PROGRAMME OF THE EUROPEAN UNION

Copernicus Europe's eyes on Earth

co-funded with esa EUMETSAT Atmosphere Monitoring ECMWF

Satellite observations, ground-based measurements, modelling simulations and everything in between.

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Fifth Joint School on Atmospheric Composition

September 14 – 29, 2023

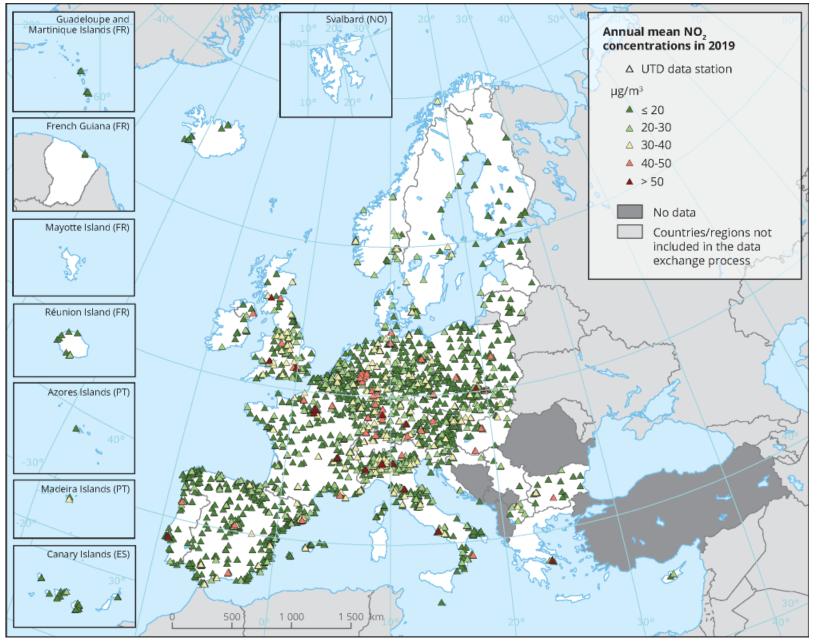
The future of space-based remote sensing

- **Urban air quality**: how satellite observations, ground-based measurements and CTM simulations each provide their unique individual picture.
- **Using satellite data to sense abrupt changes:** how satellite observations can detect anomalous air quality levels
- **Using satellite data to create new data**: how satellite observations, using mathematical formalisms and CTM simulations, can provide novel air quality datasets.
- **Using satellite data to update emission inventories**: the way to the future, the direct application of space-born observations to emission monitoring.

Why are we even interested?

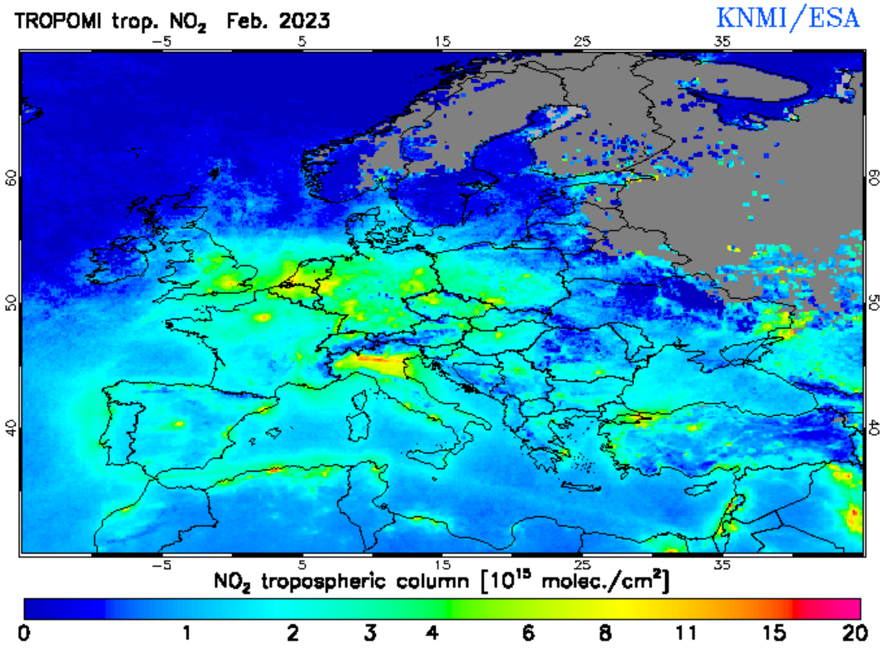
NO_2 plays a significant role in the atmospheric chemistry and causes severe health and environmental effects

Tools: in-situ (and ground-based) measurements, satellite observations and model simulations

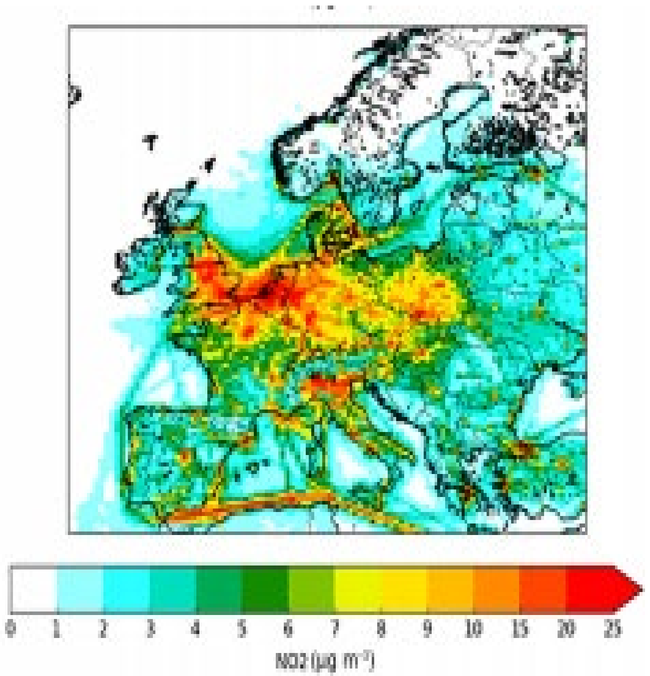


Reference data: ©ESRI | ©EuroGeographics

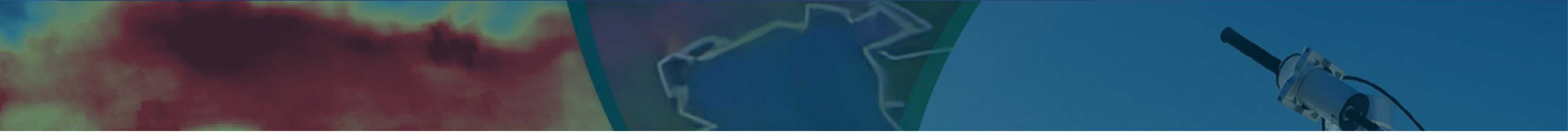
https://www.eea.europa.eu/data-and-maps/figures/annual-mean-no2-concentrations



http://www.temis.nl/



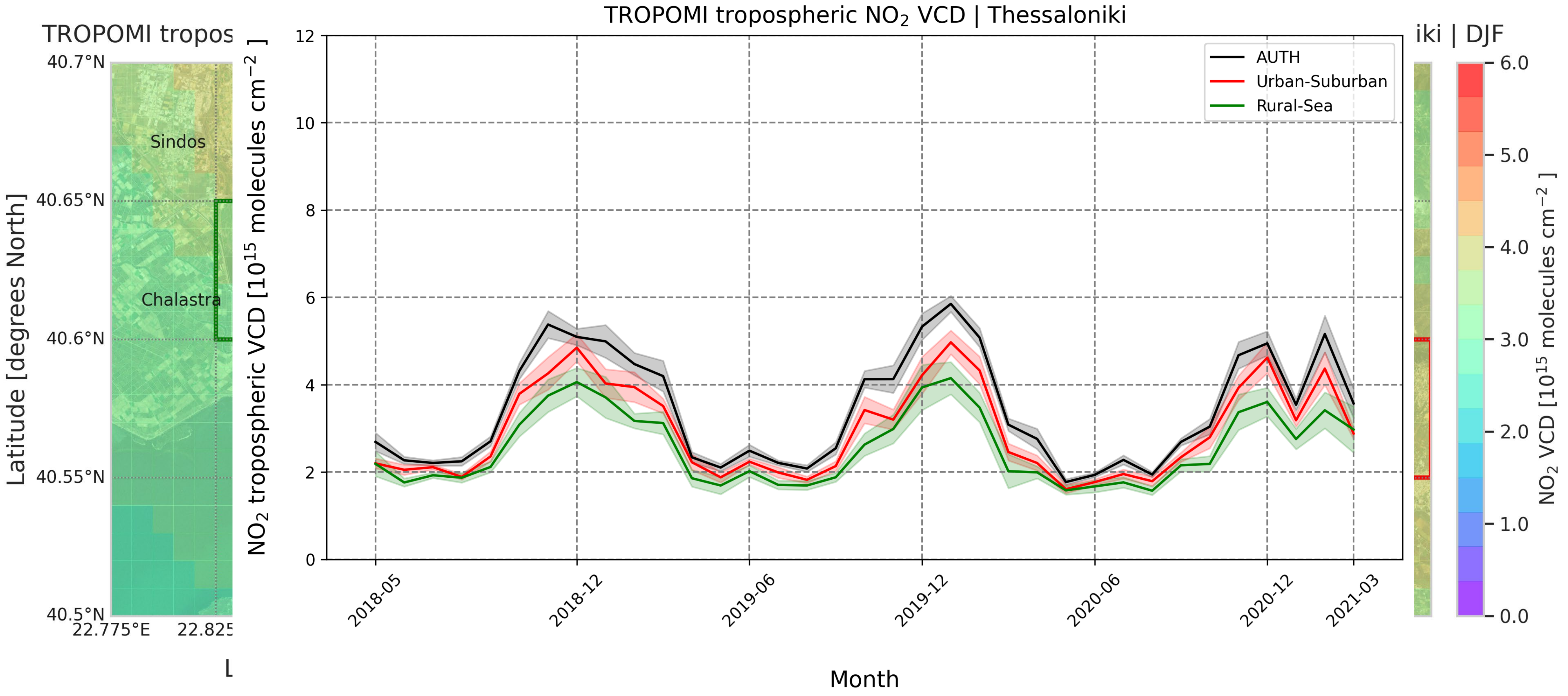
https://gmd.copernicus.org/articles/10/4145/2017/



Urban air quality

Koukouli M-E, Pseftogkas A, Karagkiozidis D, Skoulidou I, Drosoglou T, Balis D, Bais A, Melas D, Hatzianastassiou N. **Air Quality in Two Northern Greek Cities Revealed by Their Tropospheric NO_2 Levels**. *Atmosphere*. 2022; 13(5):840. https://doi.org/10.3390/atmos13050840

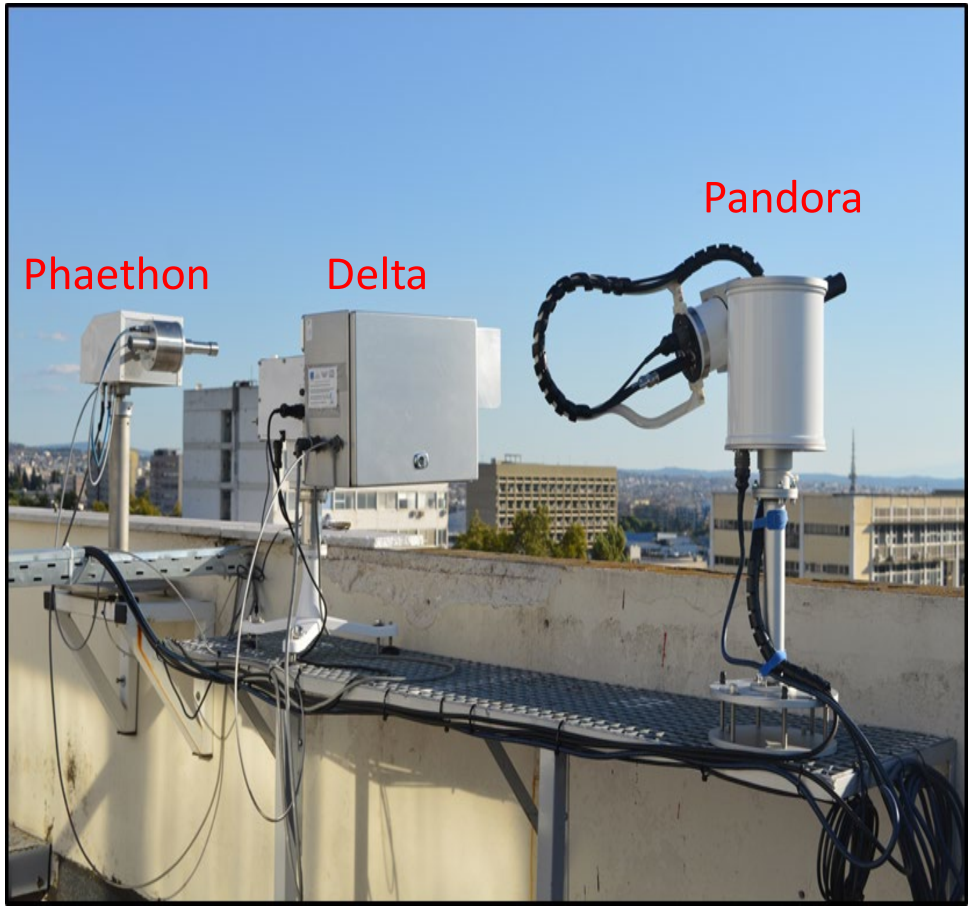
Spatial observations of tropospheric NO_2



MAX-DOAS & DOAS observational systems

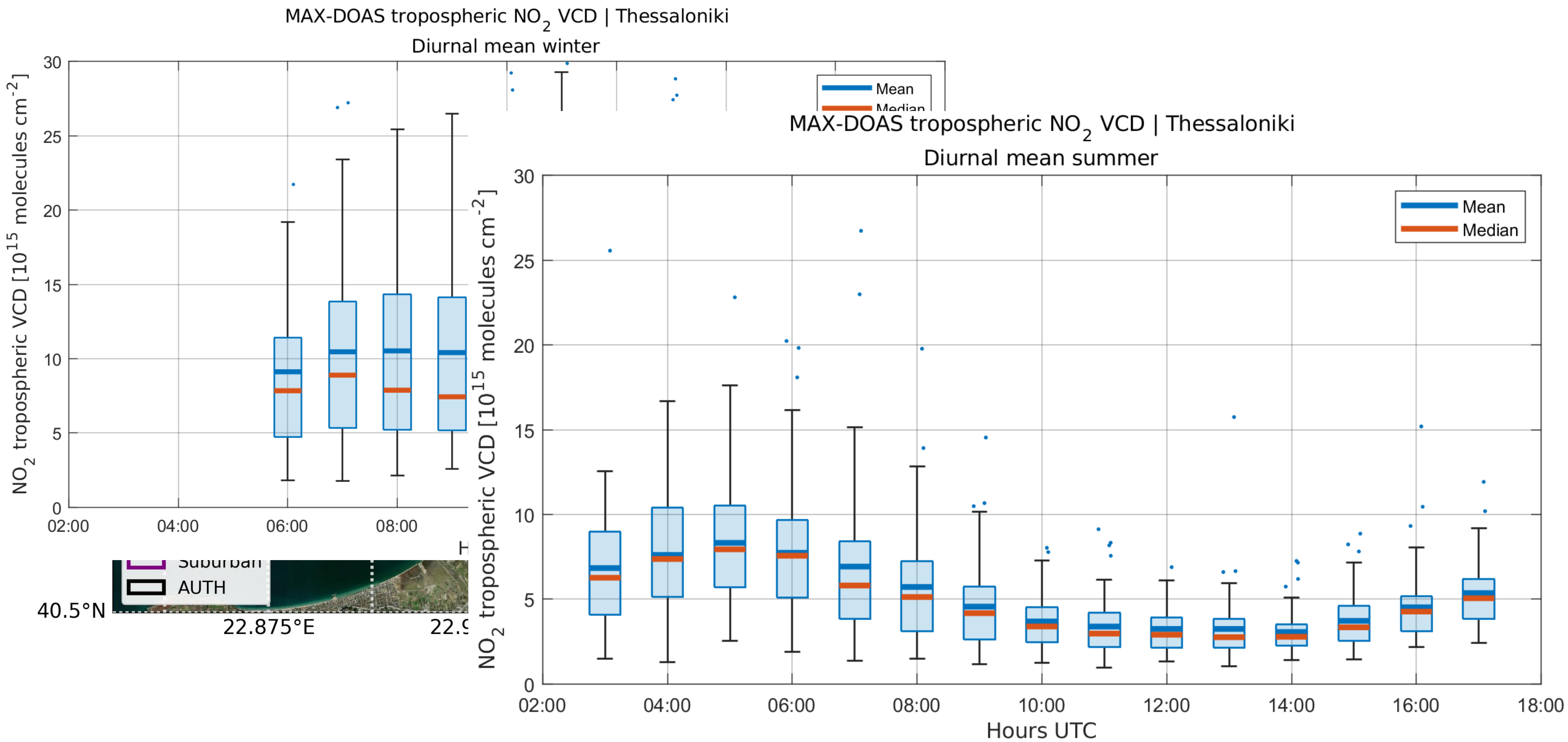
Instruments:
- **Phaethon** (home made – since 2006)
- **Delta** (research grade – since 2022)
- **Pandora** (Pandonia network) – since 2022)

Measurements:
- Direct-sun/sky-radiance spectra (UV / VIS ranges)
- 2-axis trackers (3D observations elevation/azimuth)
- CCD-based spectrographs



Products:
- Total and tropospheric columns
- Vertical profiles – surface concentrations
- Species NO_2, O_3, HCHO, SO_2
- O_4 – proxy for aerosol extinction profiles & optical depth

Temporal variations of tropospheric NO_2



The LOTOS-EUROS model and input data

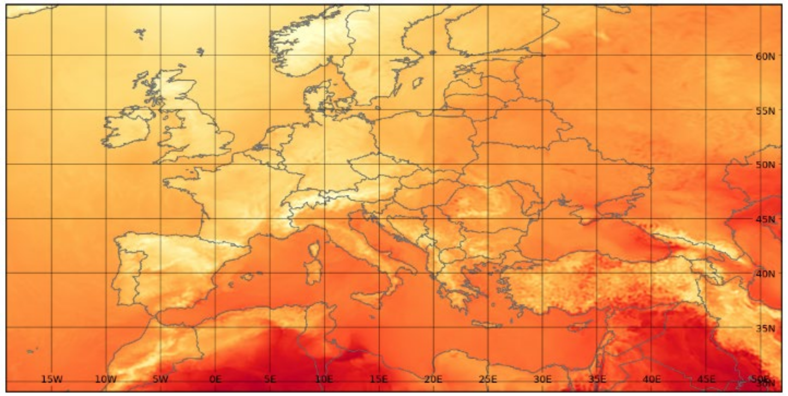
Input data

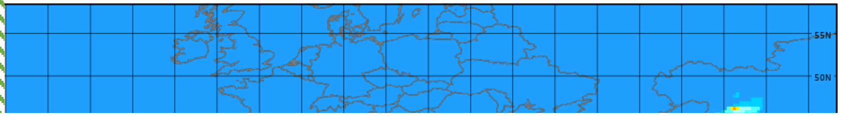
- **Meteorology**
- **Boundary and Initial conditions**
- **Land use**
- **Emissions**

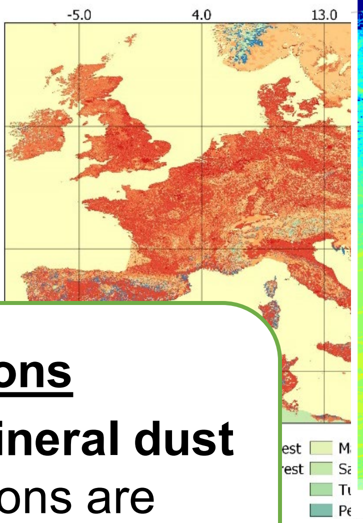
<u>**Biomass burning and wildfires**</u>

The Global Fire Assimilation System v1.2 (GFAS) is used

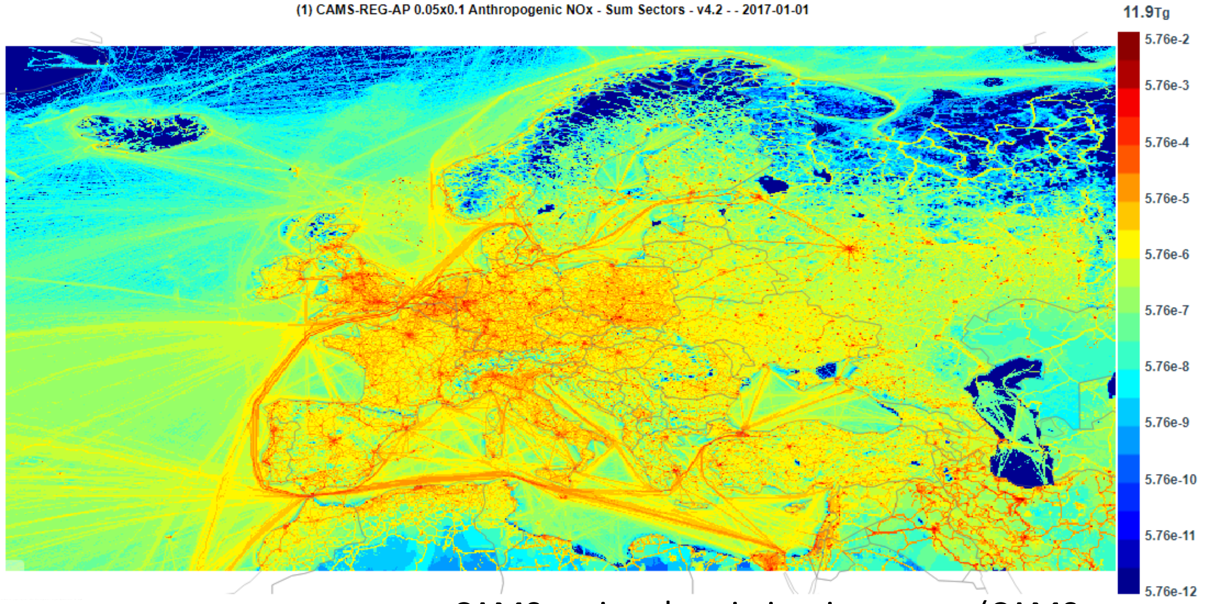
turbulence)
Emissions







(https://land.copernicus.eu/)



CAMS regional emission inventory (CAMS-REG) (Kuenen et al., 2022)

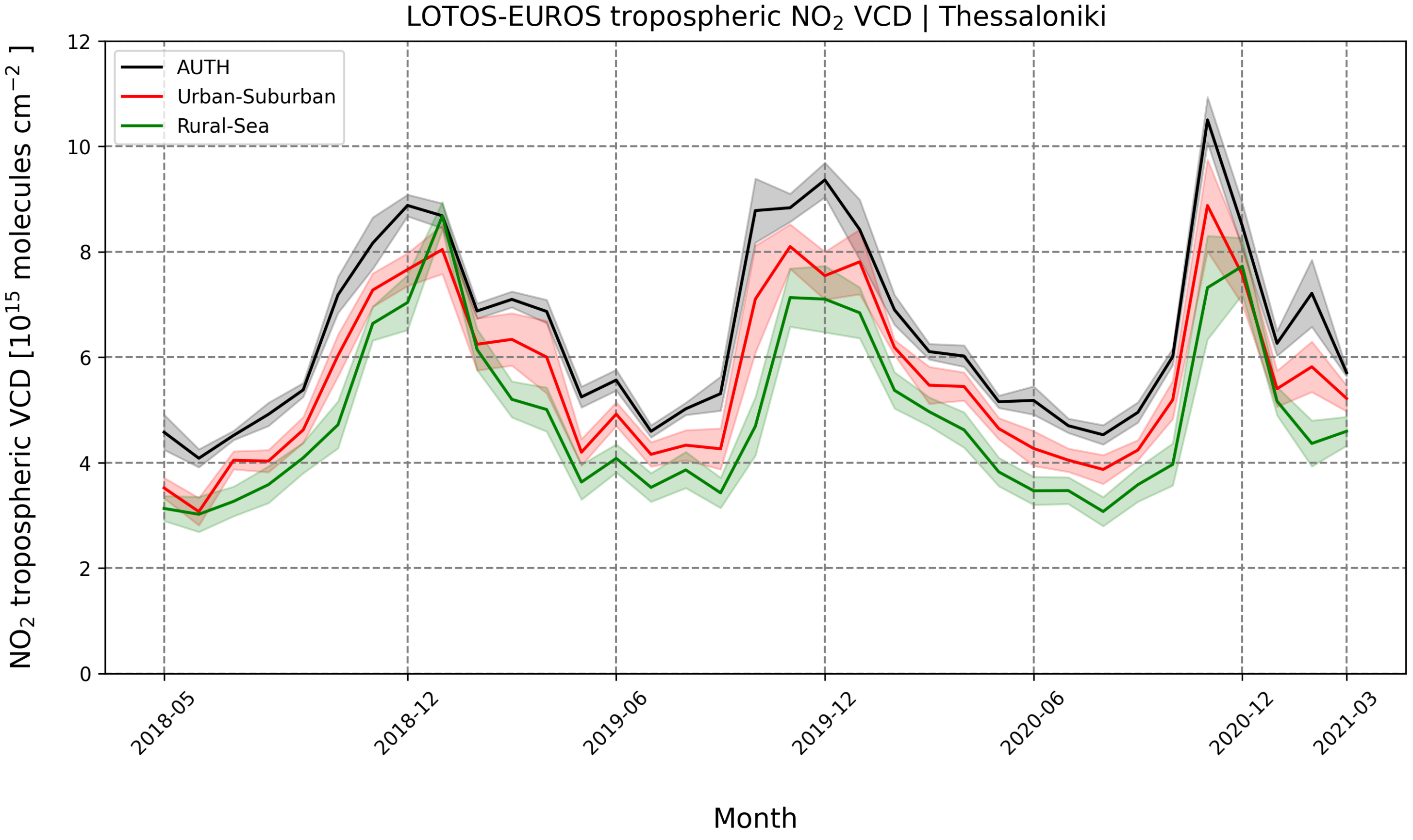
<u>**Natural emissions**</u>

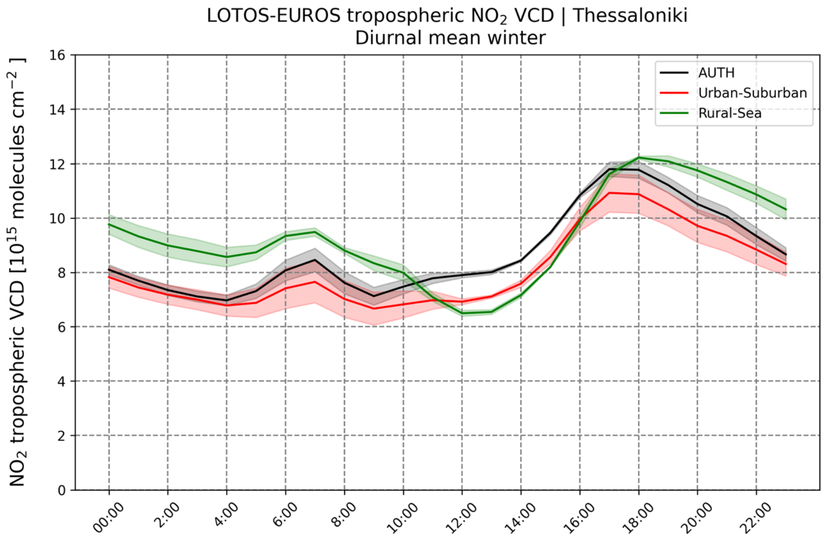
Biogenic, **soil NOx**, **mineral dust** and **sea salt** emissions are calculated **on-line** using meteorological variables

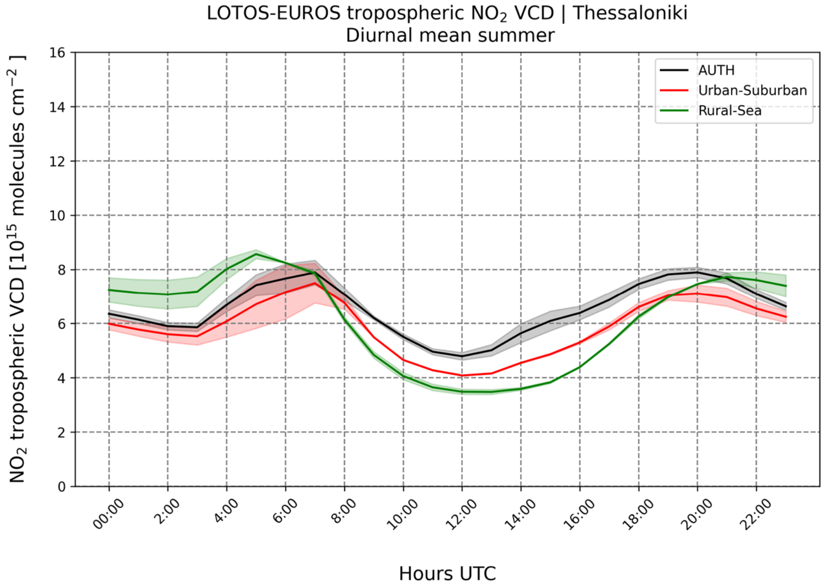
https://airqualitymodeling.tno.nl/lotos-euros/

TNO innovation for life

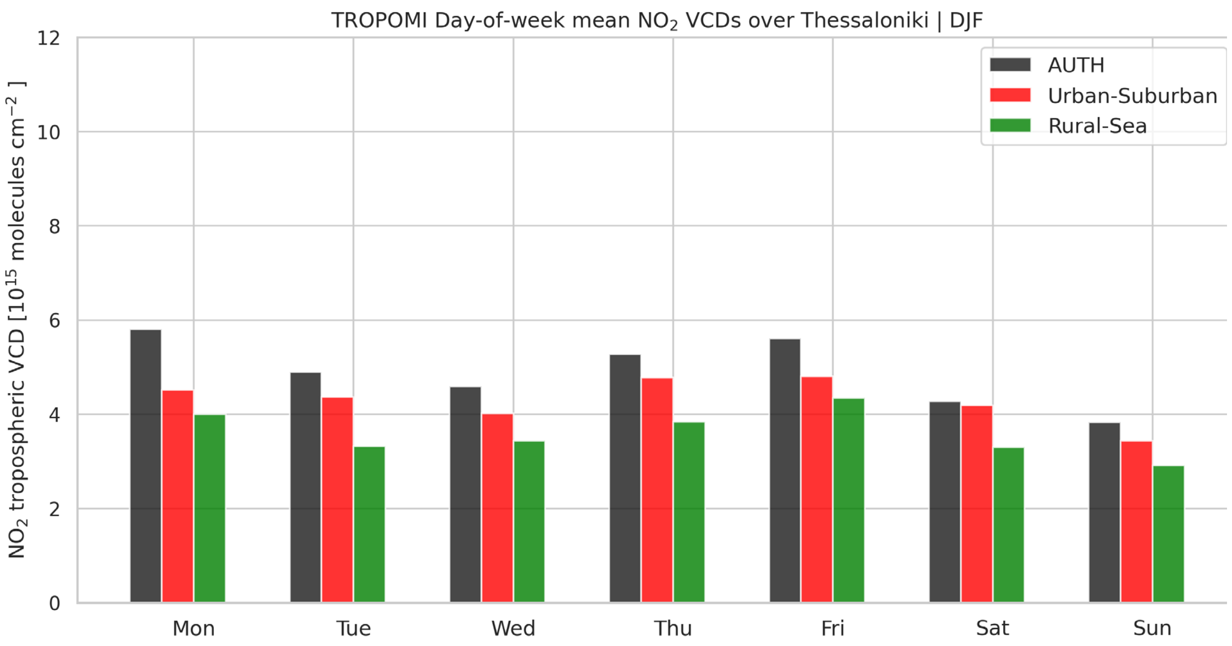
Spatio-Temporal variations of tropospheric NO_2

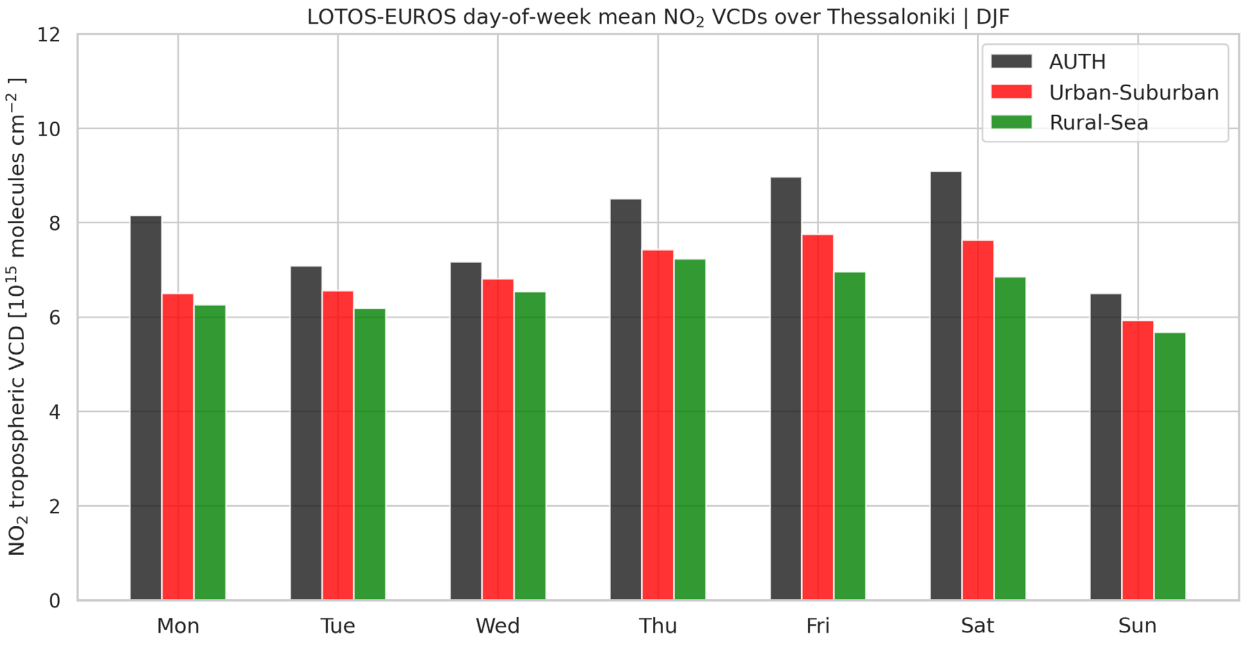


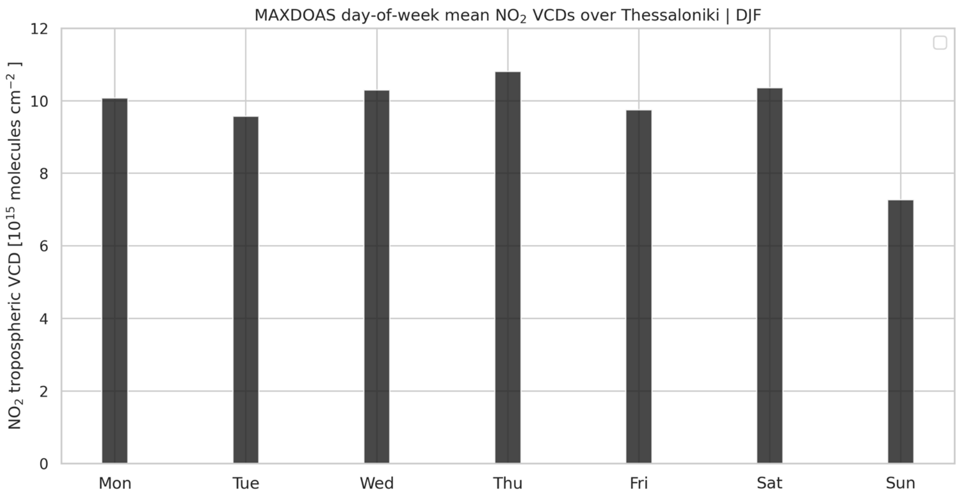




Day-of-week variations of tropospheric NO_2







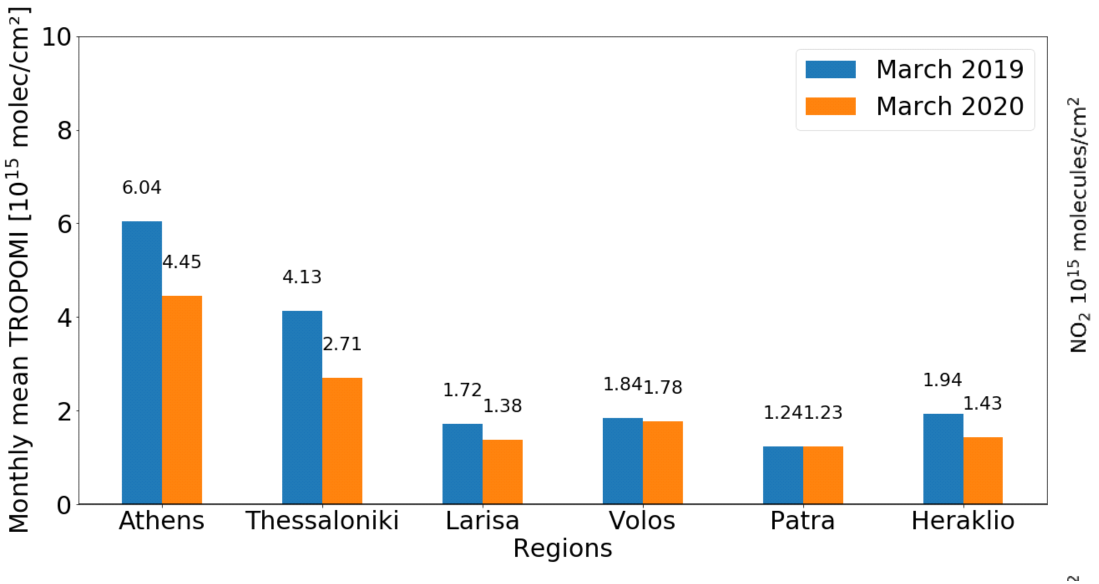
Dataset	Temporal Resolution	Spatial Resolution	Strong Points	Limitations
TROPOMI/S5P	Once per day	3.5 × 5.5 km pixel	High spatial coverage	Temporal coverage
MAX-DOAS	Every 15 m in daylight	Point location, ~15 km horizontal viewing	High temporal coverage	Spatial coverage
LOTOS-EUROS CTM	Every 1 h	Depending on input parameters	High spatiotemporal coverage	Input information

Using satellite data to sense abrupt changes in air quality

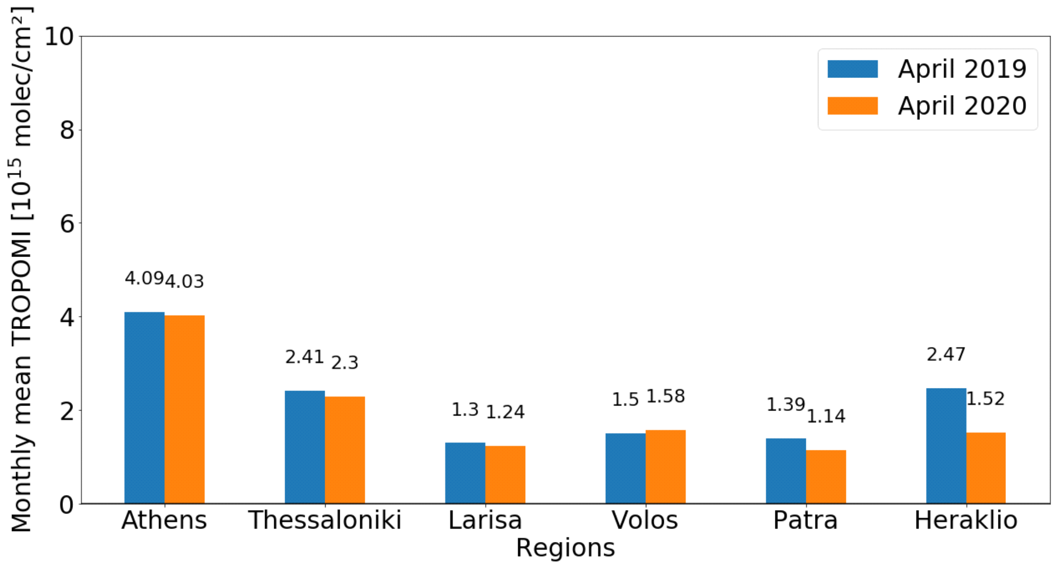
Koukouli, M.-E., Skoulidou, I., Karavias, A., Parcharidis, I., Balis, D., Manders, A., Segers, A., Eskes, H., and van Geffen, J.: **Sudden changes in nitrogen dioxide emissions over Greece due to lockdown after the outbreak of COVID-19**, Atmos. Chem. Phys., 21, 1759–1774, https://doi.org/10.5194/acp-21-1759-2021, 2021.

S5P/TROPOMI Tropospheric NO_2 monthly fields

March



April

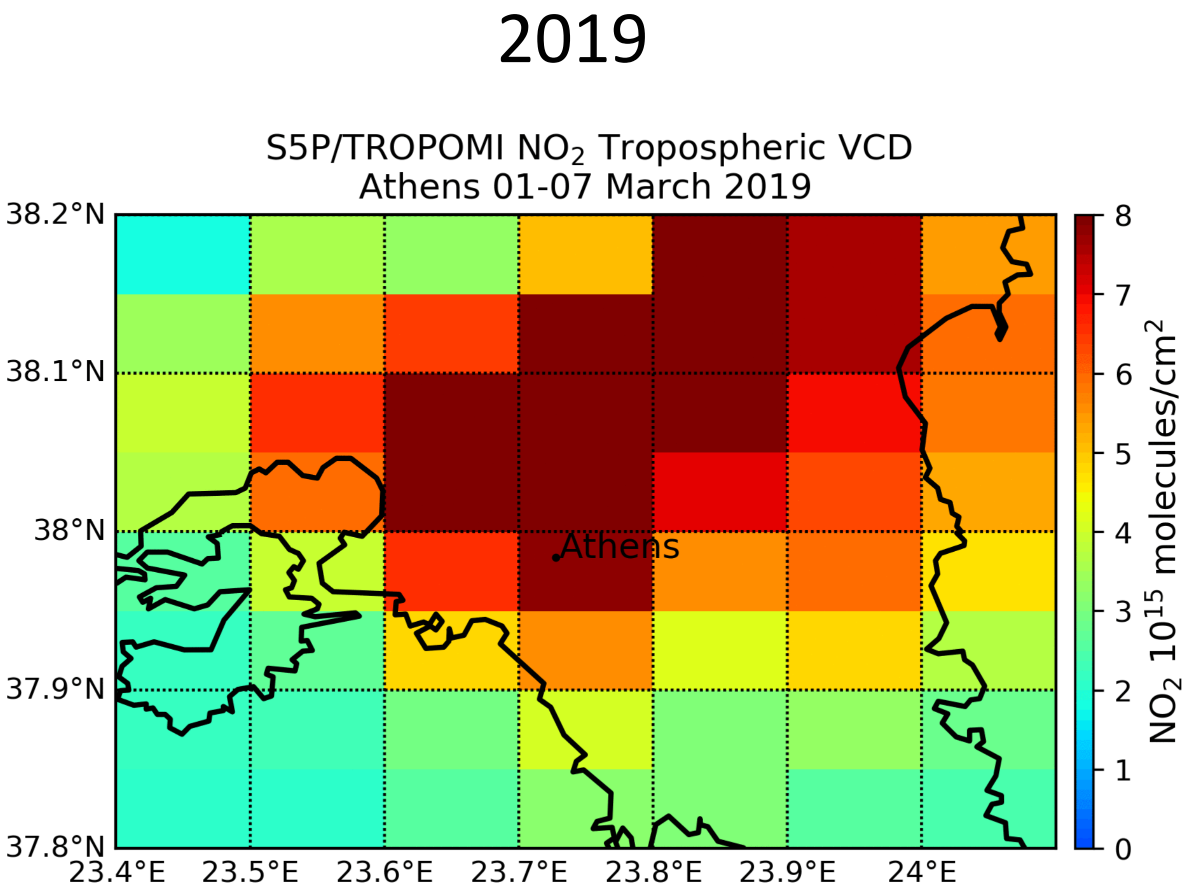


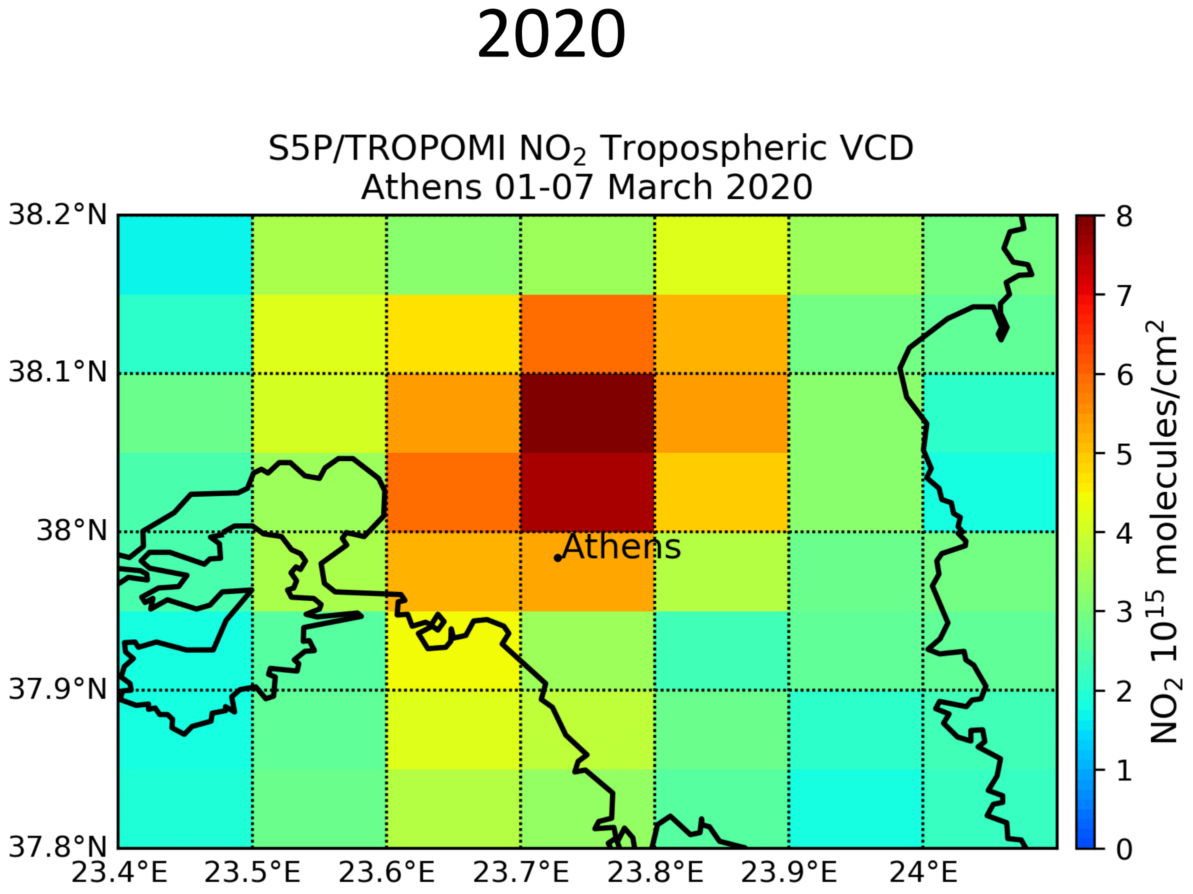
How can the effects of meteorology be compensated for?

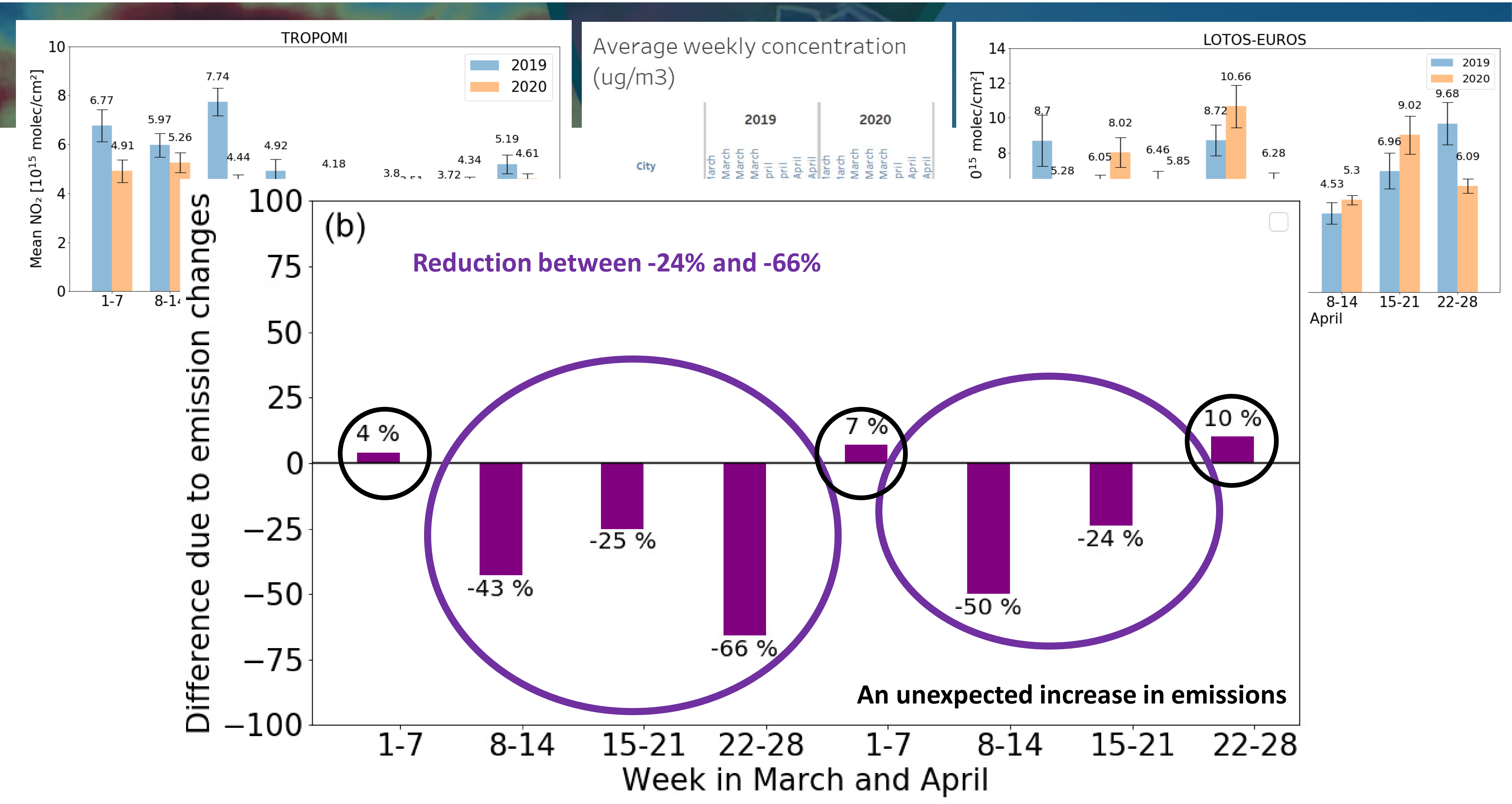
http://www.tropomi.eu/data-products/nitrogen-dioxide

https://s5phub.copernicus.eu/dhus/

Weekly NO_2 load over Athens during March & April





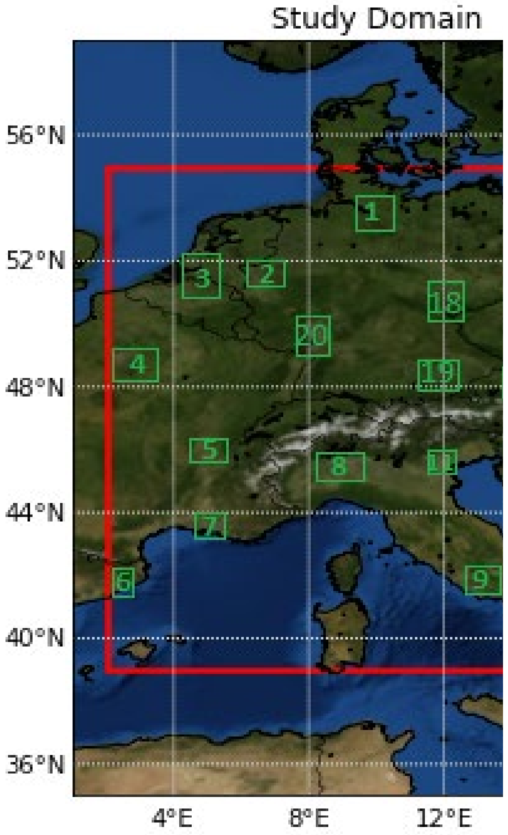


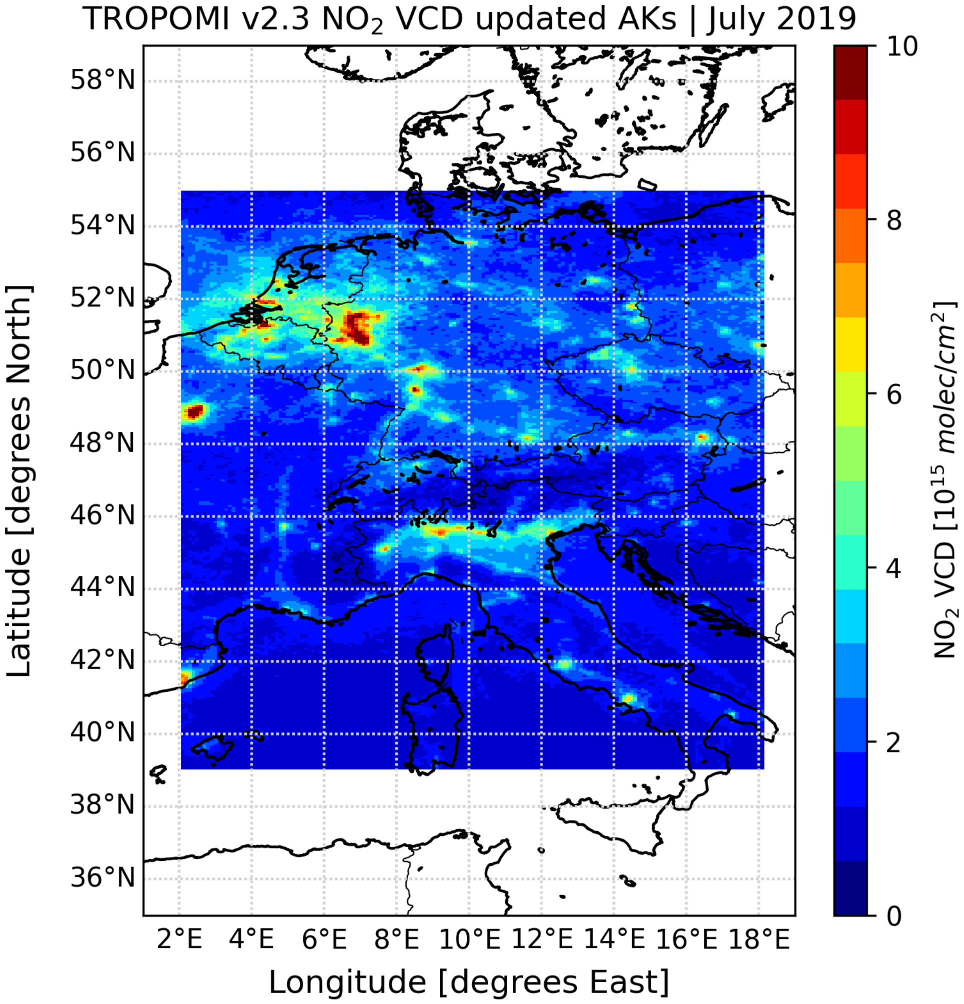
TROPOMI
Mean NO₂ [10¹⁵ molec/cm²]
Average weekly concentration (ug/m3)
2019
2020
City
LOTOS-EUROS
(b)
Reduction between -24% and -66%
4 %
-43 %
-25 %
-66 %
7 %
-50 %
-24 %
10 %
An unexpected increase in emissions
Difference due to emission changes
1-7
8-14
15-21
22-28
Week in March and April
April

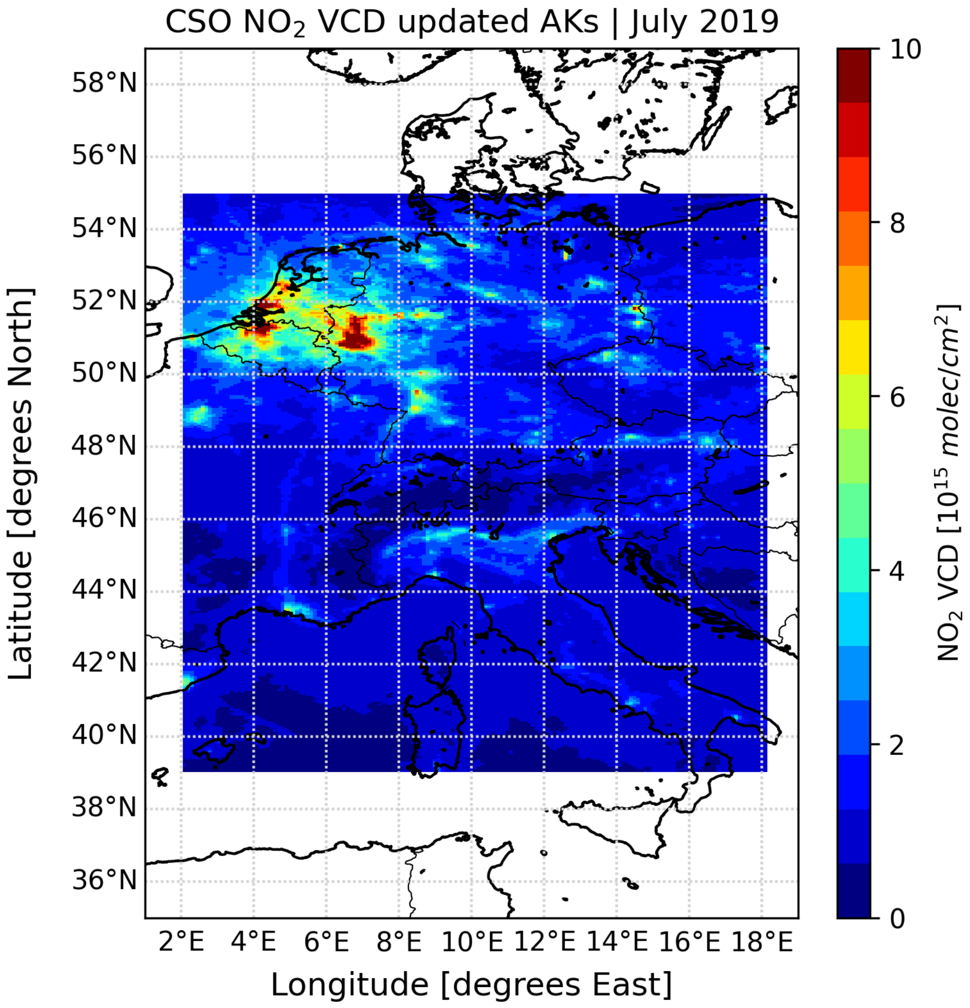
Using satellite data to make new data

Pseftogkas A, Koukouli M-E, Segers A, Manders A, Geffen Jv, Balis D, Meleti C, Stavrakou T, Eskes H. **Comparison of S5P/TROPOMI Inferred NO_2 Surface Concentrations with in situ Measurements over Central Europe**. Remote Sensing. 2022; 14(19):4886. https://doi.org/10.3390/rs14194886

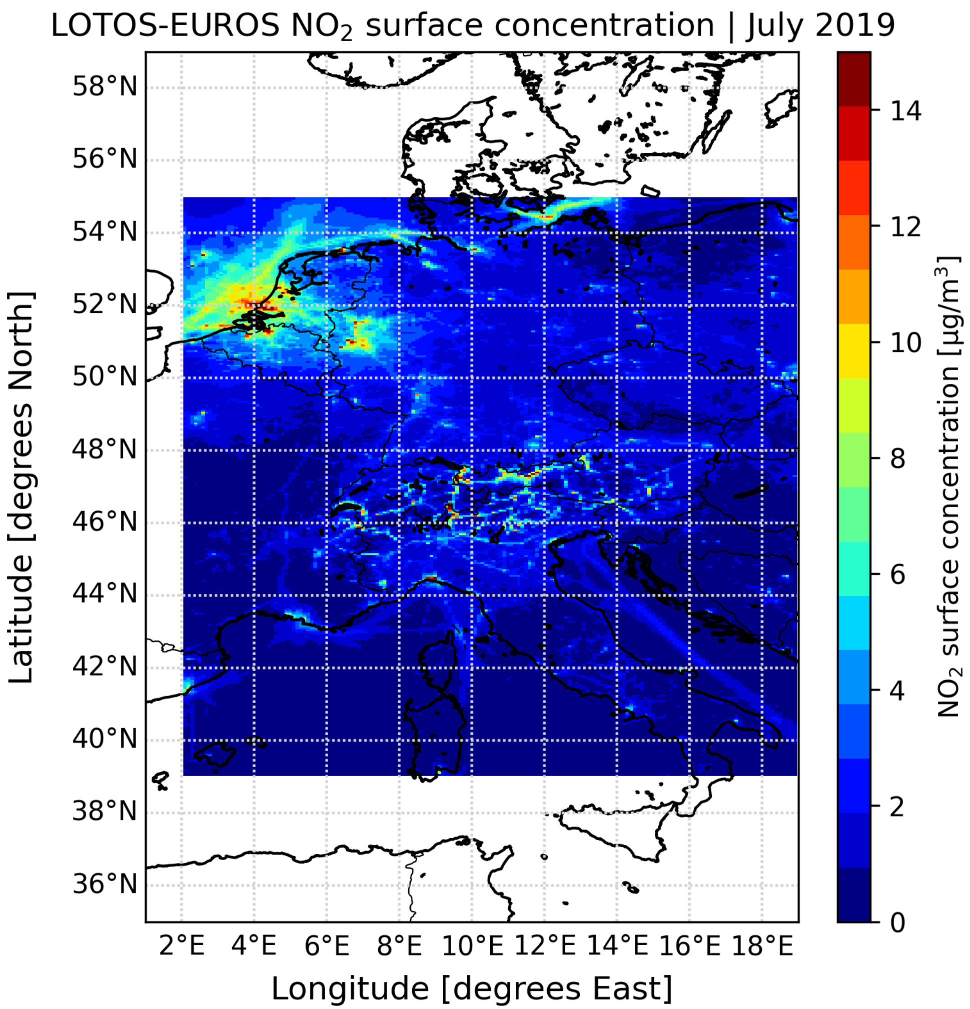
Using S5P NO_2 to infer NO_2 surface concentrations on a European Scale

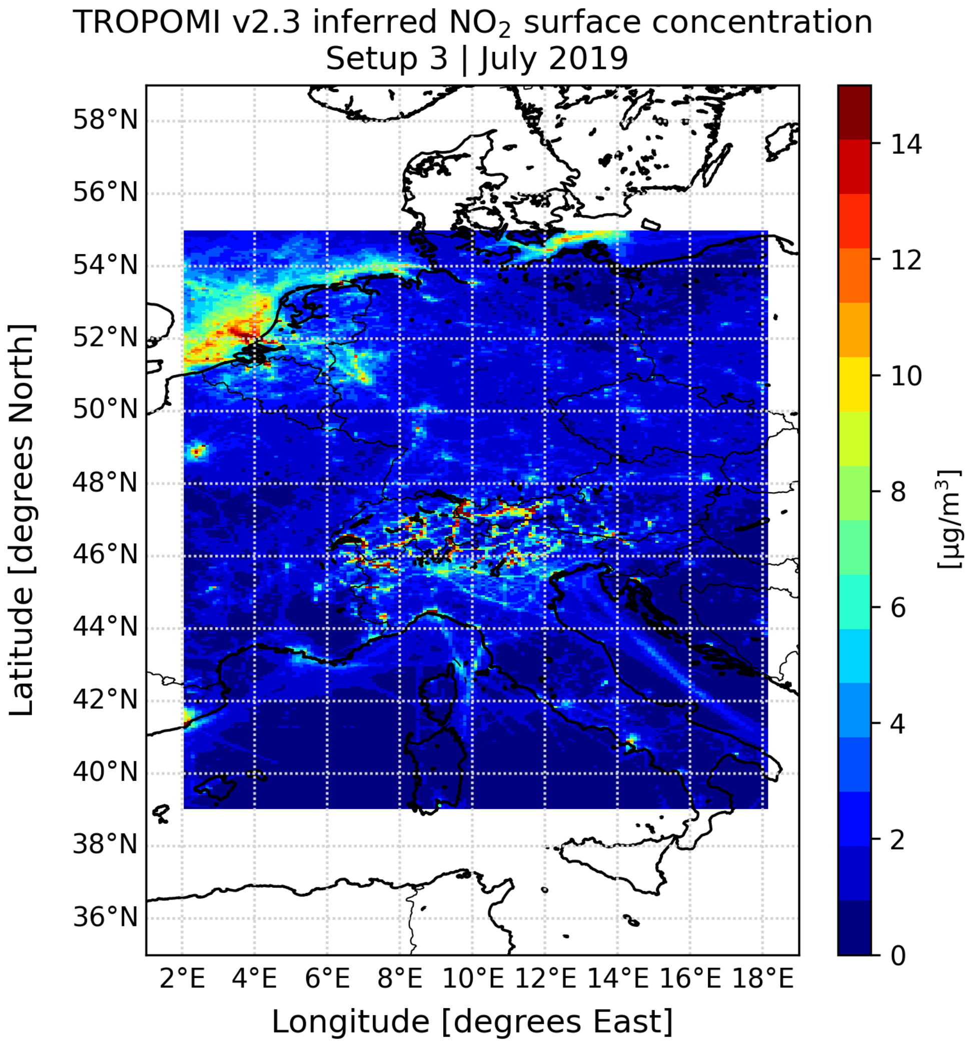




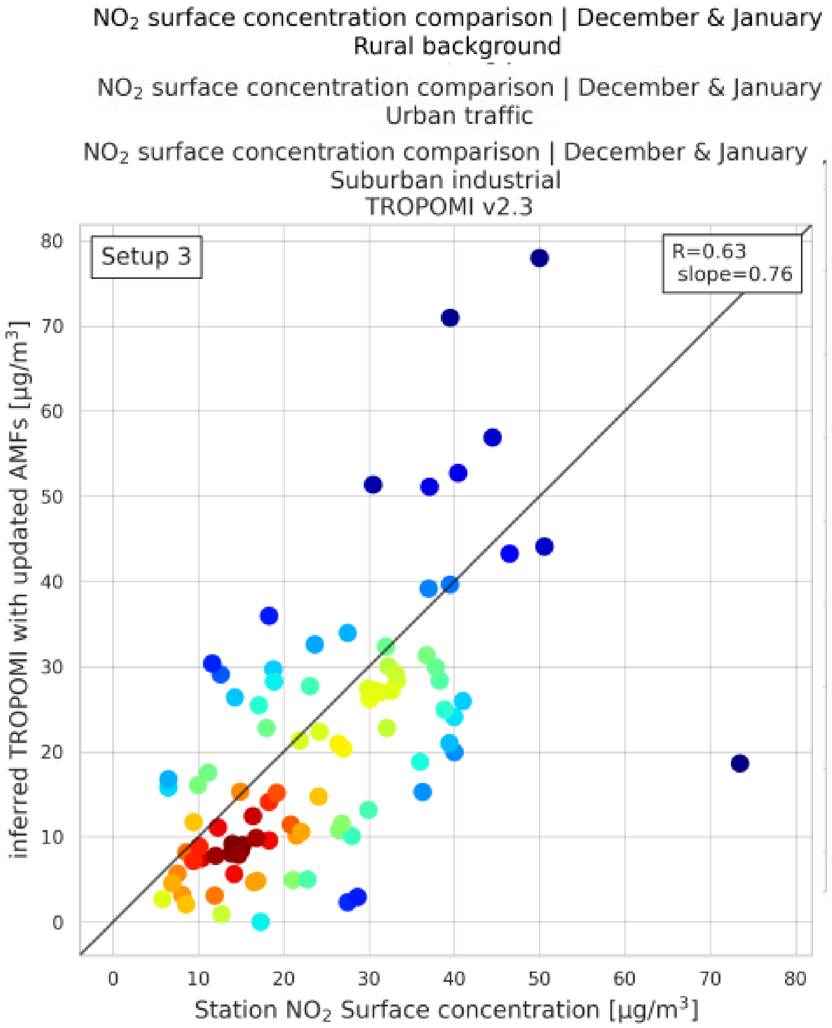


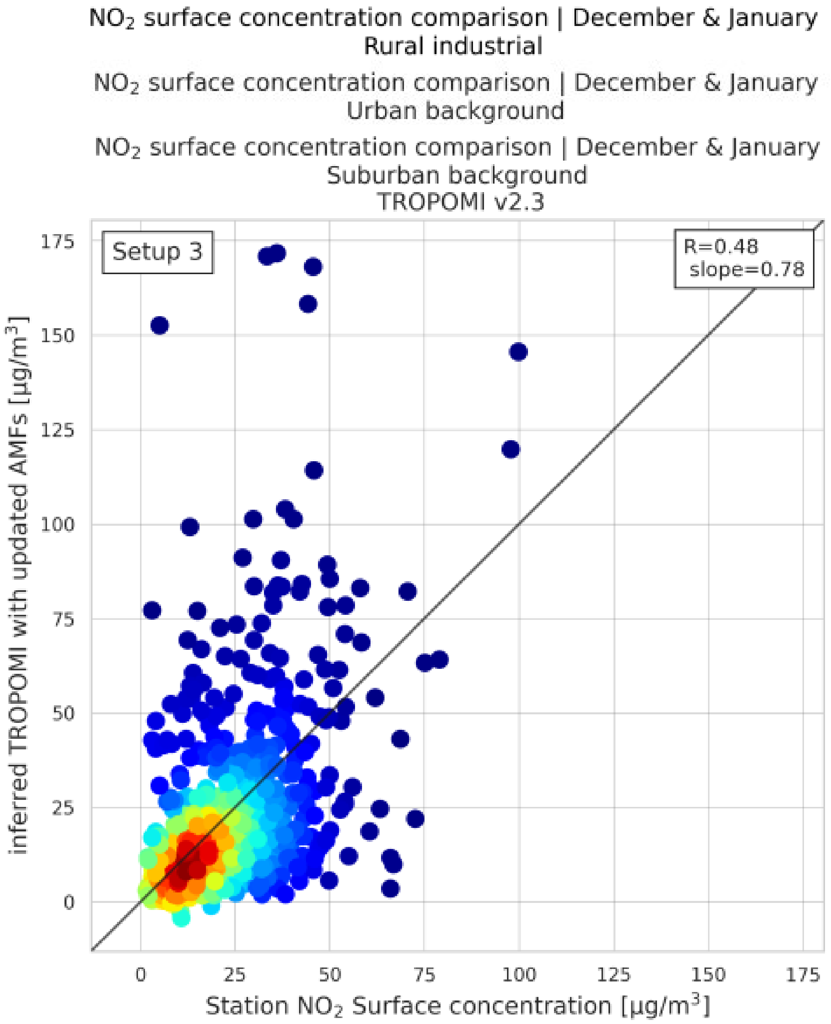
Using S5P NO_2 to infer NO_2 surface concentrations on a European Scale





Validation using the air quality monitoring network of EEA



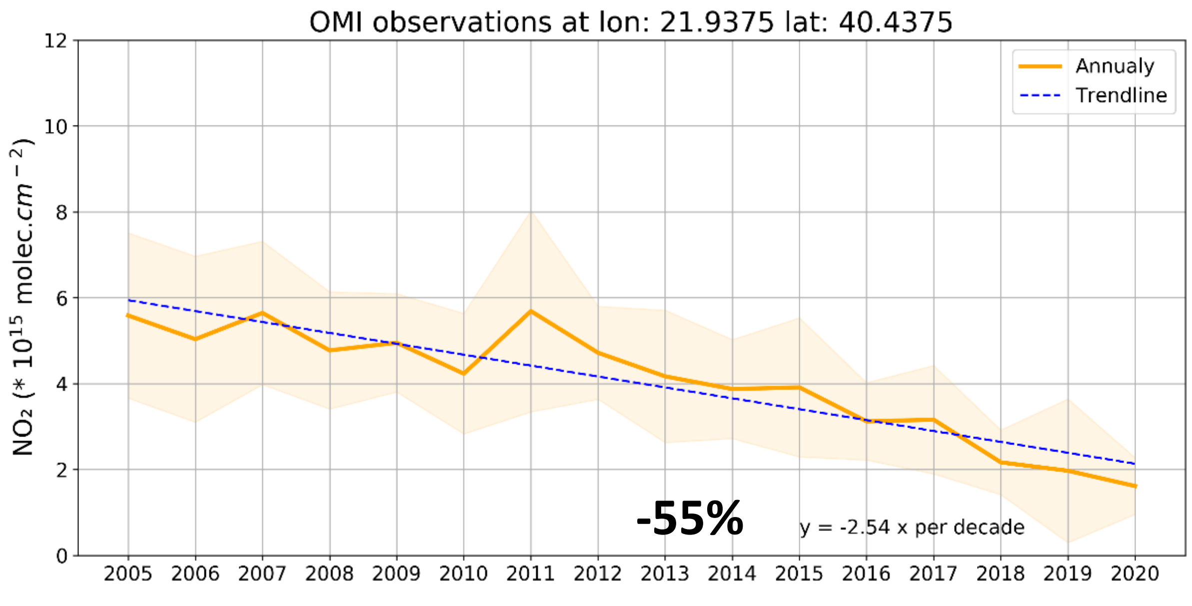


Using satellite data to update emission inventories | part A | power plants

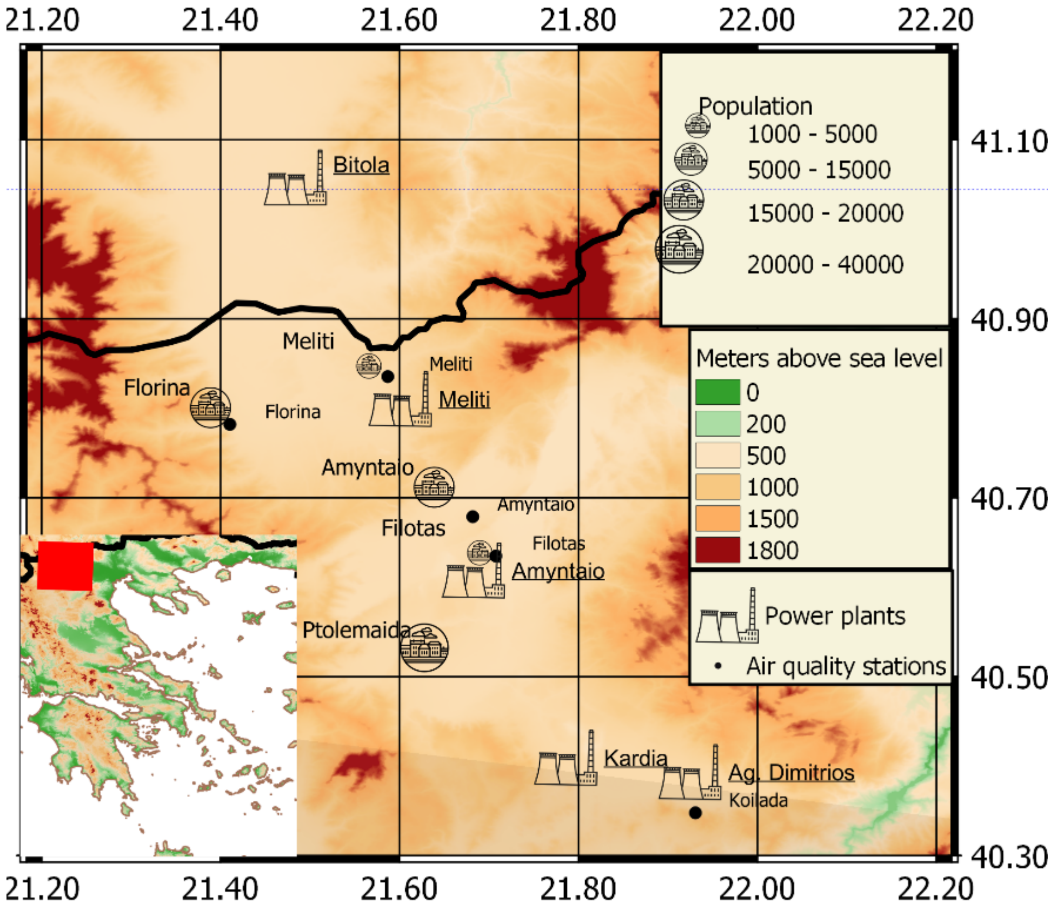
Skoulidou I, Koukouli M-E, Segers A, Manders A, Balis D, Stavrakou T, van Geffen J, Eskes H. **Changes in Power Plant NOx Emissions over Northwest Greece Using a Data Assimilation Technique**. Atmosphere. 2021; 12(7):900. https://doi.org/10.3390/atmos12070900

Large reduction in NOx emissions in Greece

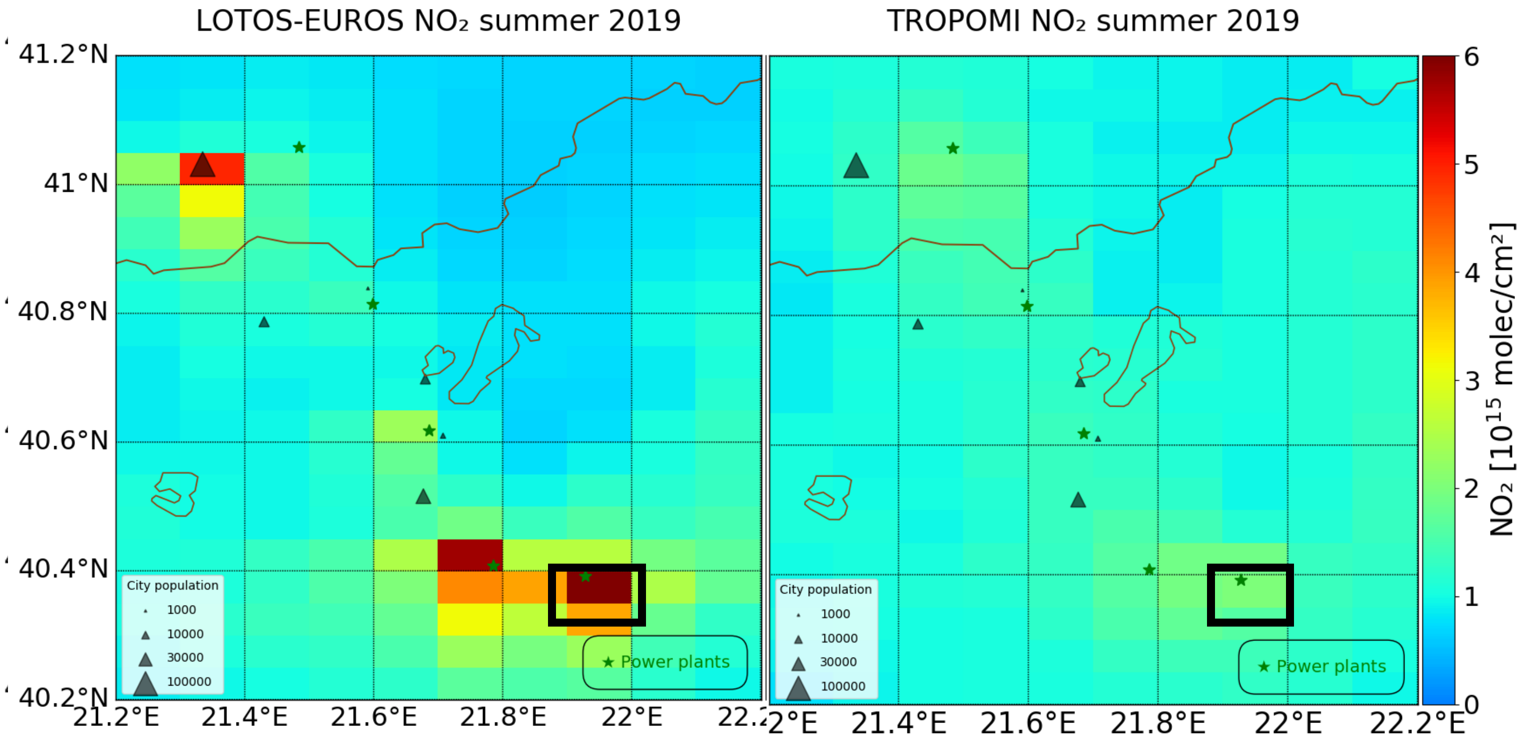
Greek National Energy and Climate Plan mandates a reduction in NO_x emissions of 31% [2020 – 2029] and of 55% [from 2030] compared to 2005.



Mean annual NO_2 columns from OMI/AURA over the larger power plant location

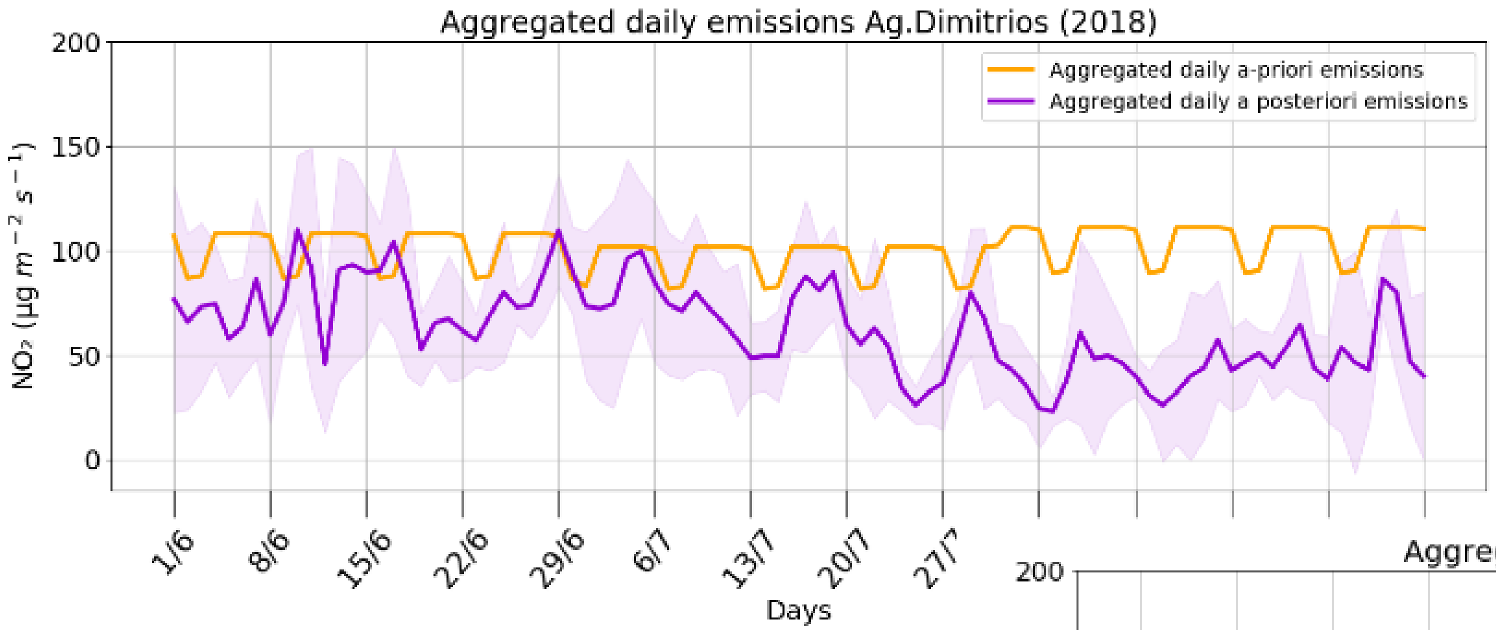


Large disagreement between model and space-borne estimates



Bias 6.86 10^{15} mole.cm^{-2}

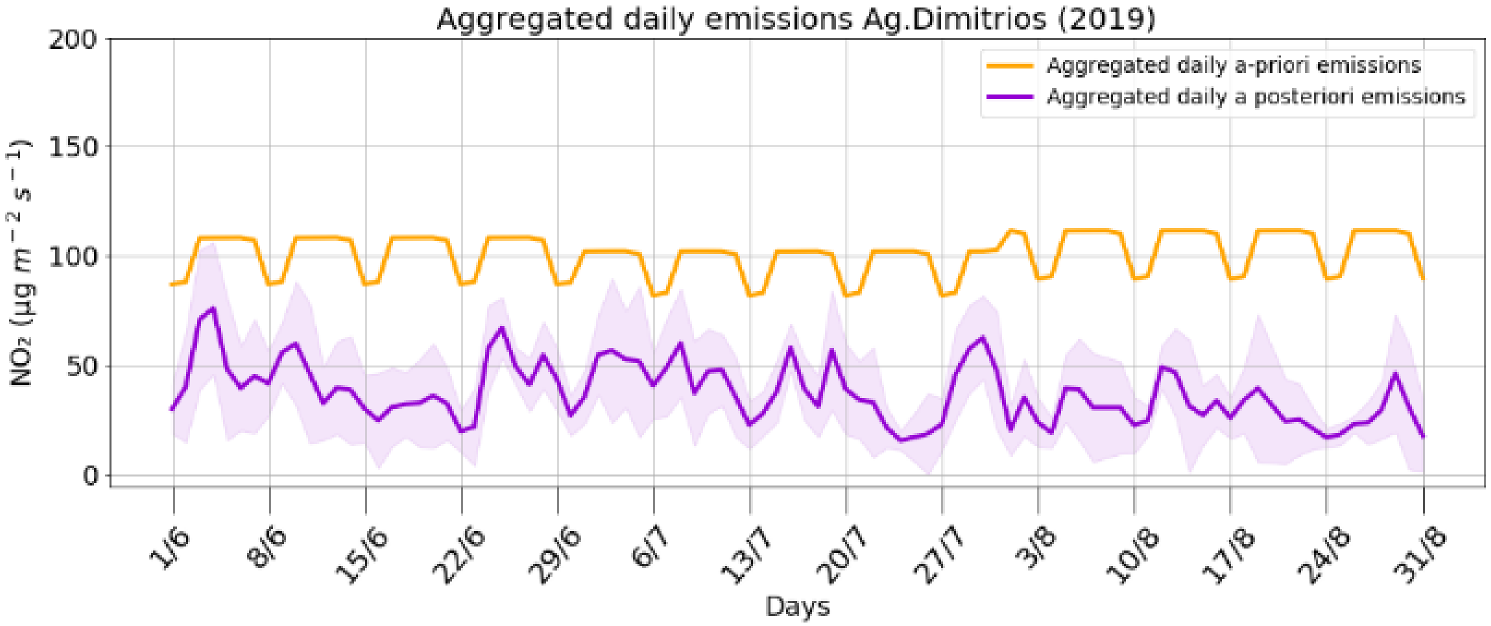
Updating the emission inventory by assimilating TROPOMI observations



In 2019 they remain low throughout the summer and decrease by 28% in August compared to June and July

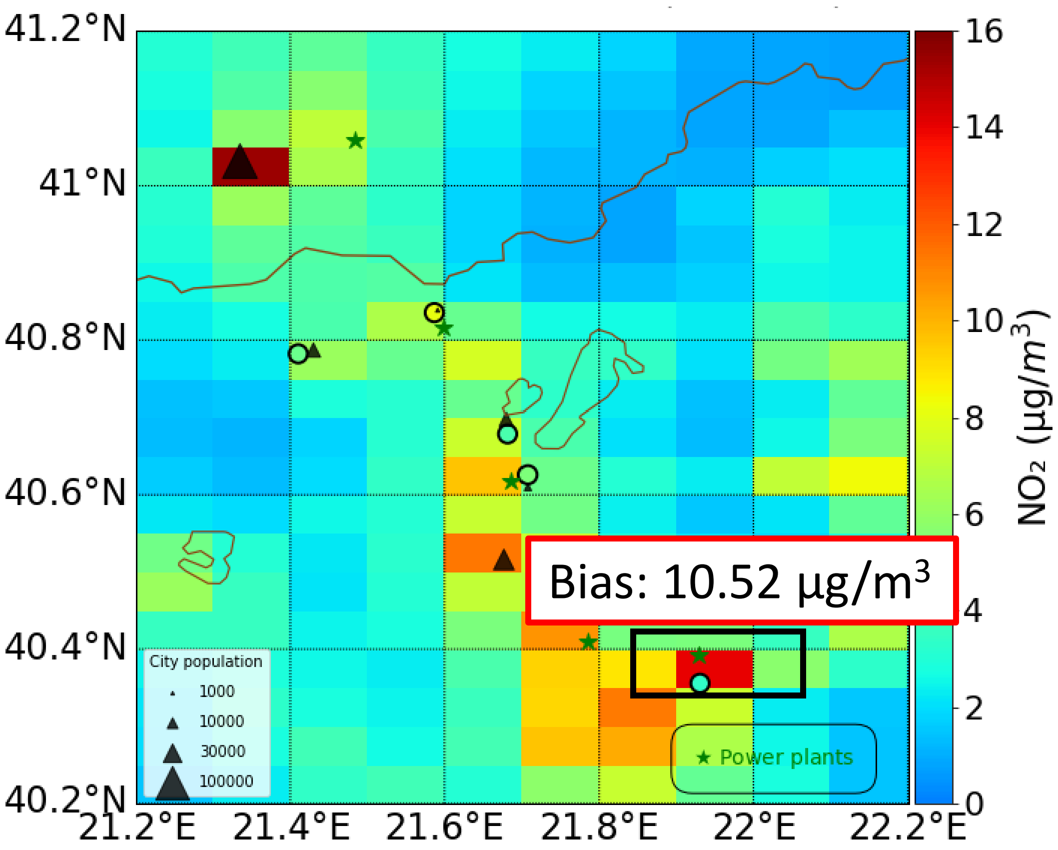
Decreased emissions after assimilation.

Emissions are found to strongly decrease in August 2018 by around 40% and 30% compared to June and July

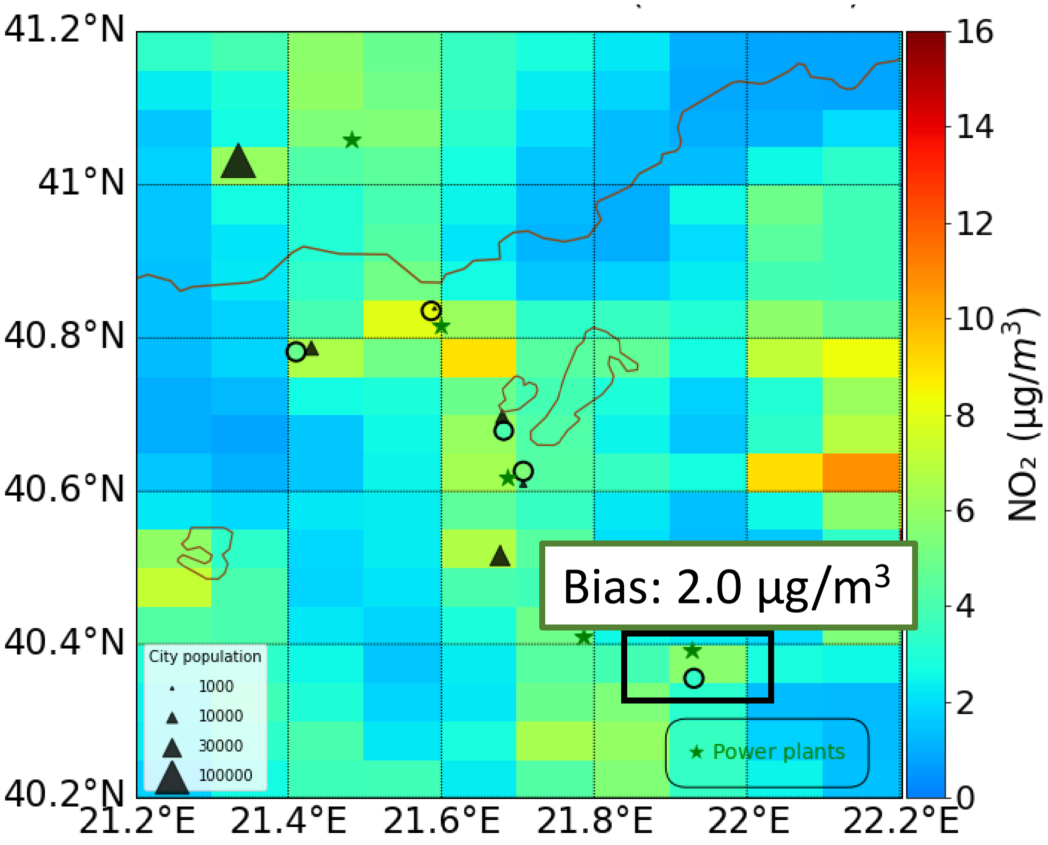


Validation – surface simulations vs in situ NO_2 measurements

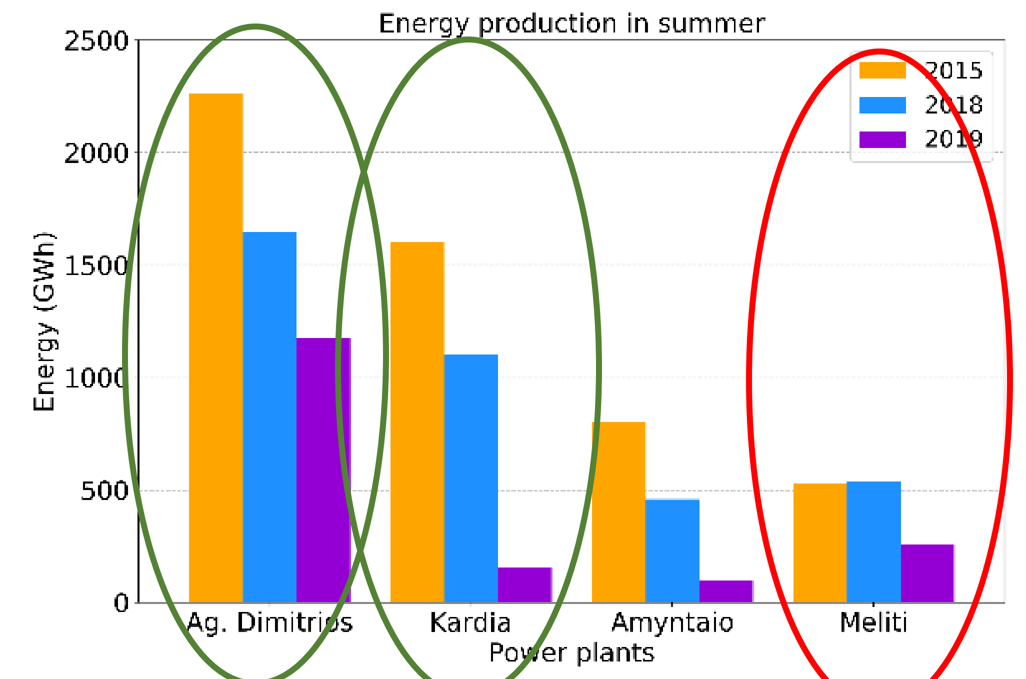
NO_2 surface simulations using **a priori** NO_x emissions

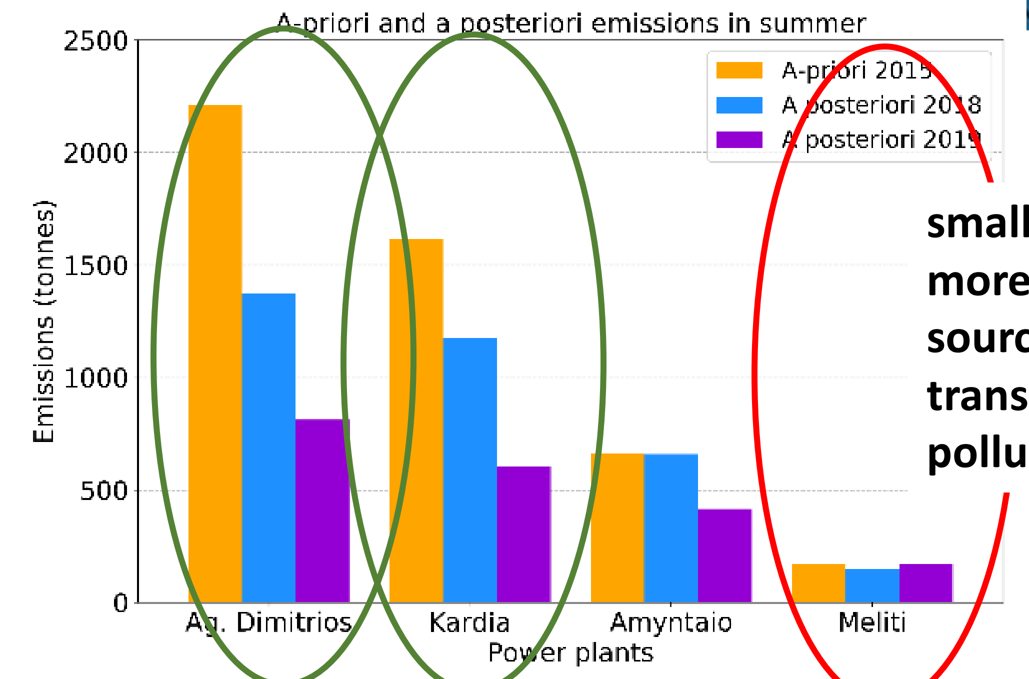


NO_2 surface simulations using **a posteriori** NO_x emissions



Validation– a posteriori emissions vs energy reports





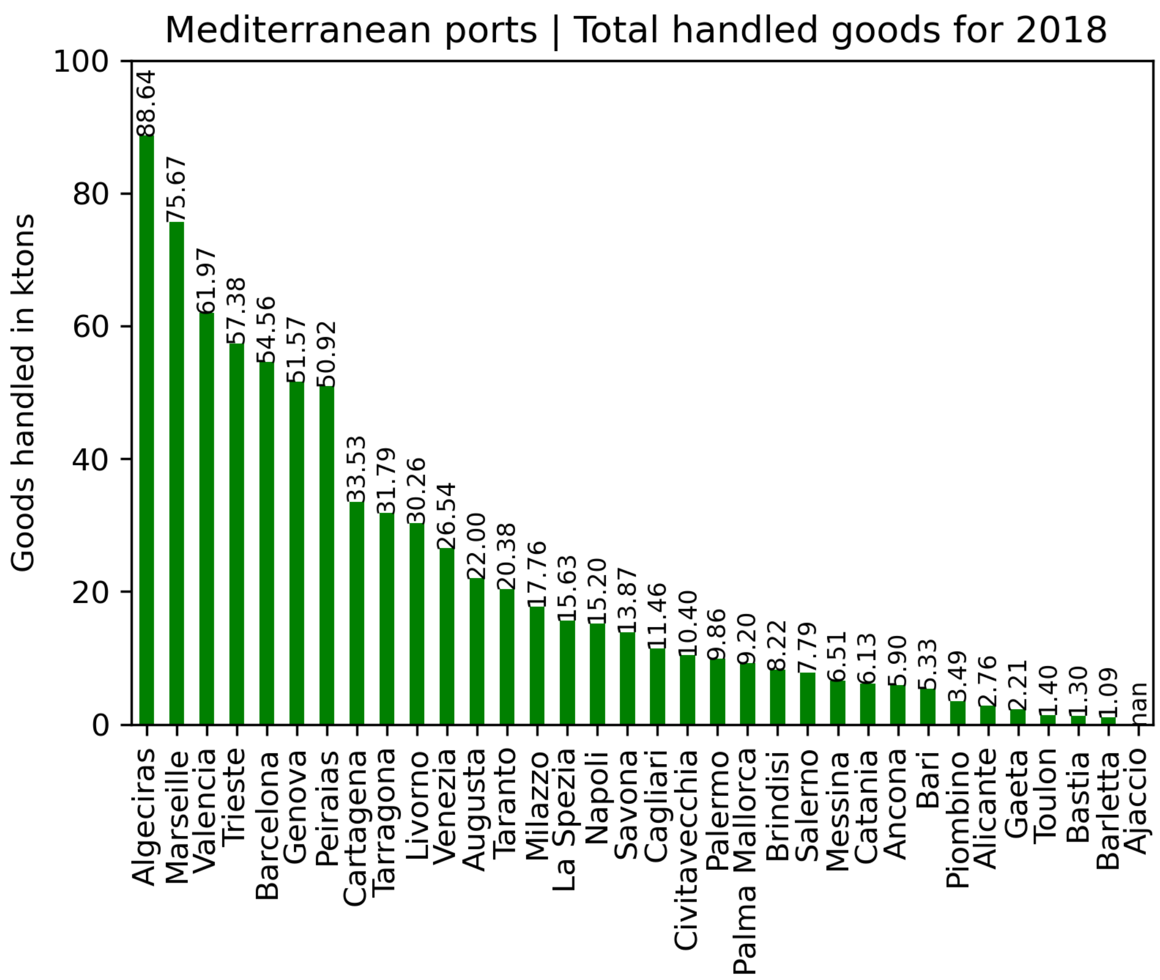
small capacity
more emissions source
transboundary pollution

Power plant	Ag. Dimitrios		Kardia		Amyntaio		Meliti	
Rel. Differences	Energy	Emissions	Energy	Emissions	Energy	Emissions	Energy	Emissions
2018-2015/ 2015	-27%	-38%	-31%	-27%	-43%	-1%	2%	-11%
2019-2015/ 2015	-48%	-63%	-90%	-63%	-88%	-37%	-51%	-1%

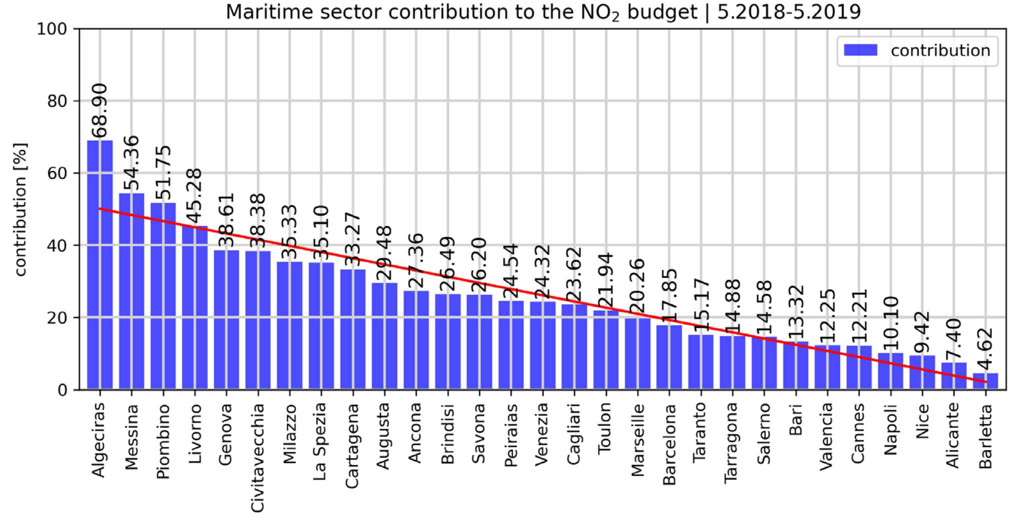
Using satellite data to update emission inventories | part B | maritime emissions

Pseftogkas A, Koukouli M-E, Skoulidou I, Balis D, Meleti C, Stavrakou T, Falco L, van Geffen J, Eskes H, Segers A, et al. **A New Separation Methodology for the Maritime Sector Emissions over the Mediterranean and Black Sea Regions**. Atmosphere. 2021; 12(11):1478. https://doi.org/10.3390/atmos12111478

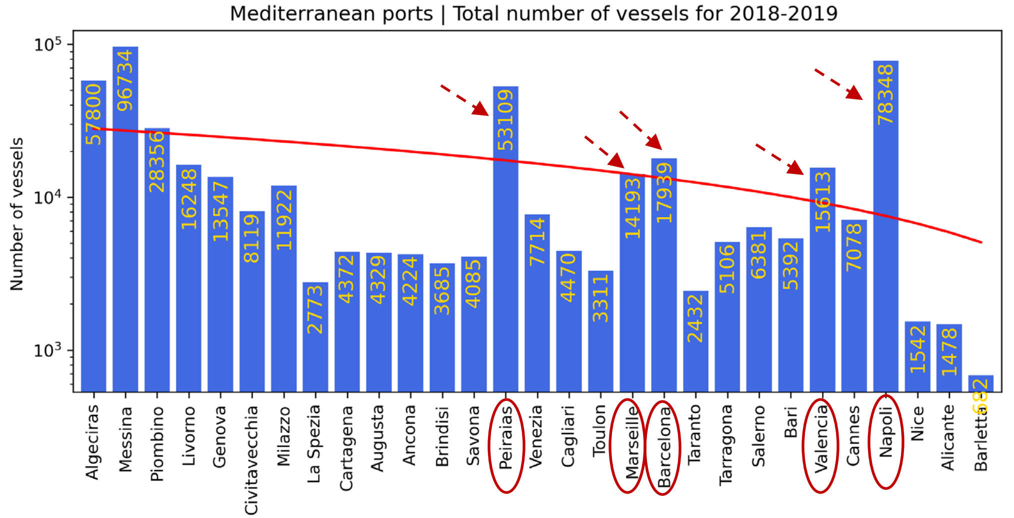
The maritime sector activities in the Mediterranean Sea



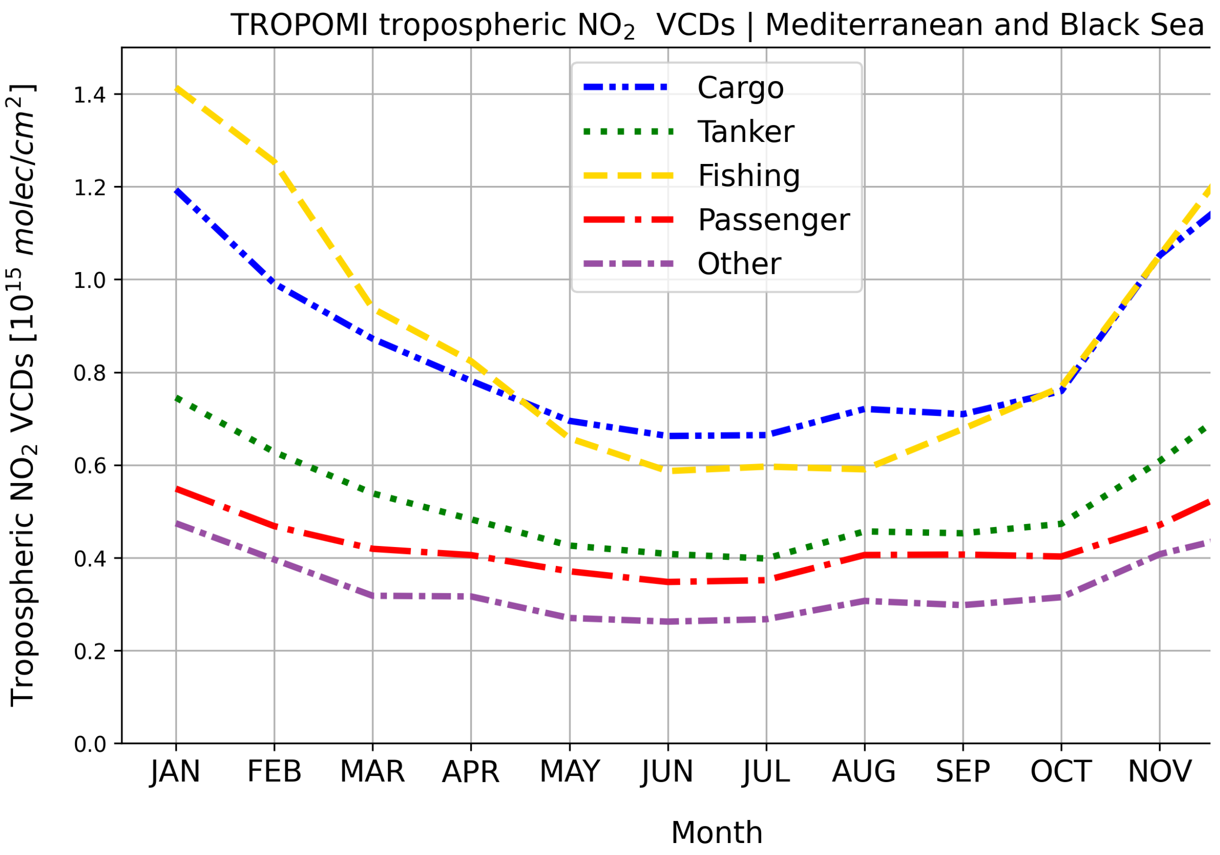
Contribution [%]

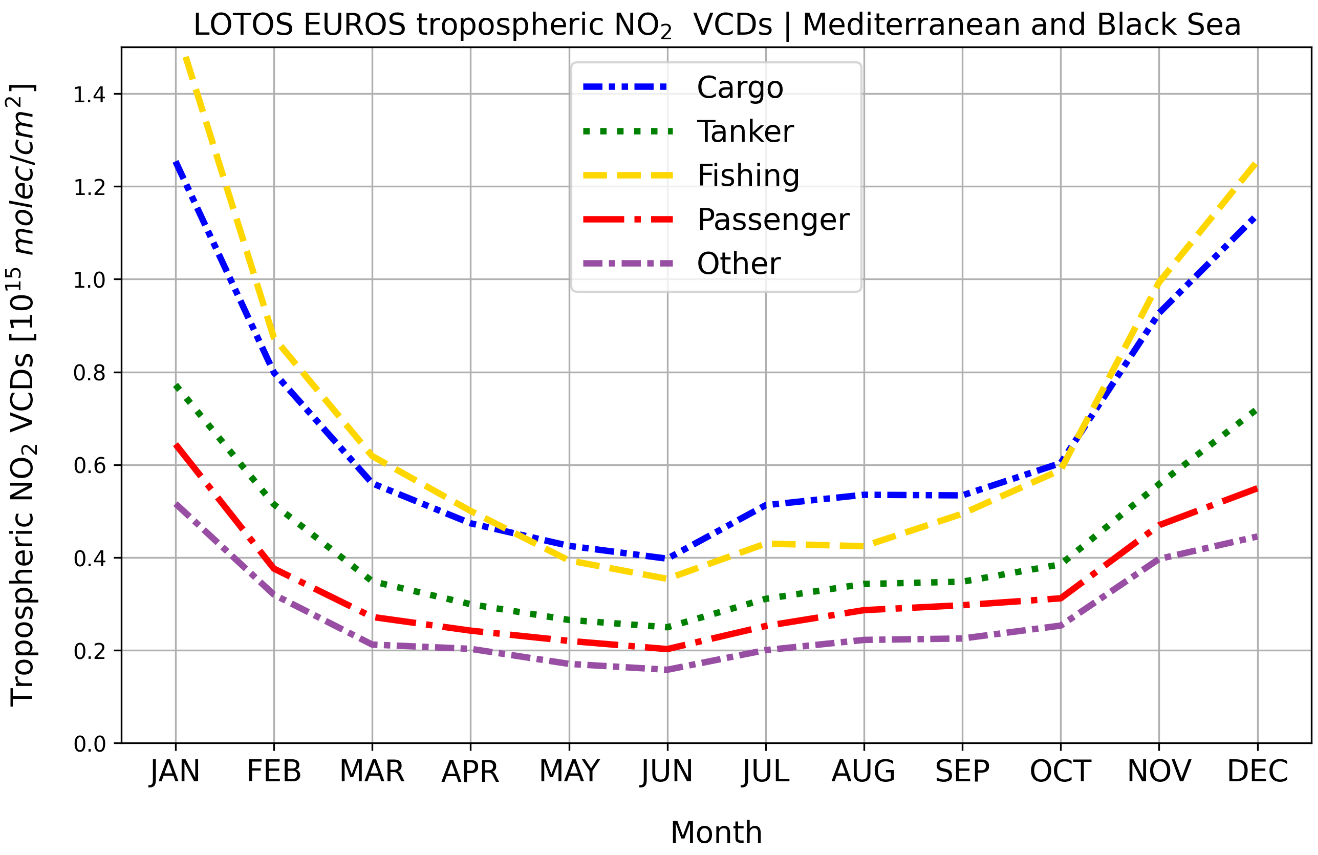


Number of vessels



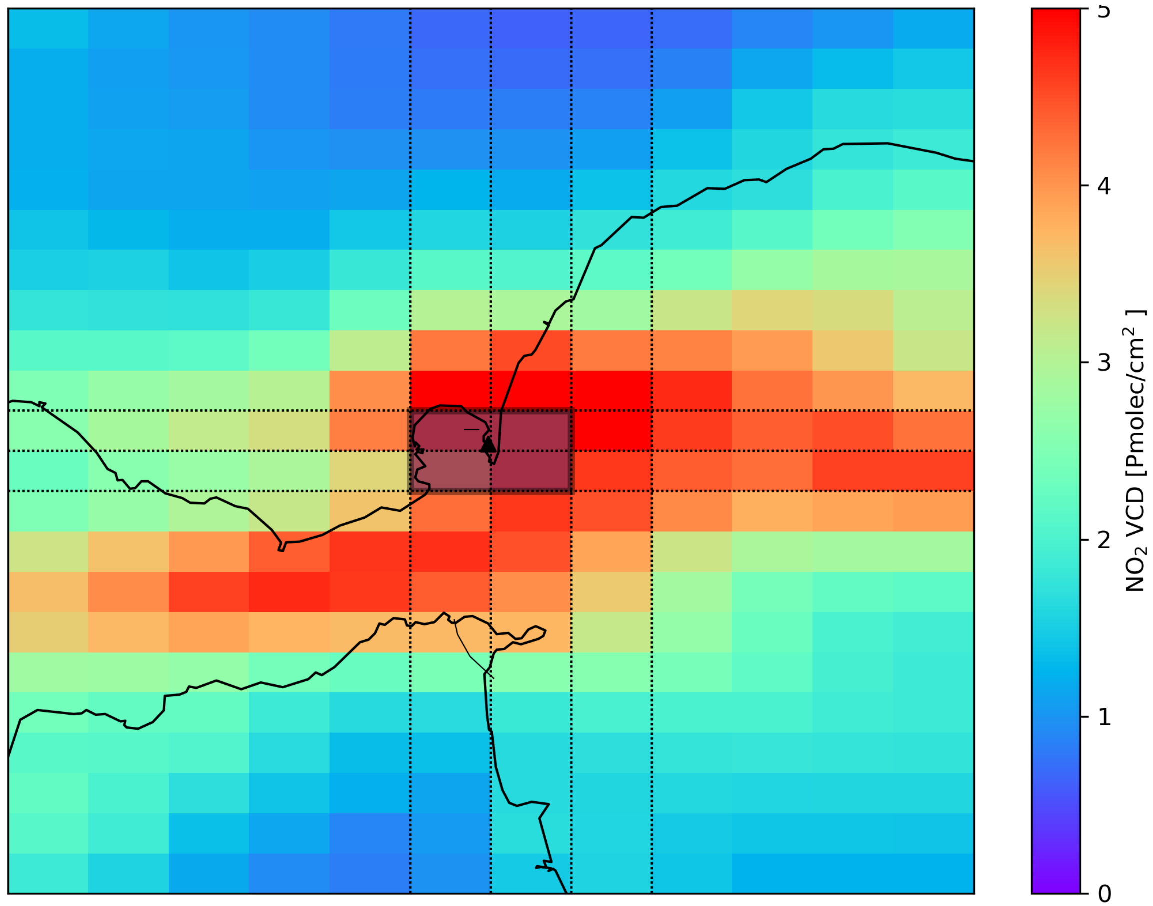
Using S5P NO_2 to relate NOx emissions to shipping activities in the Mediterranean Sea



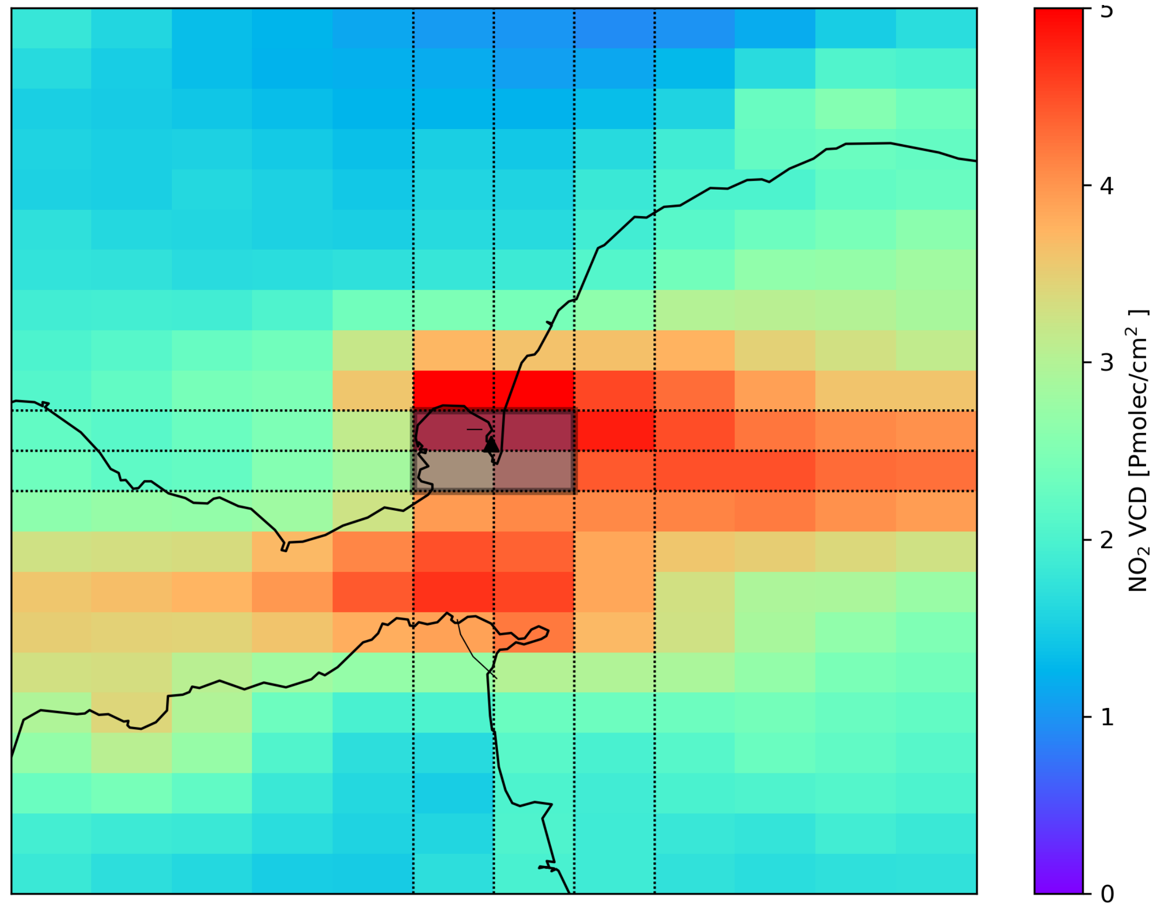


The port of Algeciras, Spain

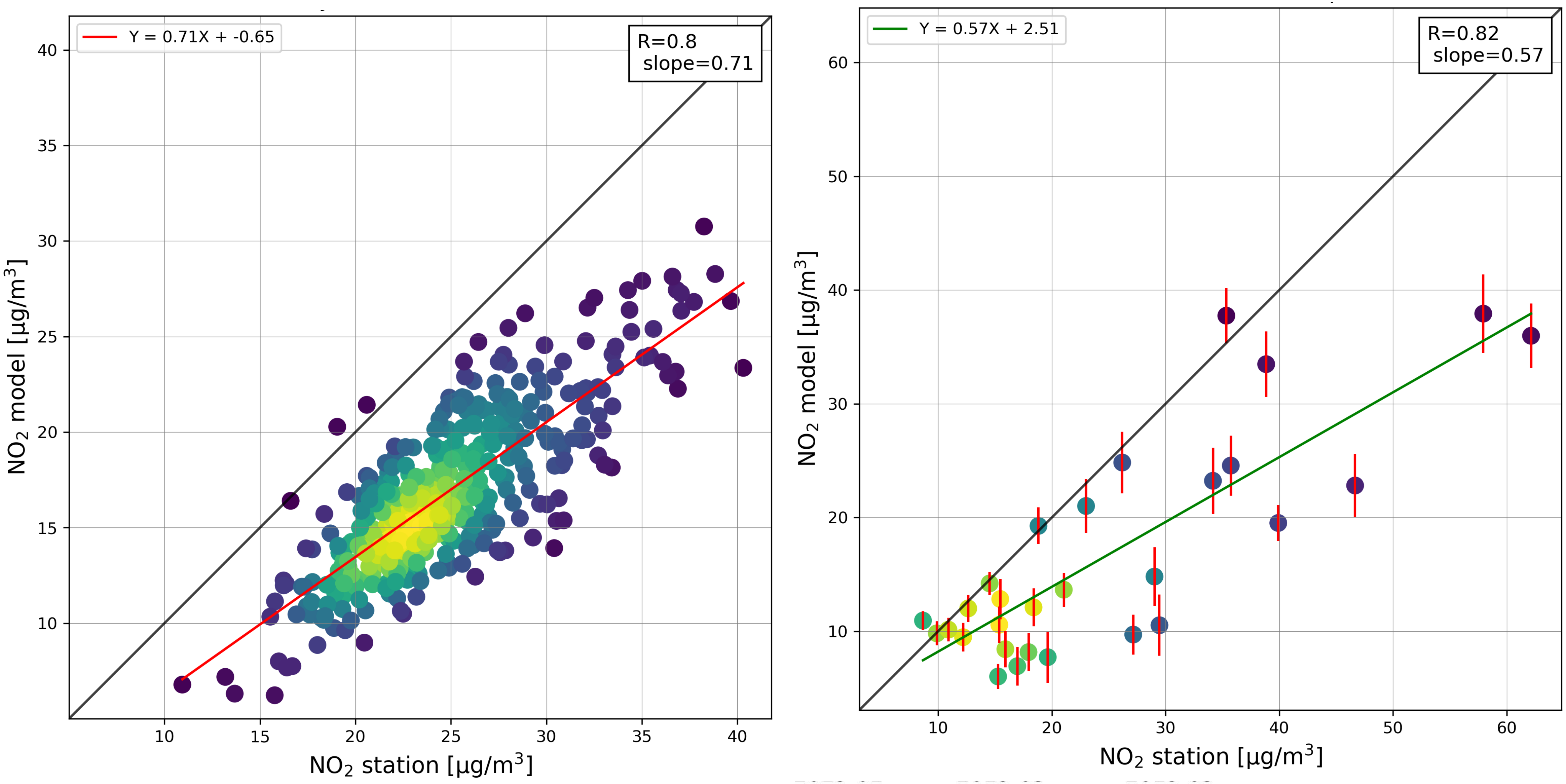
LOTOS-EUROS tropospheric column



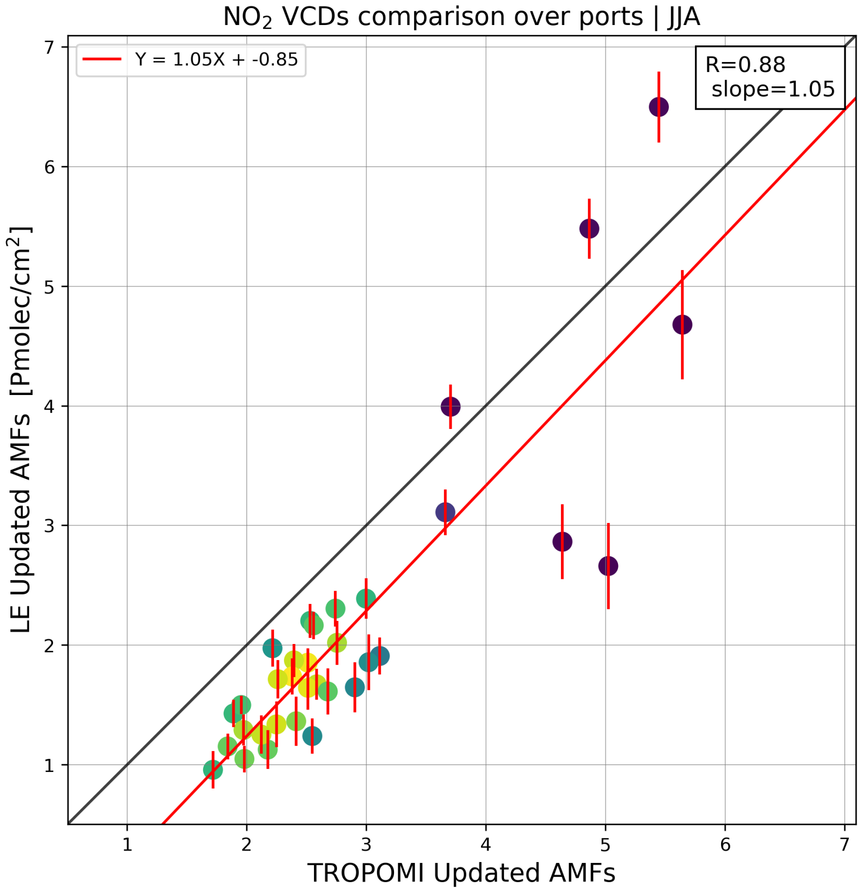
TROPOMI tropospheric column

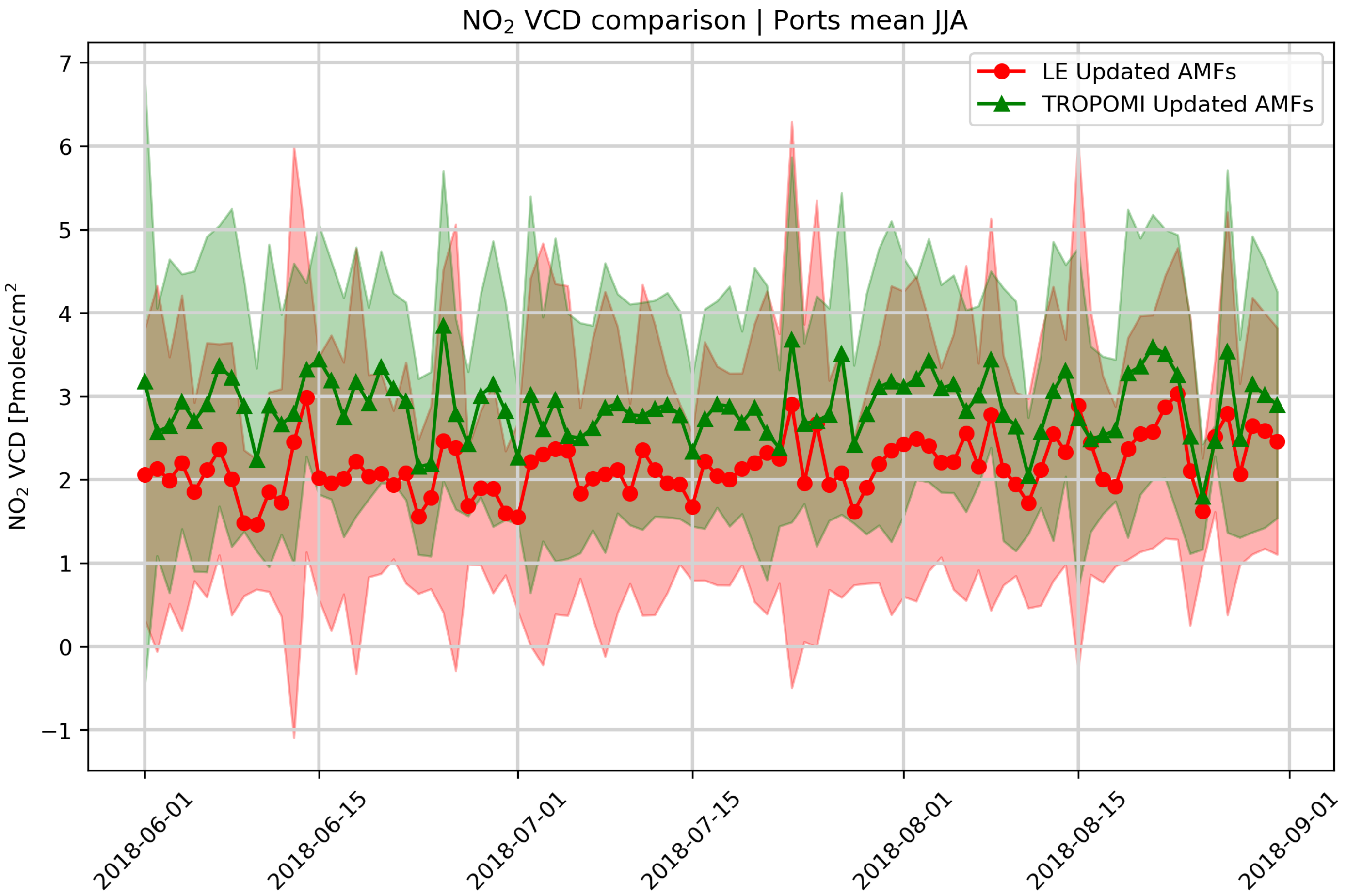


First, we verify the model using in situ measurements...

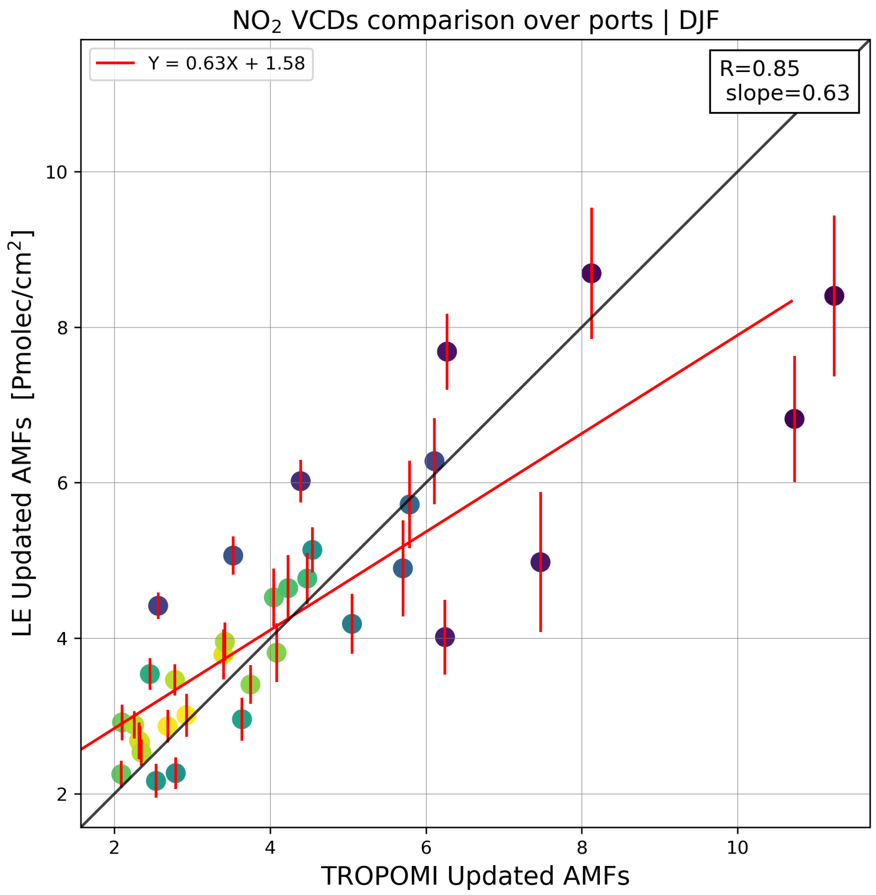


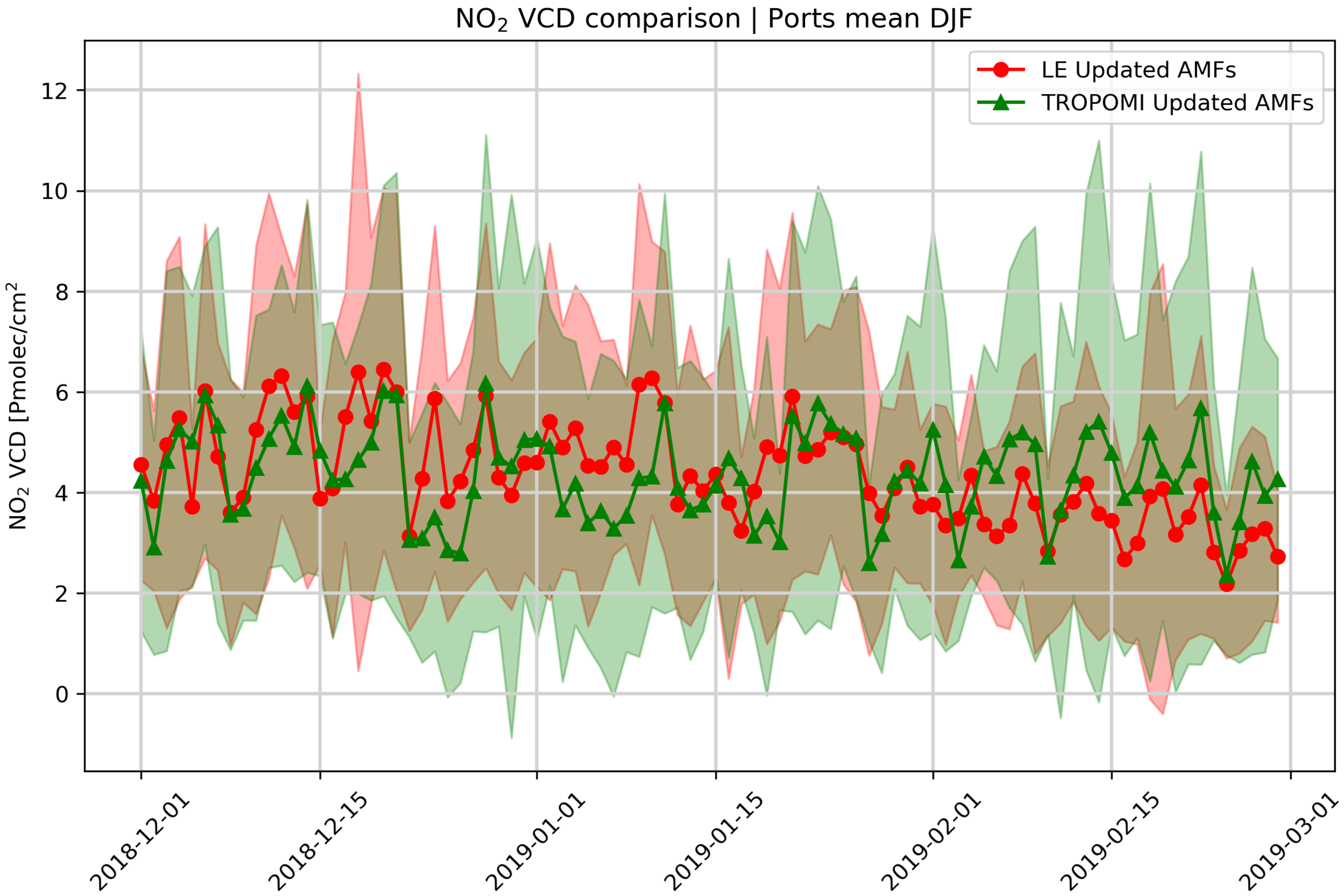
… then we compare the satellite with the model | Summer





… then we compare the satellite with the model | Winter





Take away message

- Current space-borne observations can provide a wealth of additional information on the state of our atmosphere.
- Auxiliary data are required, to verify, understand, analyze the observations as well as the model simulations.
- The age of synergy is upon us; use all available information to comprehend, classify and quantify air quality levels.

- … and always evaluate, verify, validate!

Thank
You
Shukria
Asante
Dhanyavadagalu
Vinaka
köszönöm
Kiitos
Maake
Manana
Dankon
감사합니다
Kam Sah Hammida
спасибо
Dankscheen
Matondo
Terima Kasih
Diolch i Chi
Dank Je
Mauruuru
Biyan
Taiku
Blagodaram
Tack
Ngiyabonga
Dziekuje
Chokrane
Grazie
Arigato
Juspaxar
Mochchakkeram
Gracias
Tingki
धन्यवाद
cảm ơn bạn
Bedankt
D'akujem
Grazas
Gratias Tibi
Paldies
Ua Tsaug Rau Koj
Obrigado
Děkuji
Nirringrazzjak
Di Ou Mèsi
Kia Ora
Kop Khun Khap
ありがとう
Suksama
Matur Nuwun
谢谢
Hvala
хвала
Welalin
Djiere Dieuf
Rahmat
Misaotra
Danke
Merci
Go Raibh Maith Agat
Tuke
Eskerrik Asko
ขอบคุณ