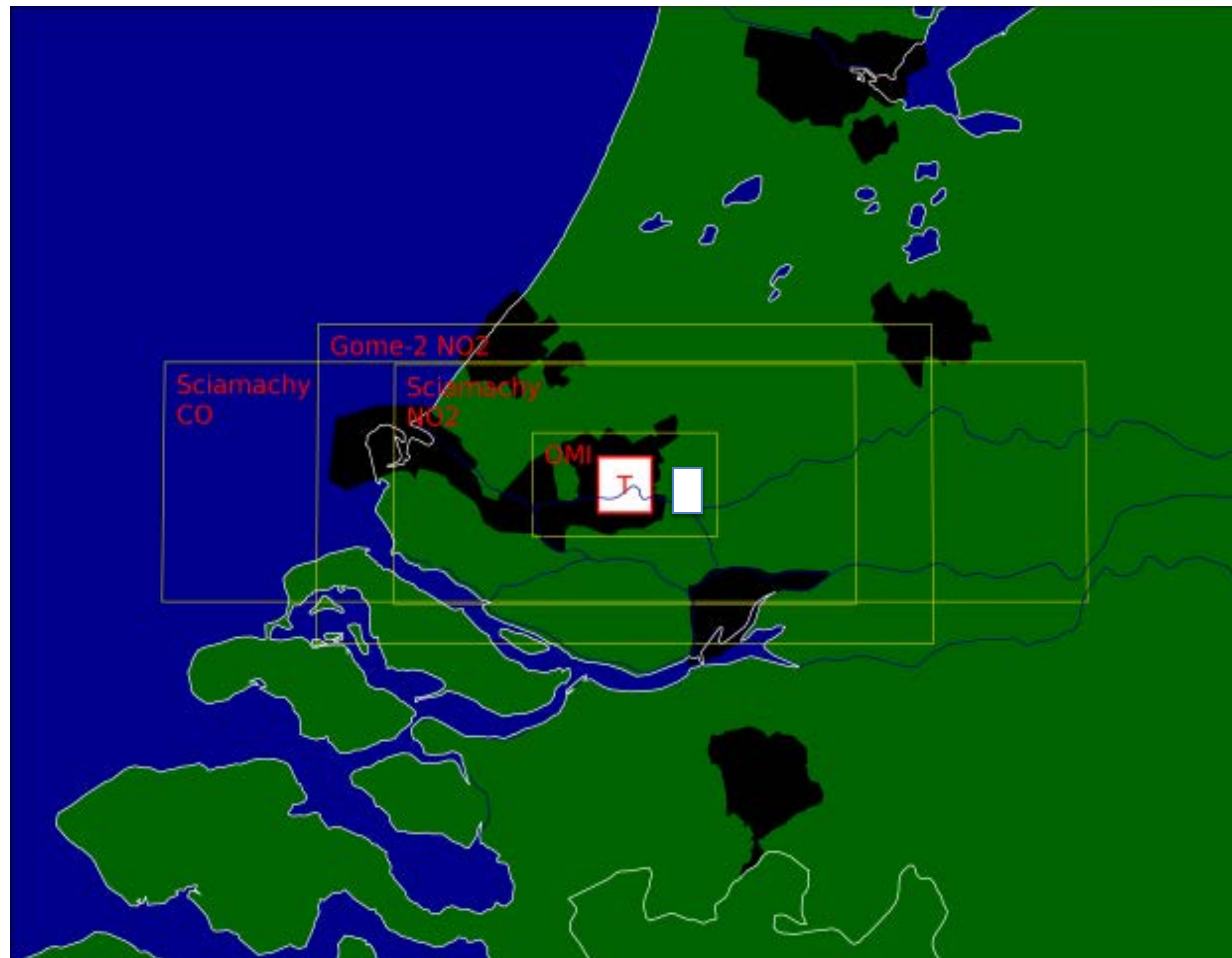
Parameter		Data Product
Ozone		Ozone Profile
		Total Ozone
		Tropospheric Ozone
NO ₂		Stratospheric NO ₂
		Tropospheric NO ₂
SO ₂		SO ₂ enhanced
		Total SO ₂
Formaldehyde		Total HCHO
CO		Total CO
Methane		Total CH ₄
Cloud		Cloud Fraction
		Albedo (Optical Thickness)
		Cloud Height (Pressure)
Aerosol		Aerosol Layer Height
		Aerosol Type
Surface UV		Provided by FMI in frame of the



**Spatial
Resolution:**

**Further decreased
to 3.5 x 5.5 km in
August 2019**

**Individual source
Identification,
Intra-city variability**

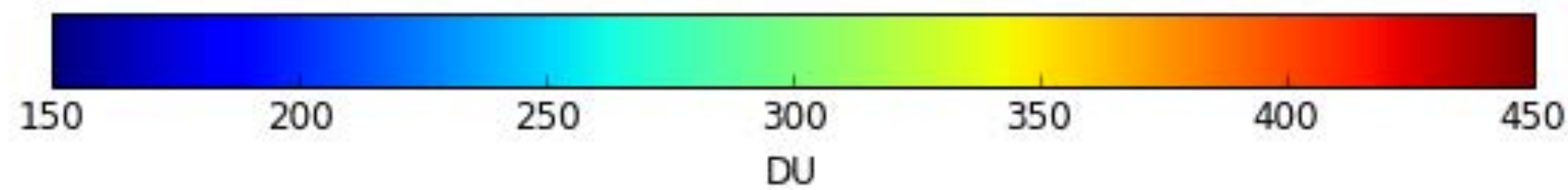
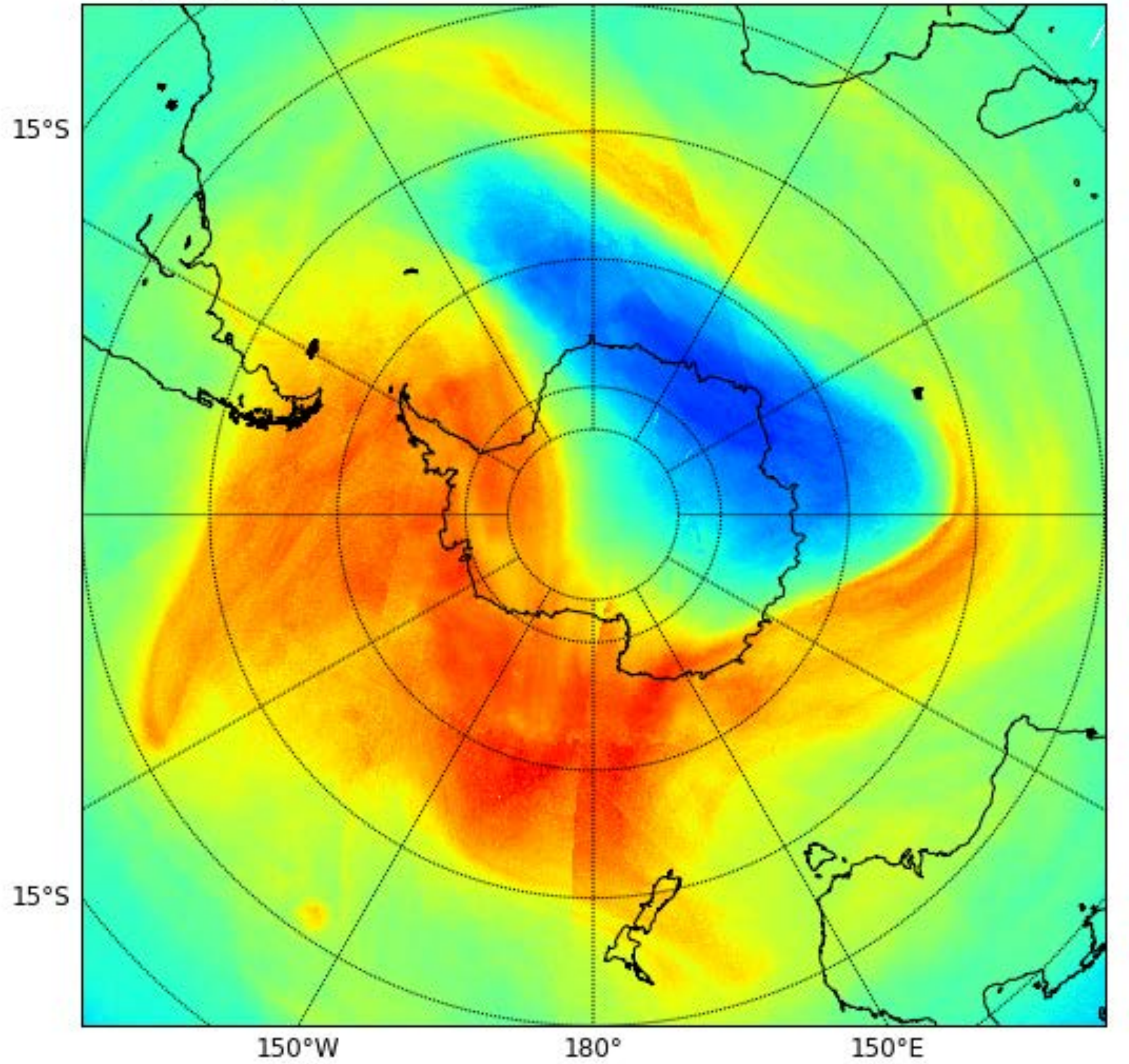


TROPOMI Ozone data products: stratosphere & troposphere



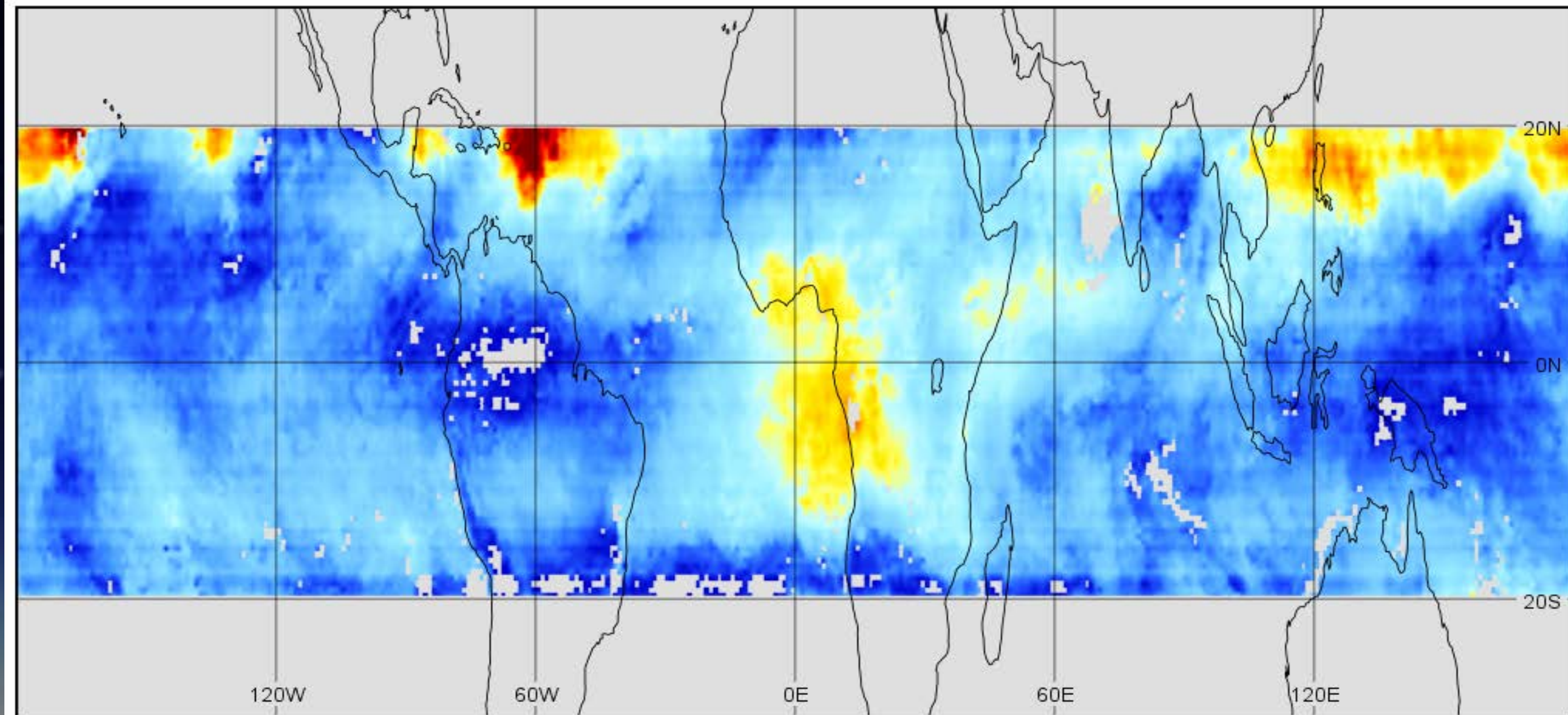
Sentinel 5 Precursor, total ozone, DLR-BIRA

2017-11-10



average tropospheric ozone column

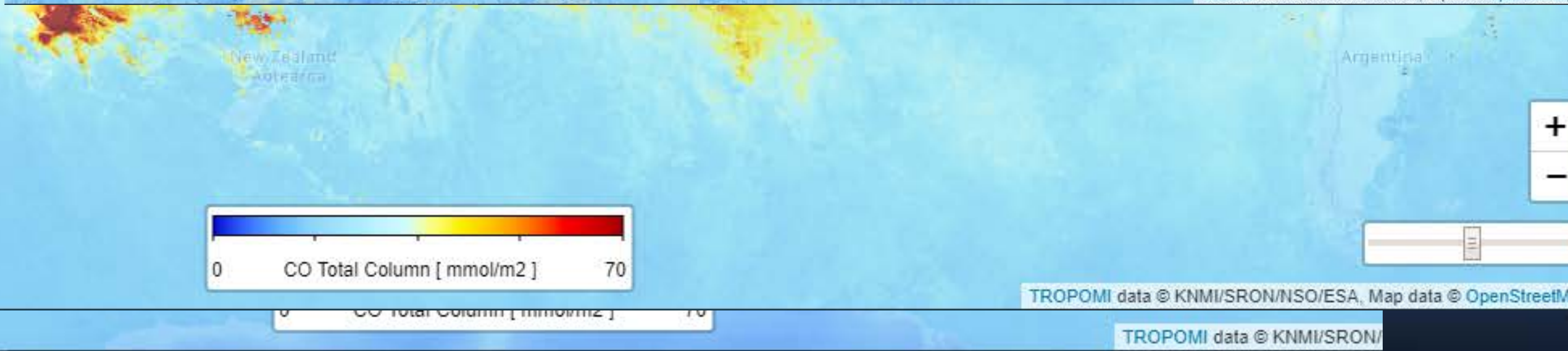
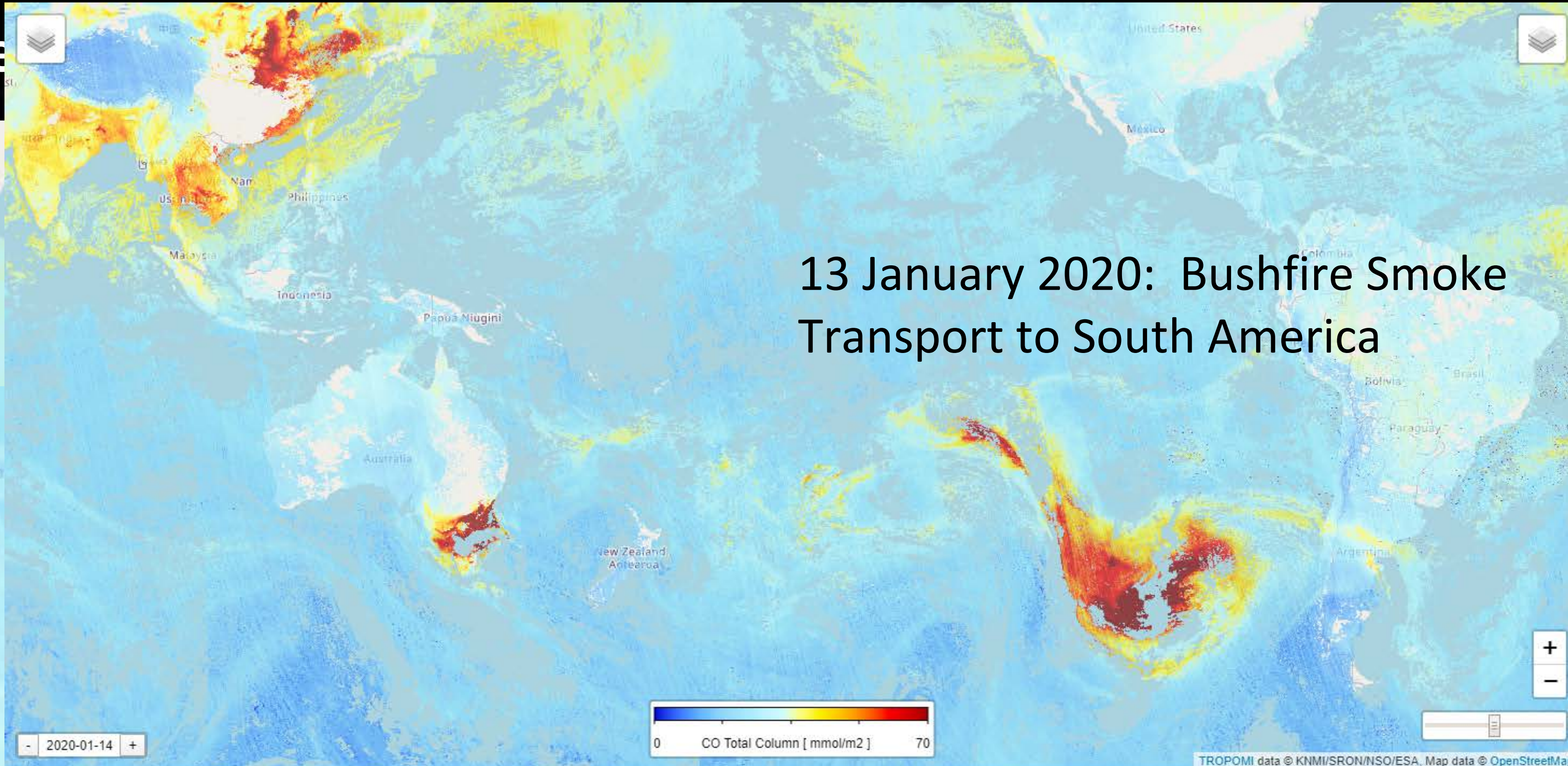
TROPOMI, S5p May 24-30 2018



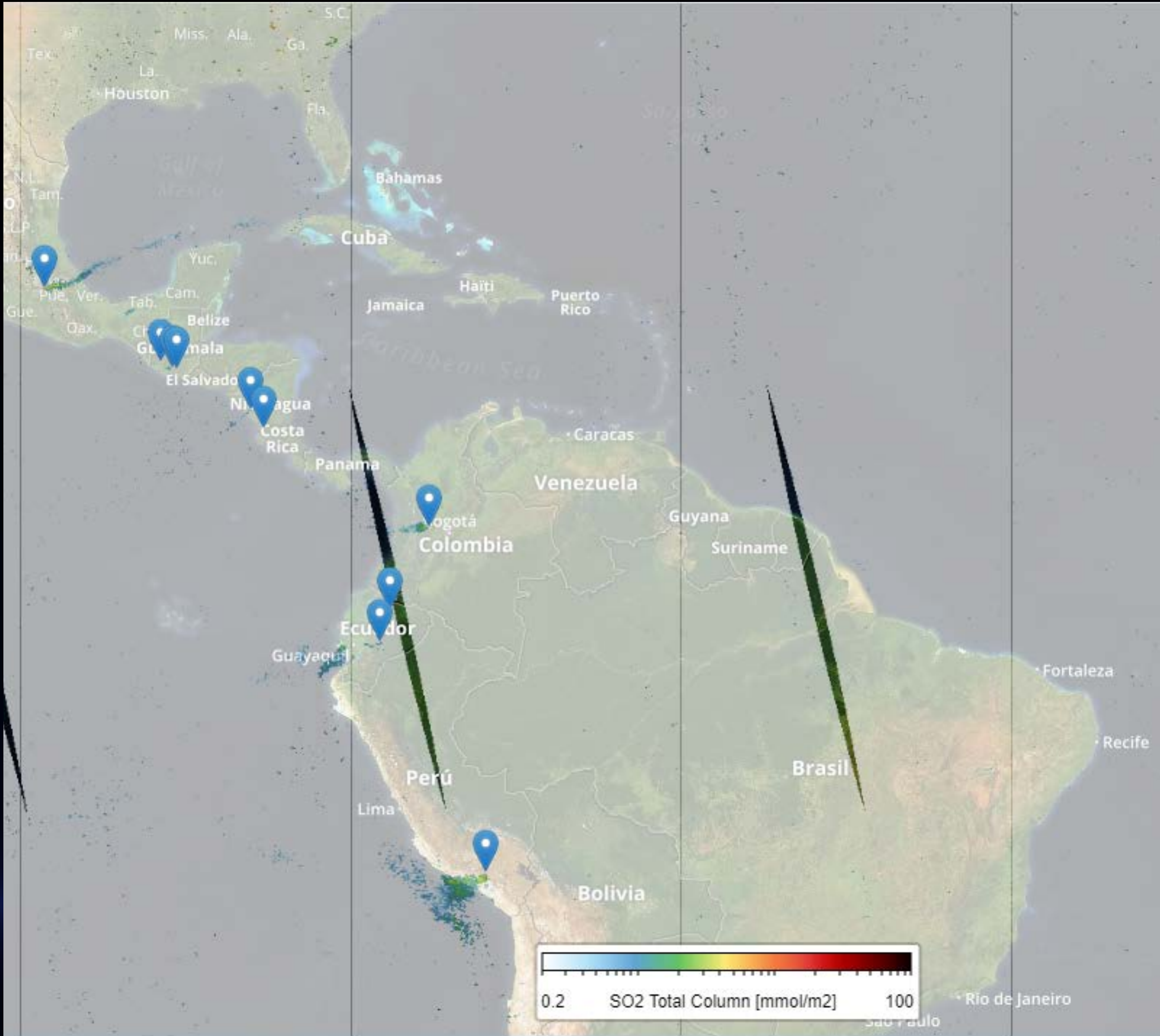
average tropospheric ozone column based on CCD algorithm ($10^{-3} \text{ mol m}^{-2}$)



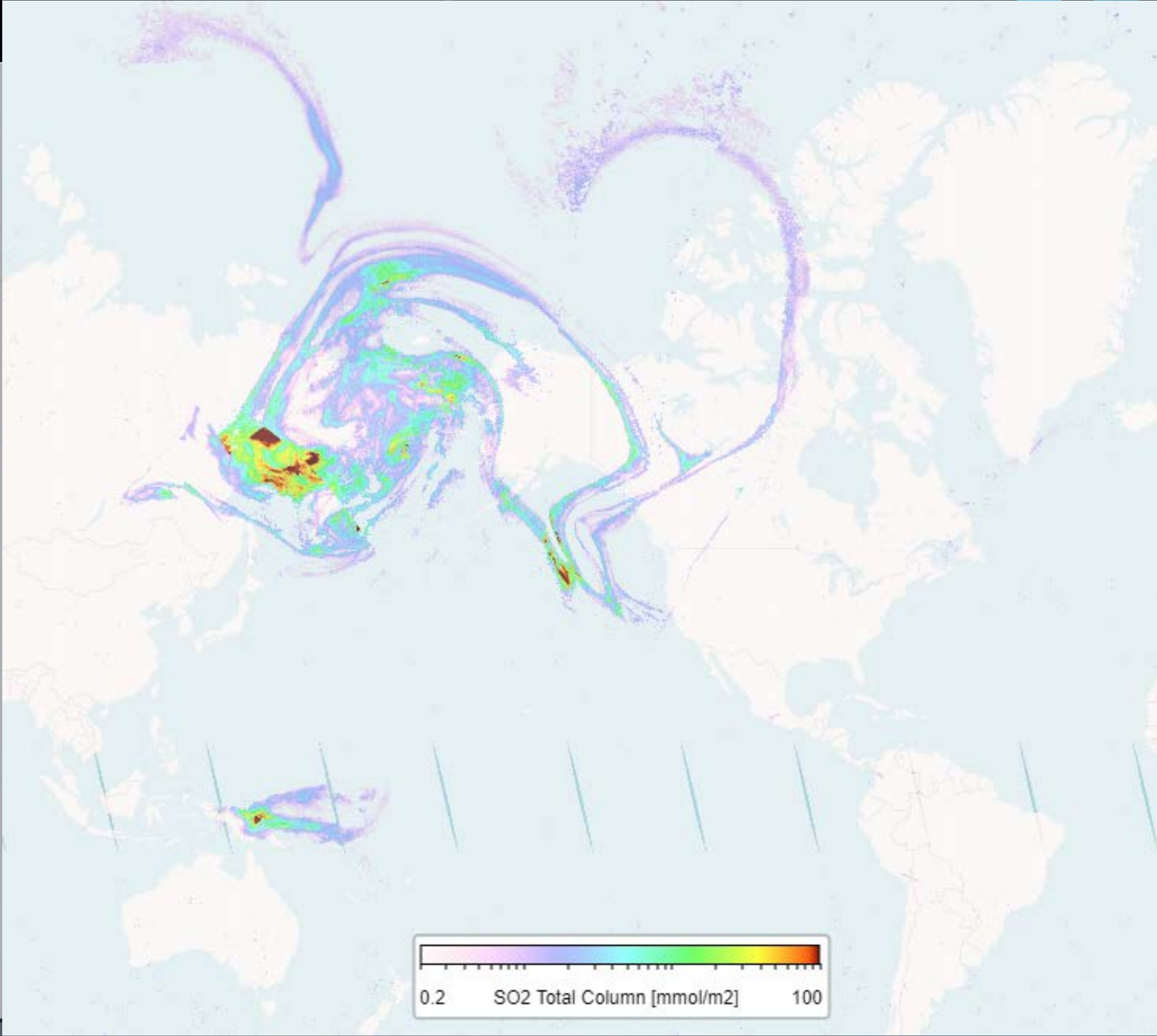
Carbon Monoxide



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



Popocatepetl & Sabancava, 19 Dec 2019



Raikoke 28 June 2019

Raikoke Volcano SO₂ in the stratosphere observed by TROPOMI



22-6-2019 0



Image Landsat / Copernicus
Image IBCAO
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image U.S. Geological Survey

Google Earth

Datum van beeldmateriaal: 14-12-2015 breedte 77.400881° lengte 37.358031° verh 0 m ooghoogte 8457.84 km

Formaldehyde:

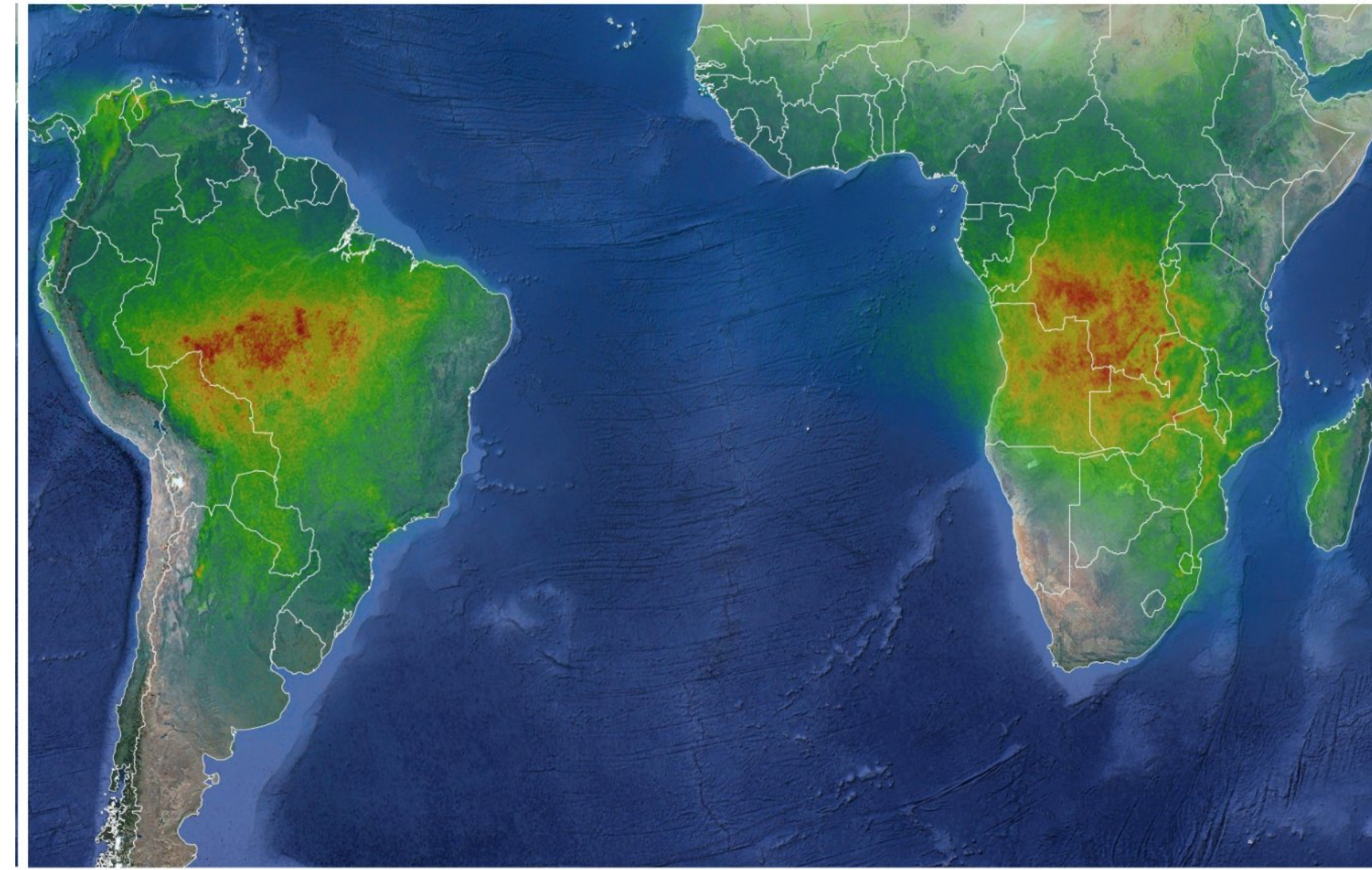
**Temperature-
dependent
emission**

**Primarily Biogenic
& Combustion
sources**

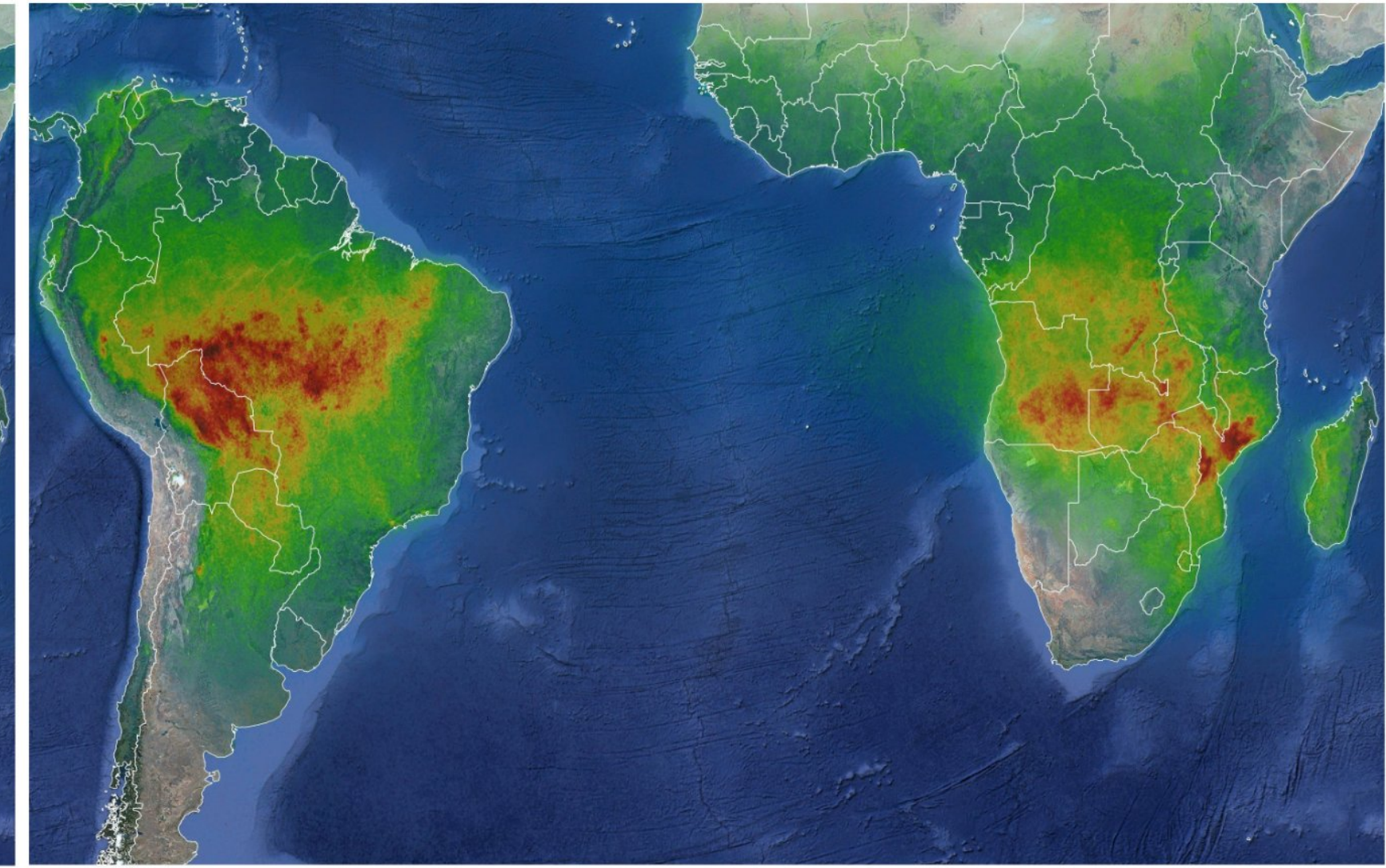
Isabelle De Smedt

BIRA-IASB

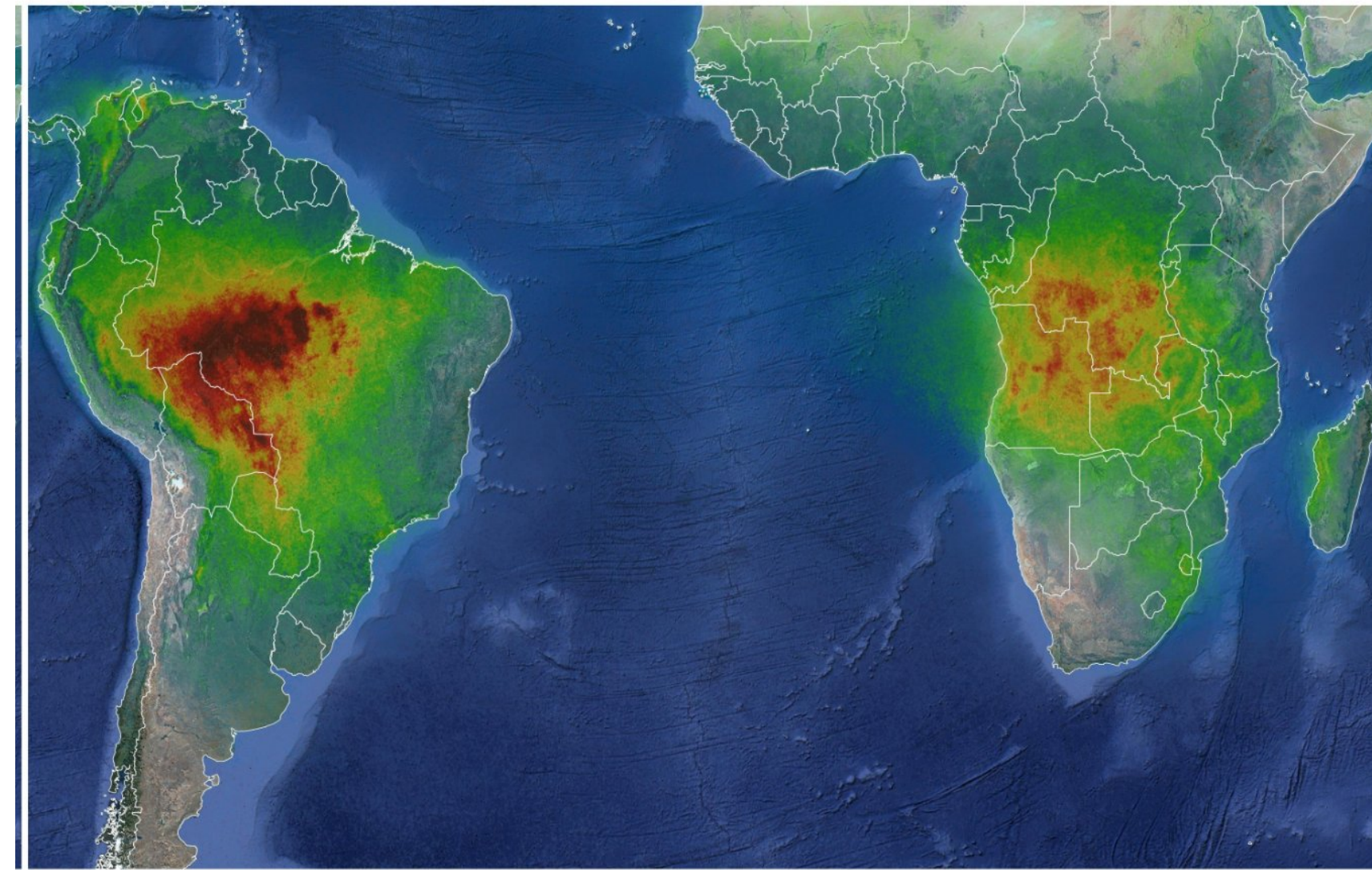
Aug.2018



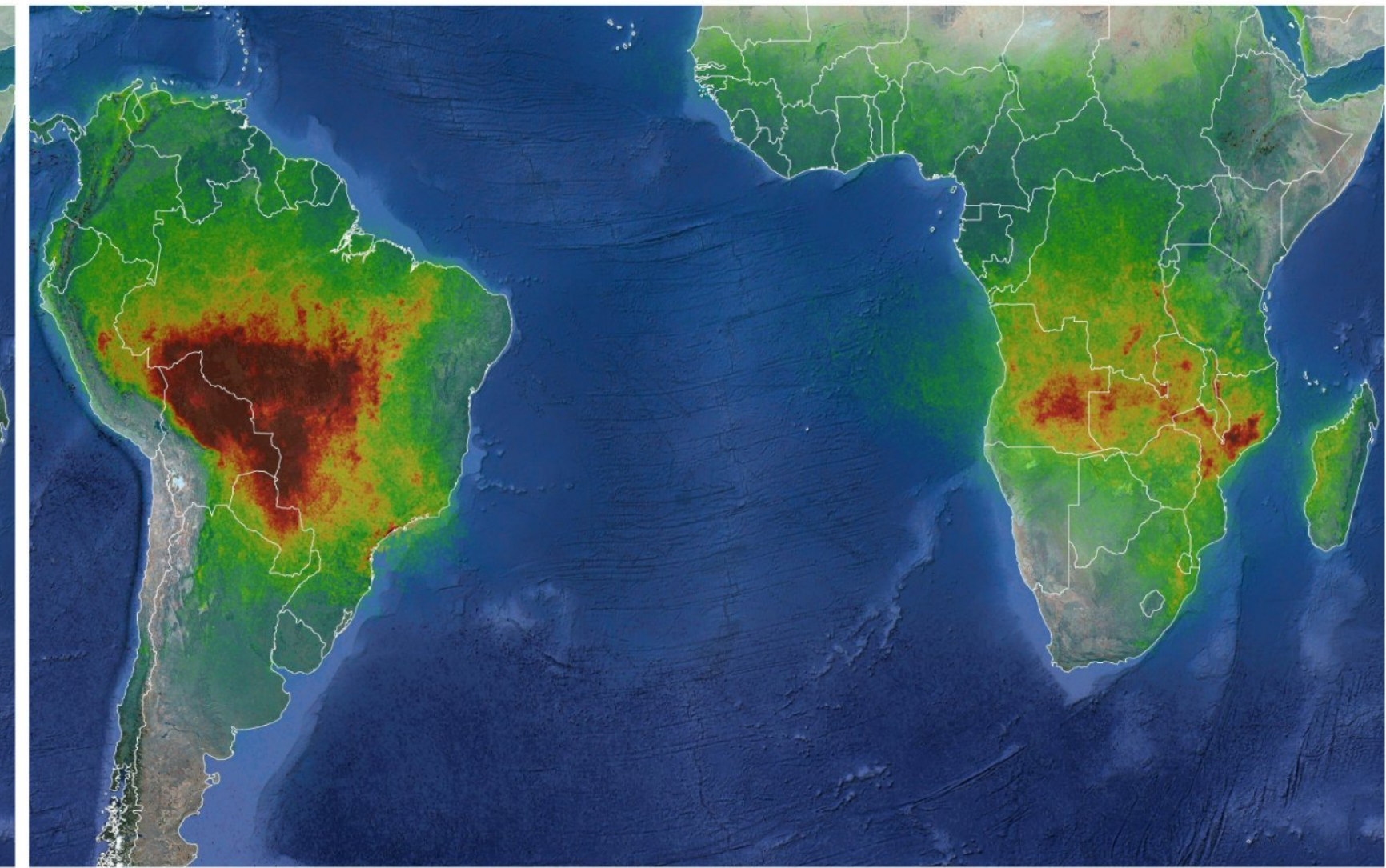
Sep.2018



Aug.2019



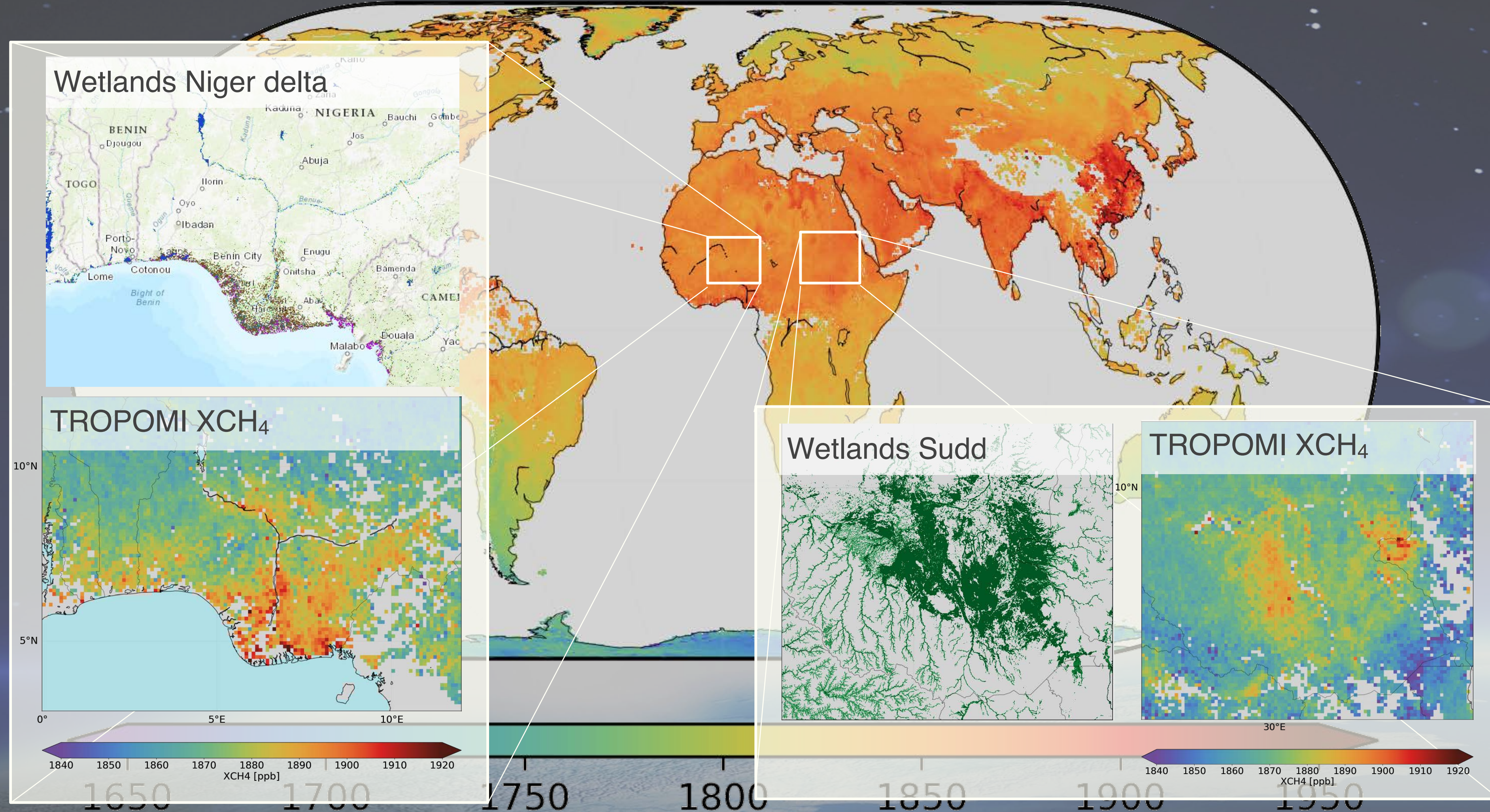
Sep.2019



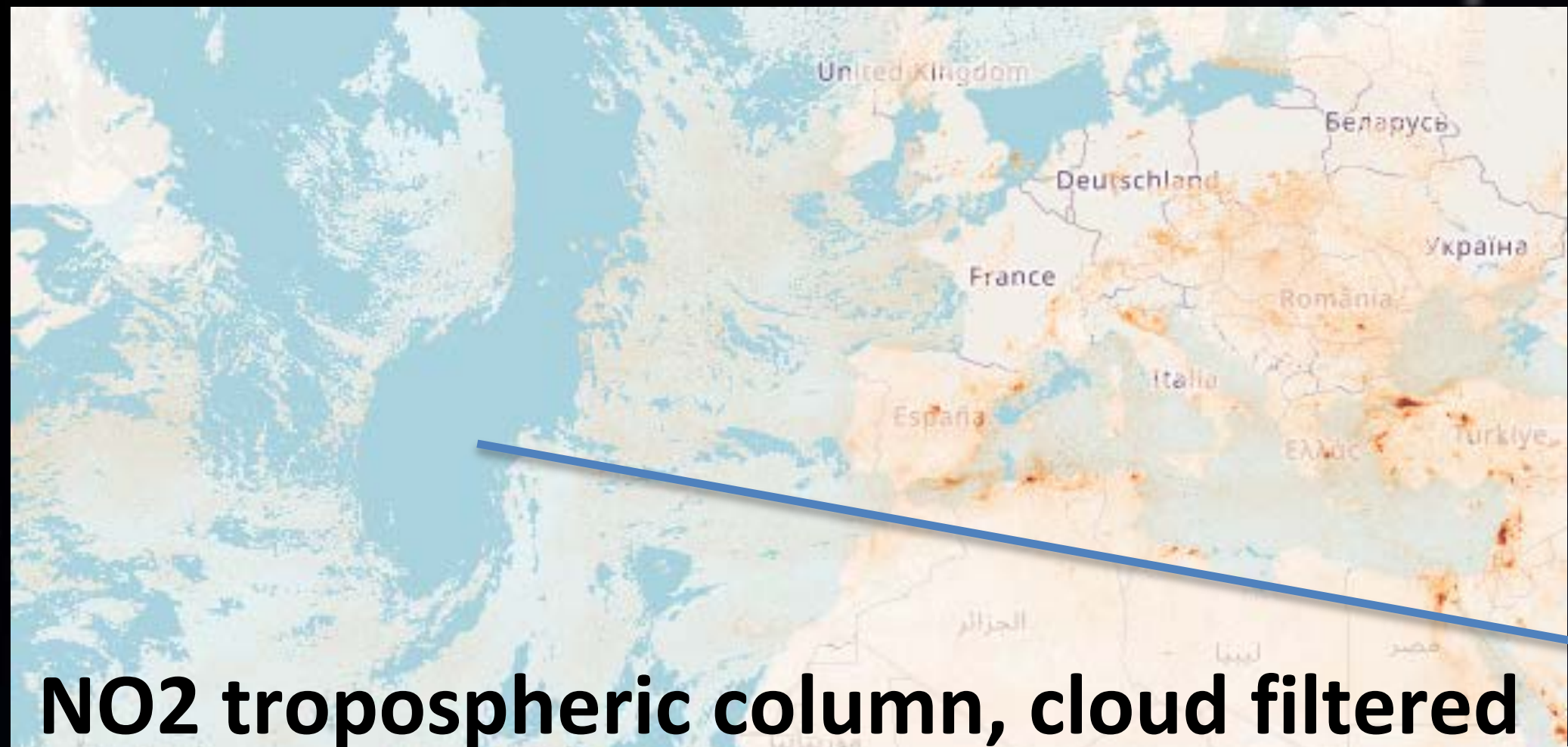
$10^{15} \text{ molec.cm}^{-2}$



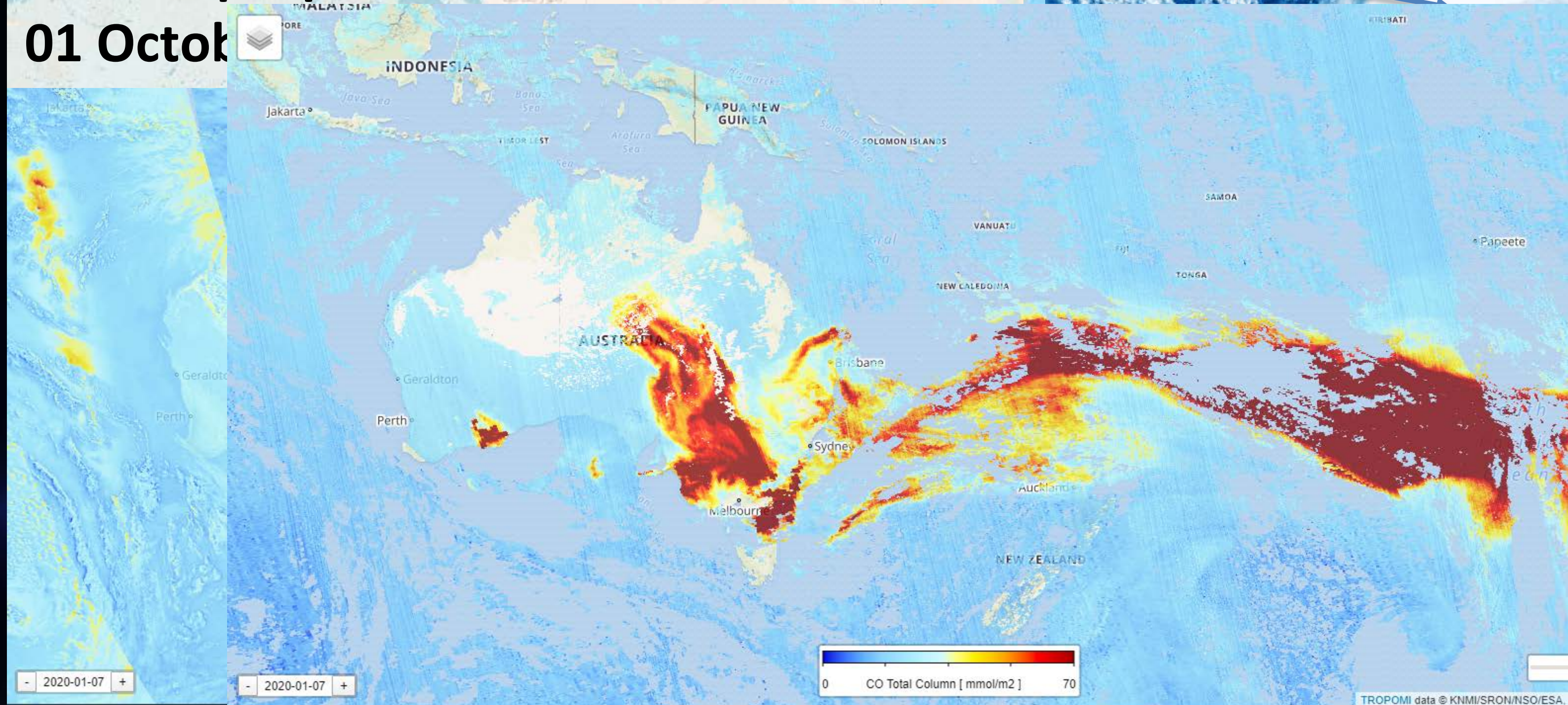
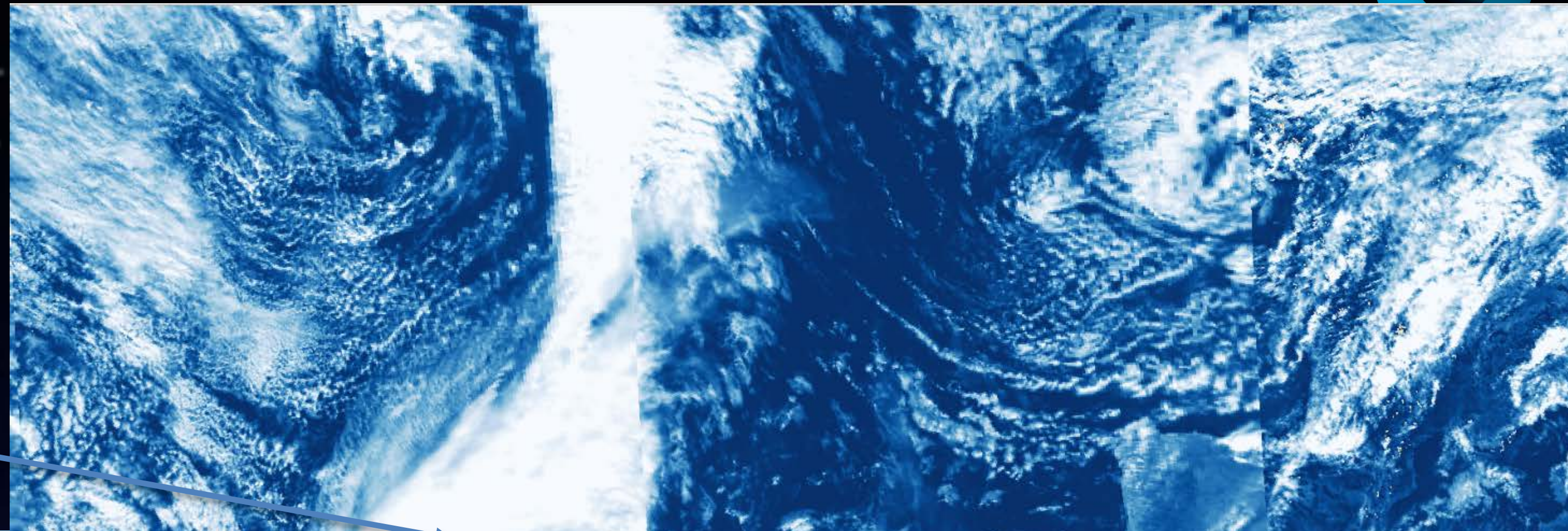
Methane (CH₄): Wetland emission seen by TROPOMI



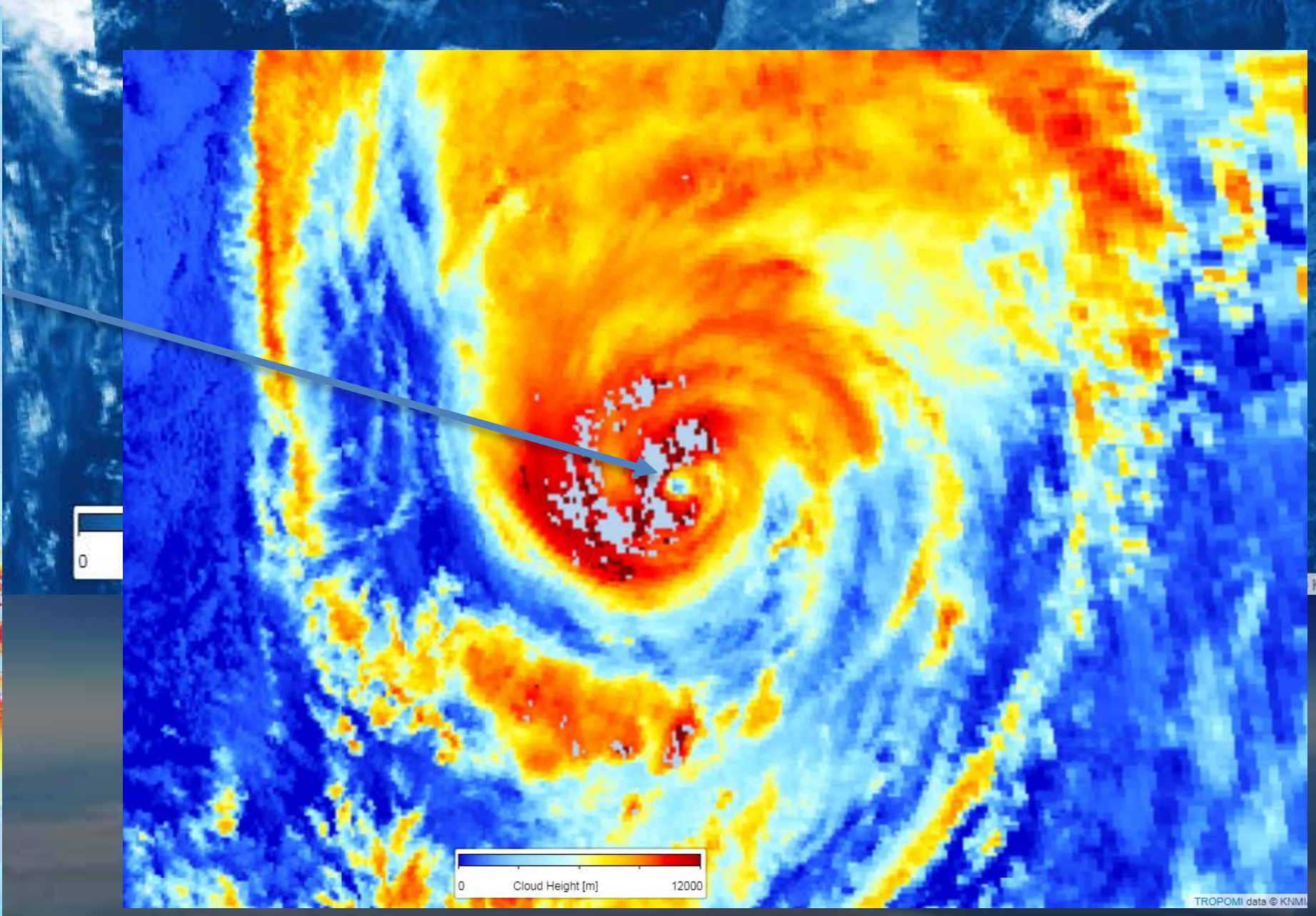
Aerosol & Cloud: Key for correcting trace gas retrievals



**NO2 tropospheric column, cloud filtered
01 Octok**



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



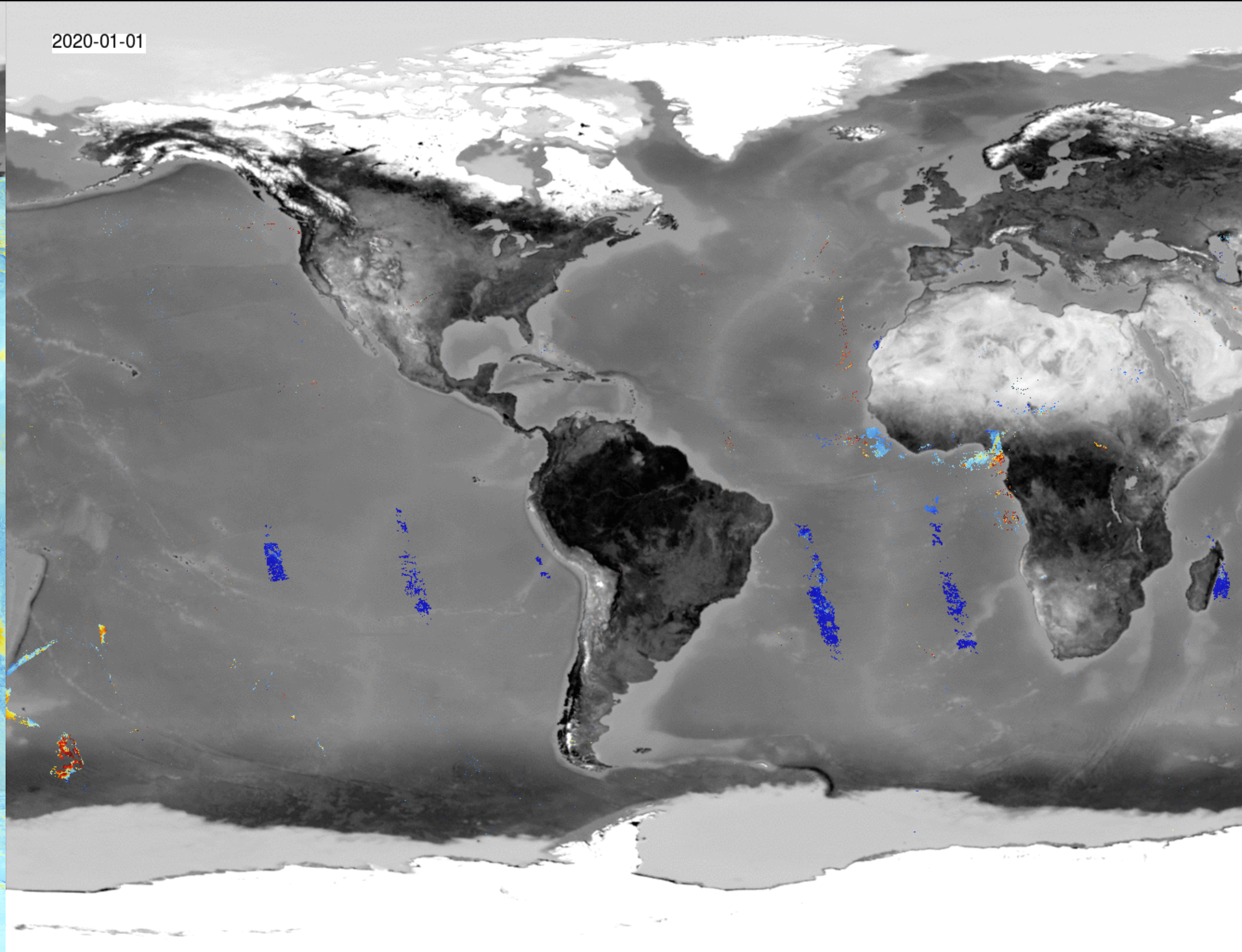
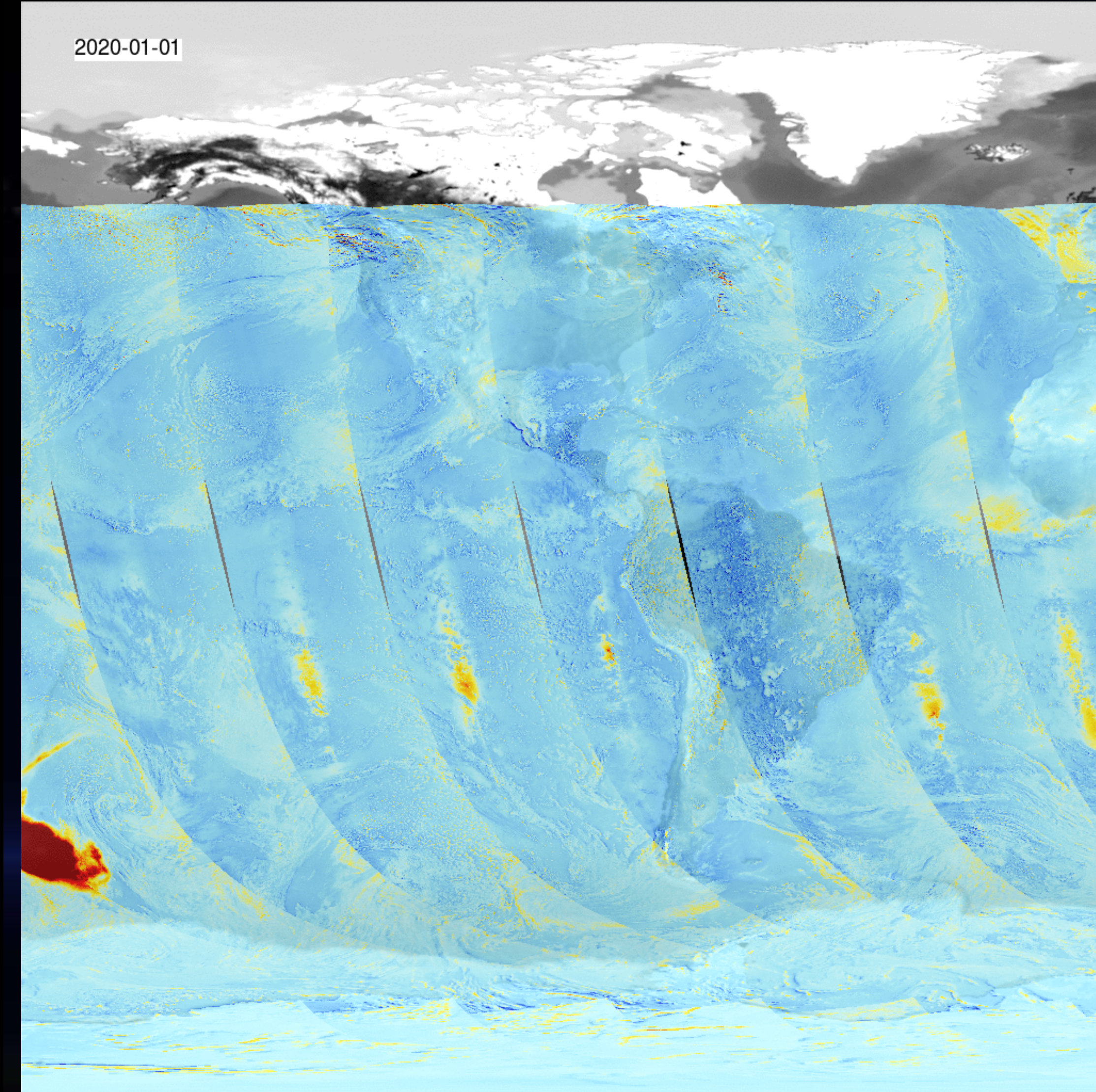
Cloud Fraction & Cloud Height

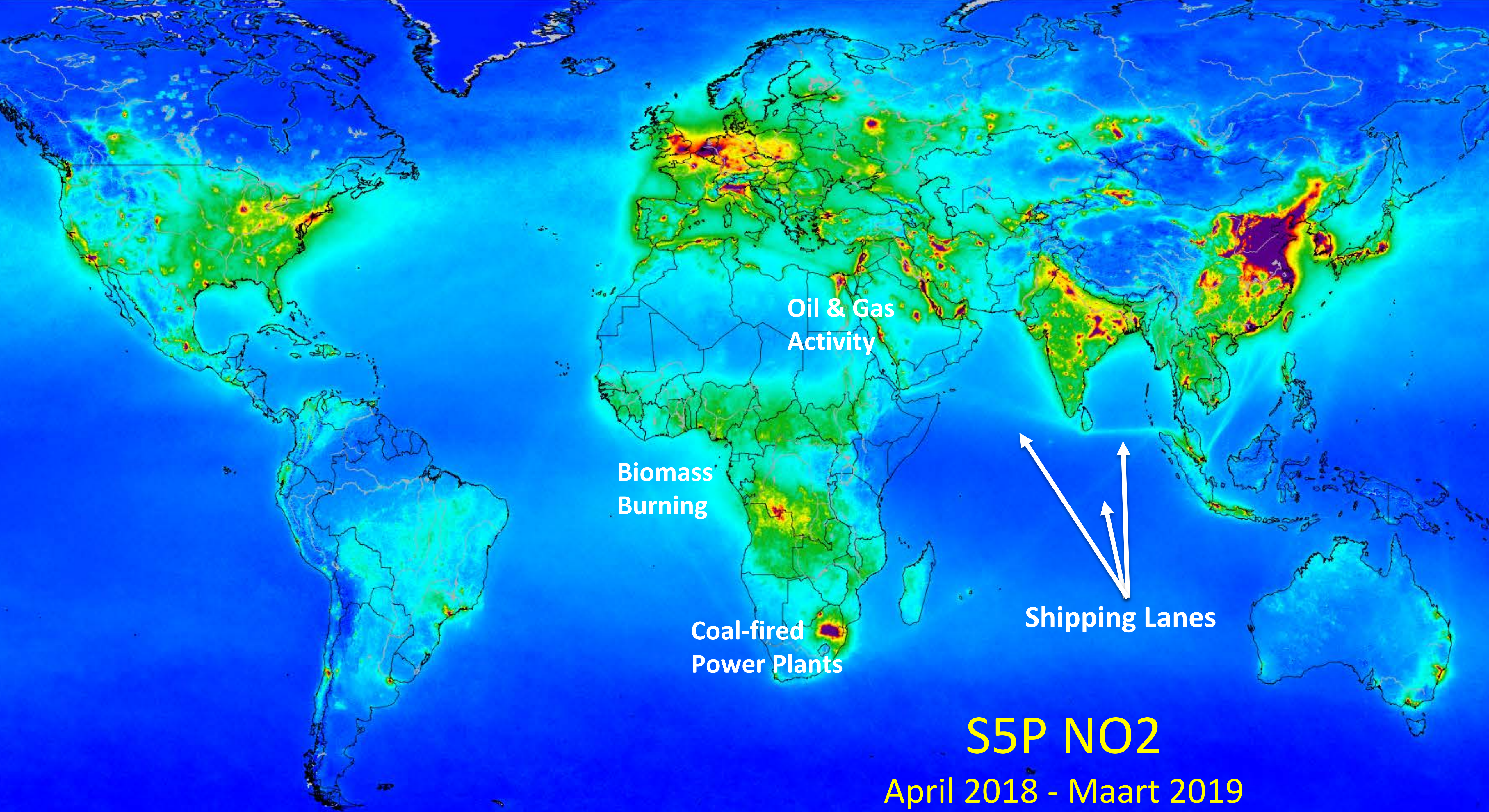
Plume Tracking: Aerosol Index and Aerosol Layer Height



2020-01-01

2020-01-01





Oil & Gas
Activity

Biomass
Burning

Coal-fired
Power Plants

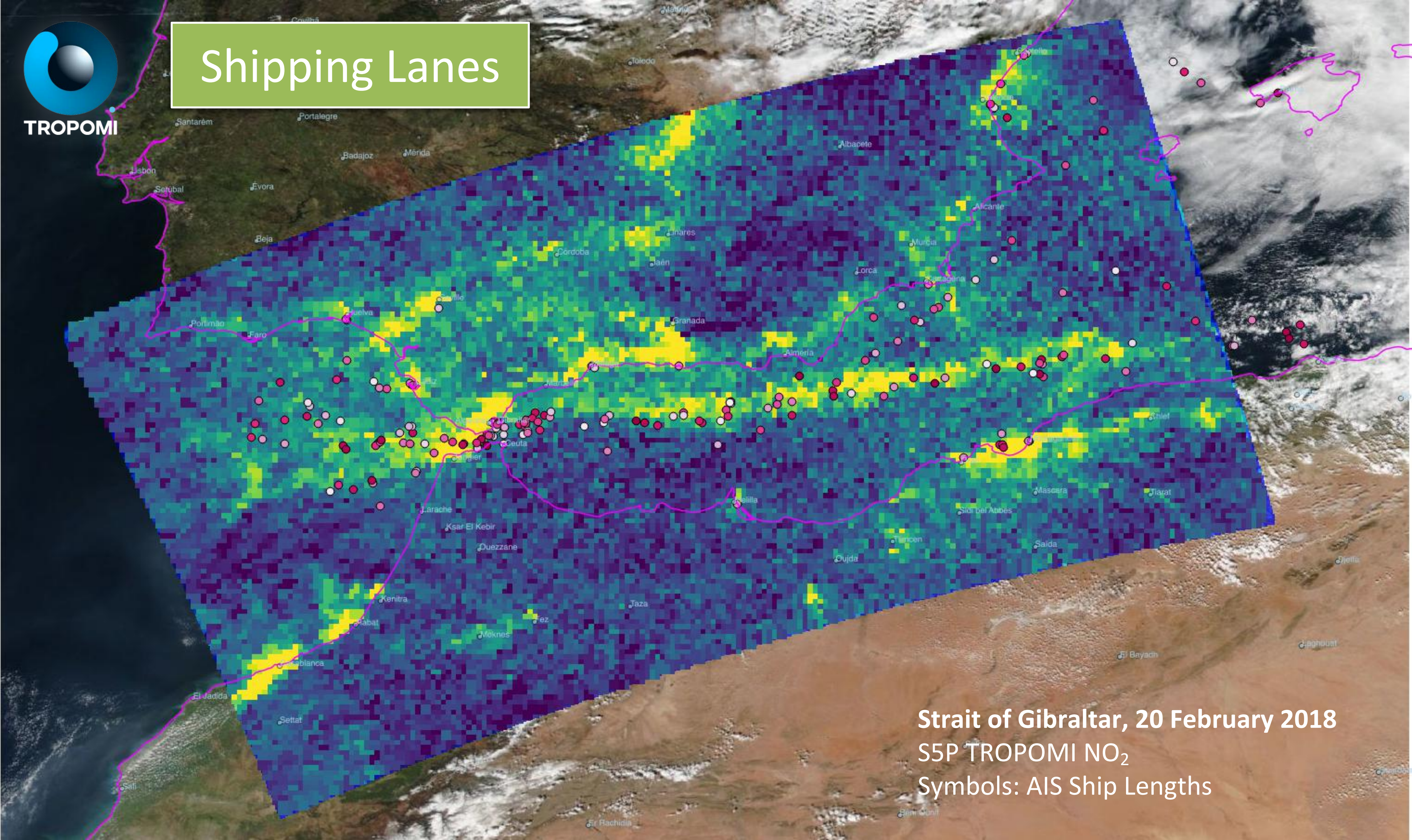
Shipping Lanes

S5P NO2

April 2018 - Maart 2019




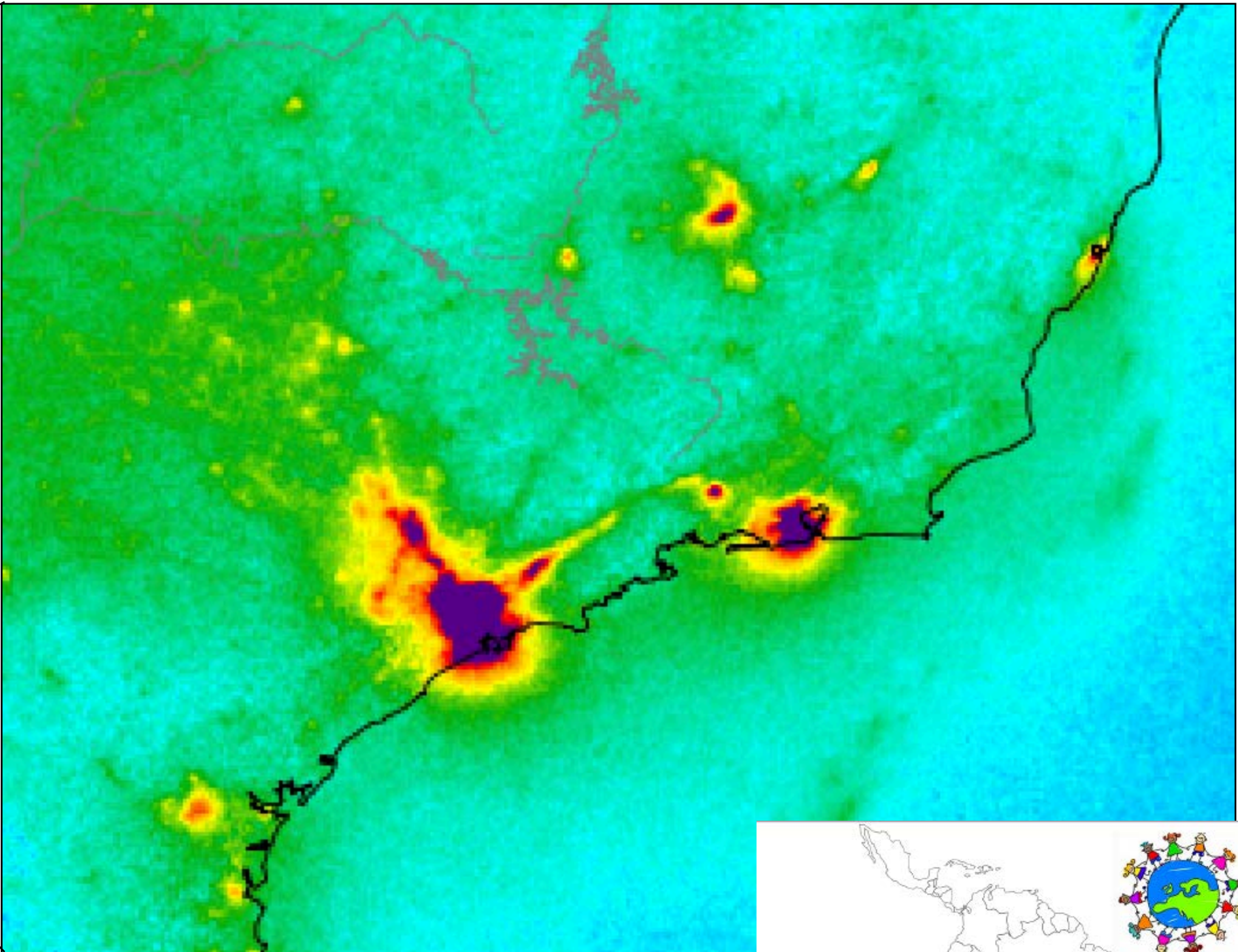
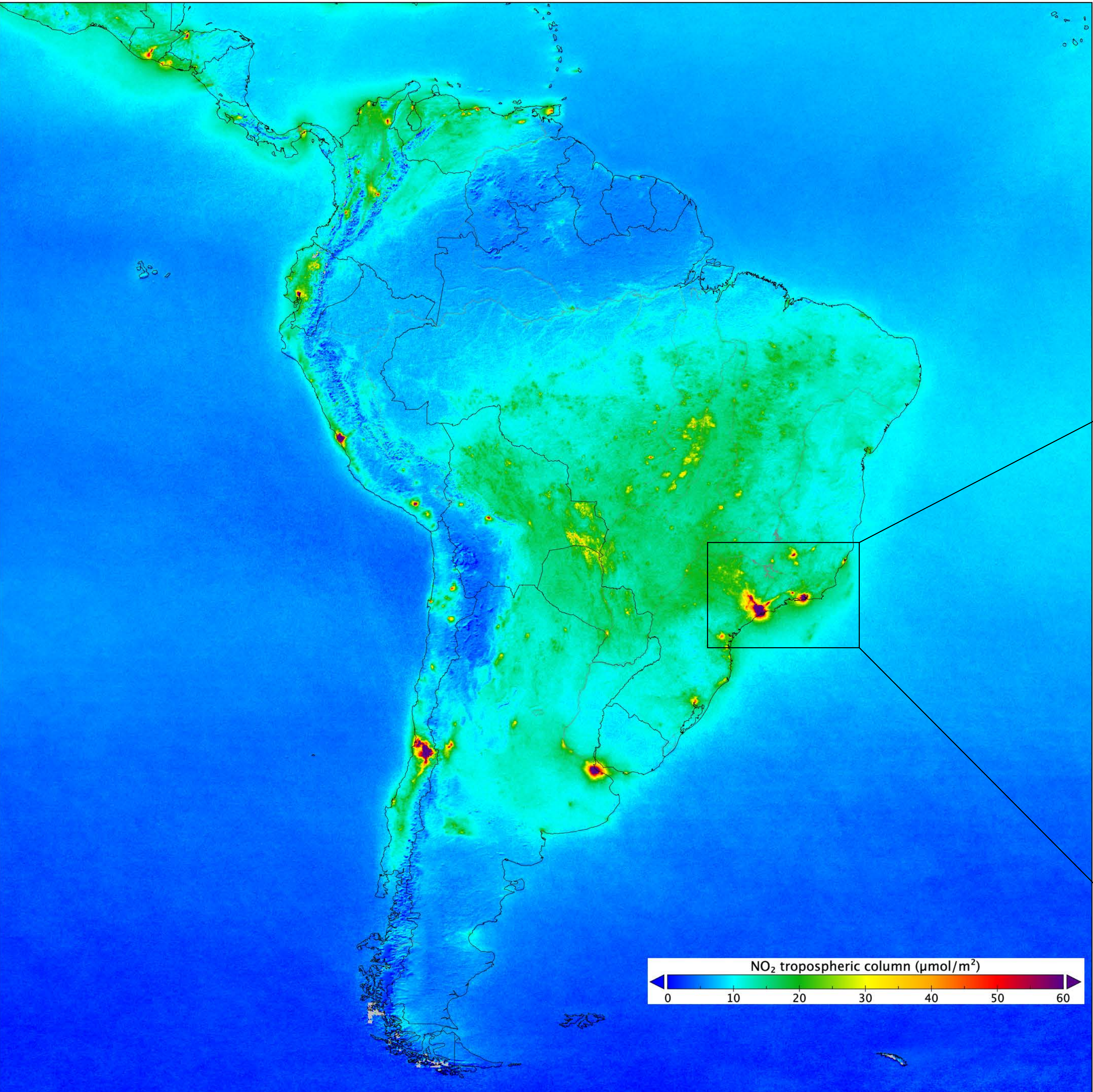
Shipping Lanes



Strait of Gibraltar, 20 February 2018
S5P TROPOMI NO₂
Symbols: AIS Ship Lengths

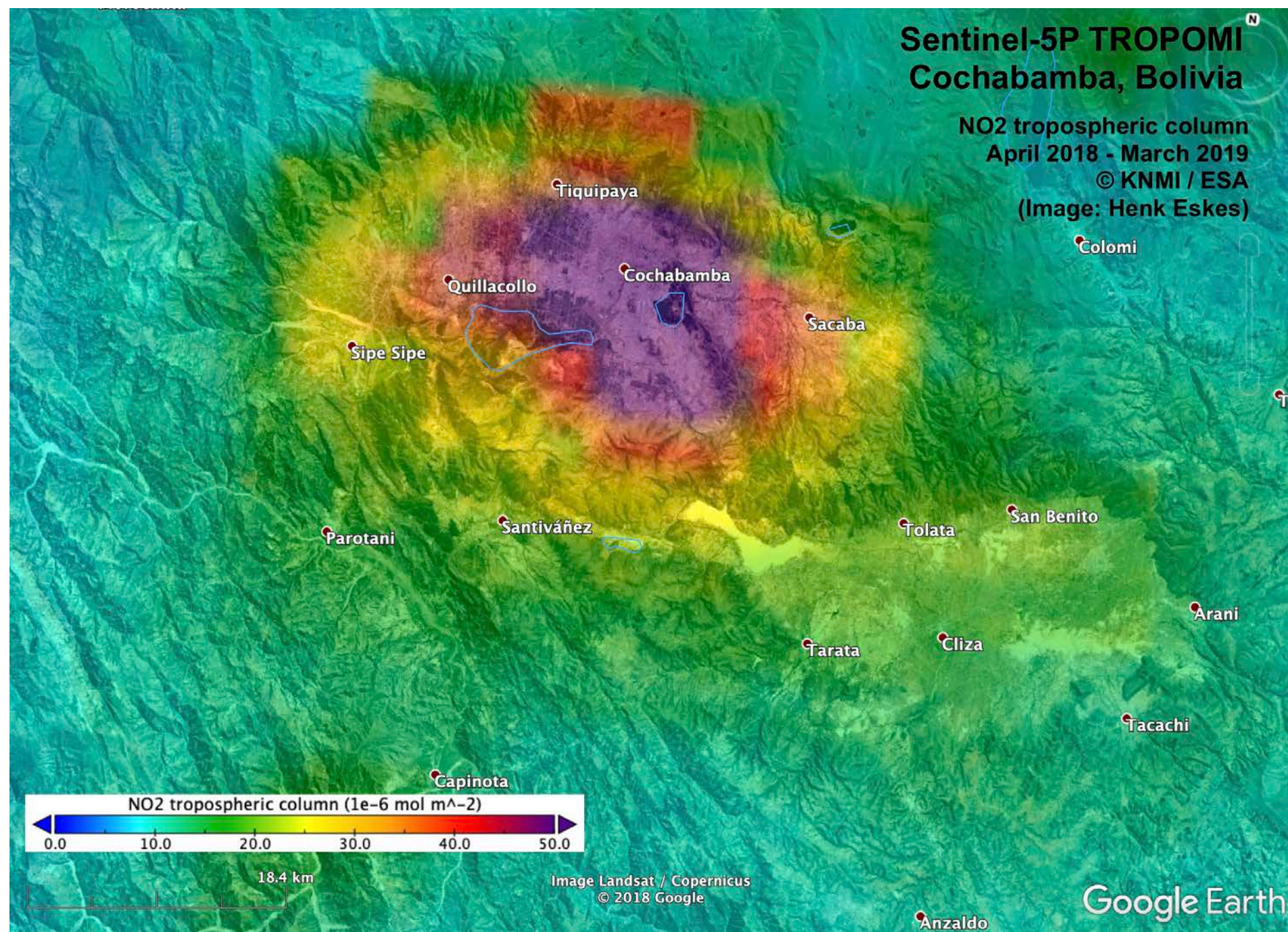
Sentinel-5P TROPOMI NO₂ tropospheric column

Annual Average 2019



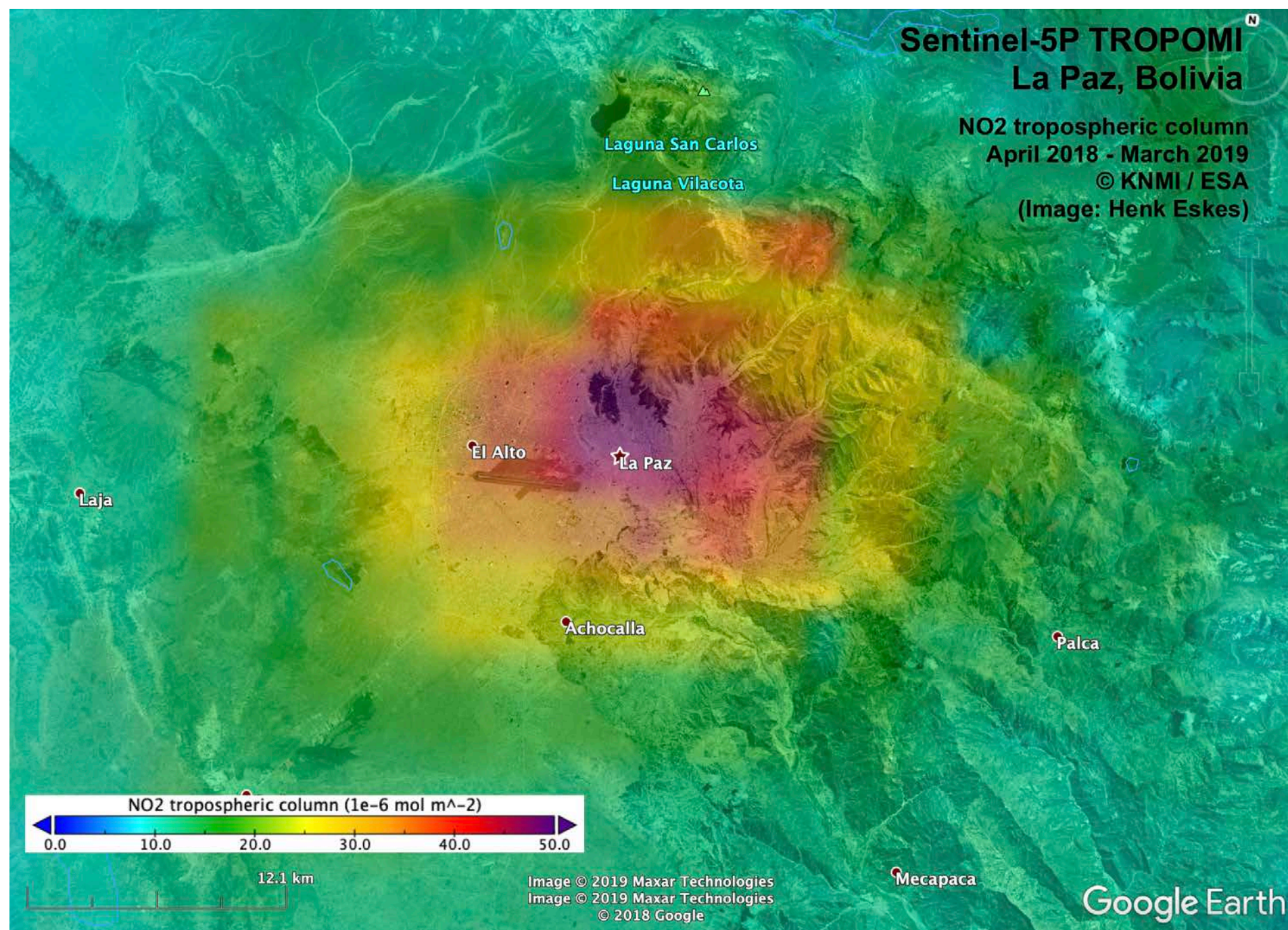
PAPILA
Prediction of Air Pollution
in Latin America and the Caribbean

Zoom images of NO₂: City footprints, Annual average

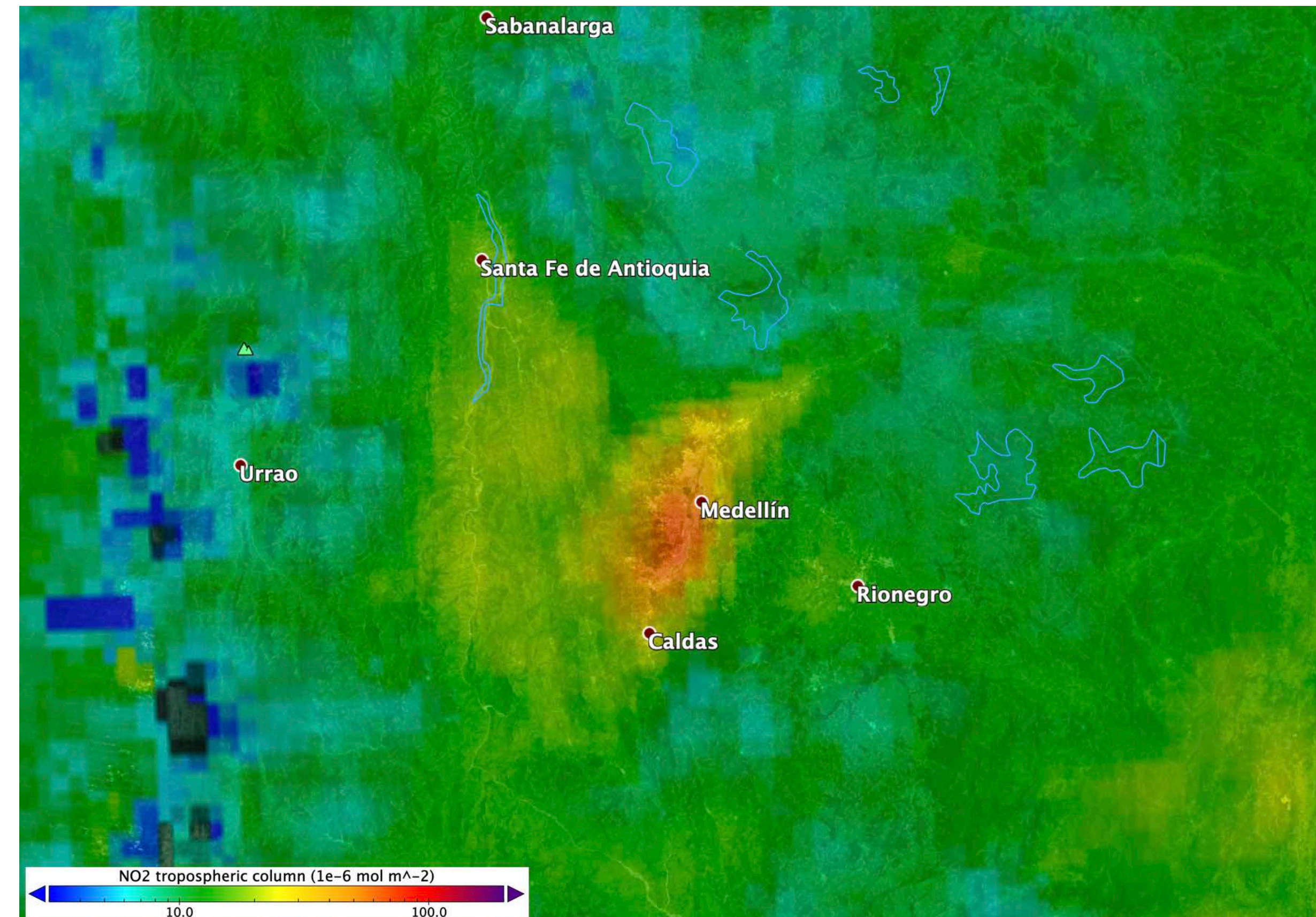


Cochabamba,
Bolivia

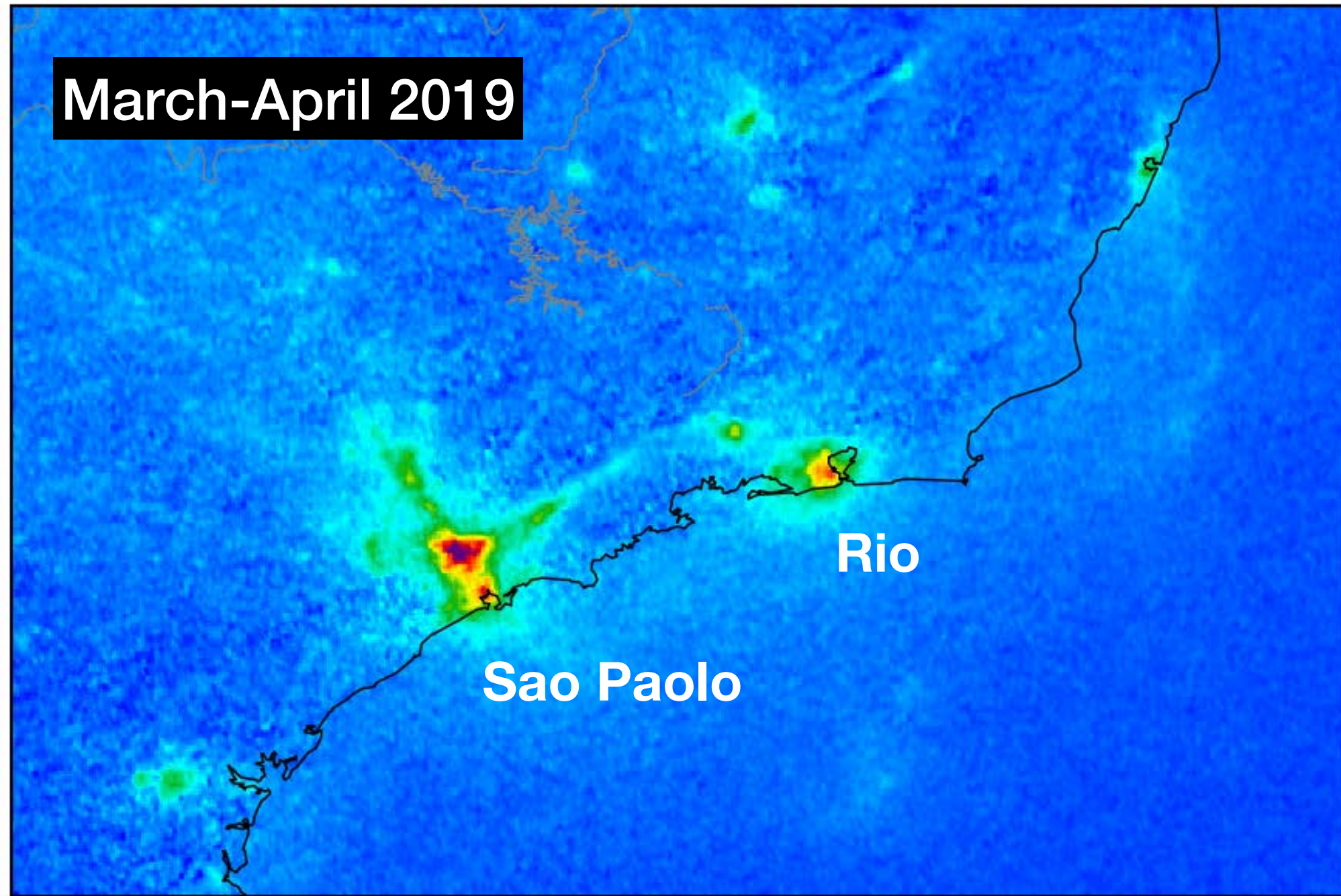
Medellin, Colombia



La Paz,
Bolivia



March-April 2019



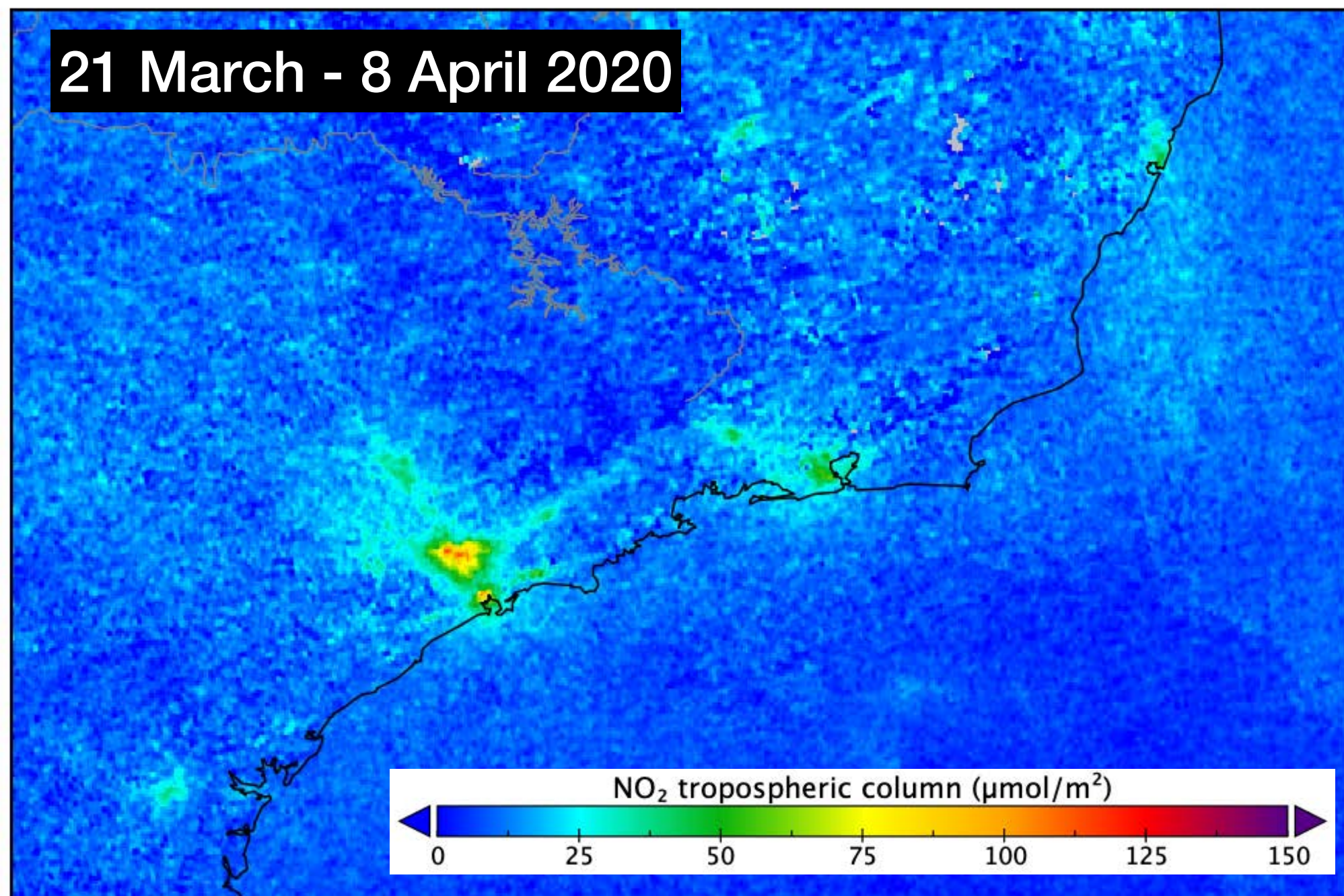
Reduction in NO₂ in Brazil related to Covid-19 measures

2019

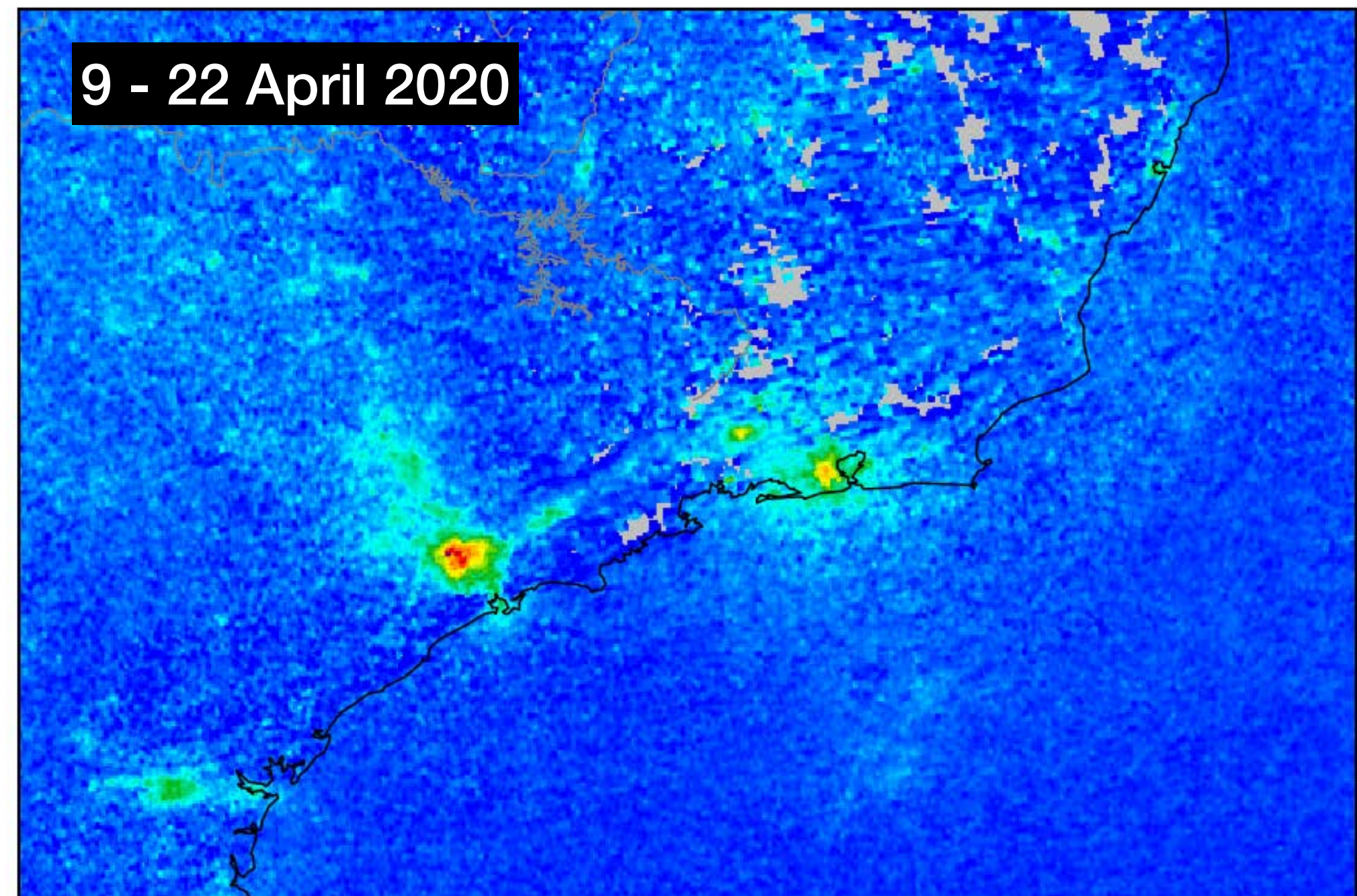
First weeks after lockdown

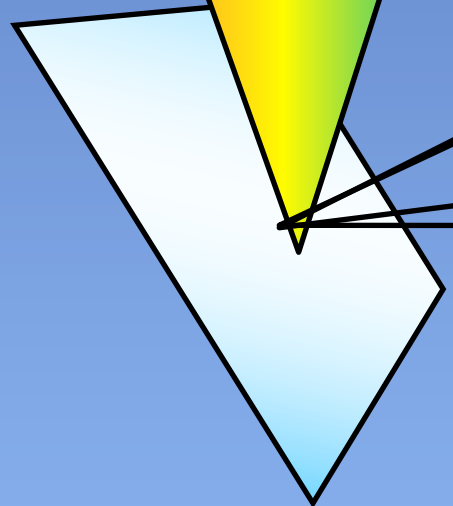
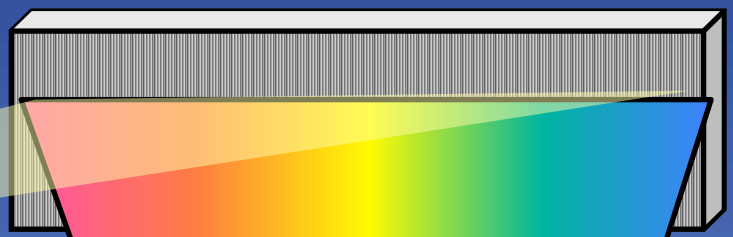
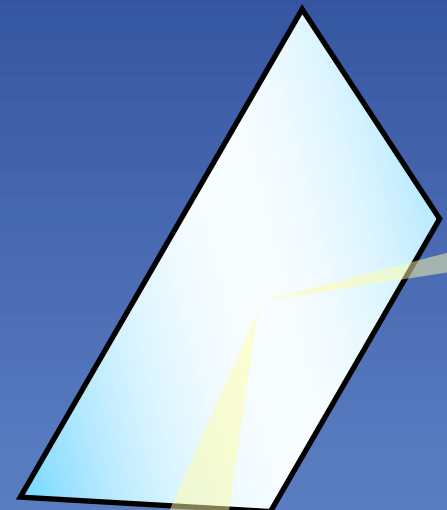
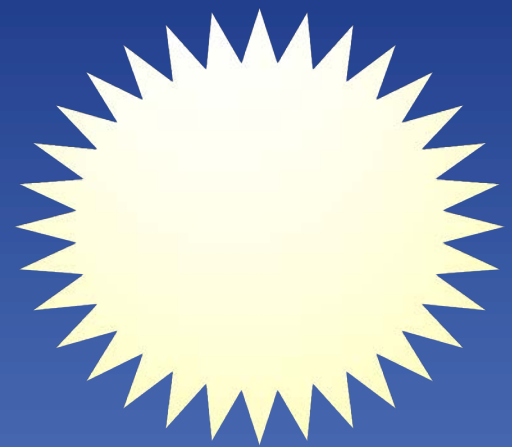
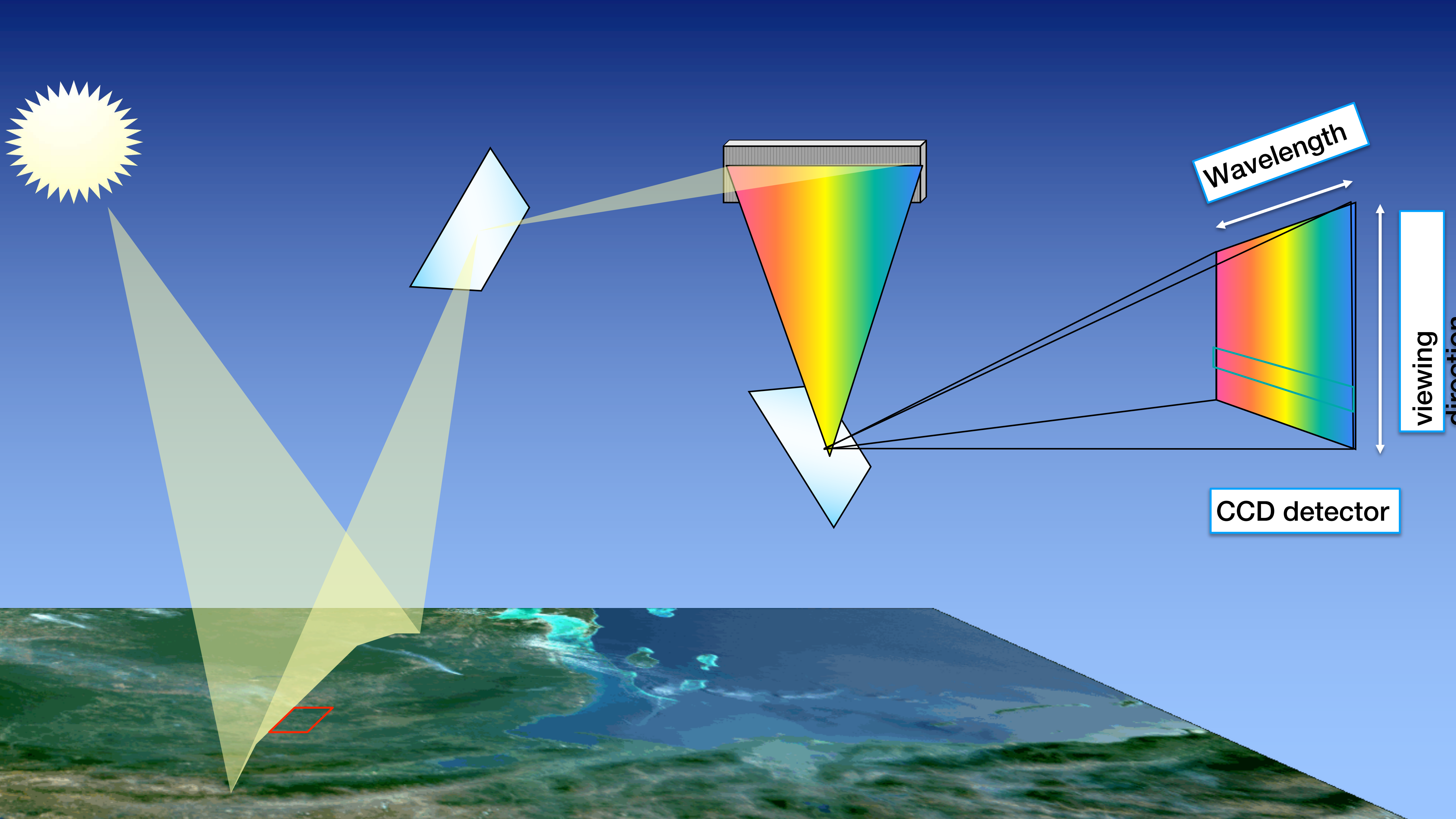
The two weeks after that:
Indication of increasing emissions.
Traffic?

21 March - 8 April 2020



9 - 22 April 2020

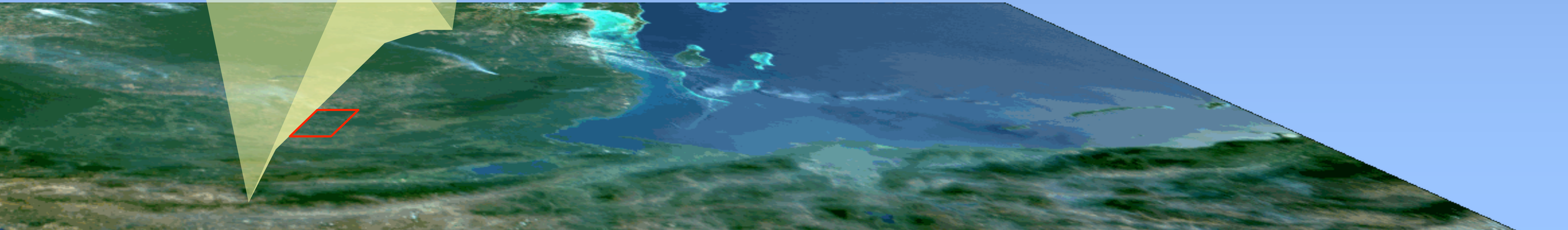




Wavelength

viewing direction

CCD detector

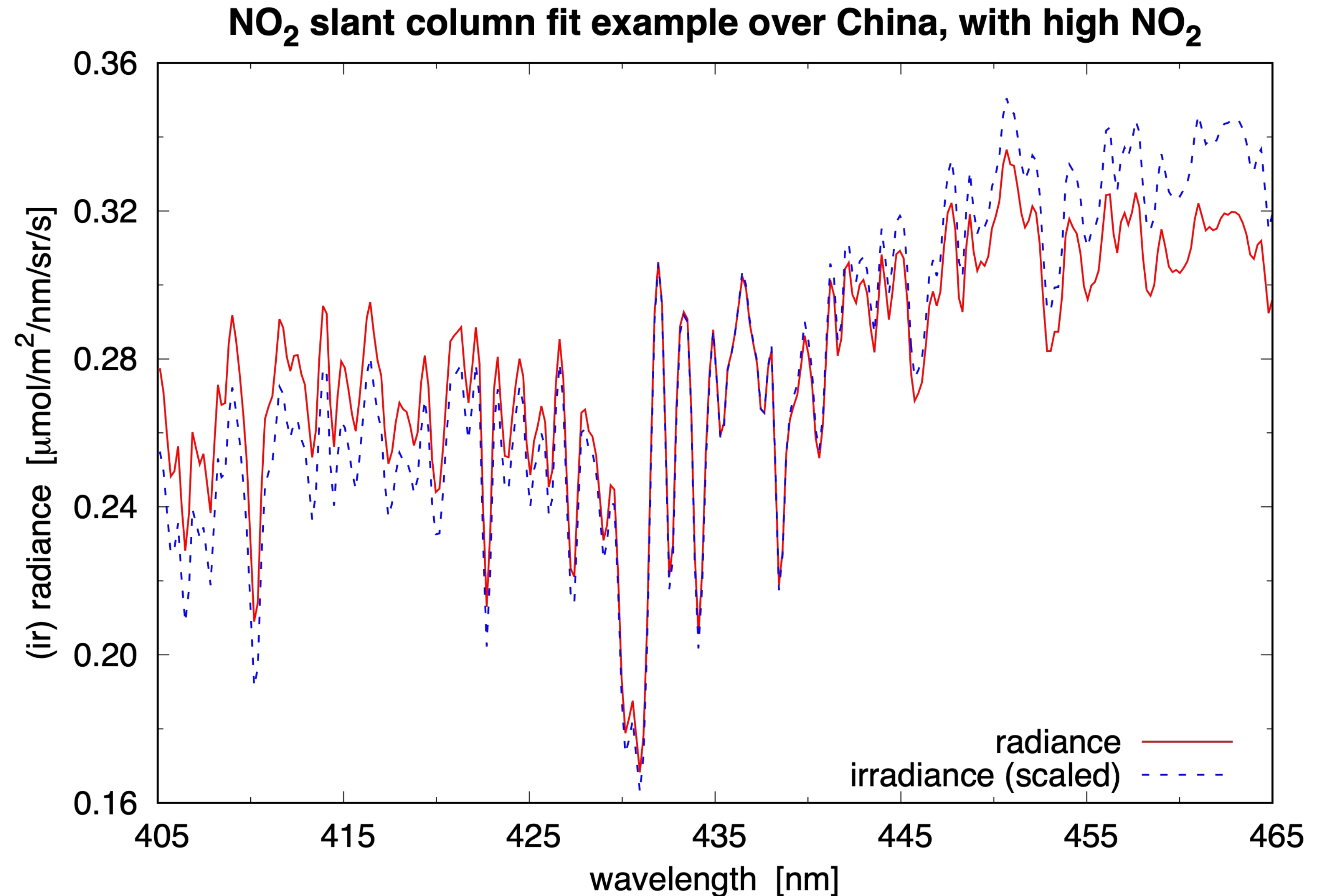


Spectral observations in the wavelength range for NO₂

TROPOMI observations
405-465 spectral range

When looking at the Earth
the main spectral features
observed are in the
solar spectrum

Jos van Geffen, KNMI

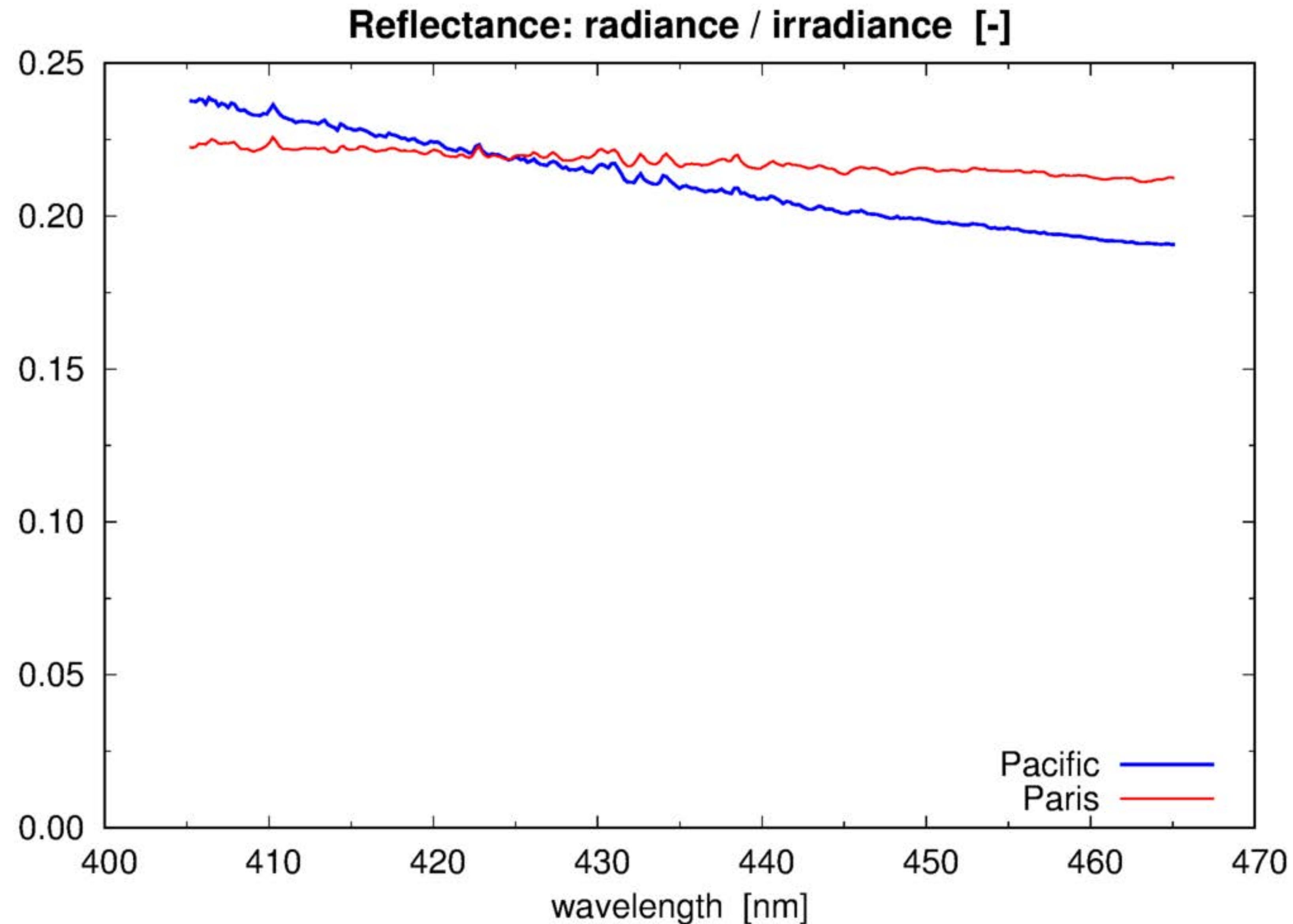


Comparison of Reflectance: 'Clean' Pacific vs. Urban Paris

TROPOMI observations
405-465 spectral range

Reflectance is a
"nearly" straight line

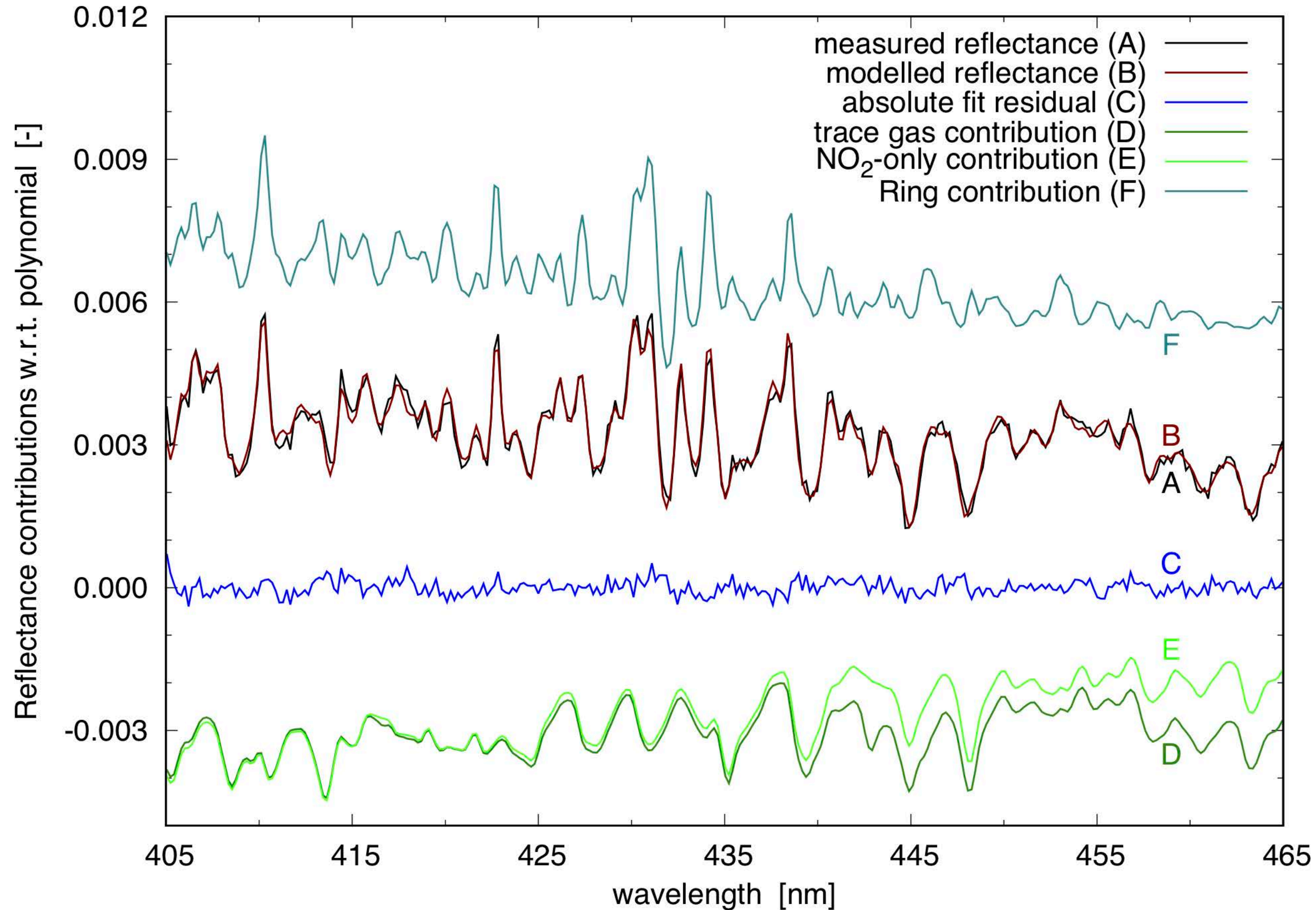
Note:
NO₂ concentration
typically 1 molecule per
10⁹ air molecules



Reflectance: Separating NO_2 contribution from other spectral features

Also in the reflectance
the solar spectral features
are still dominant

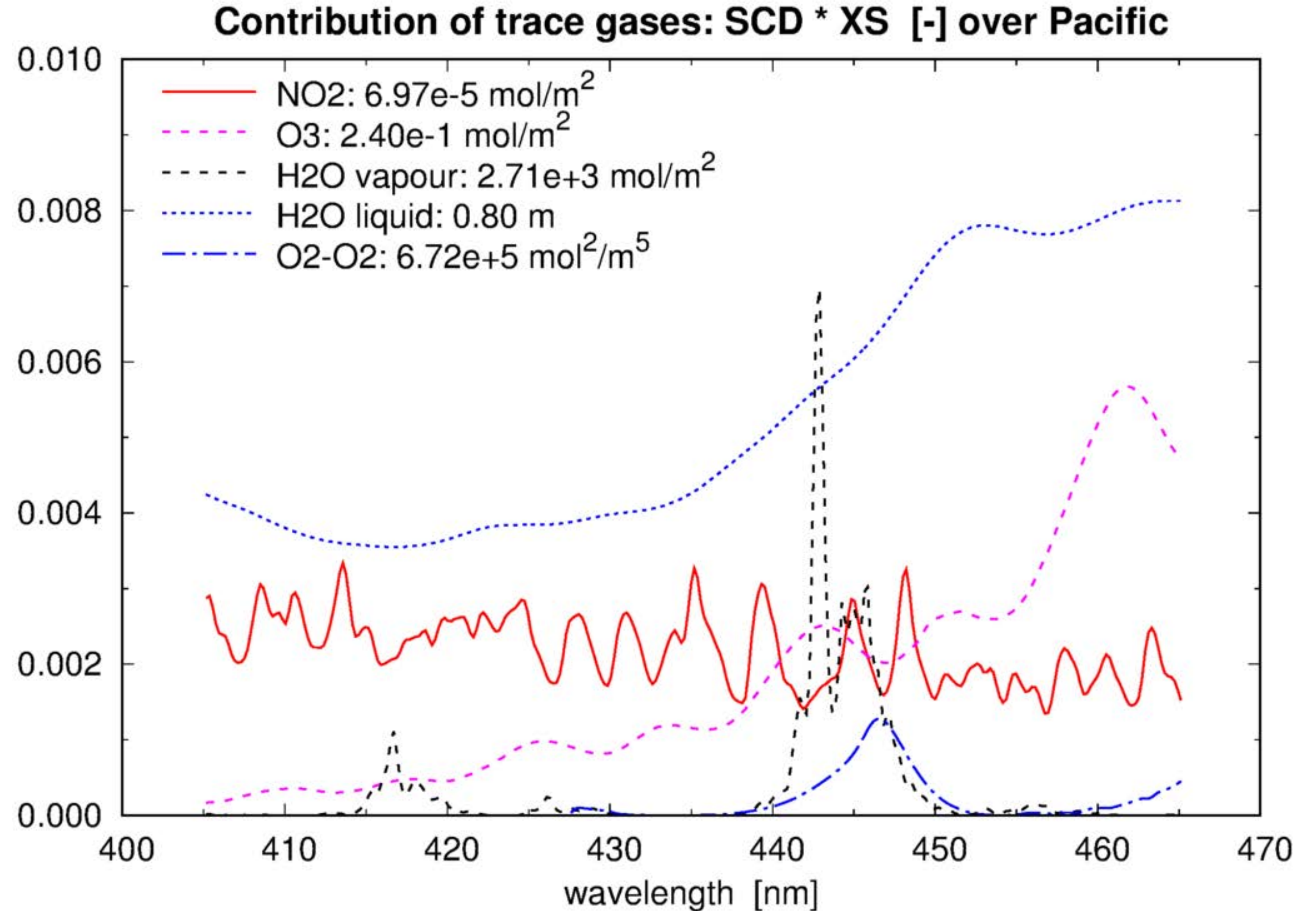
Ring effect =
inelastic Raman scattering
of sunlight in the
atmosphere



Accounting for other trace gas absorbers

Other absorbers
accounted for:

- Ozone
- Water vapour
- Liquid water
- O2-O2



Summary: DOAS (slant column) observations, End Part 1

Instrument:

- > Need high signal to noise, typically 1000.
- > Need very accurate calibration of Earth and solar spectra.

Conclusions related to the DOAS fits in NO₂ window:

- > We understand the Earth radiance in great detail, residuals $\sim 1e-4$
- > NO₂ has a very distinct spectral fingerprint and the slant column can be quantified accurately.

General Conclusion:

- > TROPOMI is a great instrument, with good L1b calibration and high SNR and is well suited for not just NO₂ but air quality & climate-relevant measurements of trace gases, cloud & aerosol
- > Will play an important role in continuing the data record and linking geostationary measurements for assimilation in global & regional models

Part 2:

But ... this was only the “easy” part of the retrieval

Easy part = most certain part, part with smallest error

What did we measure?

The amount of NO₂ along the path of the light through the atmosphere

What is still unknown?

Where did the light go?

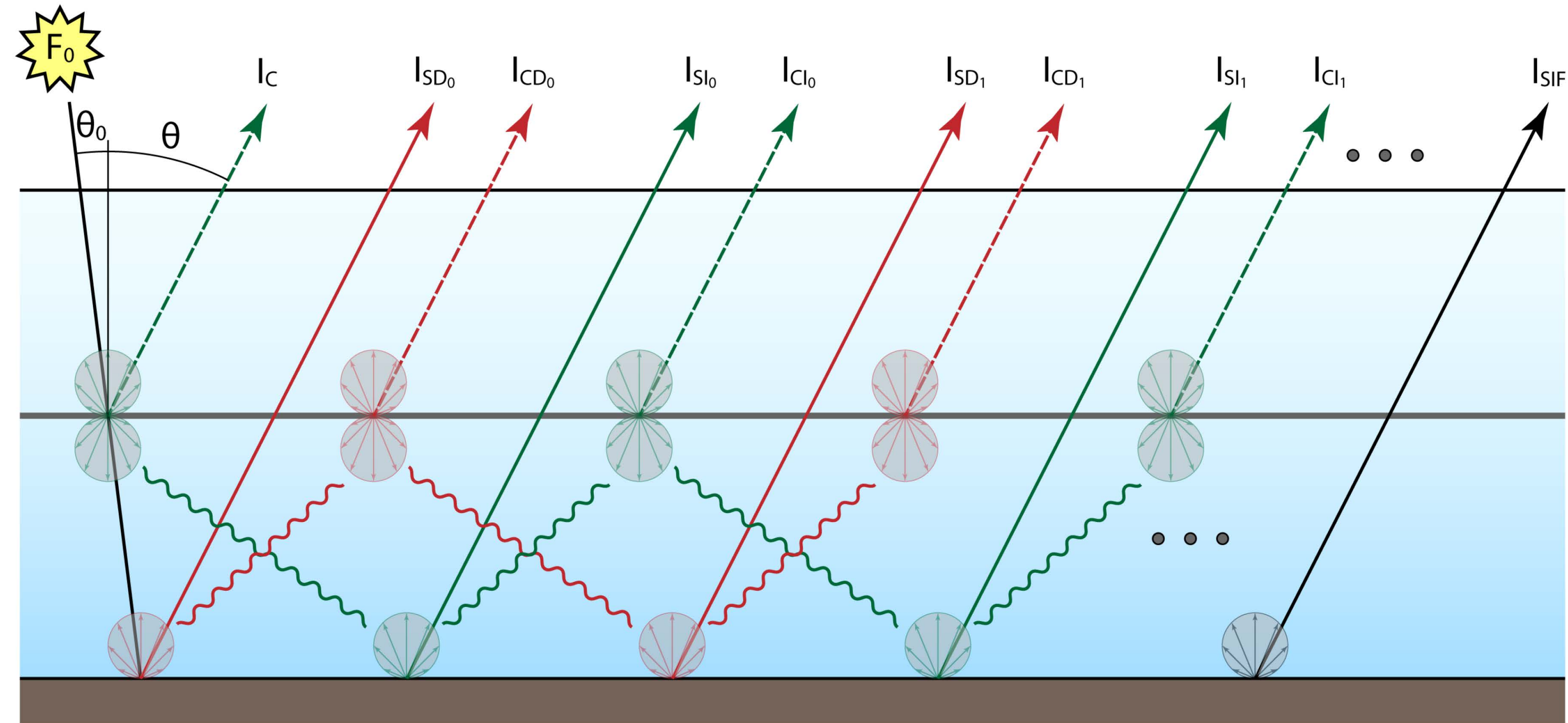
Where is the NO₂ located? (At what altitude? Vertical distribution?)

Quantify both of these unknowns using an ***air mass factor***

Where did the light travel?

Input needed from Radiative transfer models

Depending on
geometry,
clouds,
surface albedo,
aerosols



Air-mass factor

Where did the light travel?

Aspects that influence the light path:

Surface properties (reflection)



Clouds

Aerosols



Air-mass factor

Filtering to remove clouds: using the *qa_value*

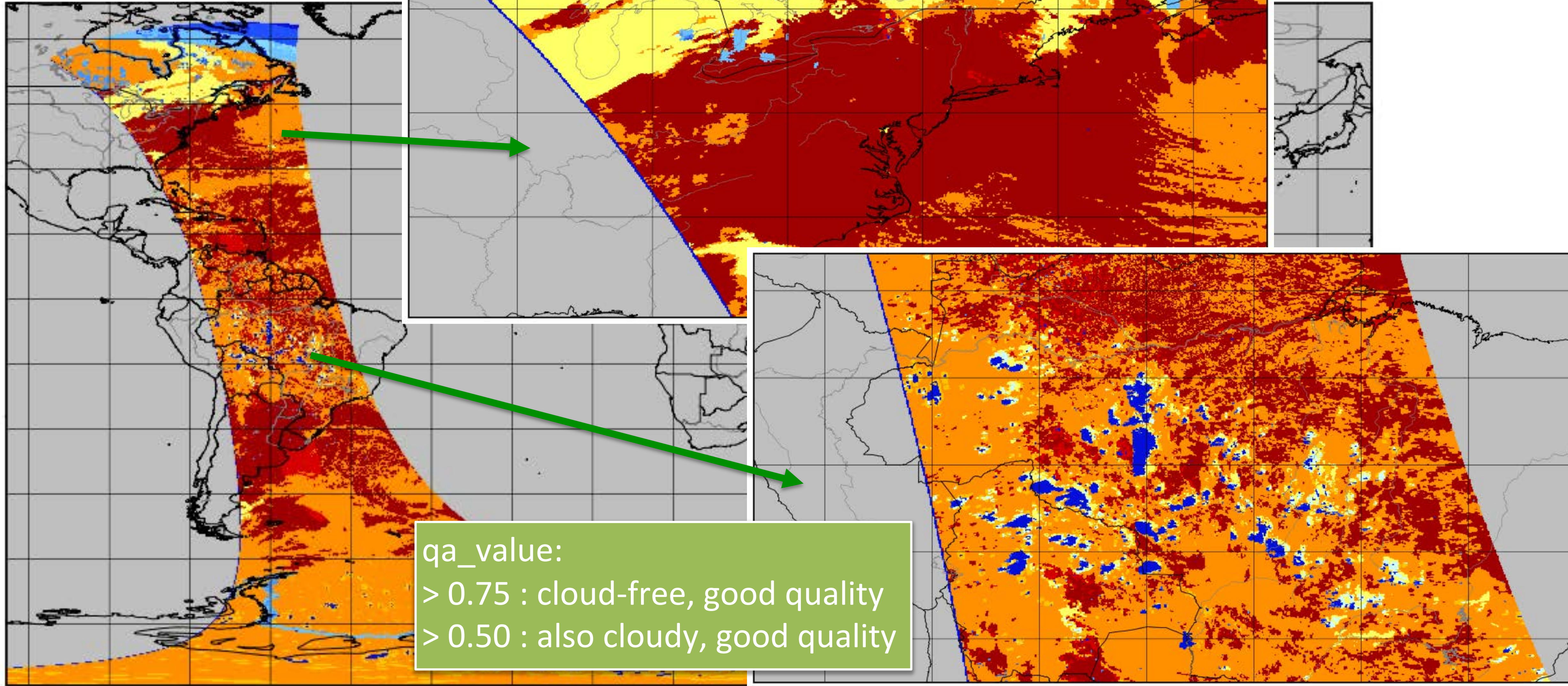
- `qa_value > 0.75`

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.

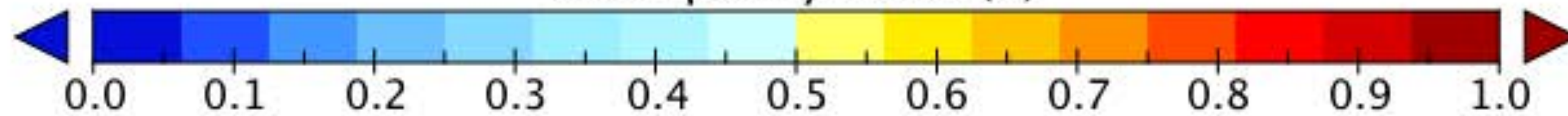
- `qa_value > 0.50`

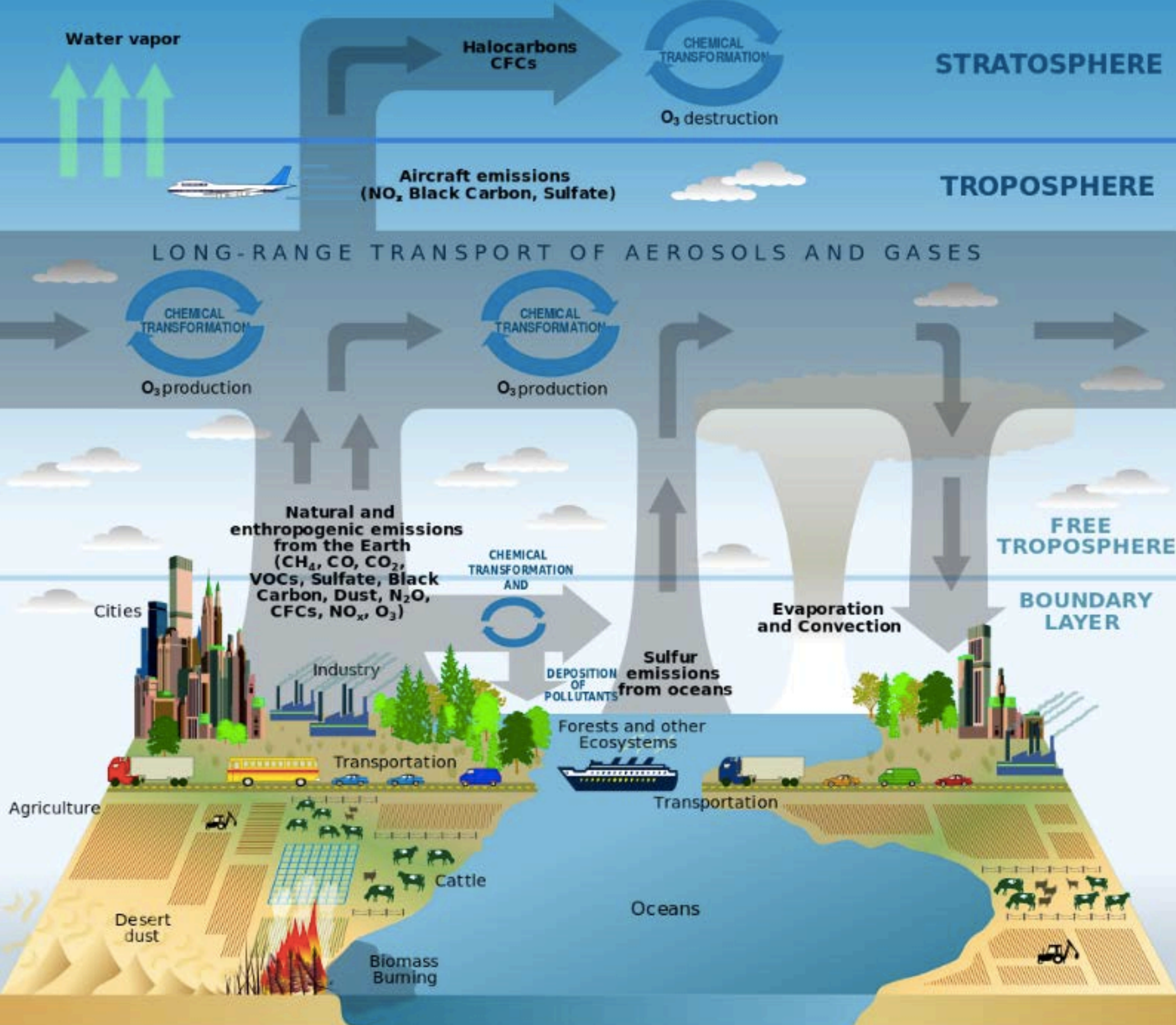
Compared to the stricter filter, this adds the good quality retrievals over clouds and over scenes covered by snow/ice. Errors and problematic retrievals are still filtered out. In particular, this filter may be useful for assimilation and model comparison studies.

Data Quality Value



data quality value (1)



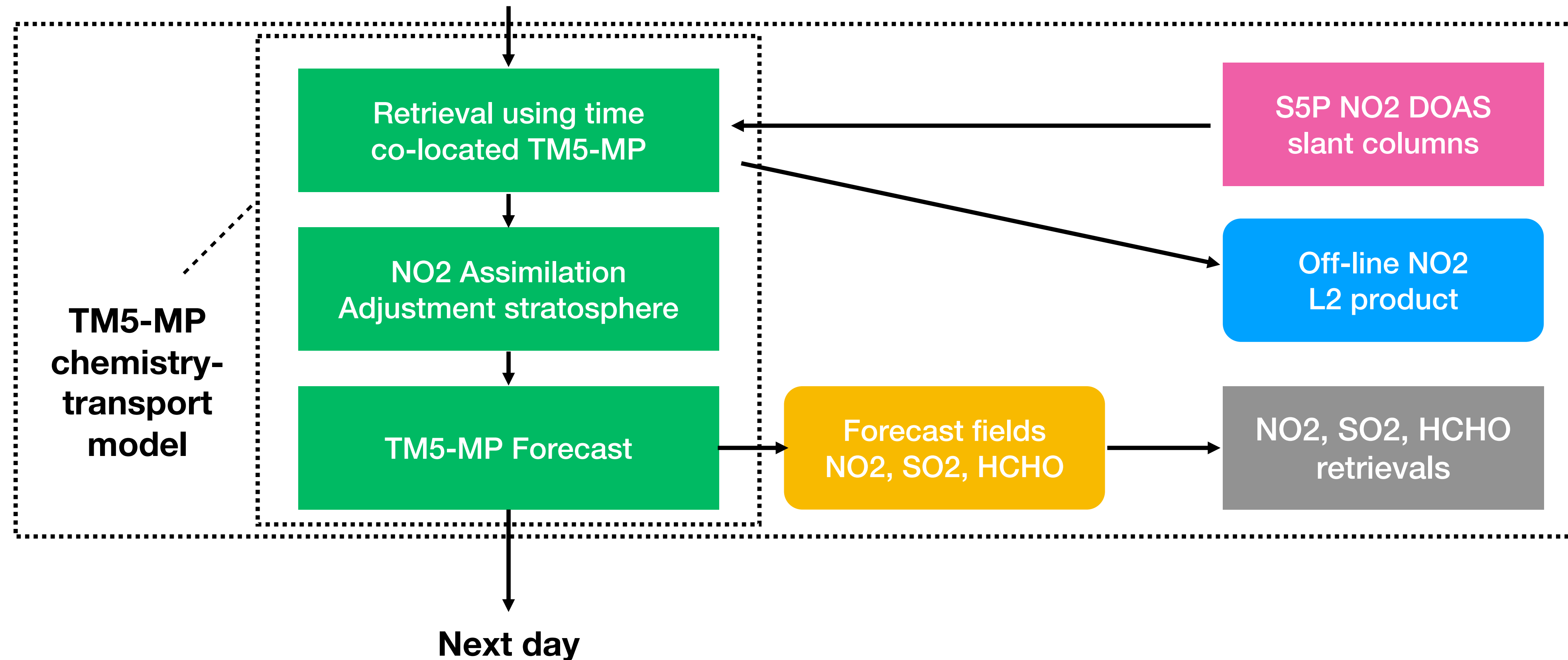


Where is the NO₂?



General circulation models including chemistry

TROPOMI NO₂ processing chain (DOMINO setup): Adding information from models

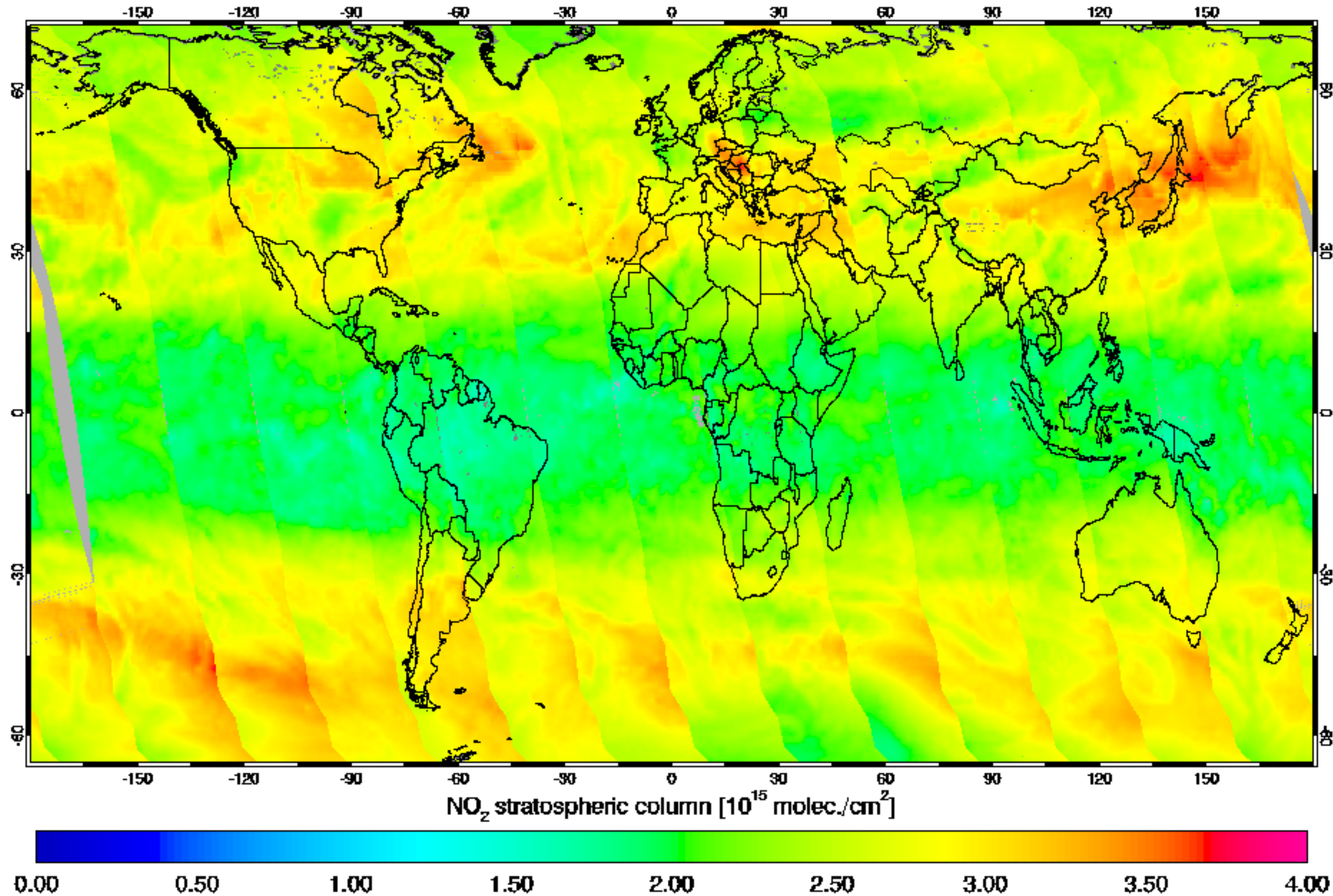


The TM5 model provides a priori information about NO₂ vertical profile

Stratosphere: from assimilation in TM5-MP

TROPOMI stratospheric NO₂ 01 Apr 2018

KNMI/ESA

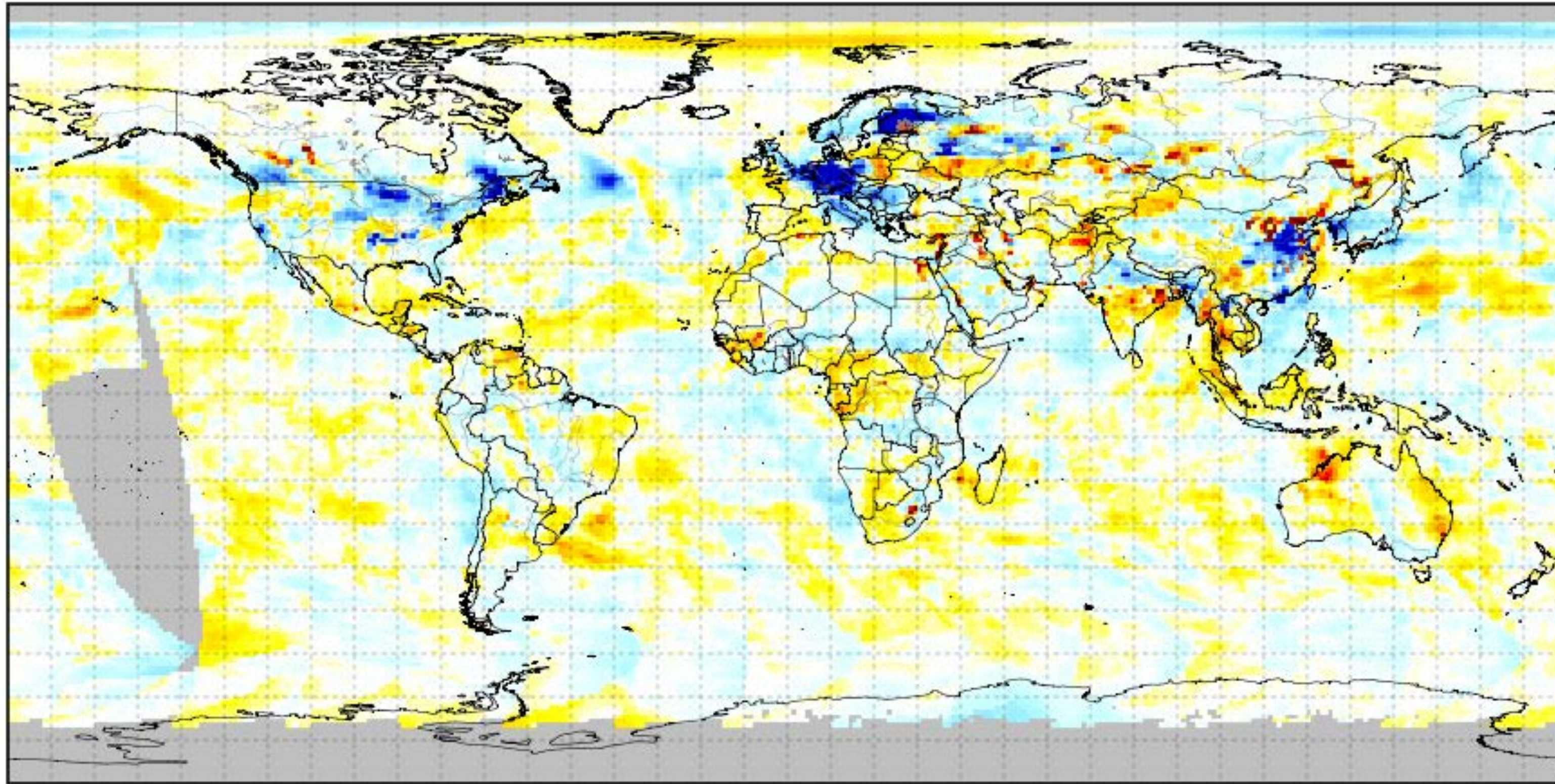


Tropospheric column =
Total column minus
stratospheric column

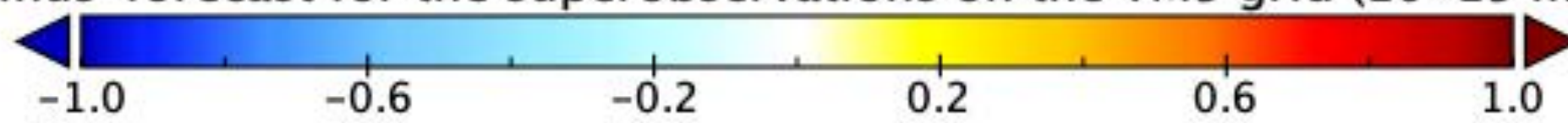
Stratospheric column
determined by:
-> Atmospheric dynamics
-> Diurnal cycle (chemistry)

Stratosphere: from assimilation in TM5-MP

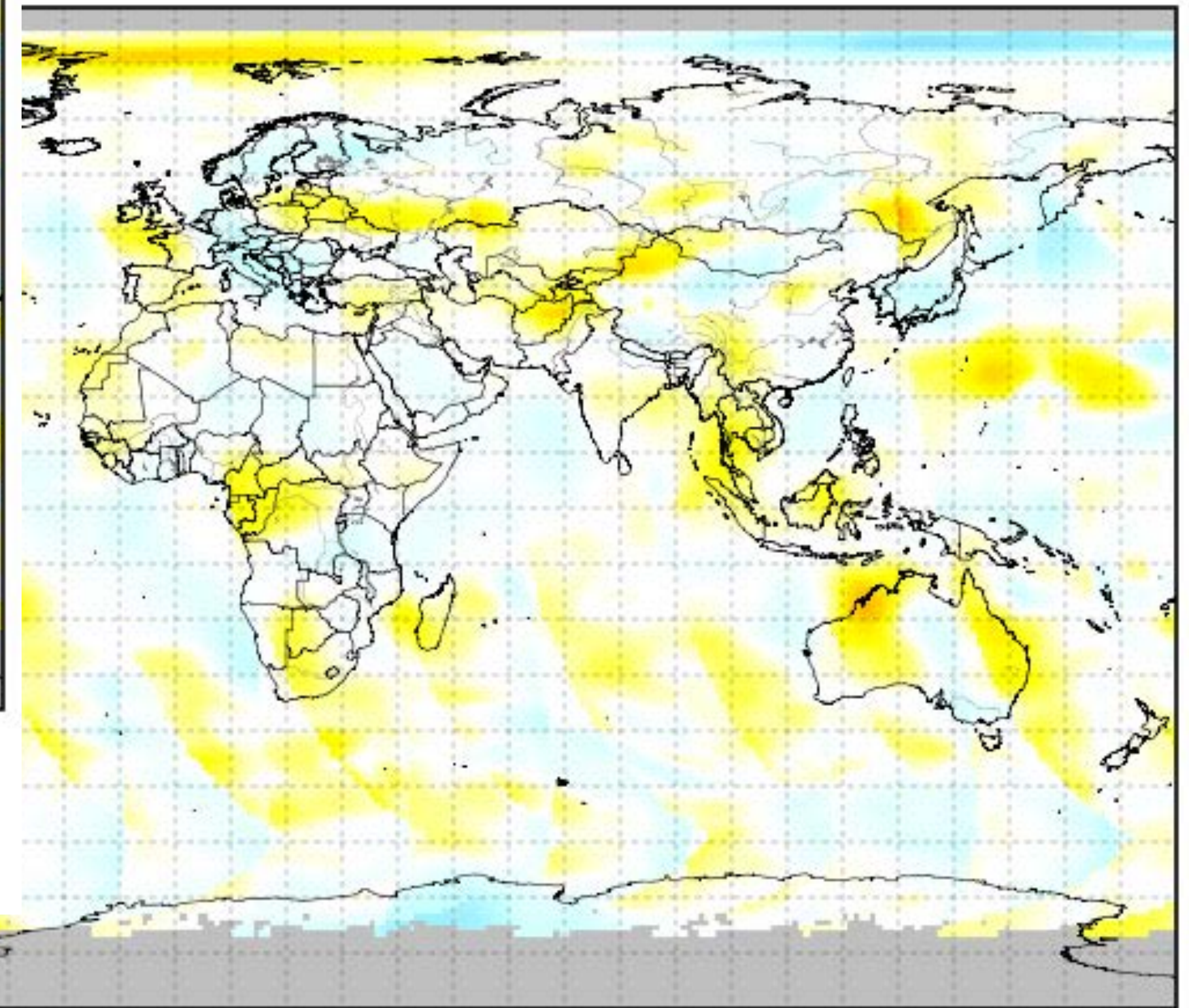
Observation-minus-forecast for the superobservations on the TM5 grid



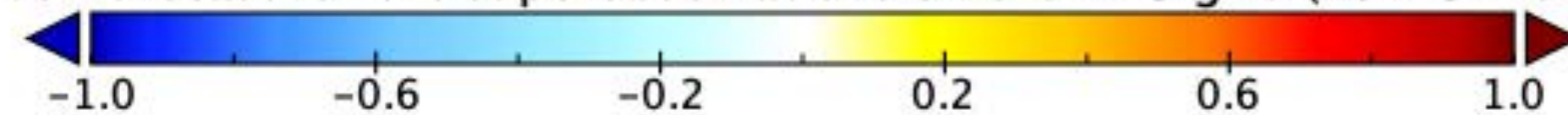
Observation-minus-forecast for the superobservations on the TM5 grid (10^{15} molecules cm^{-2})



Analysis-minus-forecast for the superobservations on the TM5 grid

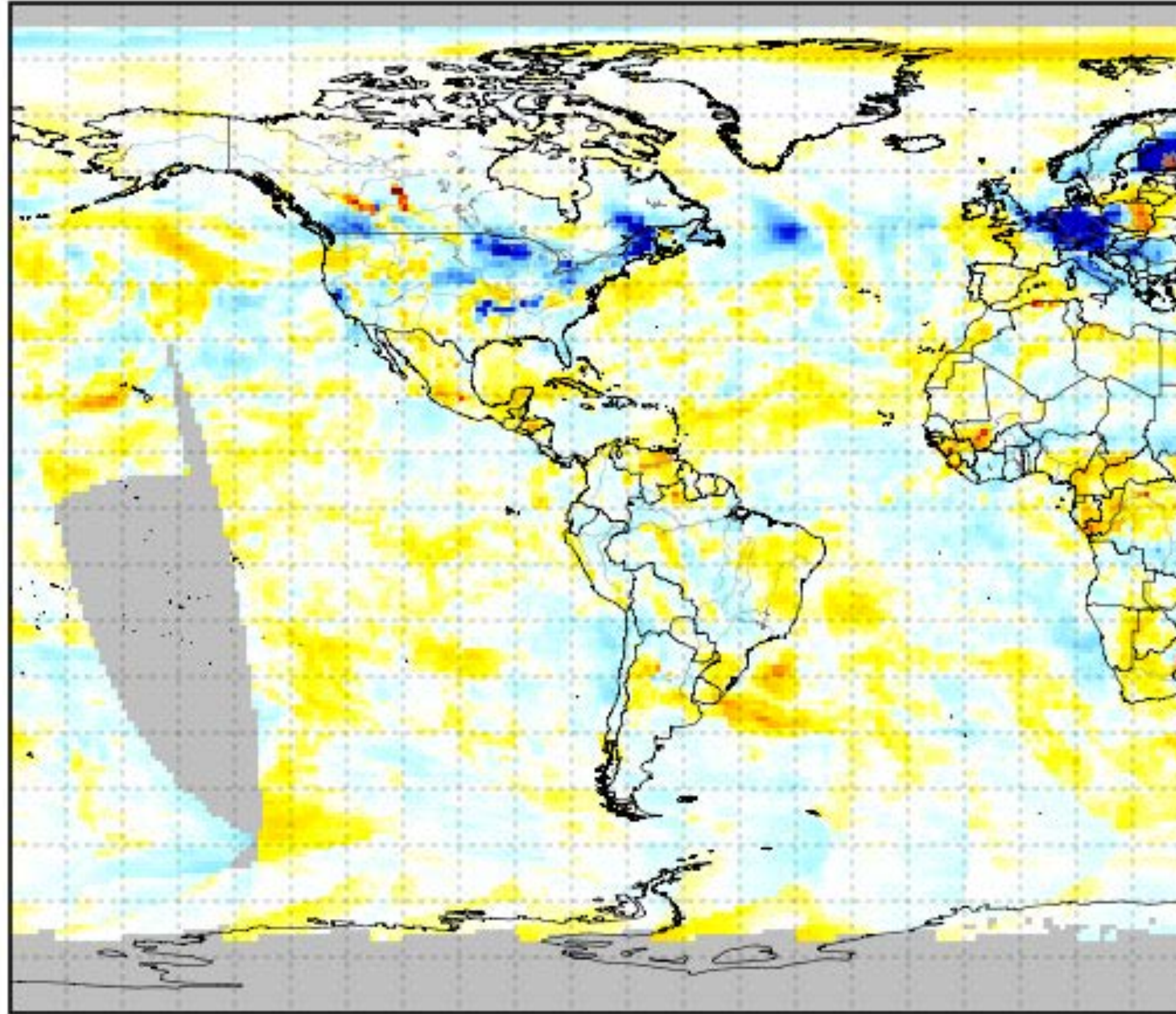


Analysis-minus-forecast for the superobservations on the TM5 grid (10^{15} molecules cm^{-2})



Stratosphere: from assimilation in TM5-MP

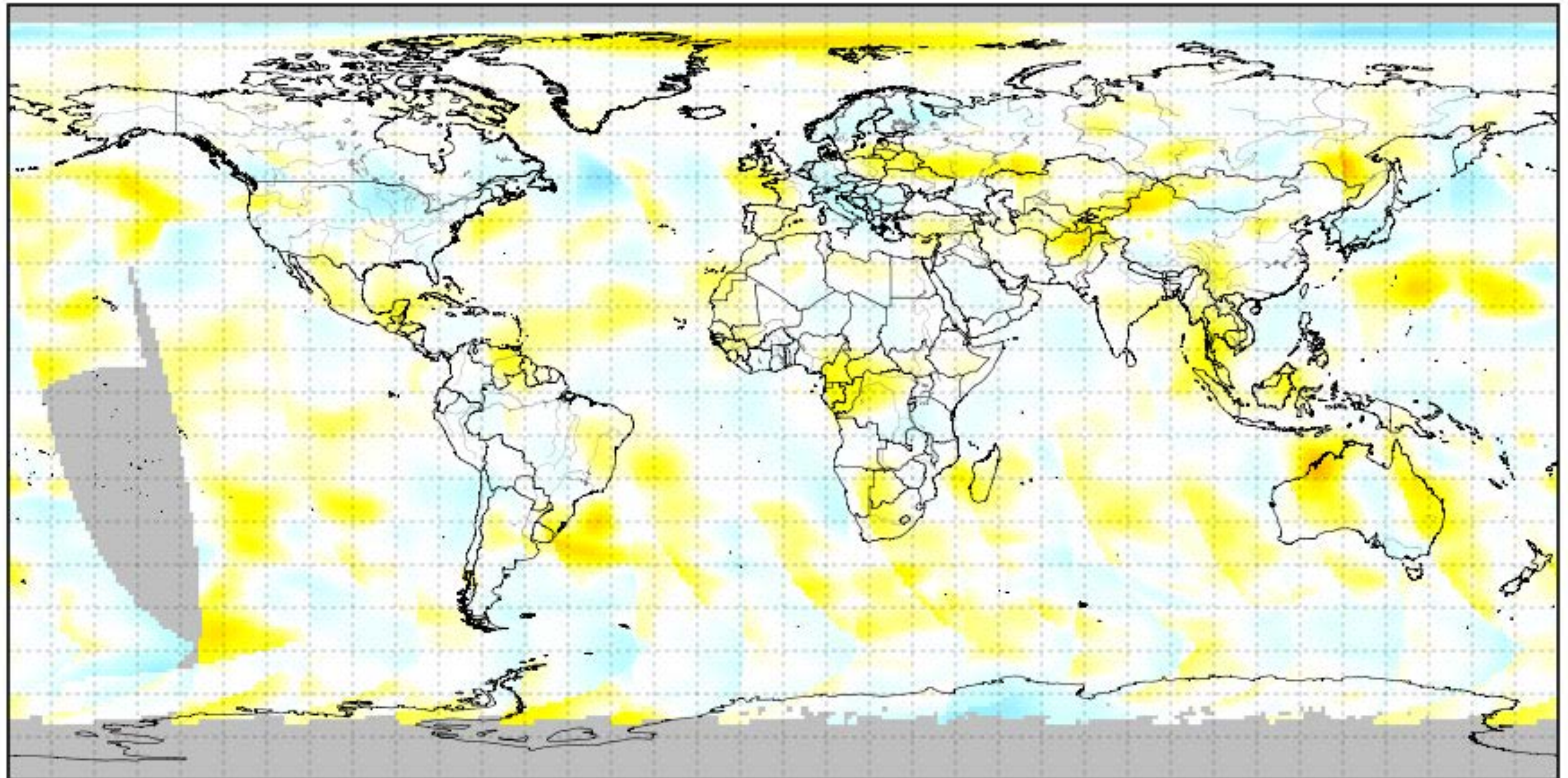
Observation-minus-forecast for the superobservations on the TM5 grid



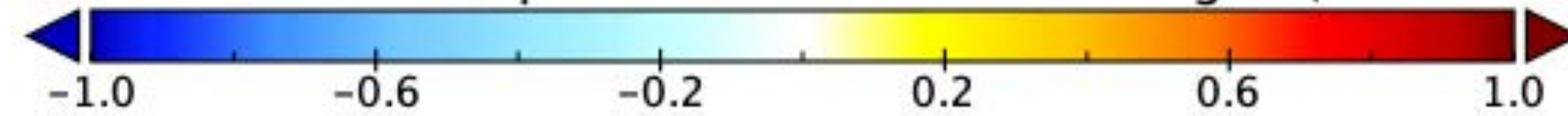
Observation-minus-forecast for the superobservations on



Analysis-minus-forecast for the superobservations on the TM5 grid



Analysis-minus-forecast for the superobservations on the TM5 grid (10^{15} molecules cm^{-2})



Validation is crucial to identify biases



Home Search VDAF

www.tropomi.eu

VALIDATION FACILITY

SENTINEL 5P MISSION PERFORMANCE CENTER



 Ozone  O3 profile  Nitrogen dioxide  Sulfur Dioxide  Formaldehyde  Surface UV-B  Aerosols  Carbon Monoxide  Methane  Cloud

Most recent contributions



First comparison results for the S5P CH4 product based on correlative reference measurements acquired by FTIR instruments contributing to NDACC and TCCON networks. This VDAF web article gives further details on the first comparison results presented in the CH4 product readme file for the methane data product release (see <http://www.tropomi.eu/data-products/methane>). The main conclusion is that the product quality of this initial L2 CH4 dataset complies with the S5P mission requirements.



Quarterly Validation Report of the Sentinel-5 Precursor Operational Data Products #01: July – October 2018

This document reports consolidated results of the routine operations validation service for the Sentinel-5 Precursor Tropospheric Monitoring



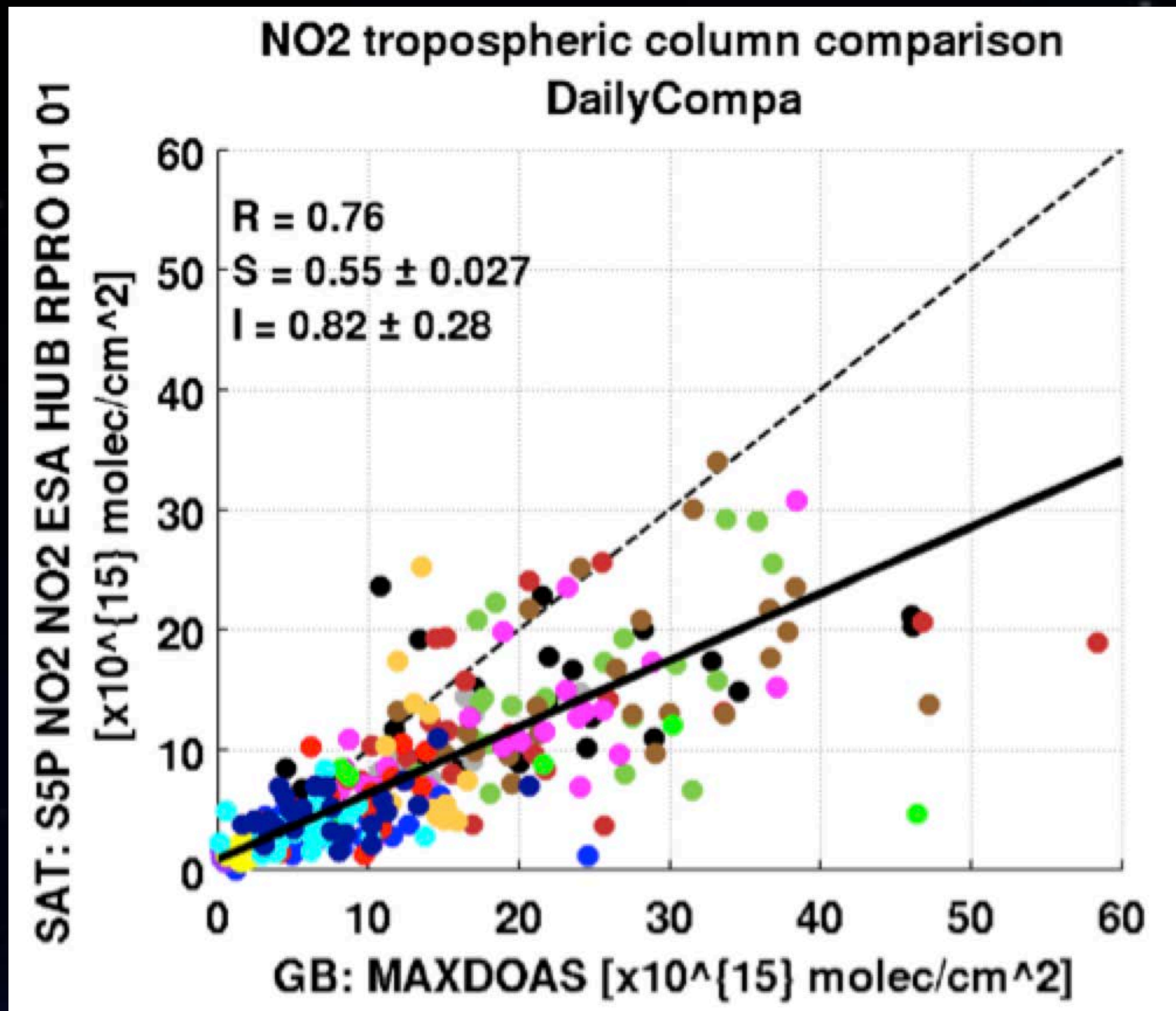
First validation results for Sentinel-5p NO2 column data.

This report describes initial validation results for Sentinel-5p TROPOMI L2_NO2 tropospheric column, stratospheric column and total column data: tropospheric and



A first validation against NDACC and WOUDC ground-based data confirms that the TROPOMI/S5p NRTI total O3 (L2_O3) product meets mission requirements. Initial Sentinel-5p TROPOMI L2_O3 O3 column data retrieved with the PDGS NRTI processor (v1.0.0) have been

TROPOMI vs. MAXDOAS



- MAXDOAS instr:
- Chiba (25)
 - ucclle (11)
 - unam (20)
 - vallejo (20)
 - xianghe (29)
 - yokosuka (31)
 - athens (27)
 - bremen (30)
 - cape_hedo (21)
 - cuautitlan (13)
 - fukue (12)
 - mainz (7)
 - thessaloniki_ciri (26)
 - thessaloniki_lap (26)

TROPOMI 30% lower than MAXDOAS

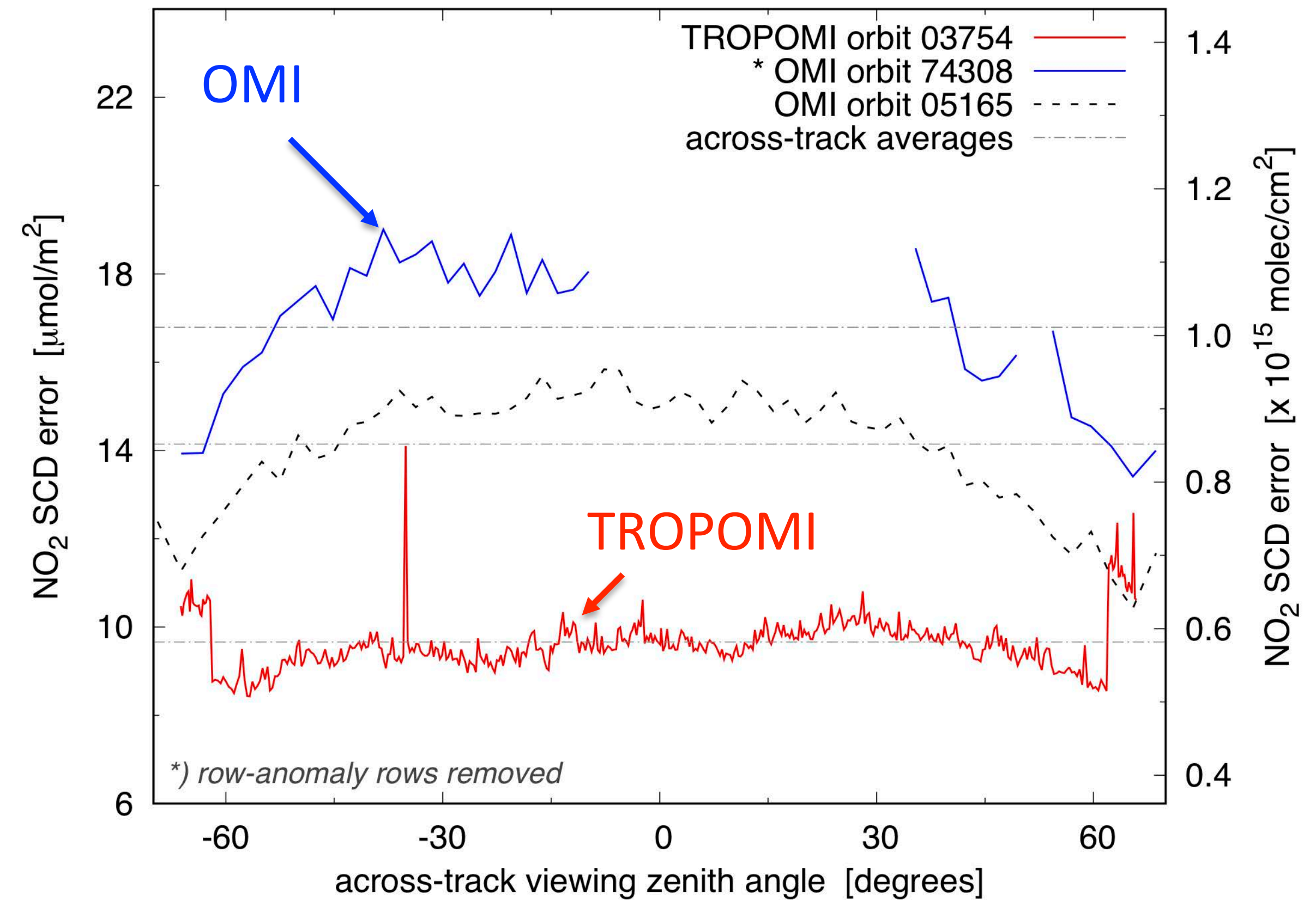
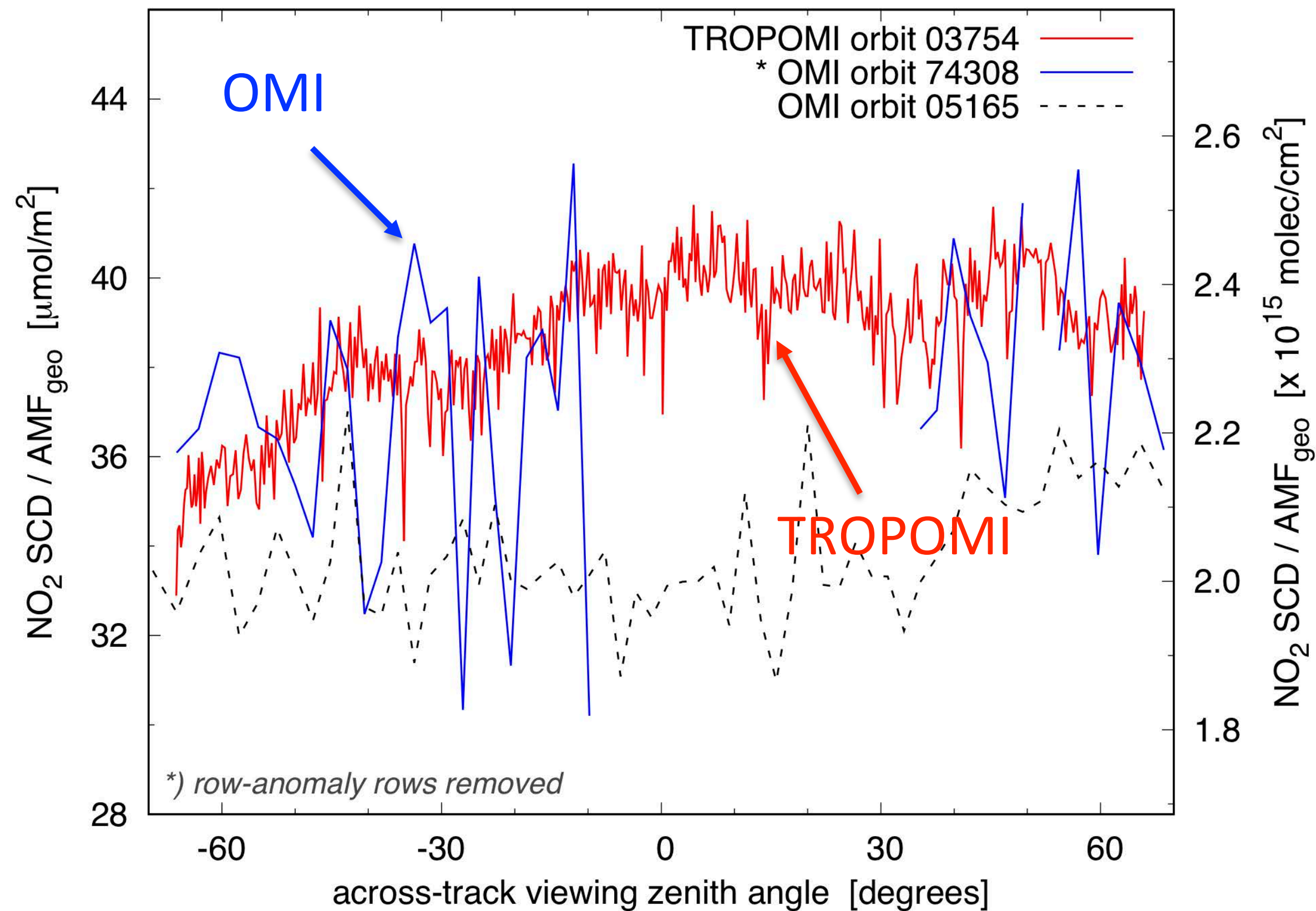
Bridging the gap ?

- Profile shape
- Clouds
- Local situation
- Kernel difference

Steven Compernelle, Tijn Verhoelst, Gaia Pinardi, José Granville, Jean-Christopher Lambert (BIRA-IASB), Kai-Uwe Eichmann (IUP-B)

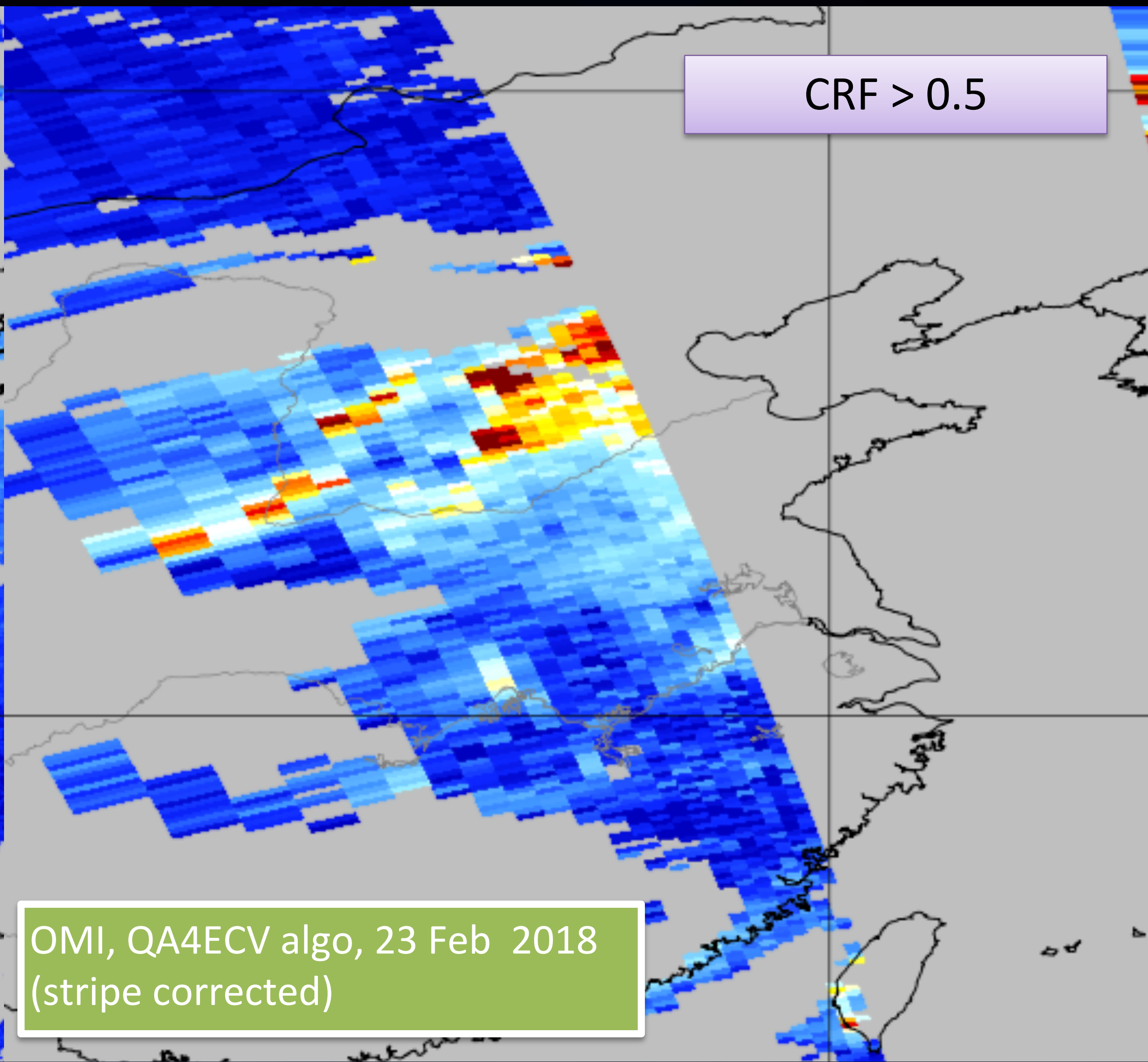
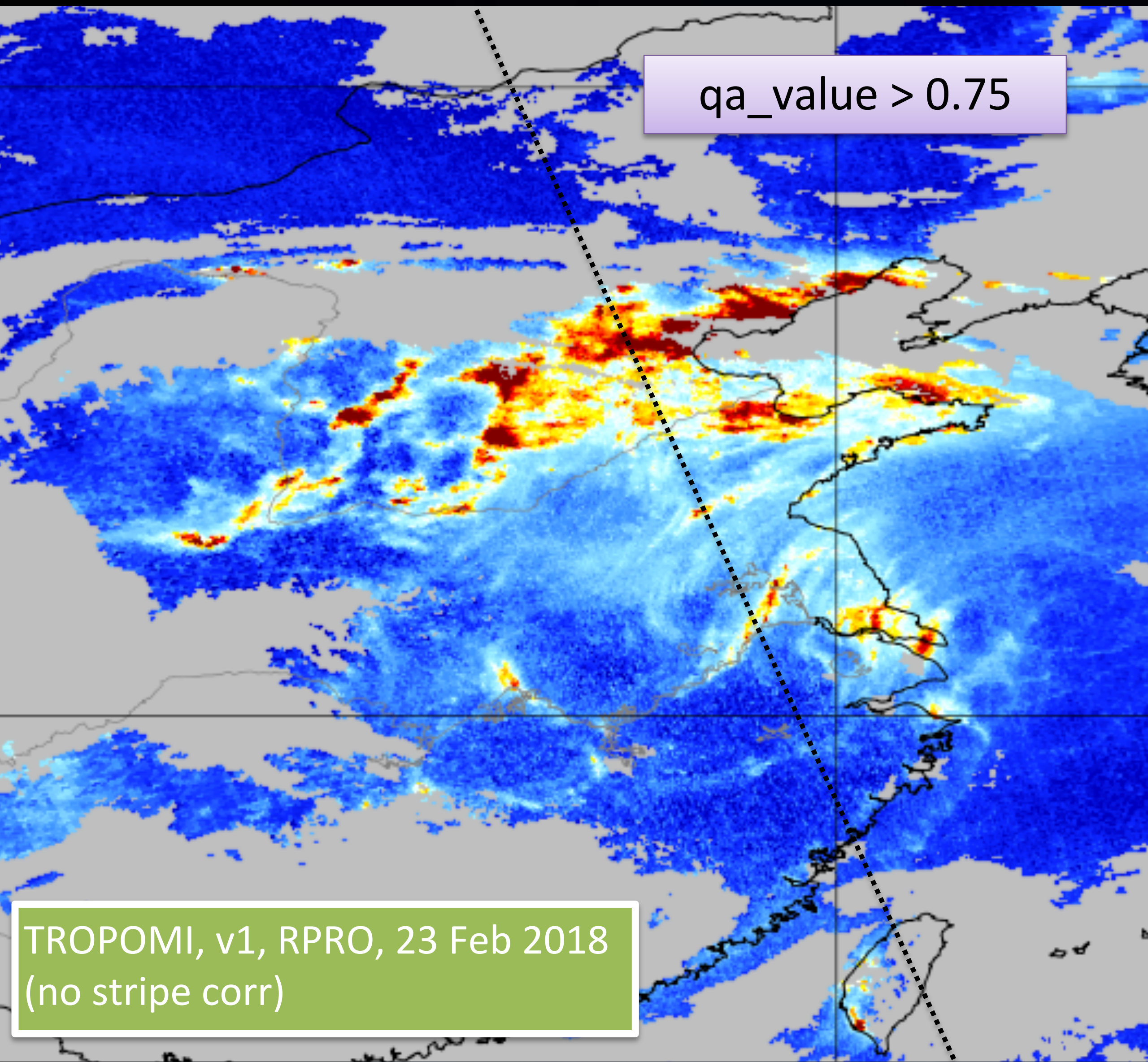


Comparison to other satellites: OMI vs. TROPOMI for DOAS slant column fits



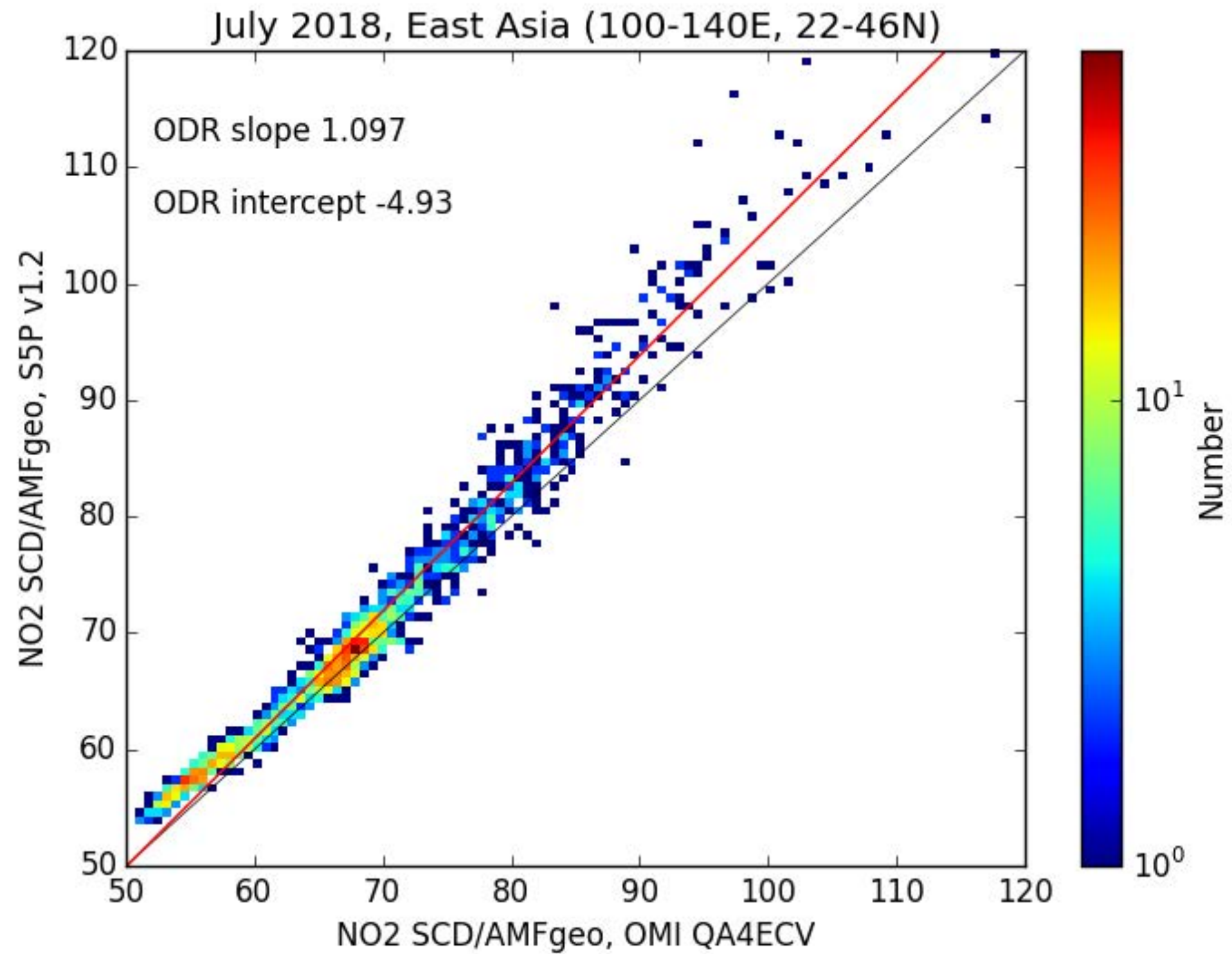
TROPOMI 10x more (smaller) pixels than OMI
But each pixel 1.5-2 times lower error bar

TROPOMI comparison with OMI - China

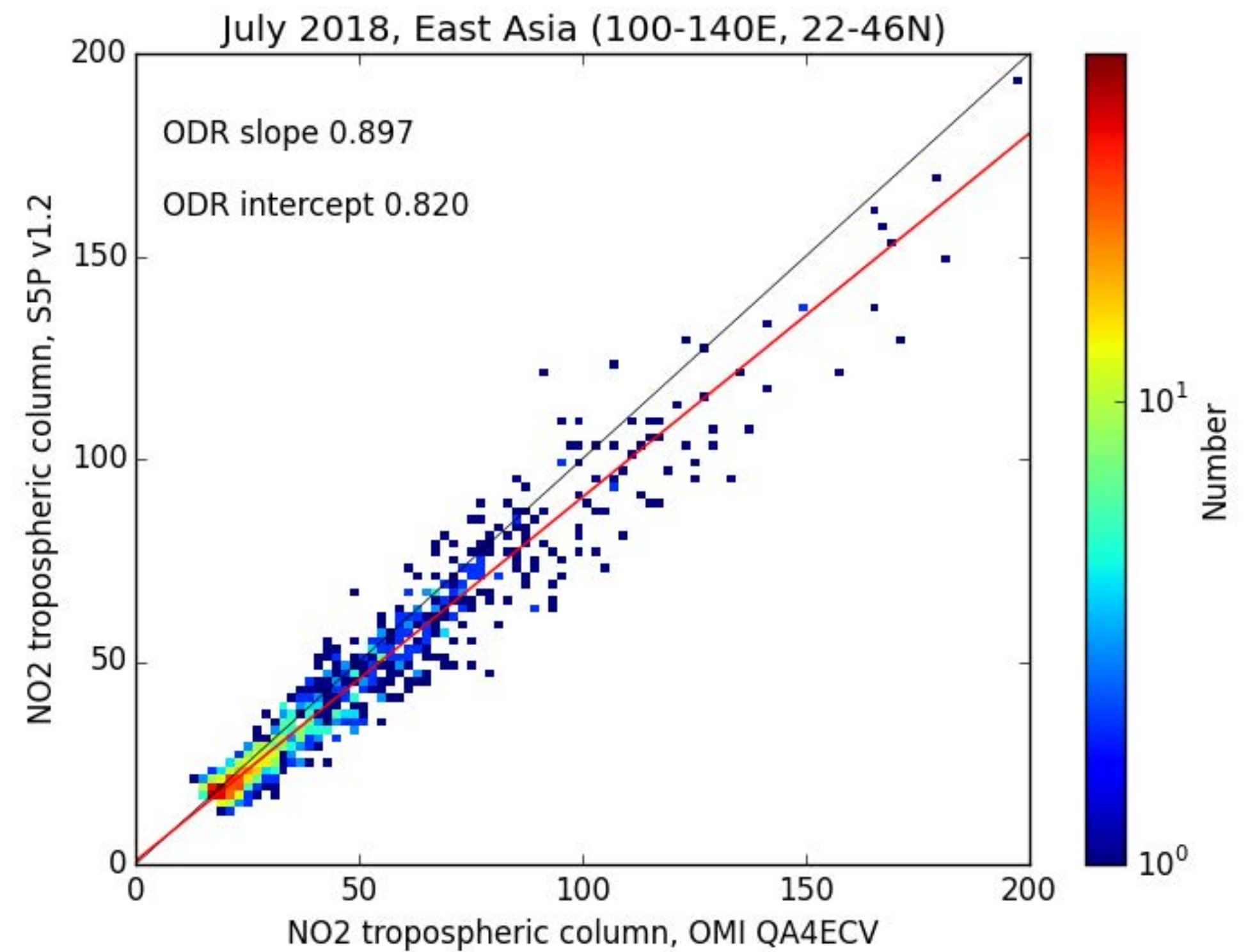


Comparison with OMI

SCD / AMFgeo



Tropospheric column

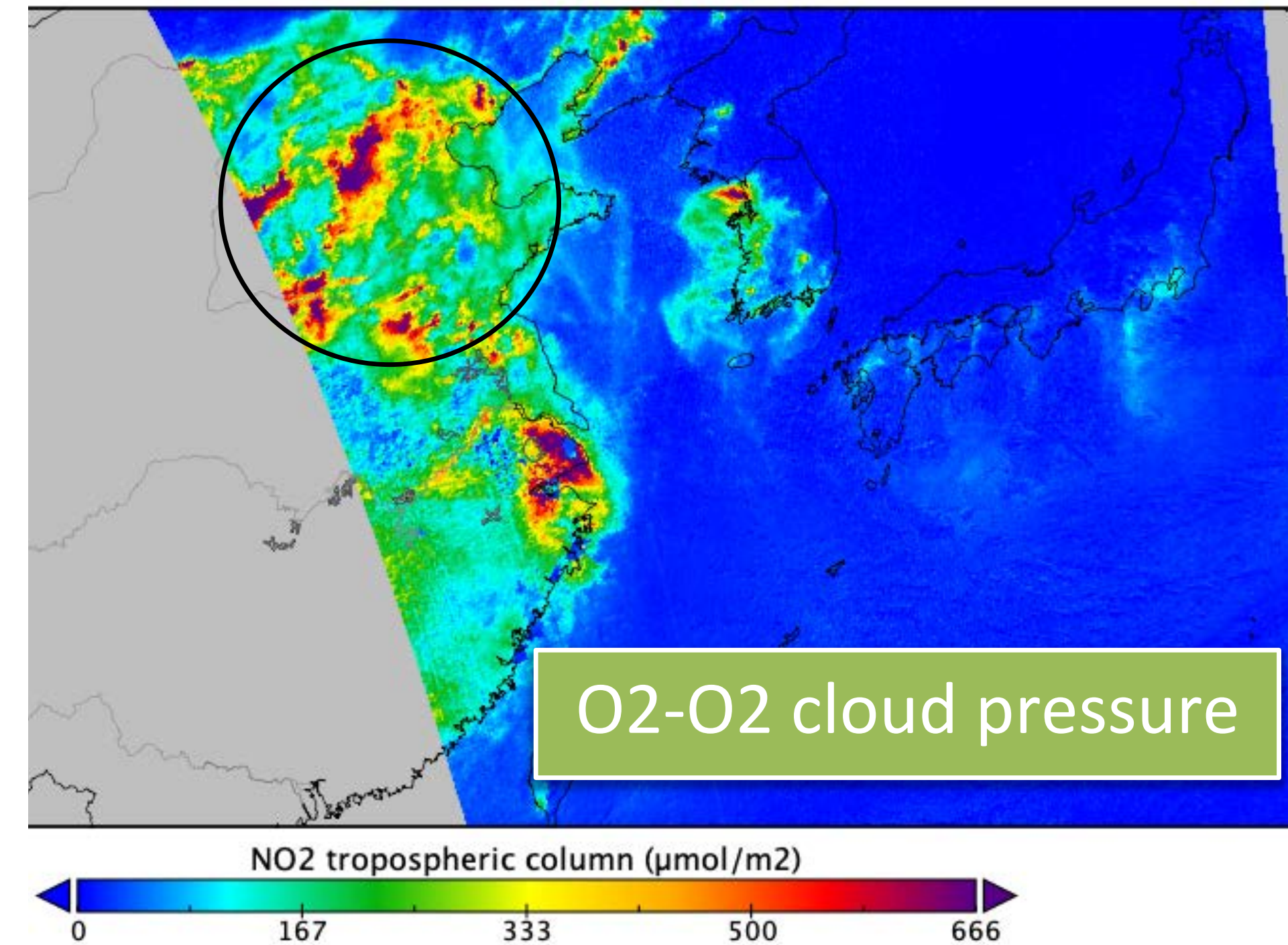
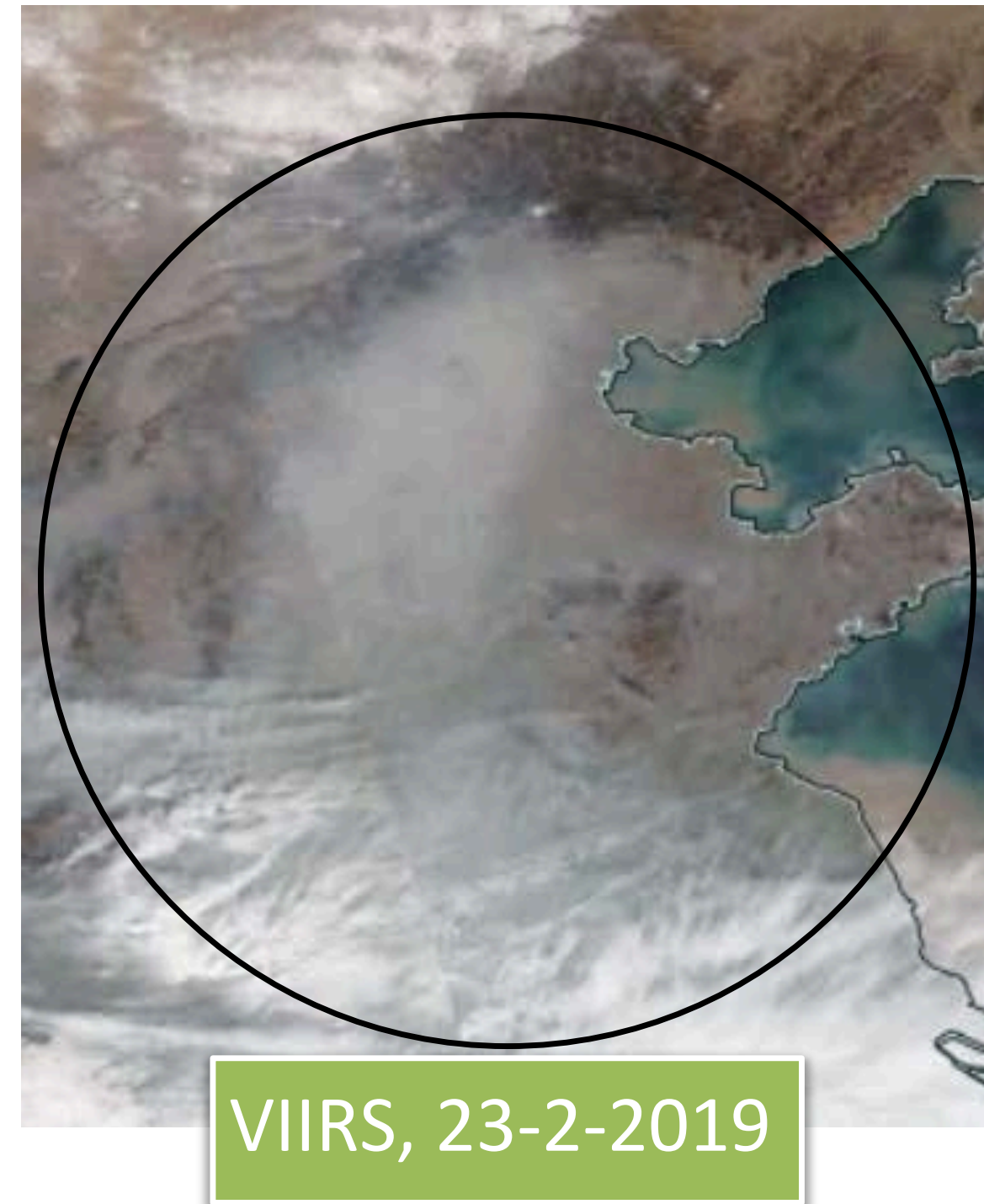
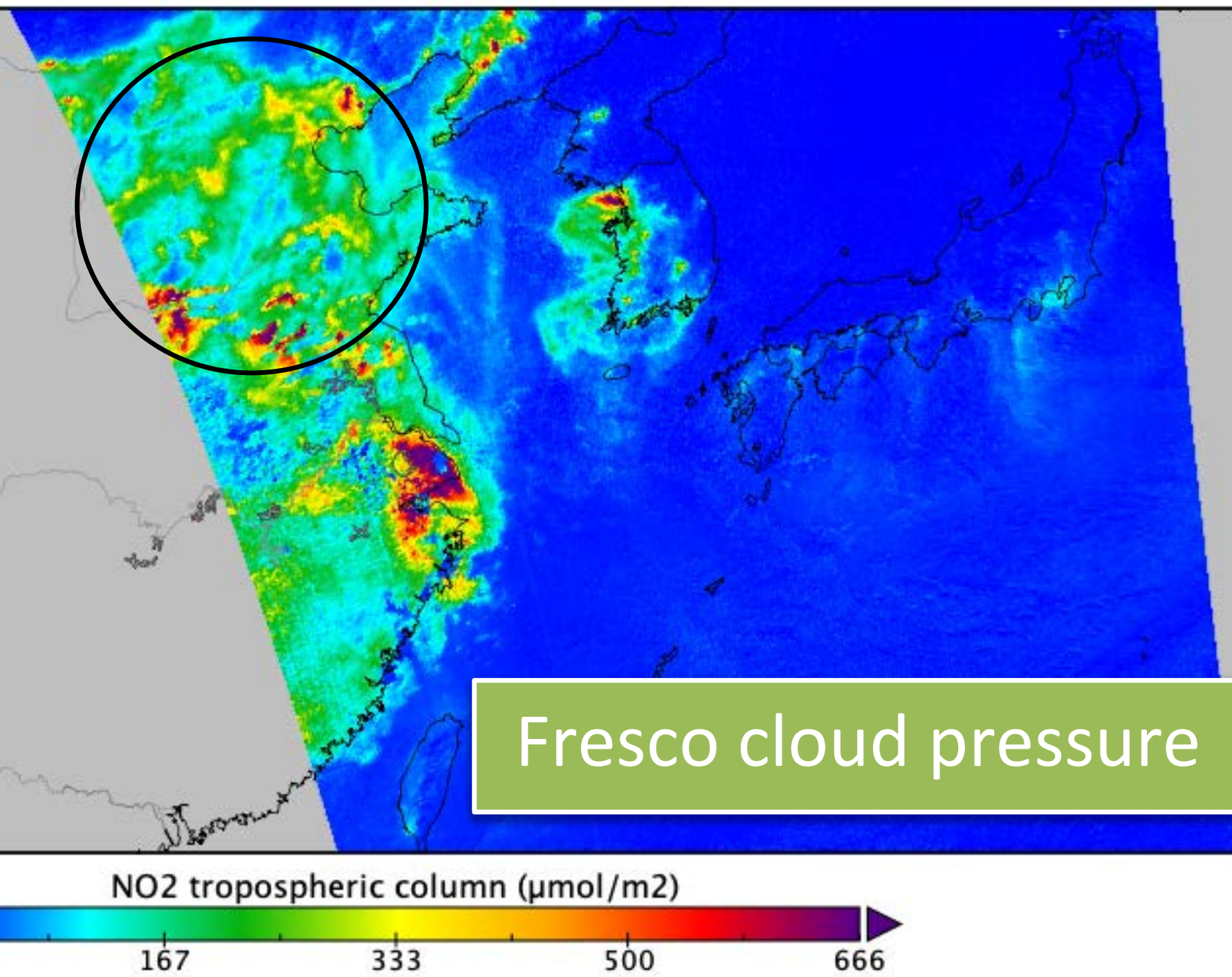


Differences in AMF ?

- Cloud product is different: Fresco (compare with O2-O2)



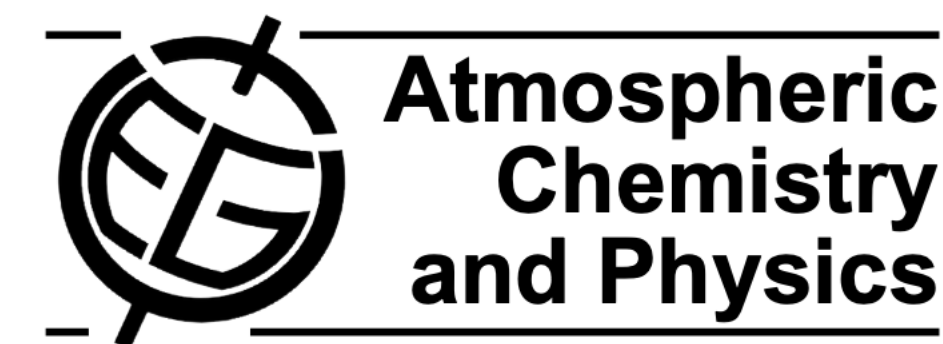
Dependence on cloud retrievals: Fresco vs O2-O2



Retrieval very sensitive to cloud height over area's with thick aerosol pollution or (broken) low clouds

Averaging kernels

Atmos. Chem. Phys., 3, 1285–1291, 2003
www.atmos-chem-phys.org/acp/3/1285/

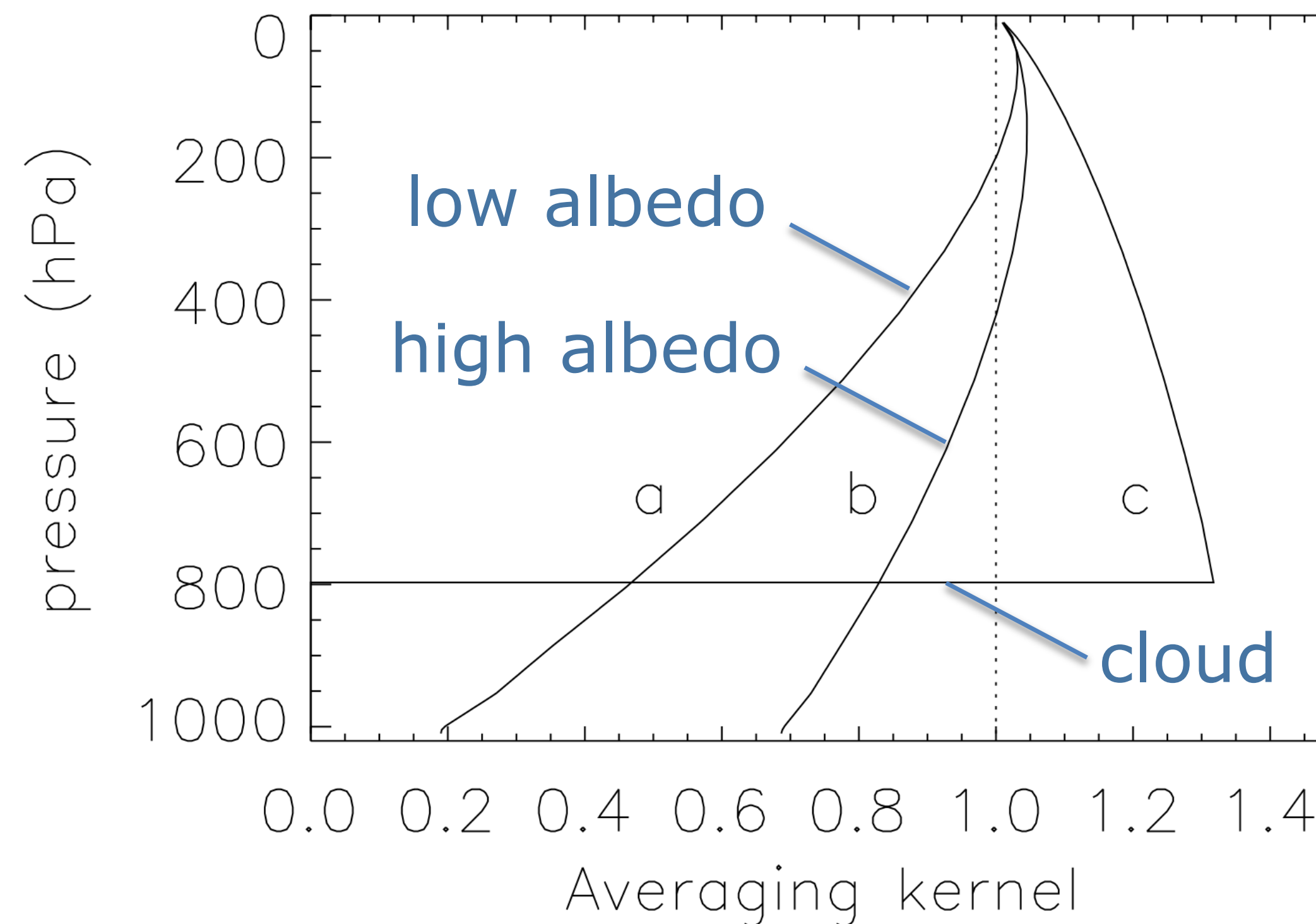


Averaging kernels for DOAS total-column satellite retrievals

H. J. Eskes and K. F. Boersma

In 2003 we showed how the DOAS retrieval may be re-formulated using Rodgers Optimal Estimation formalism.

DOAS averaging kernels profiles are proportional to the box air-mass factors



Use of TROPOMI NO₂ product

Depending on the application different datasets should be extracted from the L2_NO2 file

	<i>user application</i>	<i>data sets needed</i>
# 1	Tropospheric chemistry / air quality model evaluation and data assimilation Validation with tropospheric NO ₂ profile measurements (aircraft, balloon, MAX-DOAS)	$N_V^{\text{trop}}, \Delta N_V^{\text{trop, kernel}}$ $M^{\text{trop}}, M, \mathbf{A}^{\dagger}$ $A_l^{\text{TM5}}, B_l^{\text{TM5}}, l_{\text{tp}}^{\text{TM5}}, p_s$
# 2	Tropospheric column comparisons, e.g. with other NO ₂ column retrievals	$N_V^{\text{trop}}, \Delta N_V^{\text{trop}}$
# 3	Stratospheric chemistry model evaluation and data assimilation Validation with stratospheric NO ₂ profile measurements (limb/occultation satellite observations)	$N_V^{\text{strat}}, \Delta N_V^{\text{strat}}$ $M^{\text{strat}}, M, \mathbf{A}^{\ddagger}$ $A_l^{\text{TM5}}, B_l^{\text{TM5}}, l_{\text{tp}}^{\text{TM5}}, p_s$
# 4	Stratospheric column comparisons, e.g. with ground-based remote sensors	$N_V^{\text{strat}}, \Delta N_V^{\text{strat}}$
# 5	Whole atmosphere (troposphere + stratosphere) data assimilation systems	$N_V, \Delta N_V^{\text{kernel}} \quad \S$ \mathbf{A} $A_l^{\text{TM5}}, B_l^{\text{TM5}}, l_{\text{tp}}^{\text{TM5}}, p_s$
# 6	Whole atmosphere (troposphere + stratosphere) comparisons with ground-based remote sensing (e.g. Pandora)	$N_V^{\text{sum}}, \Delta N_V^{\text{sum}} \quad \S$
# 7	Visualisation of the NO ₂ product	$N_V^{\text{trop}}, N_V^{\text{strat}}, N_V^{\text{sum}} \quad \S$

† The tropospheric kernel \mathbf{A}^{trop} is derived from the total kernel \mathbf{A} and the air-mass factors M and M^{trop} .

‡ The stratospheric kernel $\mathbf{A}^{\text{strat}}$ is derived from the total kernel \mathbf{A} and the air-mass factors M and M^{strat} .

§ Note that the total NO₂ vertical column $N_V \equiv N_s/M$ is *not* the same as the sum $N_V^{\text{sum}} \equiv N_V^{\text{trop}} + N_V^{\text{strat}}$



Application of the averaging kernels

The file contains the averaging kernel for the total column.

The tropospheric column \mathbf{A}^{trop} is obtained in the following way

$$\mathbf{A}^{\text{trop}} = \frac{M}{M^{\text{trop}}} \mathbf{A} \quad , \quad l \leq l_{\text{tp}}^{\text{TM5}}$$
$$\mathbf{A}^{\text{trop}} = 0 \quad , \quad l > l_{\text{tp}}^{\text{TM5}}$$

A model simulated satellite tropospheric NO₂ column is obtained by multiplying the model partial column profile $x_{m,l}$ with the averaging kernel, or

$$N_{\text{v}}^{\text{trop,model}} = \sum_l A_l^{\text{trop}} x_{m,l}$$

Replacing the a-priori using the averaging kernels

The TROPOMI NO₂ tropospheric column may be re-computed using the profile $x_{m,l}$ from an alternative model (high-resolution regional air-quality model). Needed are the tropospheric averaging kernel and AMF, and the following equations:

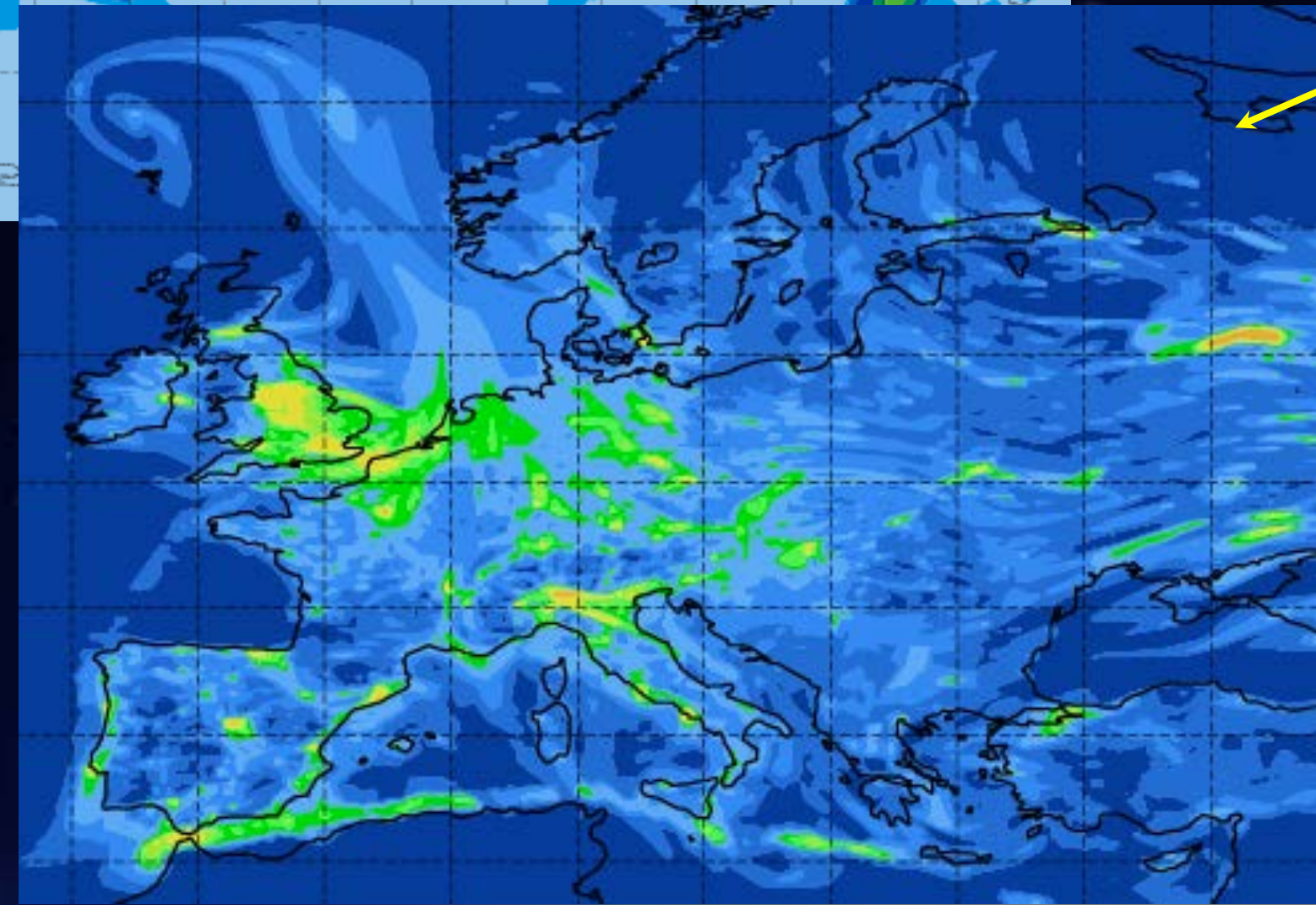
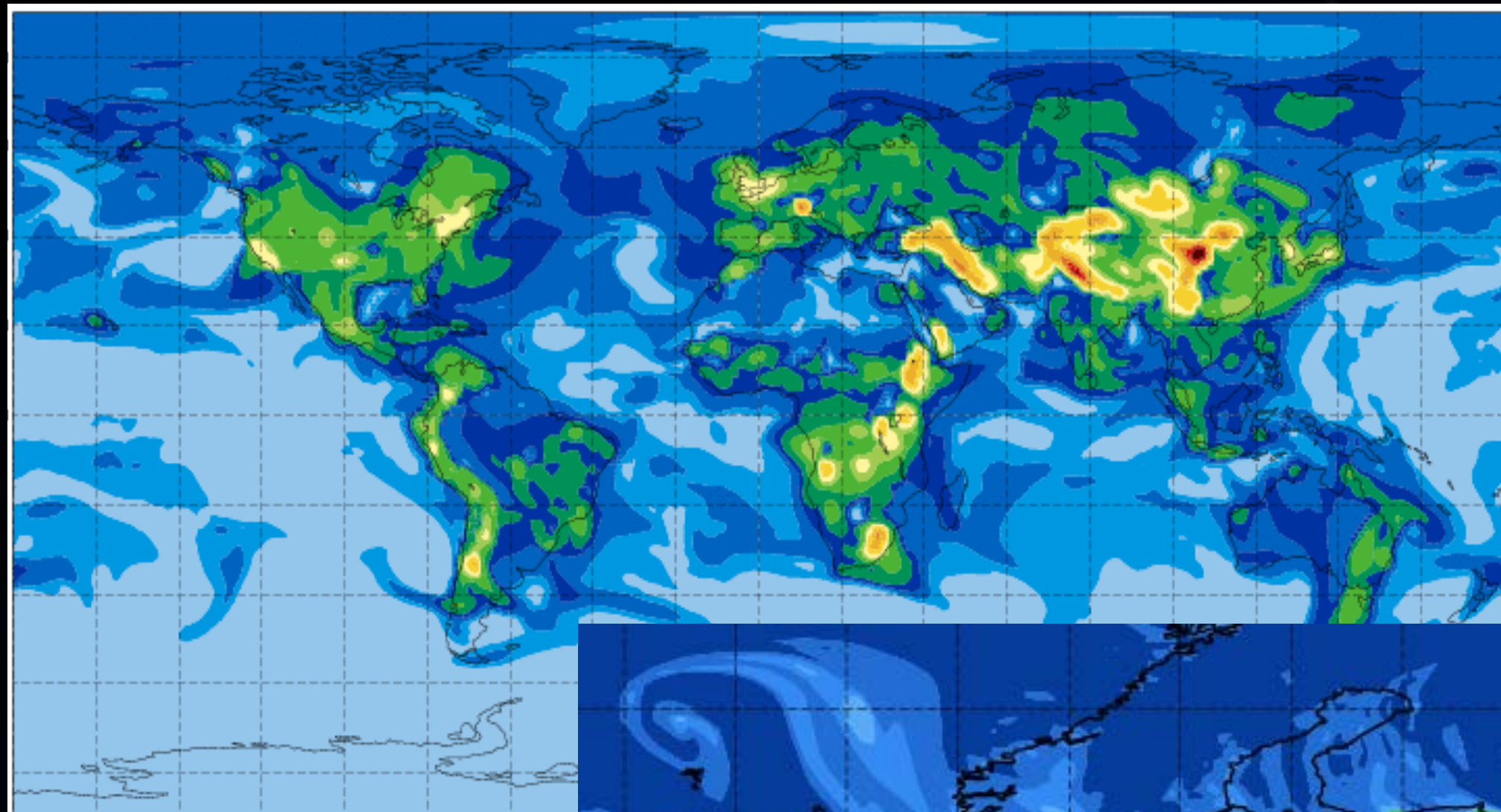
$$N_v^{\text{trop}'} = \frac{M^{\text{trop}}}{M^{\text{trop}'}} N_v^{\text{trop}}$$
$$\mathbf{A}^{\text{trop}'} = \frac{M^{\text{trop}}}{M^{\text{trop}'}} \mathbf{A}^{\text{trop}}$$
$$M^{\text{trop}'} = M^{\text{trop}} \sum_l A_l^{\text{trop}} x'_{m,l} / \sum_l x'_{m,l}$$

All quantities on the left with a prime ' are recomputed using the model NO₂ partial-column profiles $x'_{m,l}$. Other quantities are taken from the S5P_L2_NO2 file.

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

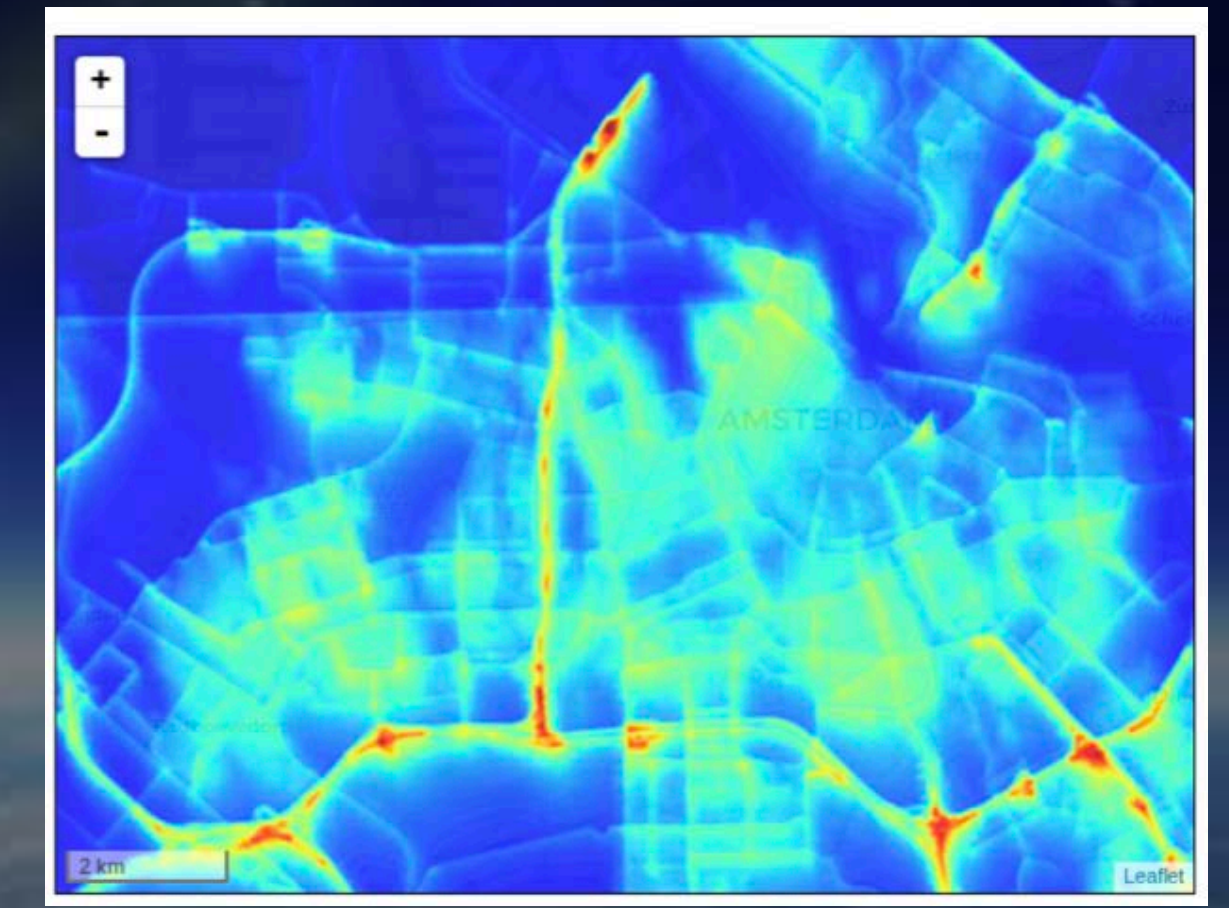
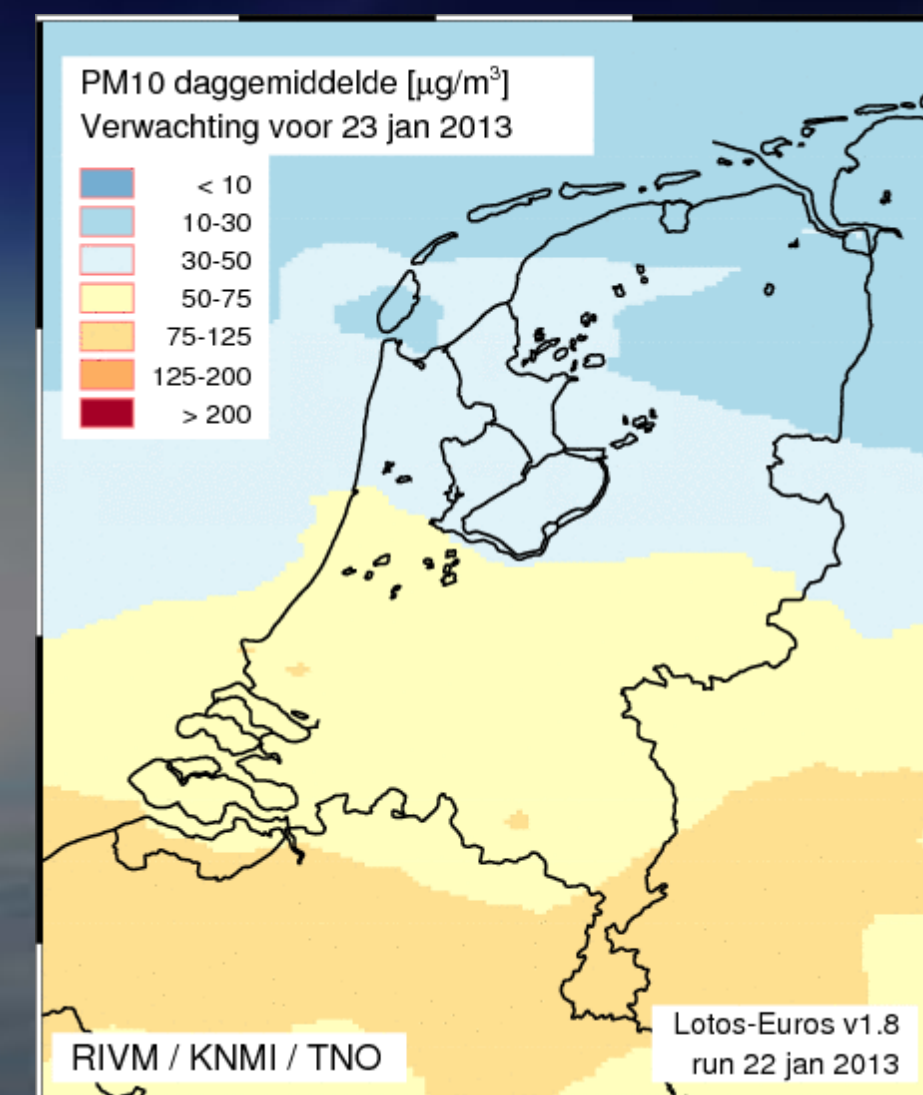


Assimilation
TROPOMI
observations



CAMS-Europe as boundary condition for
countries and city regions

Amsterdam



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

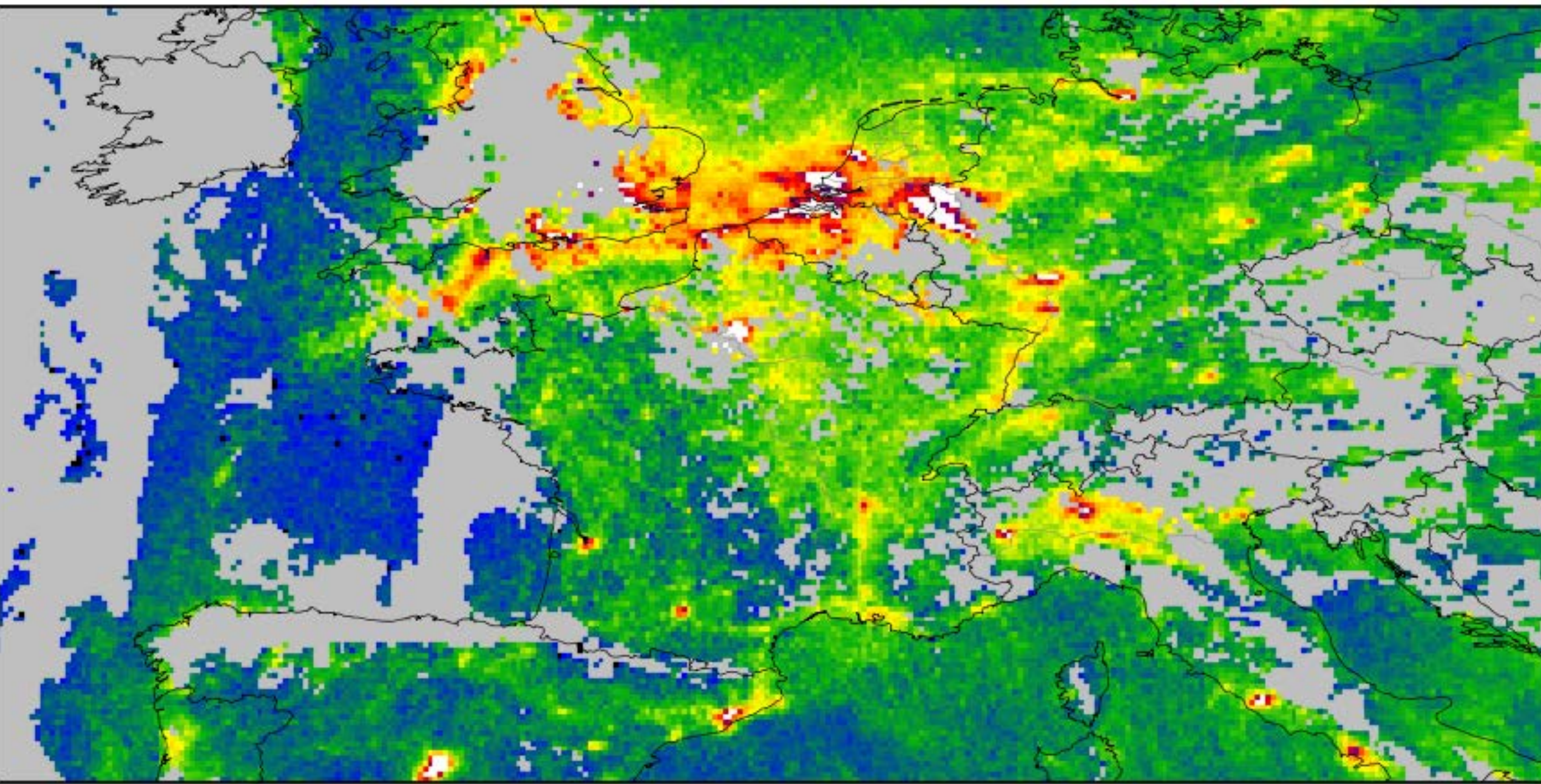
atmosphere.copernicus.eu

Lotos-Euros v1.8
run 22 jan 2013

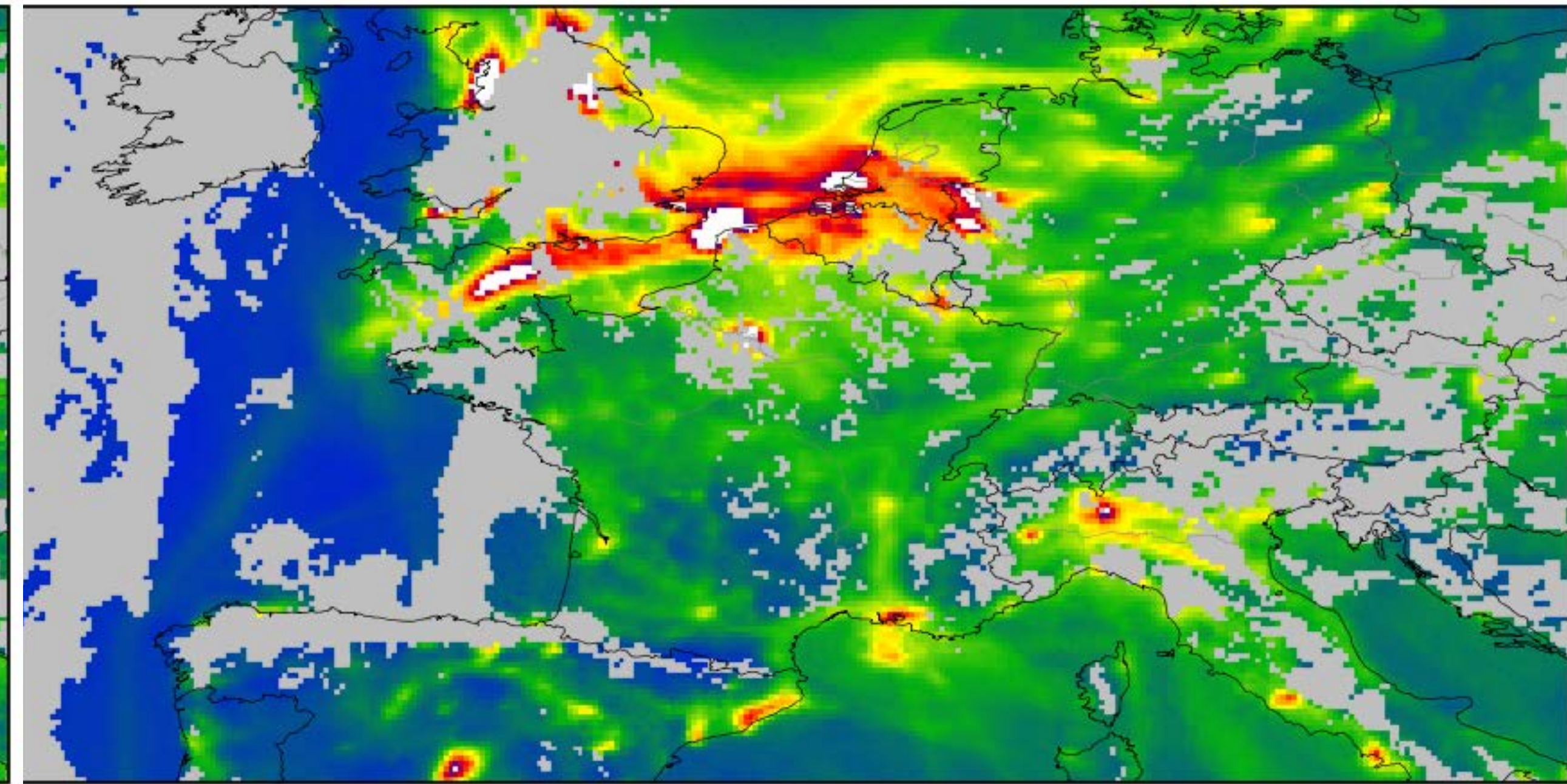
Using a-priori profiles from CAMS-regional AQ forecasts for Europe

TROPOMI NO2 based on CAMS-regional a-priori

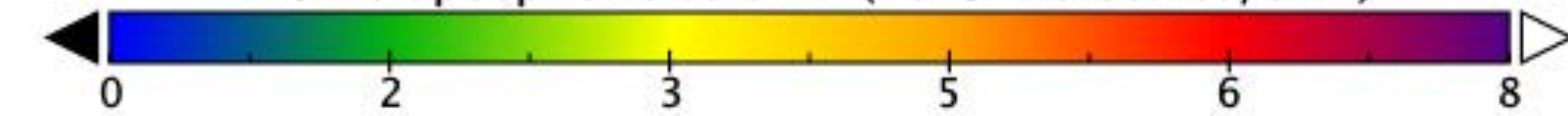
CAMS-regional vertical column NO2



TROPOMI tropospheric vertical column of nitrogen dioxide using CAMS a-priori profile (10^{15} molecules/c...



NO2 tropospheric column ($1e15$ molecules/cm²)

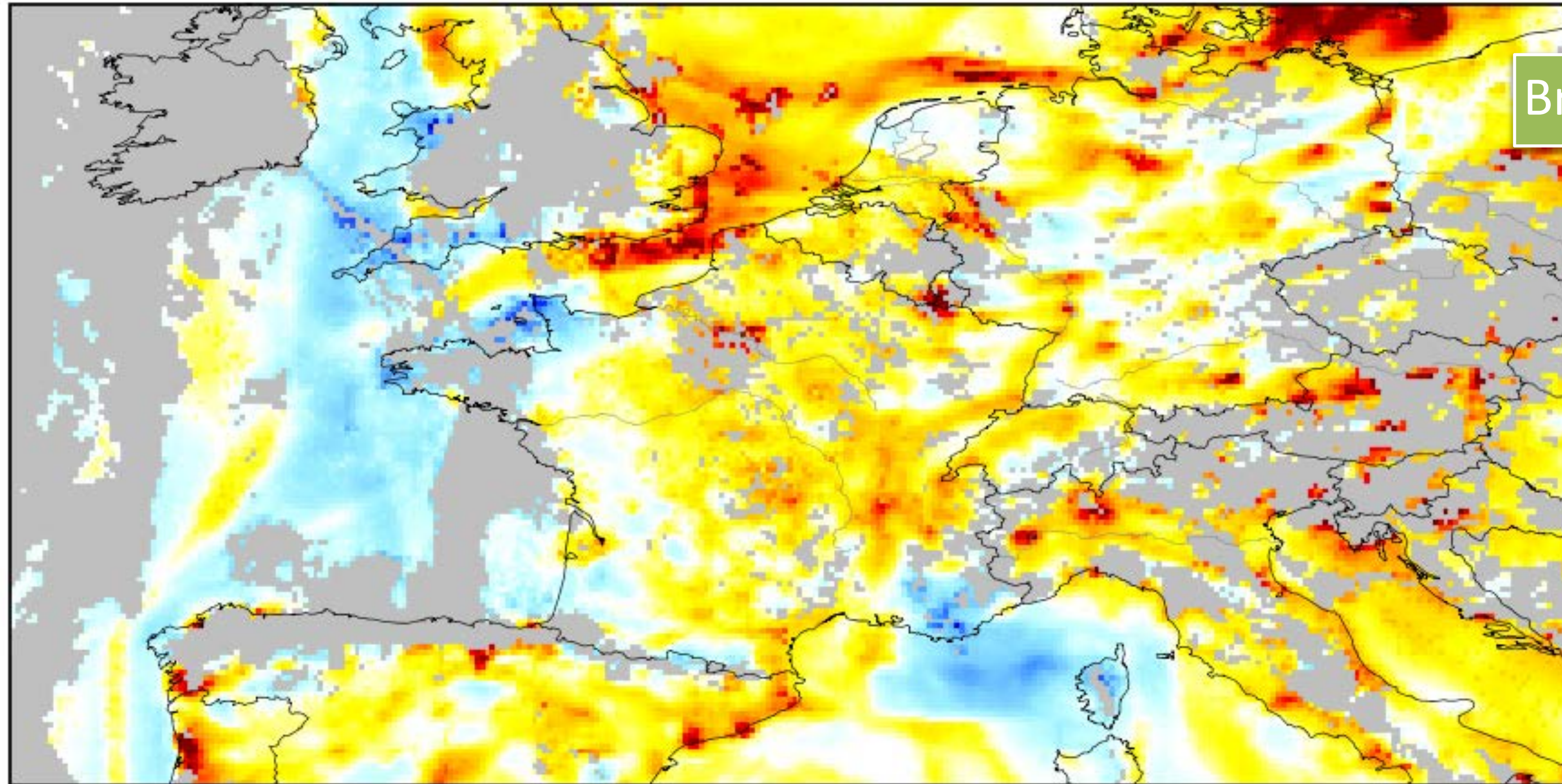


Single overpass, 26 July 2018

John Douros, KNMI

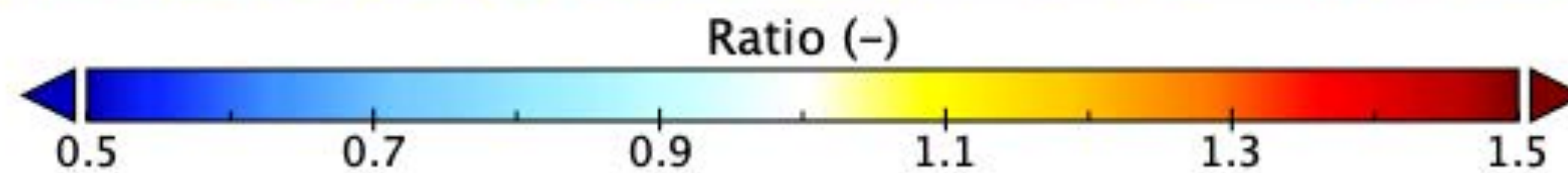
Using a-priori profiles from CAMS-regional AQ forecasts for Europe

Ratio NO₂ tropospheric column CAMS a-priori / TM5MP a-priori



Bridge the gap with MAXDOAS

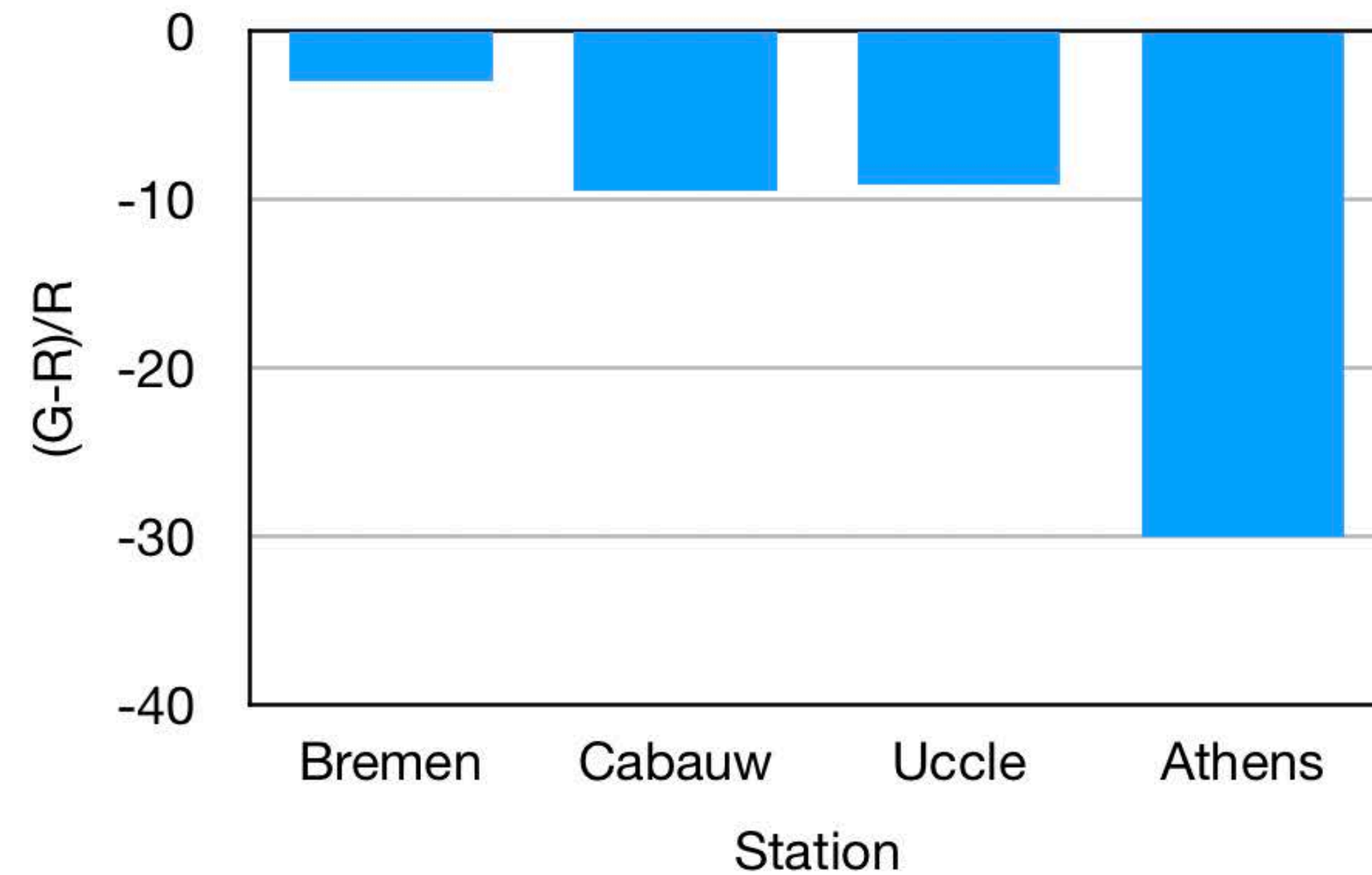
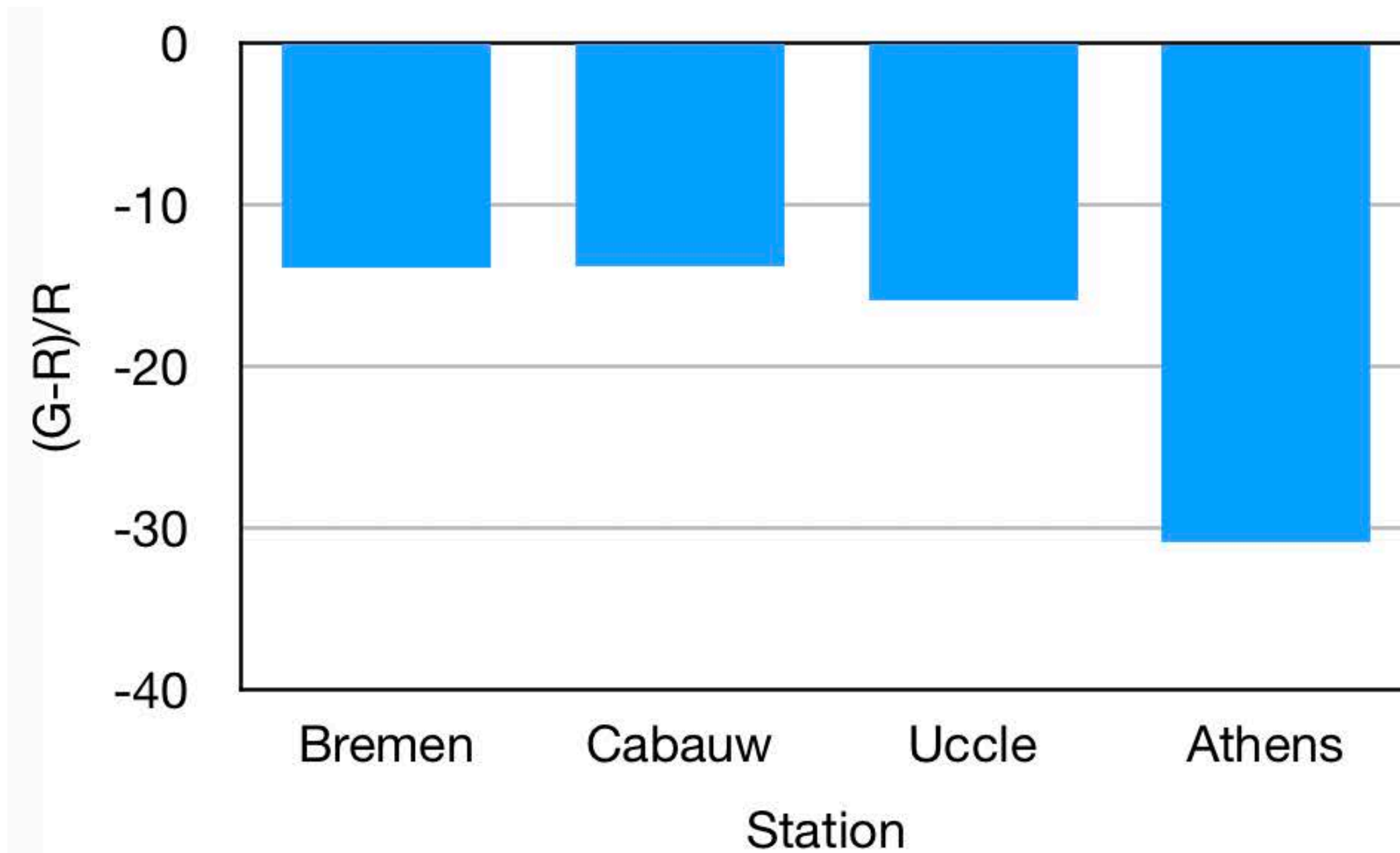
Tropospheric column increases by 10-50% over hotspots when using high-resolution regional model a-priori profiles
1x1 degree ->
0.1x0.1 degree



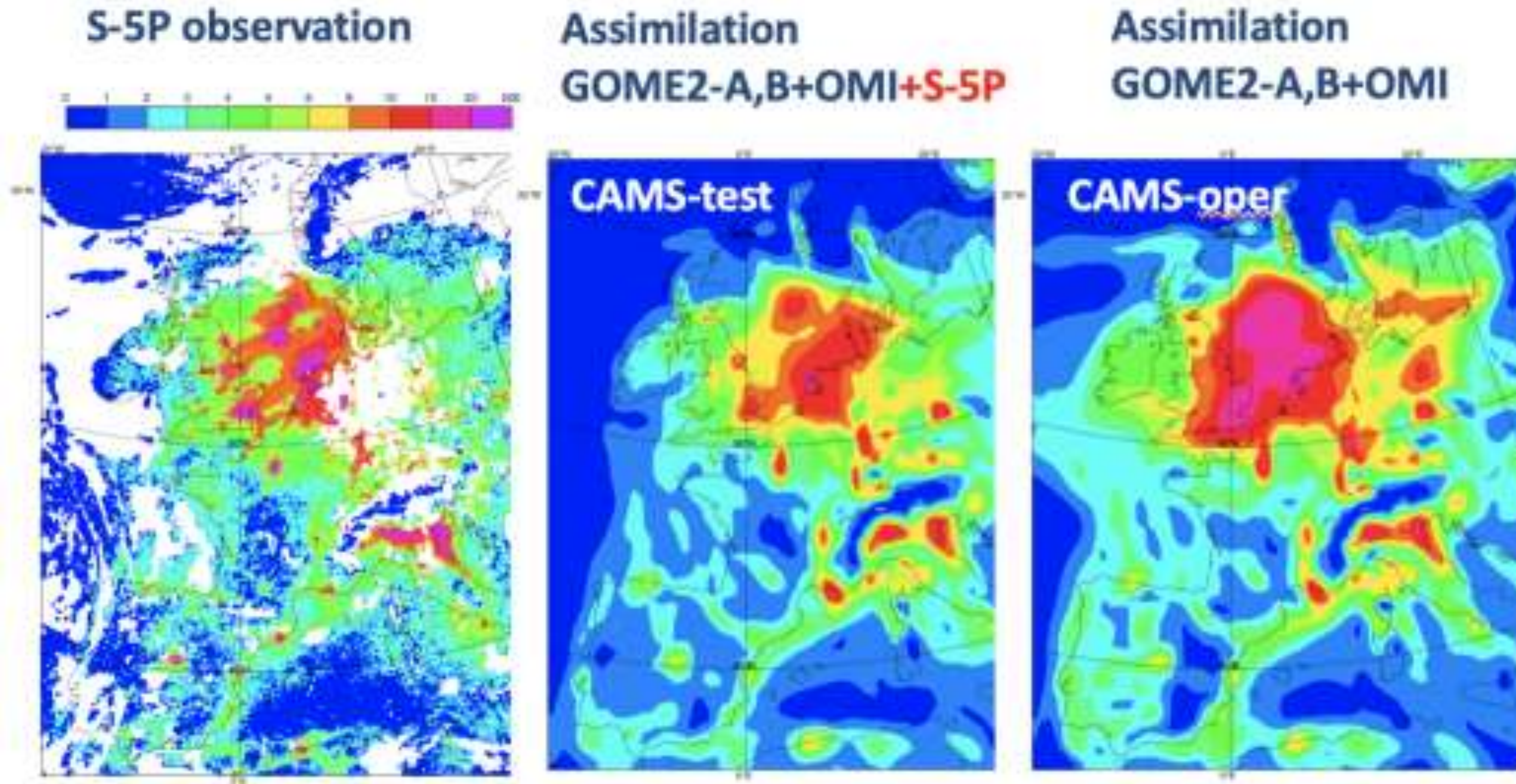
Using a-priori profiles from CAMS-regional AQ forecasts for Europe

Ratio of retrievals @ MAX-DOAS stations, performed with:

- TM5-MP at a resolution of about 100x100 km
- CAMS-regional (European domain), resolution 10x10 km



Assimilation of TROPOMI NO2 with CAMS - example



CAMS global
based on ECMWF-IFS:
assimilation of
TROPOMI NO2
(27/02/2019)

A. Inness, ECMWF

TROPOMI Conclusions

- A game changer in spatial resolution and signal-to-noise!
- NO₂ reprocessing (RPRO) for 30 April - October 2018 (v1.2) available together with v1.2/v1.3/v1.4 OFFL (1.5 year of data)
- Data product includes inputs and intermediate results, provides full traceability
- August 2019: Move to smaller pixels (5.5 x 3.5 km nadir)
- Troposphere: MAX-DOAS indicates NO₂ low bias of about 30%
 - > Resolution of the a-priori main source of uncertainty:
 need for high-resolution regional AQ model profiles
 - > Sensitivity to cloud pressure (ongoing research)
- **Keep tuned for new TROPOMI updates with new version of NO₂ and Level 1 data mid-to-end 2020**
- **TROPOMI data will be increasingly in CAMS global models**

www.tropomi.eu

www.temis.nl

sentinels.copernicus.eu

[#tropomi, @tropomi](#)

EXTRA SLIDES

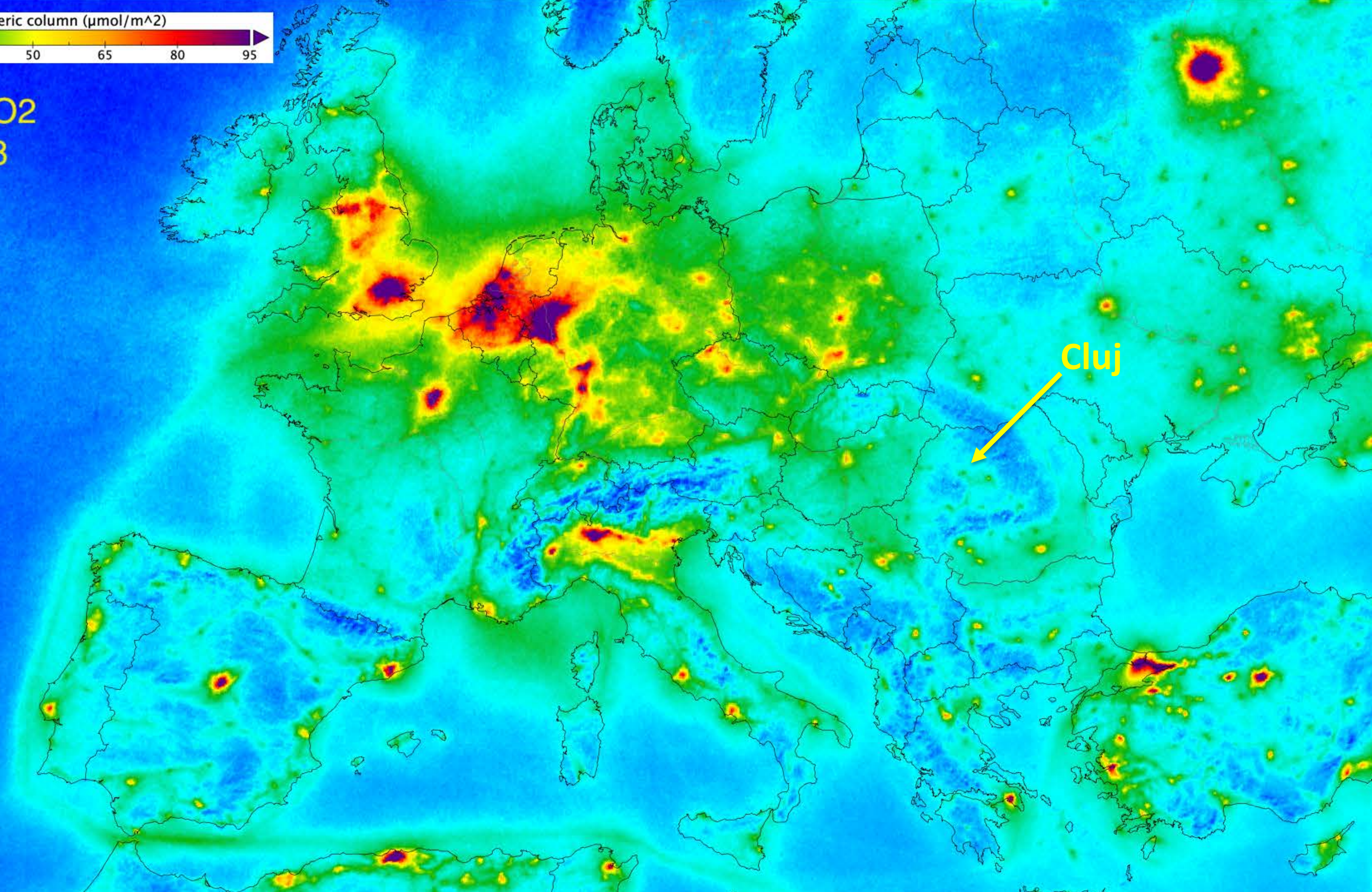
SENTINEL 5 PRECURSOR	
Launch	13 October 2017
Launcher	Rockot from Plesetsk Russia
Orbit	Polar Sun synchronous, altitude 824 km
Overpass time	13:30 local time
Mission duration	7 year
Satellite	Airbus Astrobuss-M, height 3,55 m, 5,63 m diameter, mass 820 kg
Payload	Tropospheric Monitoring Instrument (TROPOMI)
Ground stations	Svalbard (Norway), Inuvik (Canada) and Kiruna (Sweden)
Data processing	DLR Oberpfaffenhofen (Germany) KNMI De Bilt, The Netherlands



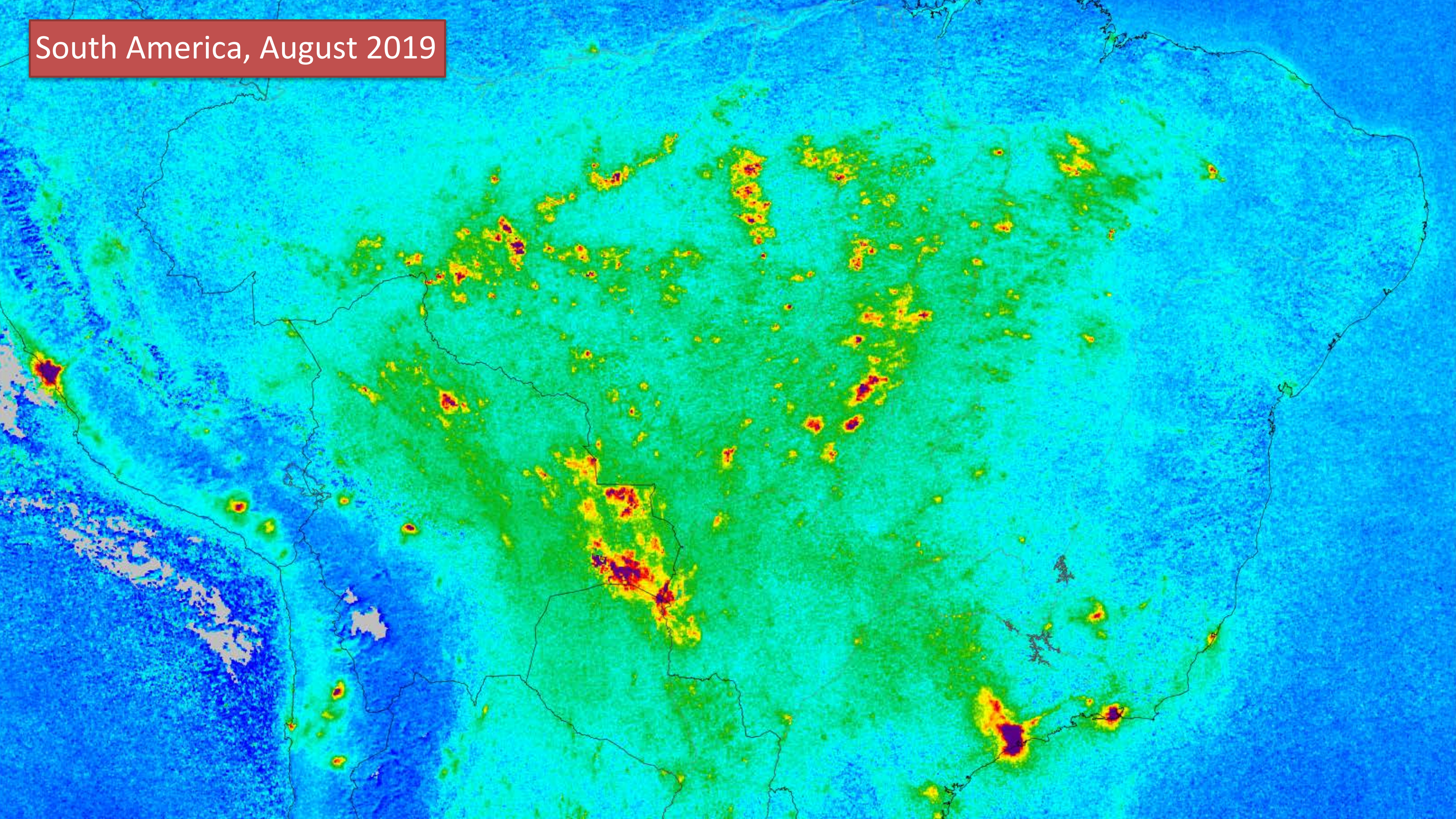
NO2 tropospheric column ($\mu\text{mol}/\text{m}^2$)

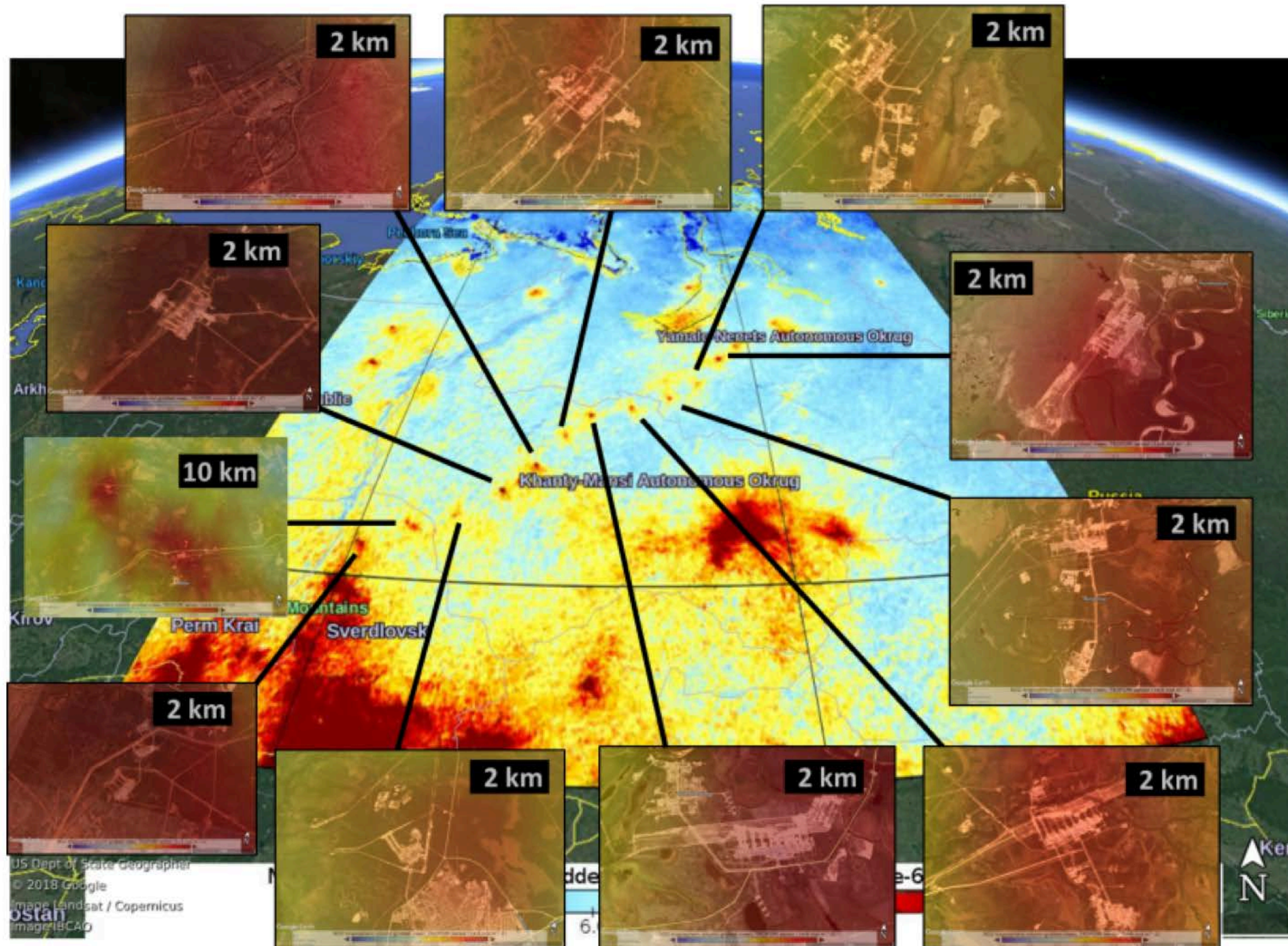
5 20 35 50 65 80 95

TROPOMI NO2
Apr-Sep 2018

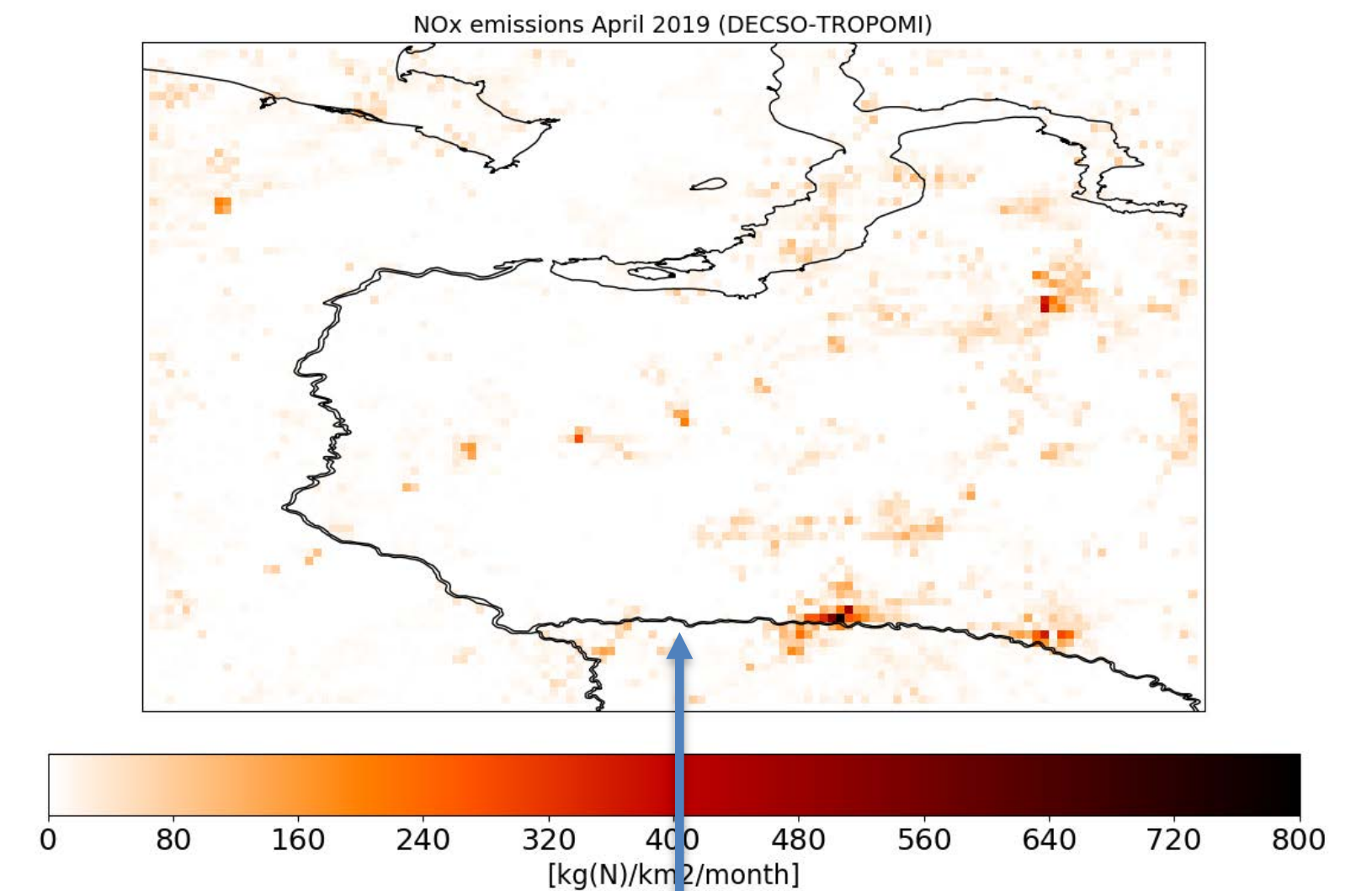


South America, August 2019

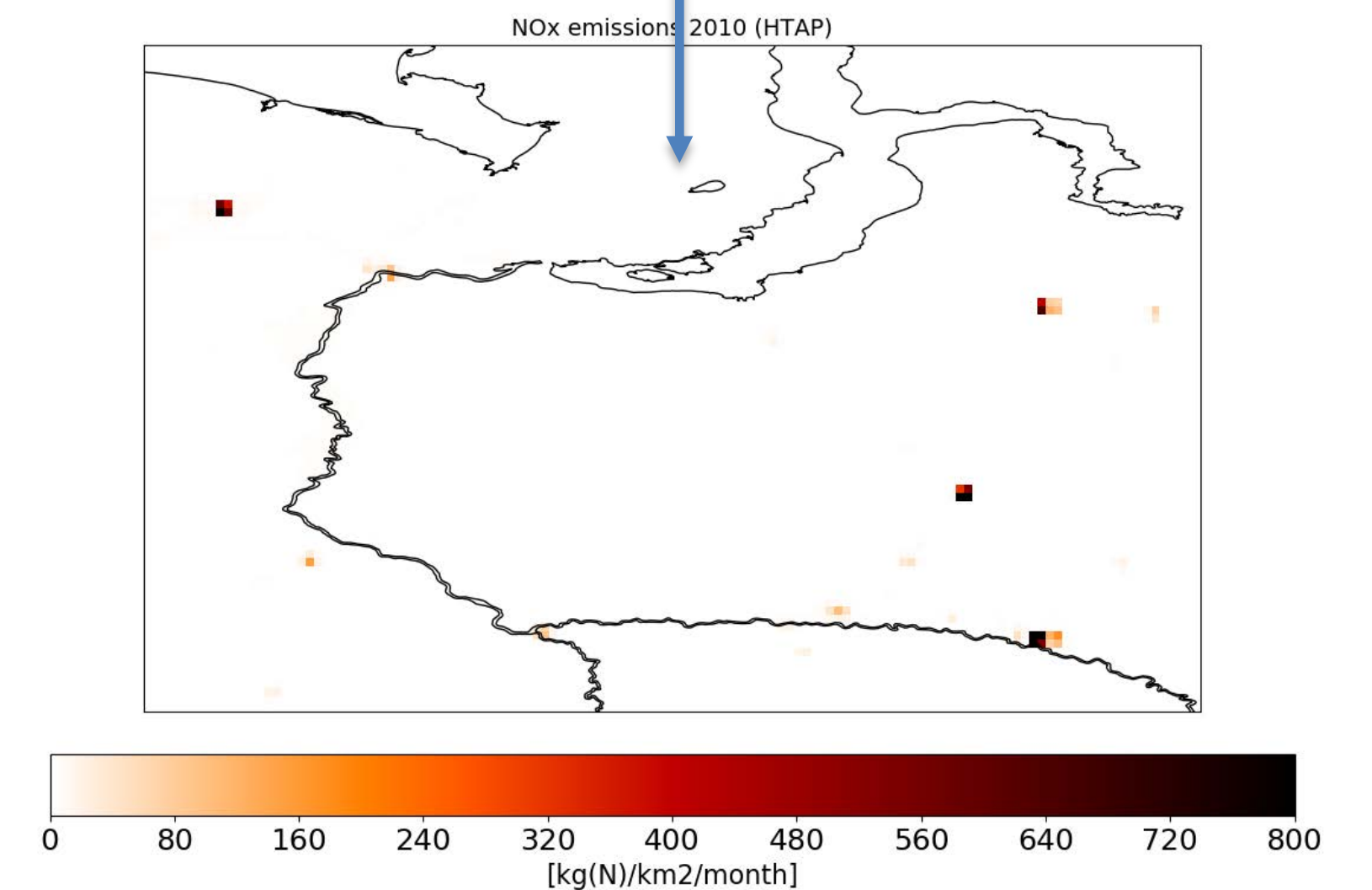




string of gas compressor stations along natural gas pipeline every ≈ 100 km



TROPOMI NO_2 emission inversion (DECSO) for April 2019 compared with bottom up emission inventory (HTAP/EDGAR)



NO2: upgrades and reprocessing

◆ 4 July 2018: v1.0 public release (NRT + OFFL)

◆ 24 October 2018: v1.2 release

~~Reprocessing v1.2.2 (March 2019)~~

◆ 27 March 2019: v1.3 release

◆ 6 Aug 2019: small pixels

→ Phase E2 (Data available from 30 April 2018)

Jan 2018 Mar 2018 May 2018 Jul 2018 Sep 2018 Nov 2018 Jan 2019 Mar 2019 May 2019 Jul 2019 Sep 2019 Nov 2019

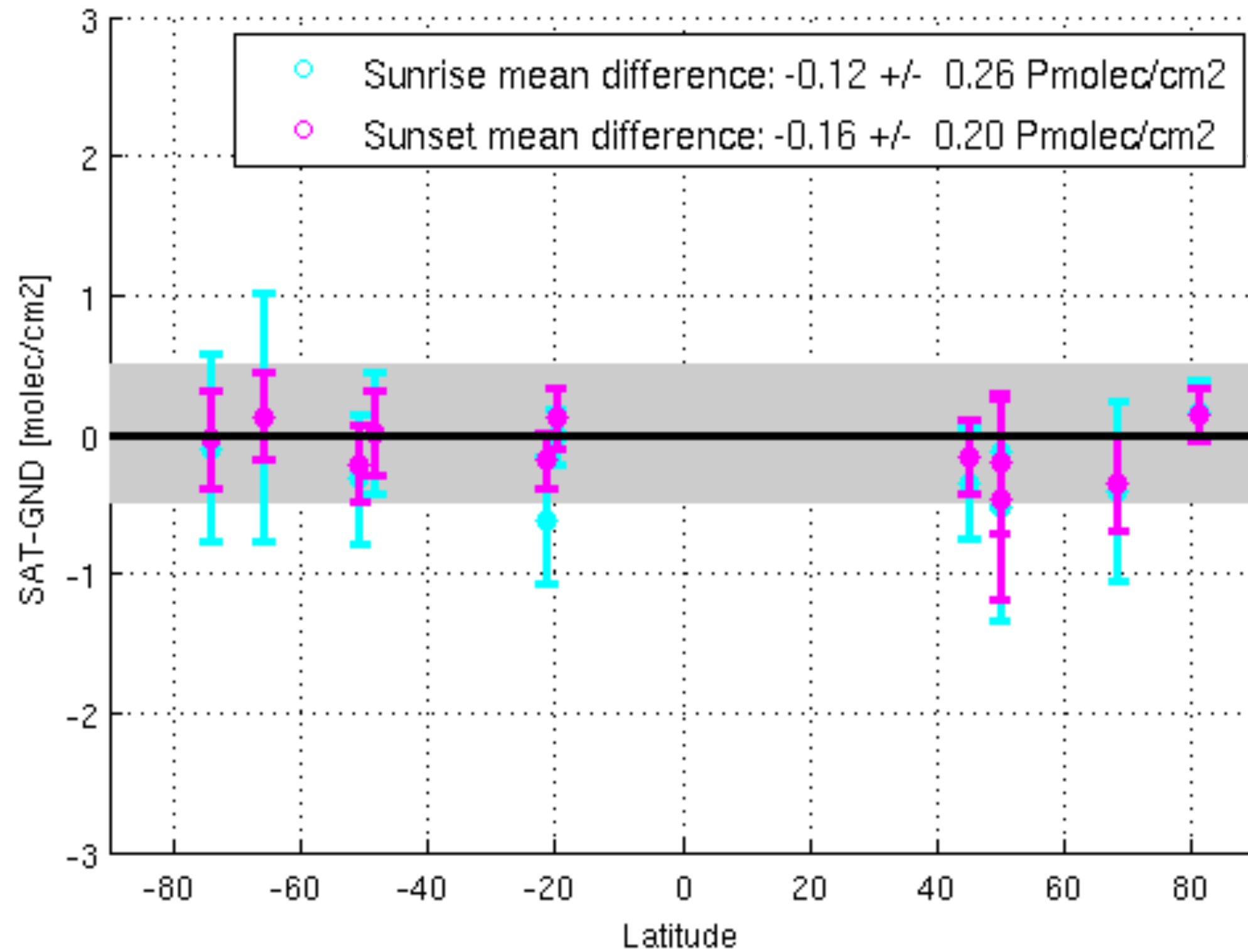
Each of these releases accompanied with documentation updates:

- **ReadMe (PRF)**
- **Product User Manual (PUM)**
- **Algorithm description (ATBD)**

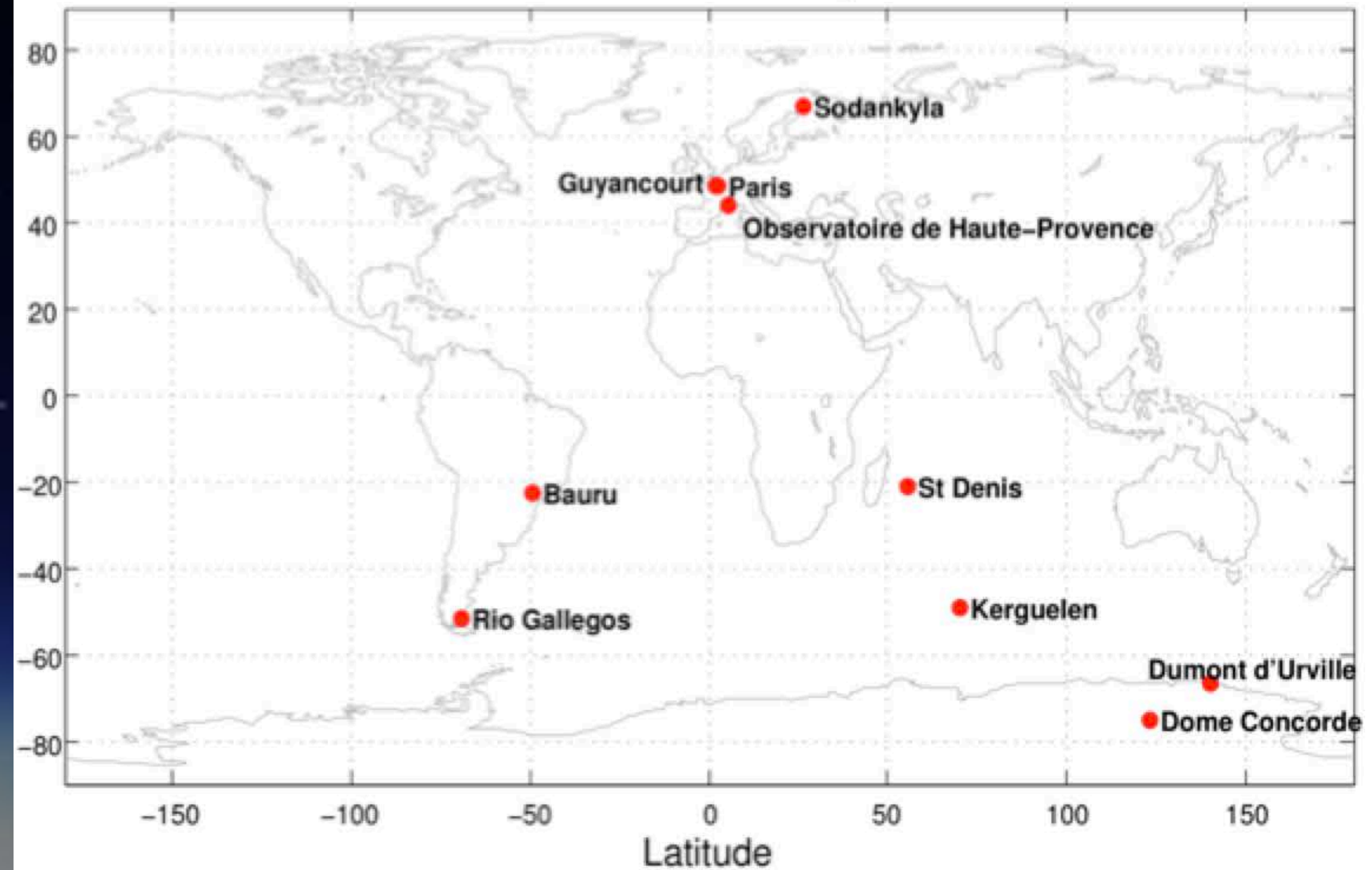
S5P MPC: TROPOMI vs SAOZ

S5p stratospheric NO₂ (OFFL Phase E2 up to 1 April 2019) vs.

NDACC SAOZ (LATMOS_RT) measurements



NDACC SAOZ stations with S5p co-locations



Steven Compernelle, Tijn Verhoelst, Gaia Pinardi, José Granville, Jean-Christopher Lambert (BIRA-IASB), Kai-Uwe Eichmann (IUP-B)