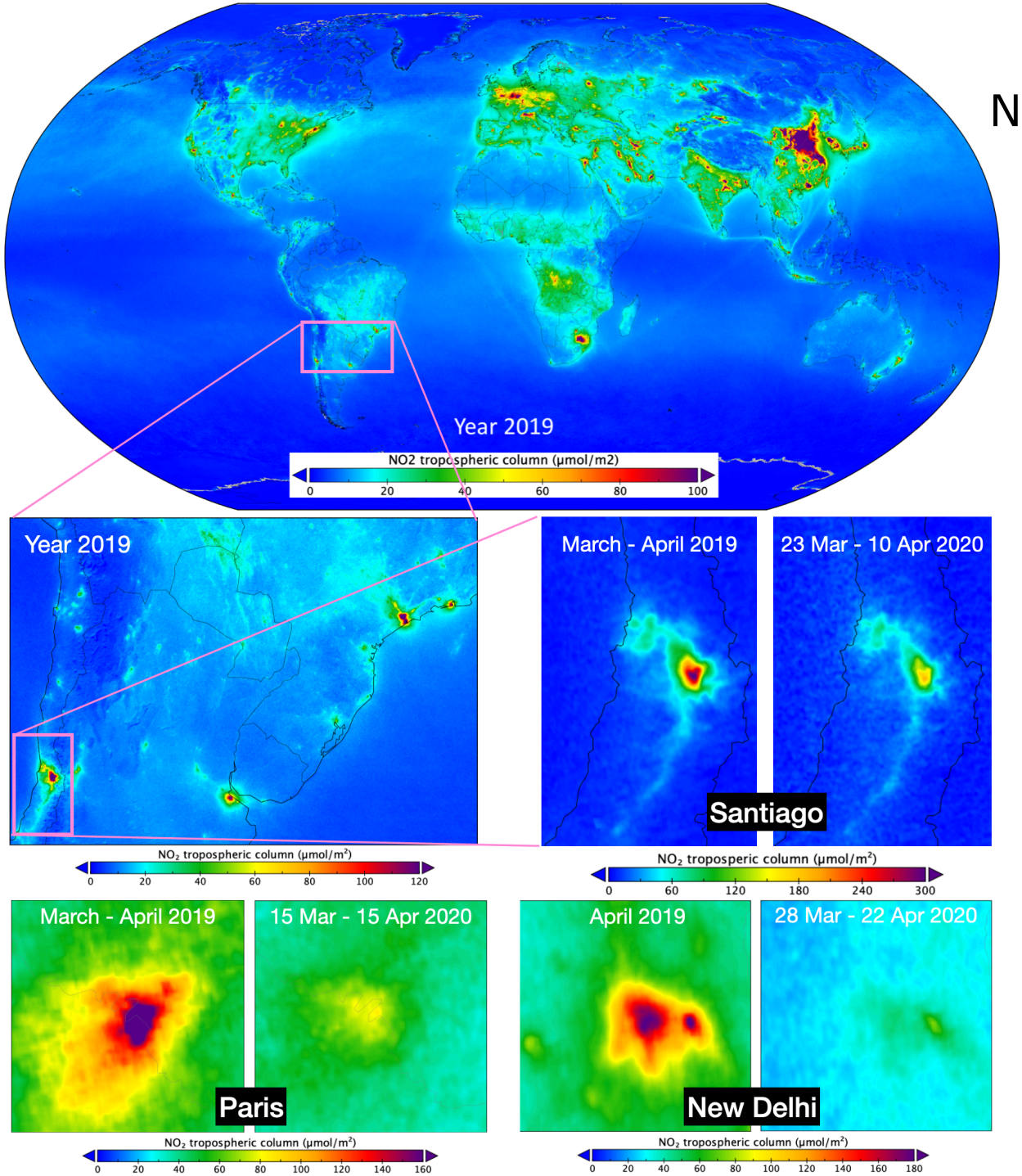
Reductions of NO2 Air Pollution during Covid-19 Lockdowns as Observed by Sentinel-5P TROPOMI

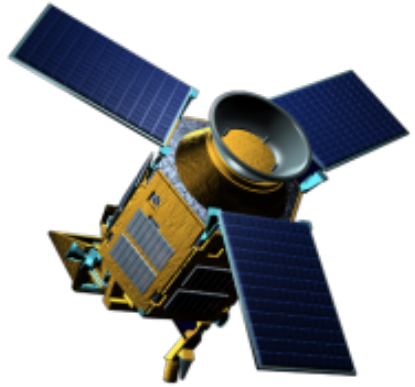
Henk Eskes, KNMI

With contributions from:
Pepijn Veefkind, Folkert Boersma, Jos van Geffen, Ronald vd A, Jieying Ding, Maarten Sneep, John Douros, Bas Mijling,
ESA ICOVAC, S5P-PAL partners,
colleagues from BIRA, SRON, DLR, ESA …

AC-VC topical seminar: Covid-19 impact: what can be learned from satellites
13 July 2021



NO2 world map 2019

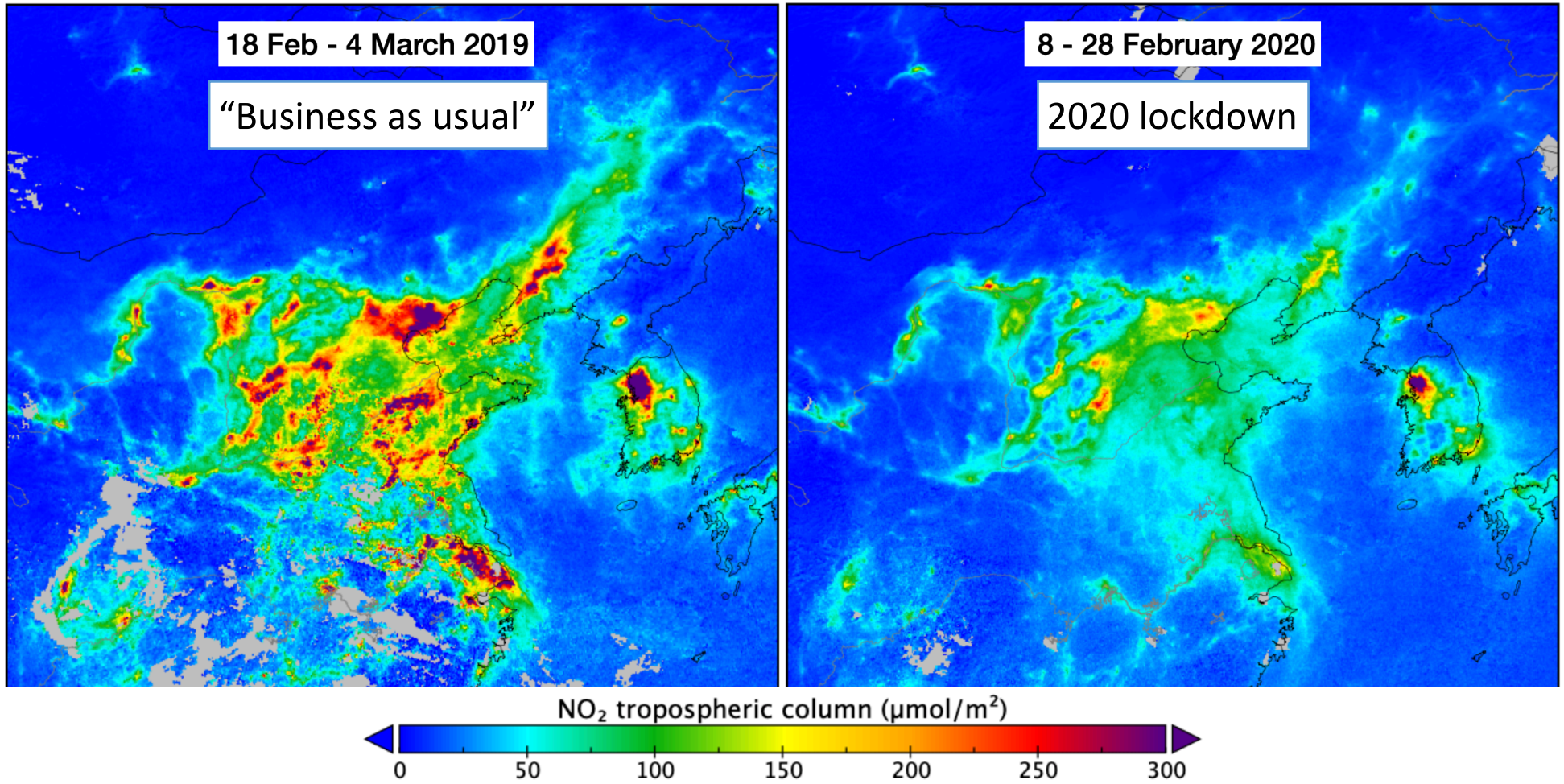


TROPOMI
High resolution and
daily coverage allow
zooming in to city-scale,
and looking at short time periods
(one day, one month …)

Examples:

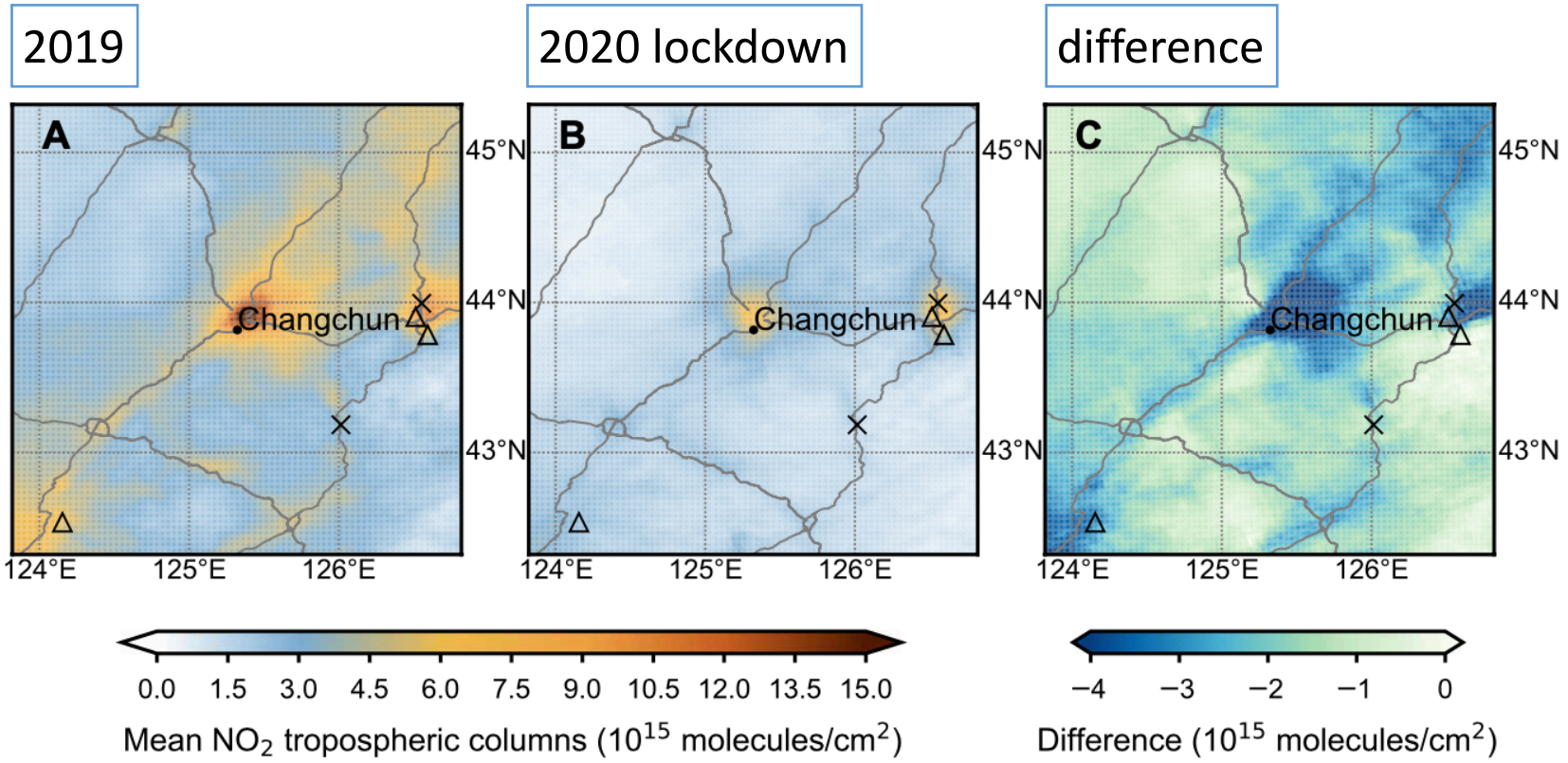
Large COVID-19 related
reductions in observed
concentrations over cities like
Santiago, Paris, New Delhi
during lockdown

NO2 pollution reduction related to COVID-19 lockdown in China



- Unprecedented nation-wide reductions in NO2 observed by TROPOMI during the China lockdown in Febrary 2020

Using the high resolution of TROPOMI to distinguish sources

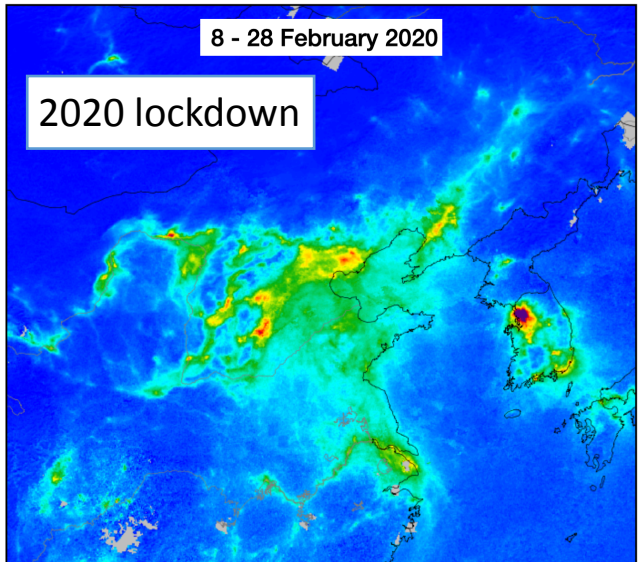


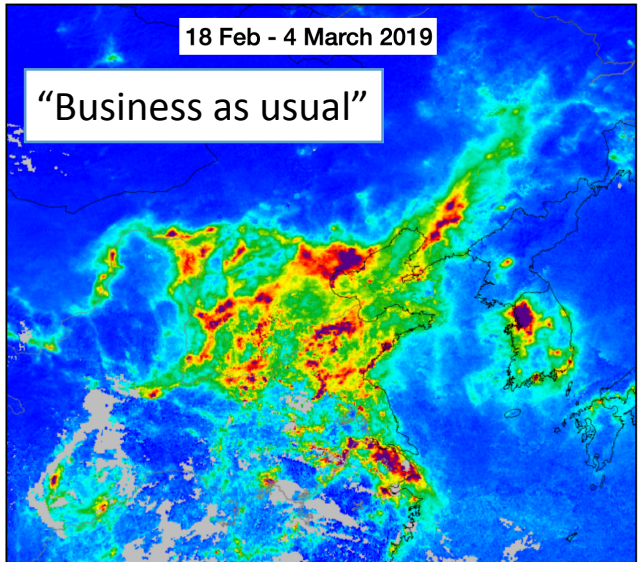
The high resolution of TROPOMI may be used to isolate emission (reductions) from different sources

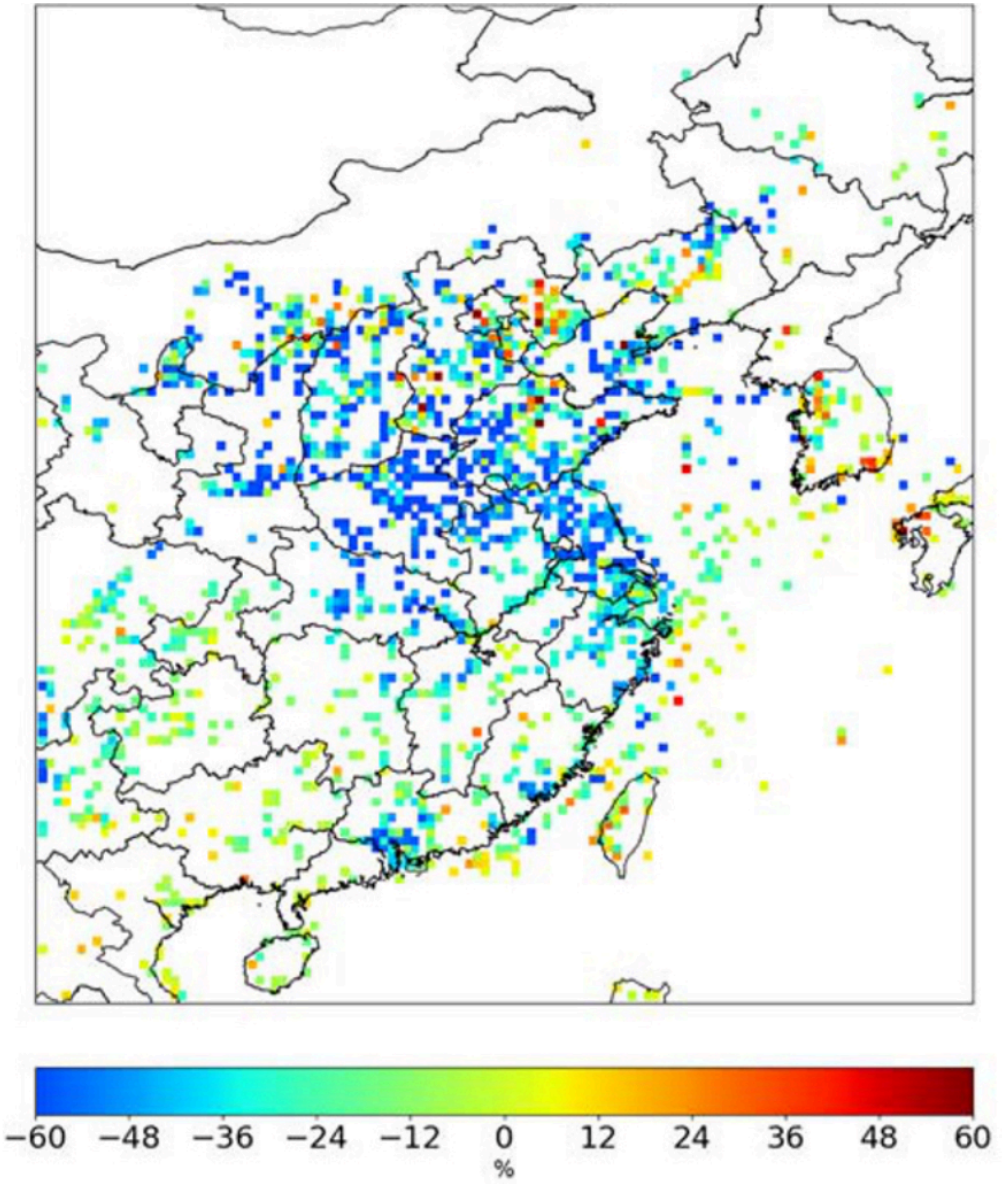
Image shows:
- Highways (lines)
- Cities
- Power plants (△)
- Industrial complexes (X)

F. Liu et al., Science Advances 2020

NO2 emission reduction related to COVID-19 lockdown in China





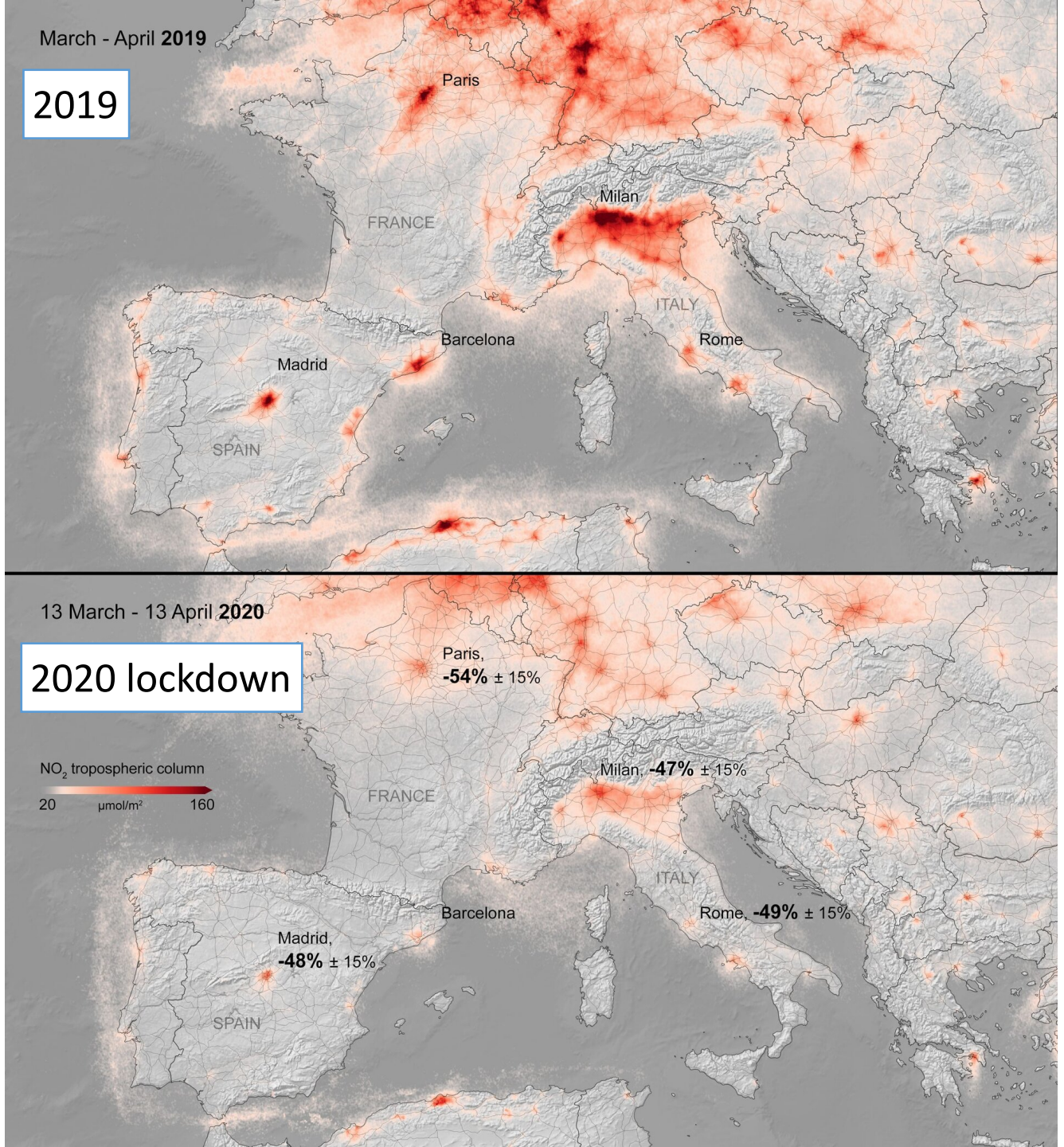


KNMI “DECSO” emission inversion based on Chimère model

NOx emission relative difference during-minus-before lockdown

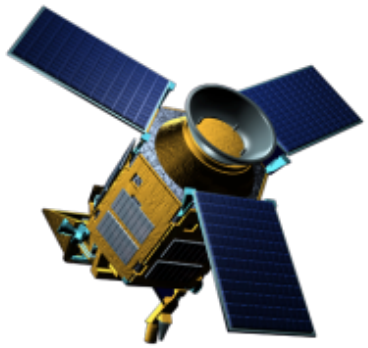
Detailed emission maps may be derived from the satellite data

Ding et al., GRL 2020



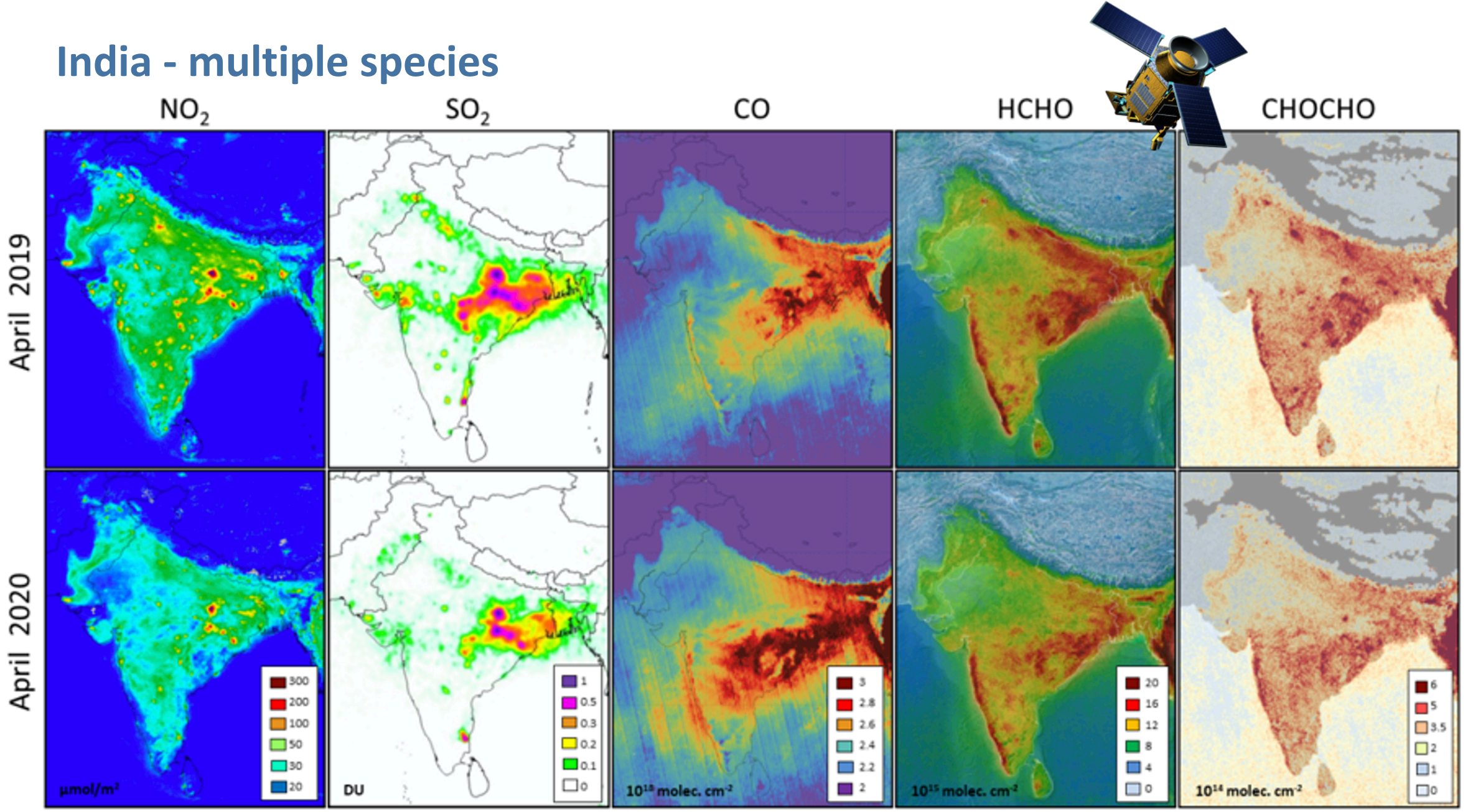
Strong reductions in NO_2 during lockdown in Italy, France, Spain in March-April 2020

About 50% less NO2 in the major cities compared to 2019



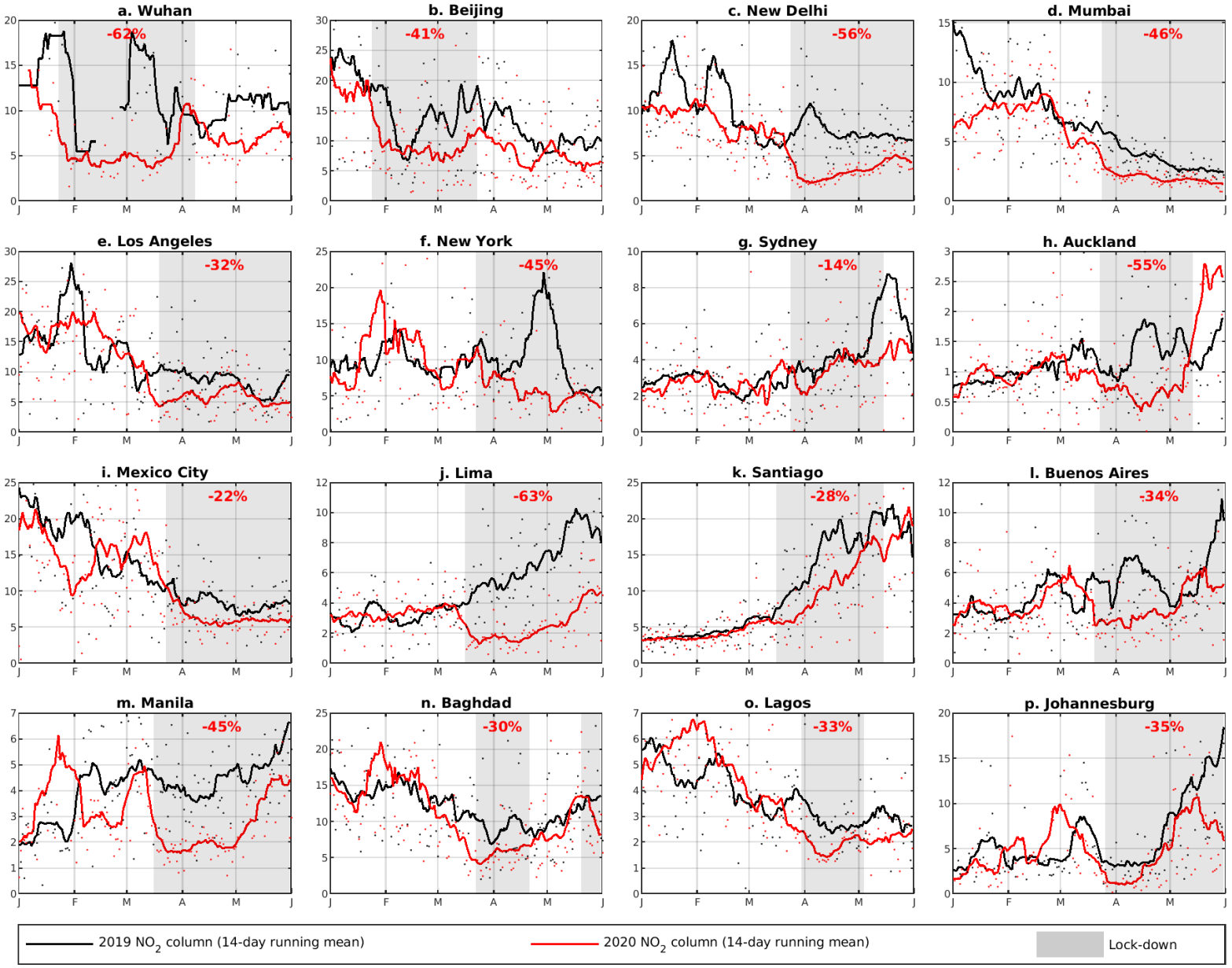
Graphics: ESA

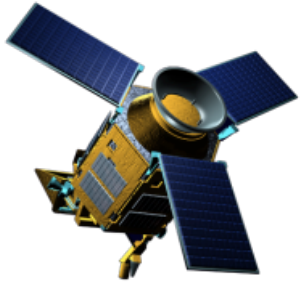
India - multiple species



Levelt et al., 2021 (submitted)

NO2 time series worldwide





Strong reductions in NO_2 concentrations during lockdown observed on all continents

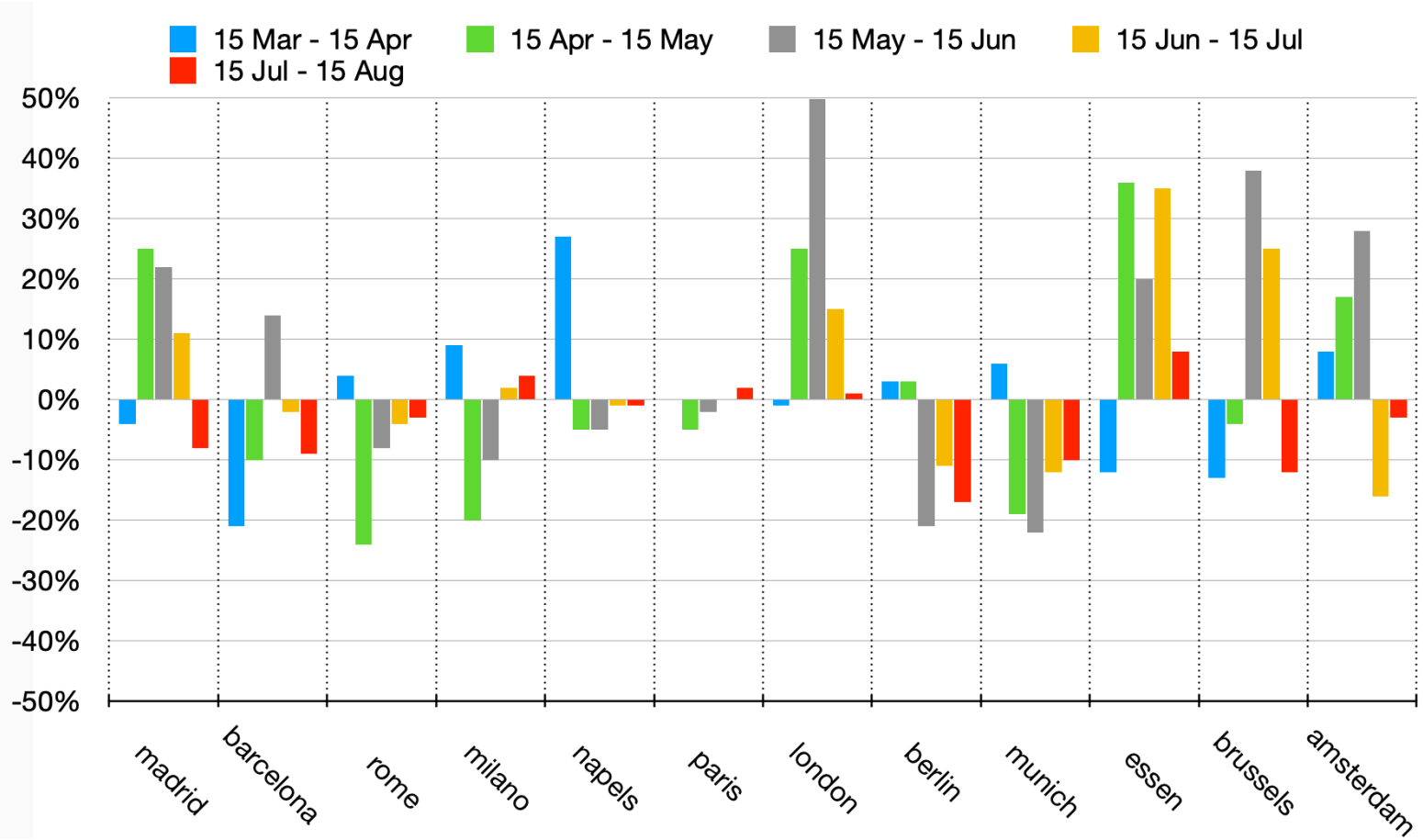
Red: 2020 time series
Black: 2019 time series

Grey shading: lockdown period

Numbers: reduction % 2020-2019 during lockdown

Maite Bauwens BIRA

Weather-indiced variability should be included for accurate analyses



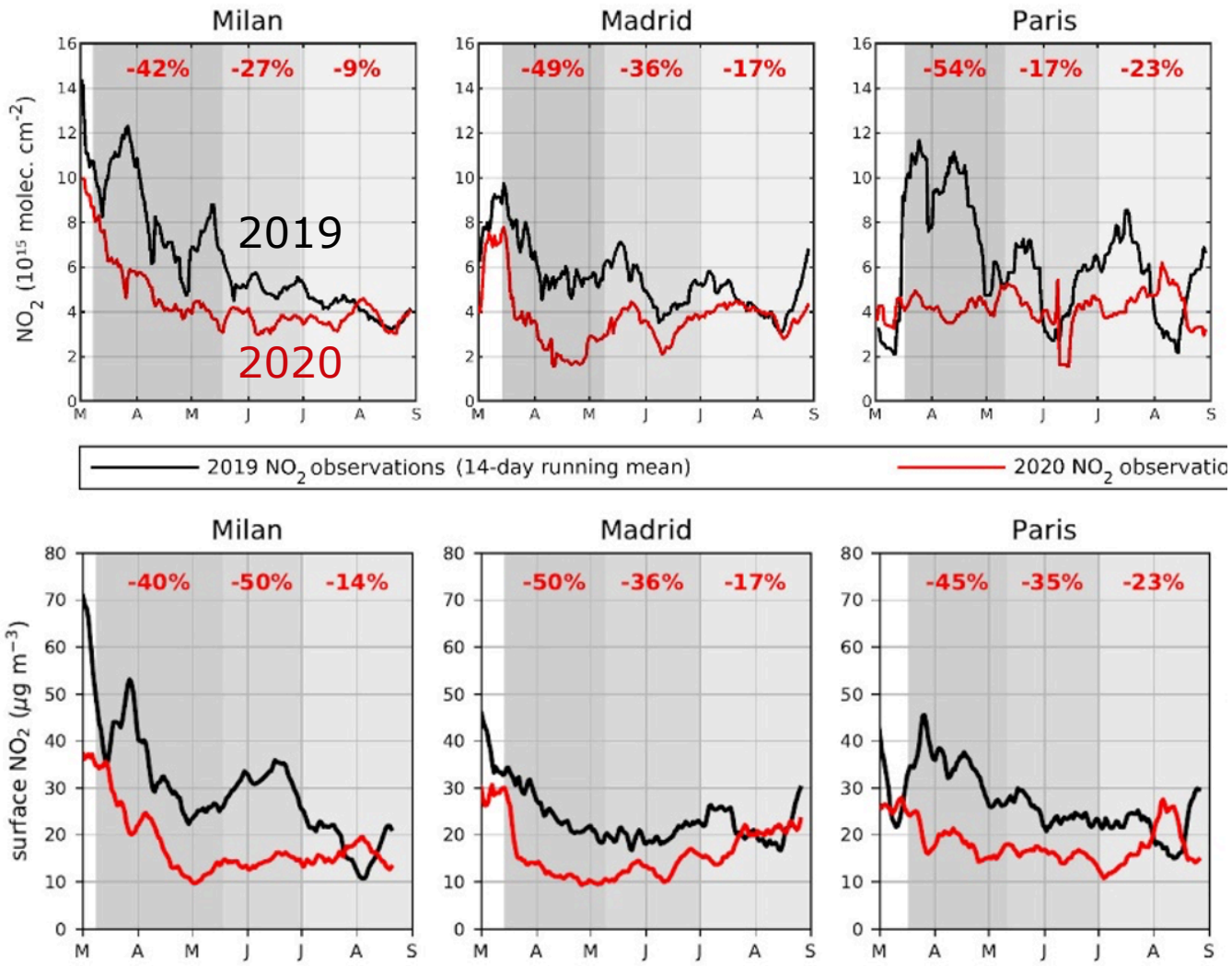
Model-estimated difference (2020 - 2019) / 2019 for fixed emissions cities in Europe

Estimated weather-induced variability in monthly means for individual cities on average: **13%**

Can be much larger for individual cities

Simulations with the LOTOS-EUROS model for 2019 and 2020 with fixed emissions,
John Douros, KNMI

TROPOMI observed reductions compared to surface observations



TROPOMI NO2

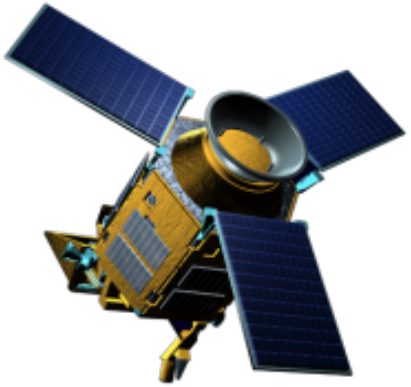
Good consistency between reductions observed by TROPOMI versus surface (EEA European air-quality monitoring stations)

Surface NO2

Bas Mijling, KNMI; Maite Bauwens BIRA ICOVAC ESA project

Summary: Impact COVID-19 measures on air quality observed by TROPOMI

- **Advantages TROPOMI**: pixel size 3.5x5.5 km^2, daily global coverage, high signal to noise, large spectral range (large number of species retrieved).
- TROPOMI observes **unprecedented sudden major reductions in NO_2** concentrations on **all continents** related to world-wide **COVID-19 lockdown measures**. Reductions up to 50-60% are observed, mainly due to the transportation sector (cars, trucks, aircraft, ships). Relative reductions are generally consistent with surface concentration measurements.
- Massive public media and scientific attention for TROPOMI NO_2 data,
  40+ published scientific papers using TROPOMI (october 2020 status), many to follow.
- After the lockdowns, lasting typically a month, concentrations increased again,
  but not fully back to normal (10-20% reductions remain in Europe).
- Concentration observations have been used to estimate NOx **emission** reductions and impact on **other air pollutants** (ozone, aerosol) and **health** and **(free) tropospheric ozone.**
- Compared to independent observations the operational TROPOMI NO_2 (version 1.2/1.3) shows a low bias. Validation results indicate a proportionality of the bias with the tropospheric column. **Relative changes**, e.g. (2020-2019)/2019, are likely less affected, and we advise to focus on relative differences in COVID-19 studies.
- *Warning:* on 2 December 2020 the NO_2 product received an upgrade (to v1.4) resulting in higher NO_2 values. The 2021 values should not be combined with 2020 observations for trend studies.
  A reprocessing is foreseen to become available at the end of 2021.



Spare slides

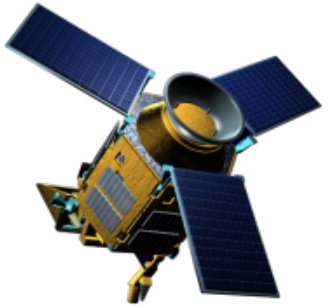
Papers on Impact COVID-19 on NO2, as observed by TROPOMI

- Kazuyuki Miyazaki, Kevin Bowman, Takashi Sekiya, Masayuki Takigawa, Jessica L. Neu, Kengo Sudo, Greg Osterman, Henk Eskes, Global tropospheric ozone responses to reduced NOx emissions linked to the COVID-19 world-wide,
- Gkatzelis, et al., The global impacts of COVID-19 lockdowns on urban air pollution: A critical review and recommendations. Elementa: Science of the Anthropocene 21 January 2021; 9 (1): 00176. doi: https://doi.org/10.1525/elementa.2021.00176
- 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.
- Griffin, D.; McLinden, C.A.; Racine, J.; Moran, M.D.; Fioletov, V.; Pavlovic, R.; Mashayekhi, R.; Zhao, X.; Eskes, H., Assessing the Impact of Corona-Virus-19 on Nitrogen Dioxide Levels over Southern Ontario, Canada, Remote Sens. 12, 4112, https://doi.org/10.3390/rs12244112, 2020.
- Miyazaki, K., Bowman, K., Sekiya, T., Jiang, Z., Chen, X., Eskes, H., et al., Air quality response in China linked to the 2019 novel coronavirus (COVID-19) lockdown, Geophysical Research Letters, 47, e2020GL089252, https://doi.org/10.1029/2020GL089252, 2020.
- Ding, J., van der A, R. J., Eskes, H. J., Mijling, B., Stavrakou, T., van Geffen, J. H. G. M., et al., NOx emissions reduction and rebound in China due to the COVID-19 crisis, Geophysical Research Letters, 46, e2020GL089912, https://doi.org/10.1029/2020GL089912, 2020.
- Liu, F., A. Page, S. A. Strode, Y. Yoshida, S. Choi, B. Zheng, L. N. Lamsal, C. Li, N. A. Krotkov, H. Eskes, R. van der A, P. Veefkind, P. F. Levelt, O. P. Hauser, J. Joiner, Abrupt decline in tropospheric nitrogen dioxide over China after the outbreak of COVID-19, Sci. Adv. 6, eabc2992, DOI: 10.1126/sciadv.abc2992 (2020).
- Bauwens, M., Compernolle, S., Stavrakou, T., Müller, J.-F., van Gent, J., Eskes, H., et al., Impact of coronavirus outbreak on NO2 pollution assessed using TROPOMI and OMI observations, Geophysical Research Letters, 47, e2020GL087978. https://doi.org/10.1029/2020GL087978, 2020.

Copernicus Sentinel-5P TROPOMI instrument

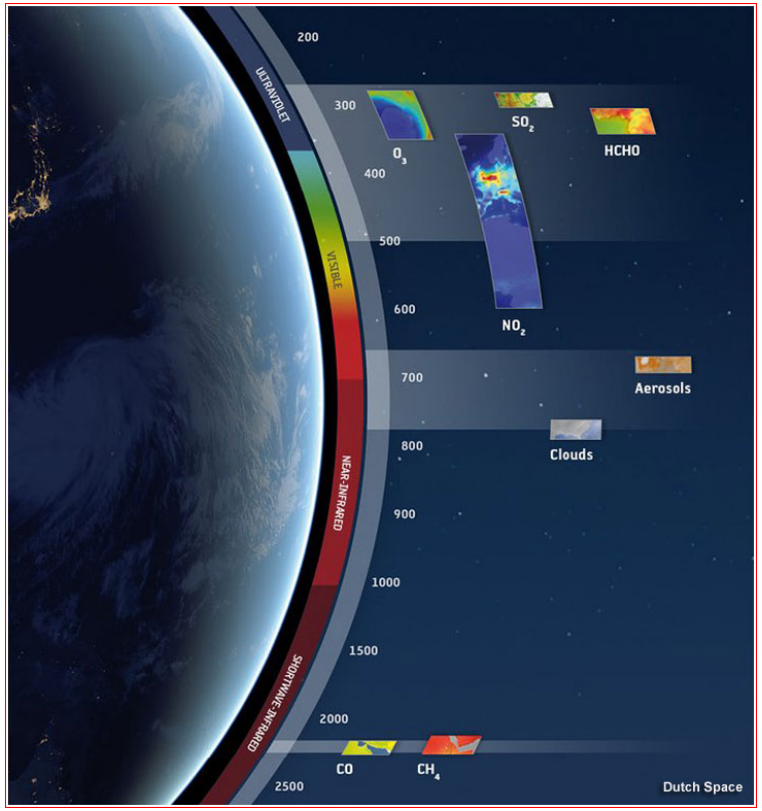
Dutch instrument Pepijn Veefkind PI (KNMI) Airbus DS, TNO, SRON, KNMI, NSO, ESA, EU

Mission objectives: **Air Quality, Climate Change, Ozone layer**

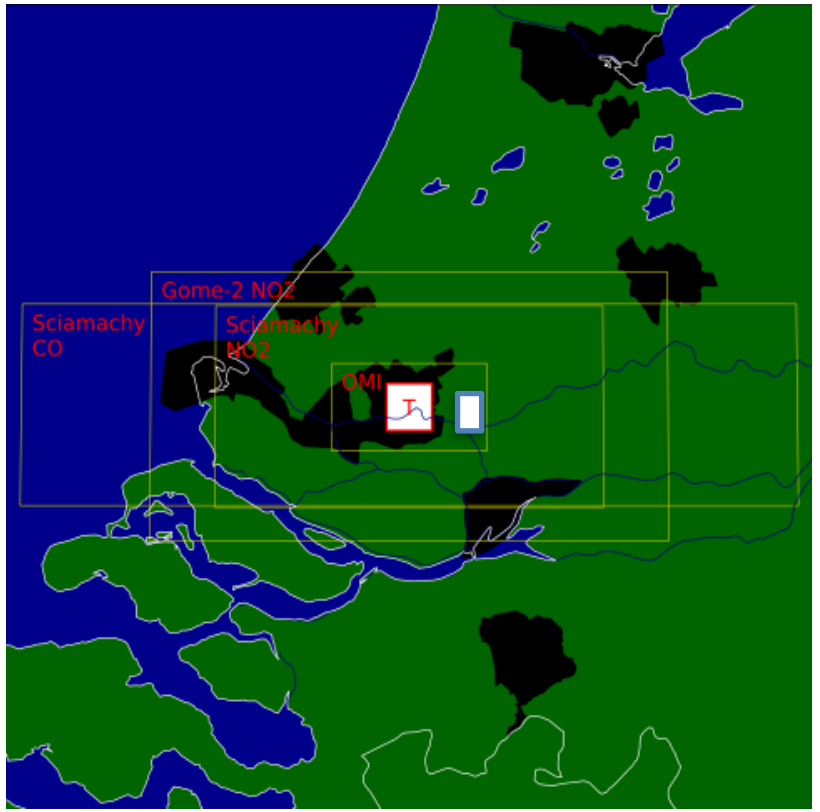


TROPOMI combines:

High signal-to-noise
Large spectra range
(large number of trace gas species)

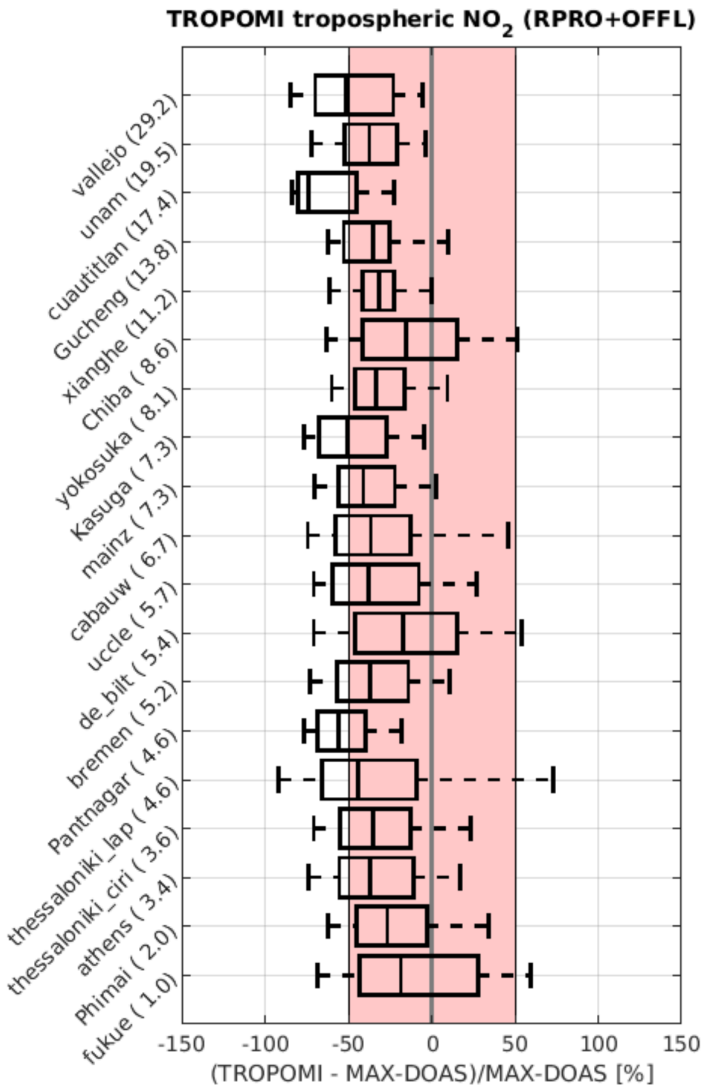


High spatial resolution (3.5 x 5.5 km)



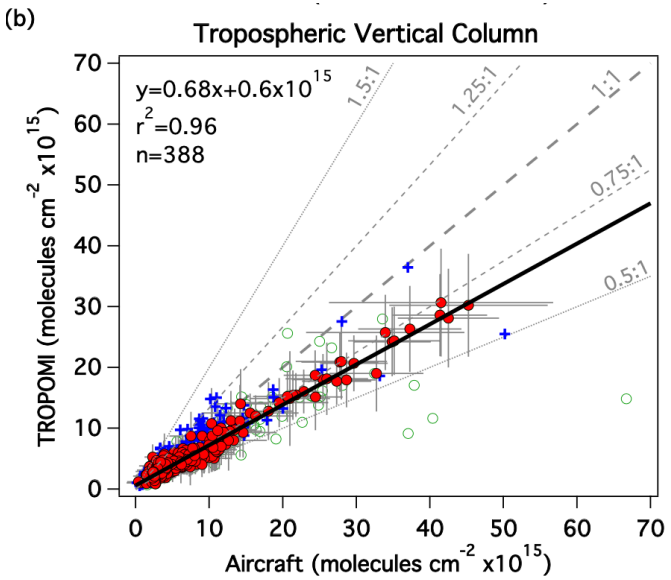
Daily global coverage

TROPOMI NO_2 v1.3: Validation summary

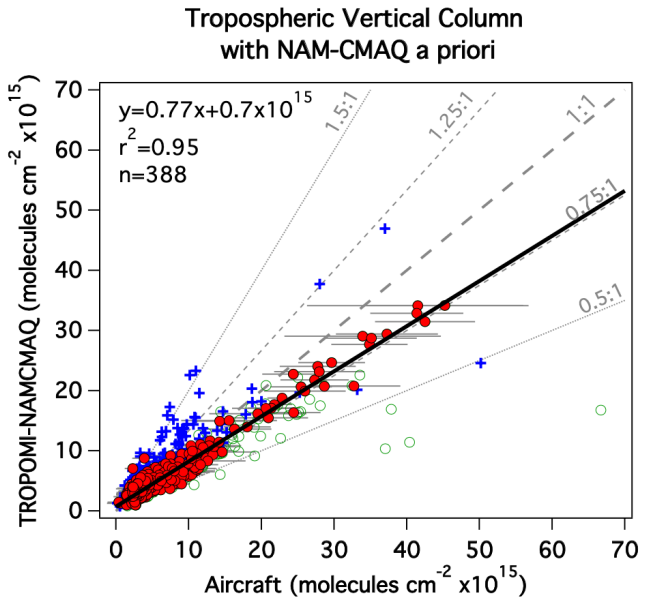


TROPOMI 20-50% lower than MAX-DOAS

Verhoelst et al., 2020



TROPOMI vs aircraft
Slope 0.68
R^2 = 0.96

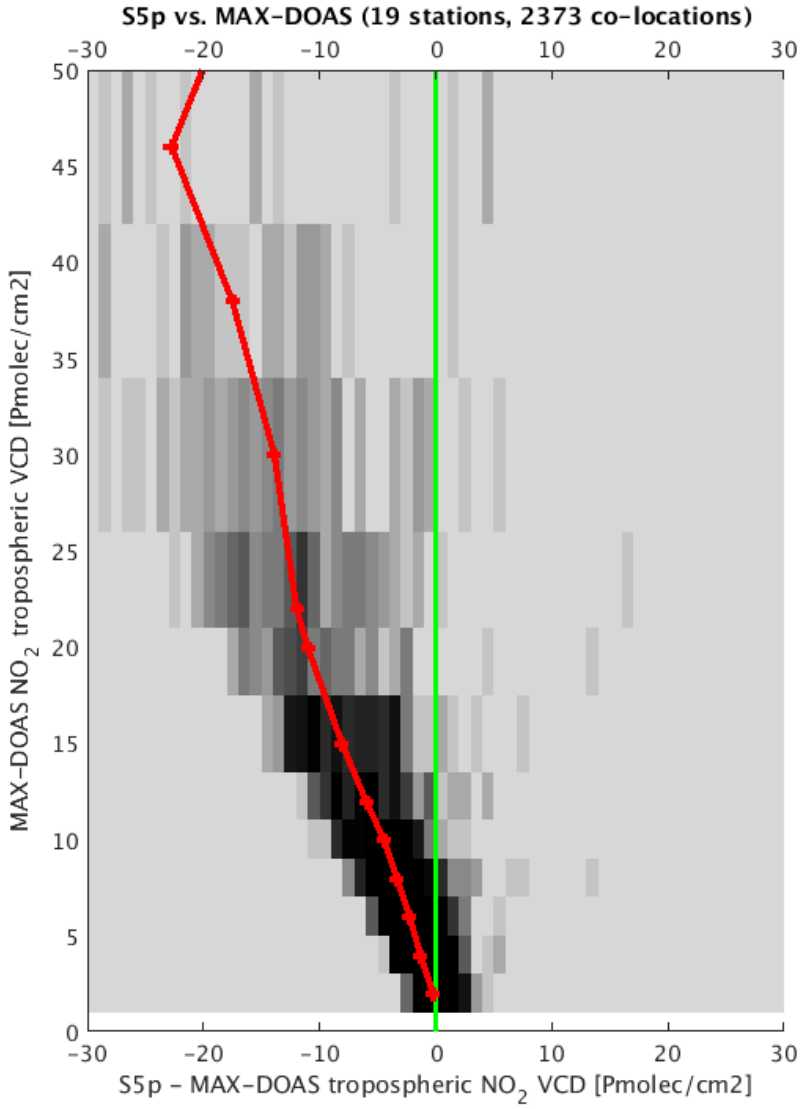


With high-res a-priori
Slope 0.77
R^2 = 0.95

Judd et al., 2020
Tack et al., 2020

Conclusions:
- TROPOMI has low bias
- Partly due to (resolution of) the a-priori NO2 profile.
- High correlation vs aircraft

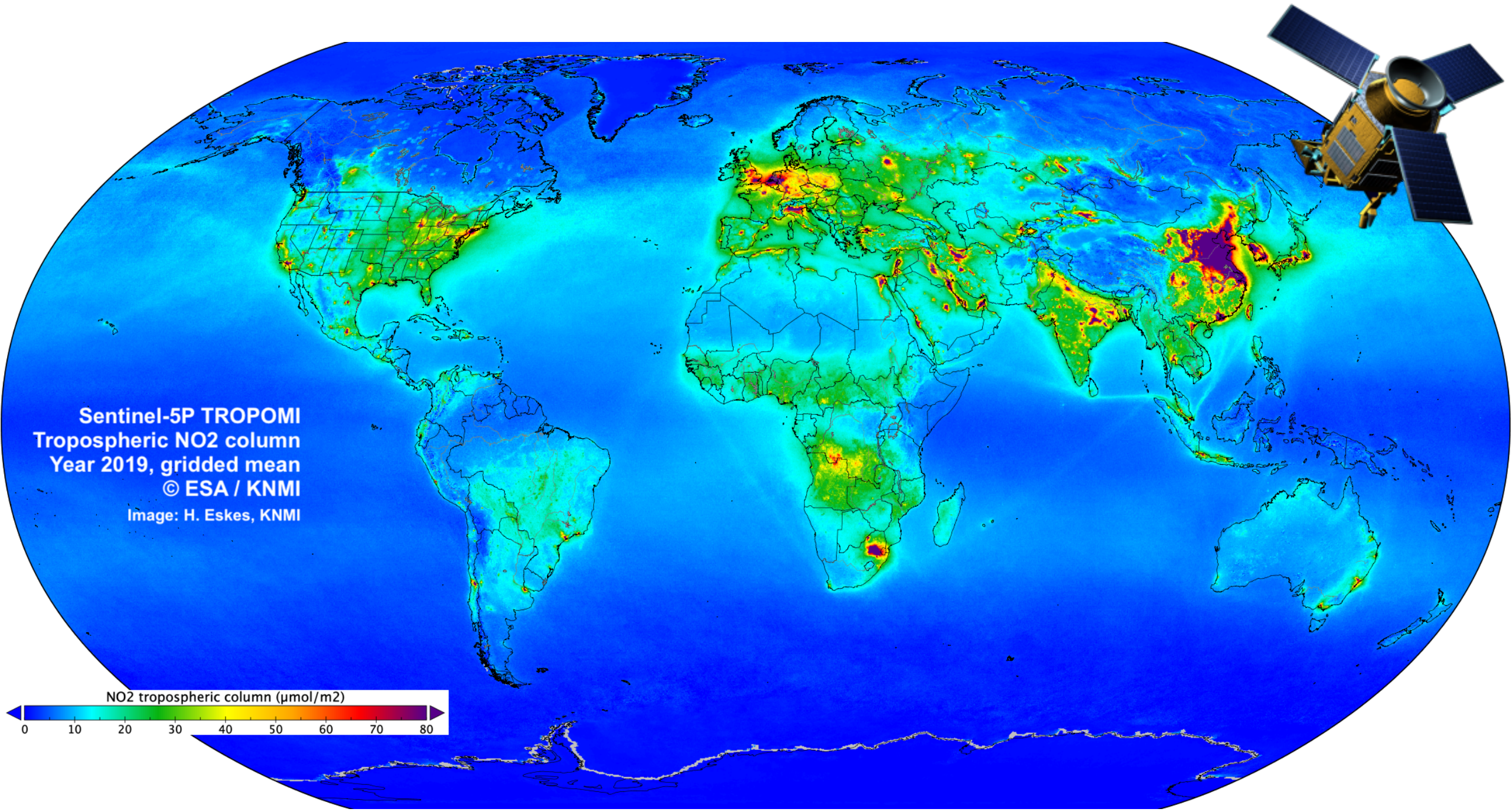
TROPOMI NO_2 v1.3: Validation summary



The bias observed between TROPOMI and MAXDOAS scales roughly linearly with the tropospheric column amount.

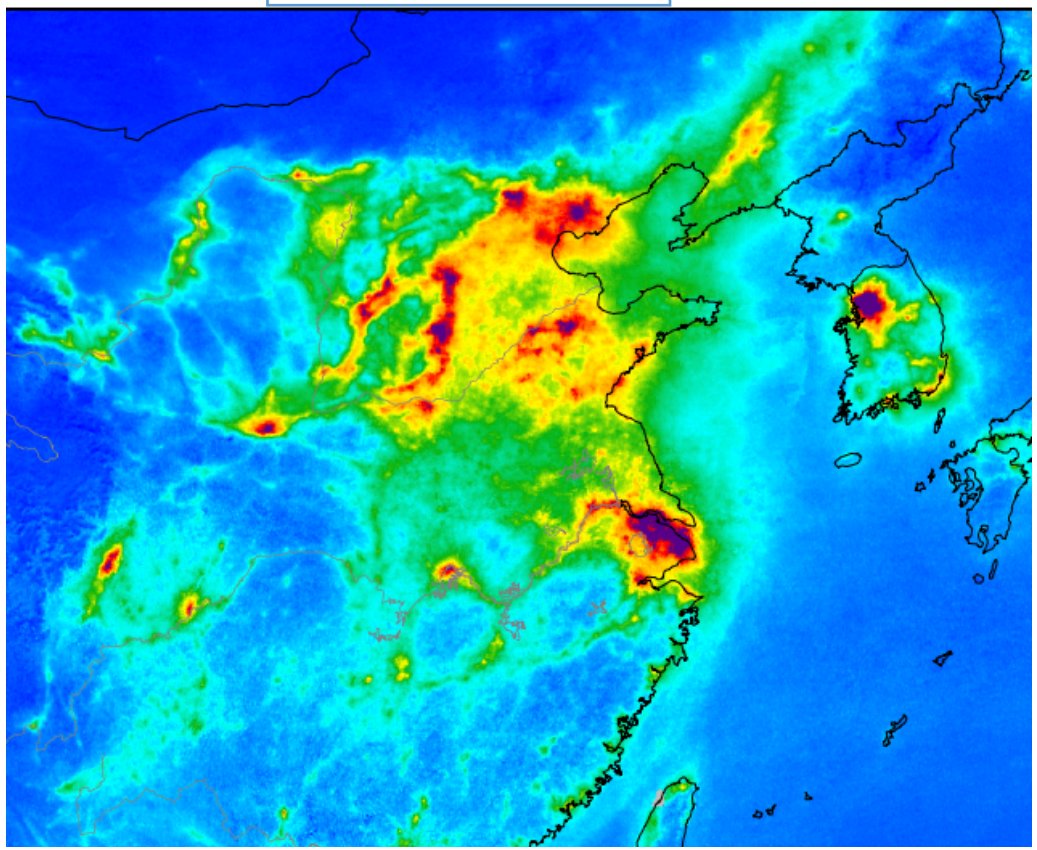
This suggests that relative changes, e.g. (2020-2019)/2019, should not be affected too much by the likely negative bias of the TROPOMI product.

Image by Tijl Verhoelst, BIRA-IASB
Verhoelst et al., 2020

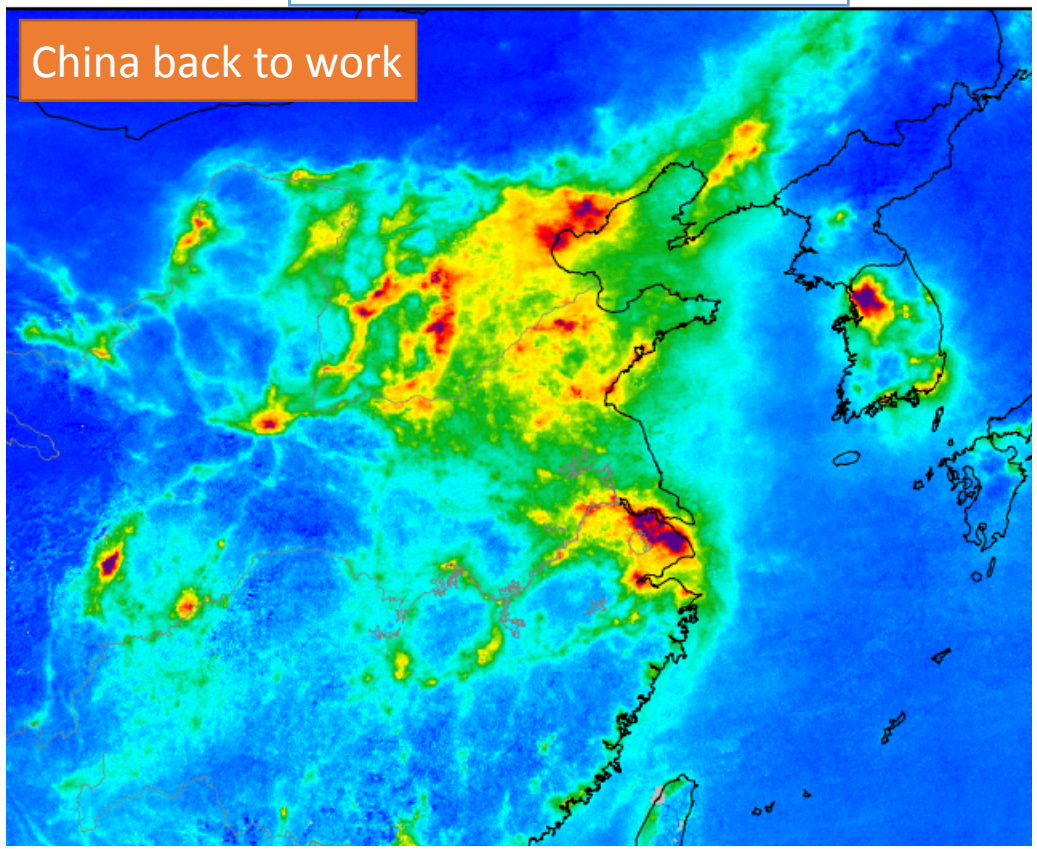

Sentinel-5P TROPOMI
Tropospheric NO2 column
Year 2019, gridded mean
© ESA / KNMI
Image: H. Eskes, KNMI
NO2 tropospheric column (µmol/m2)
0
10
20
30
40
50
60
70
80

At the same time: China back to work in March-April

March-April 2019



13 March - 13 April 2020



NO_2 tropospheric column ($\mu mol/m^2$)

0 50 100 150 200 250

- Indication of reductions in NO_2 pollution compared to 2019 after lockdown was lifted, depending on the region

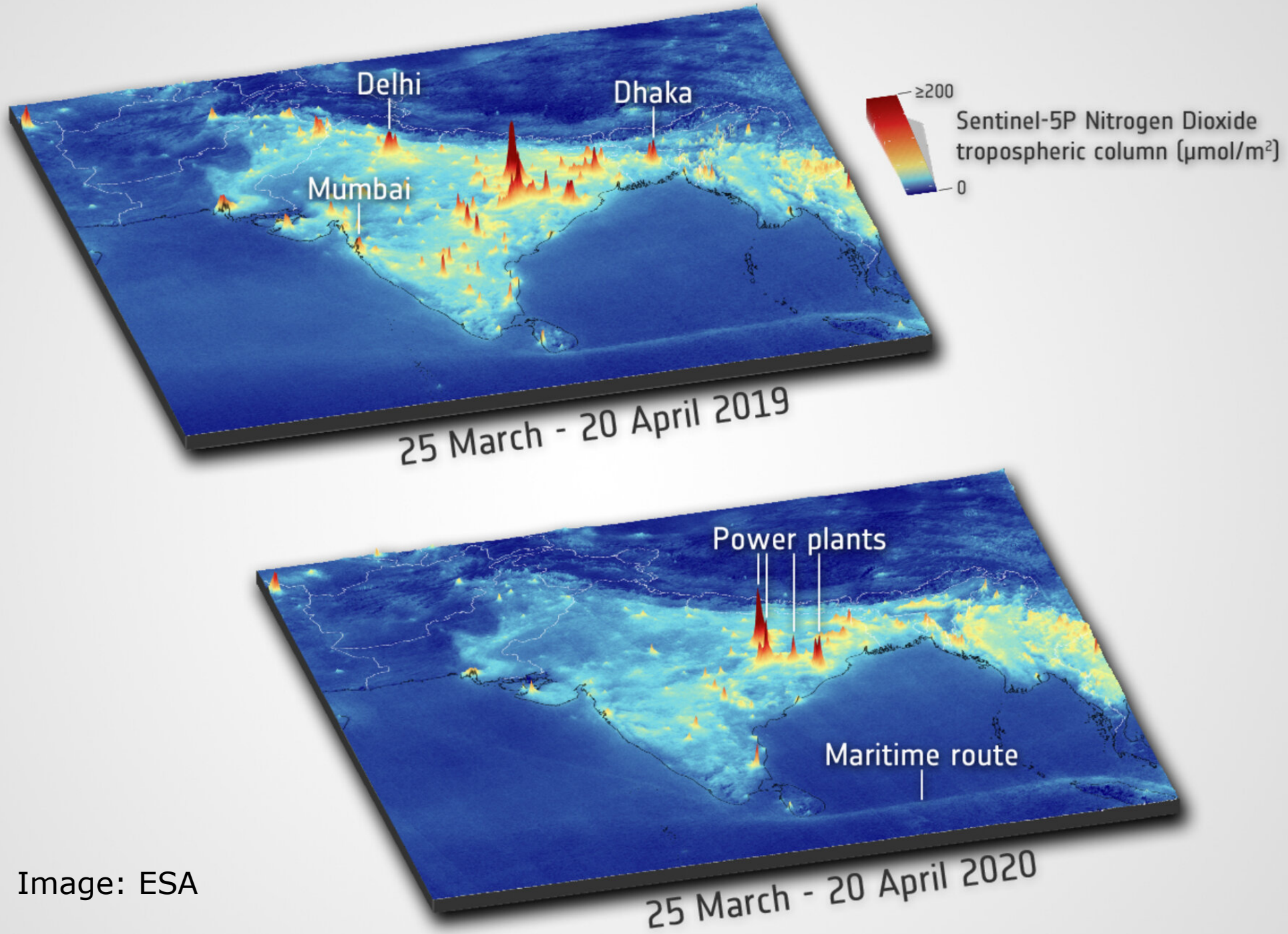
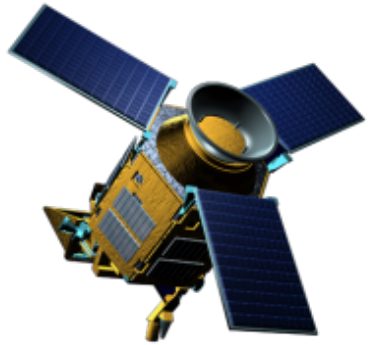


Image: ESA

Strong reductions in NO_2 during lockdown in India

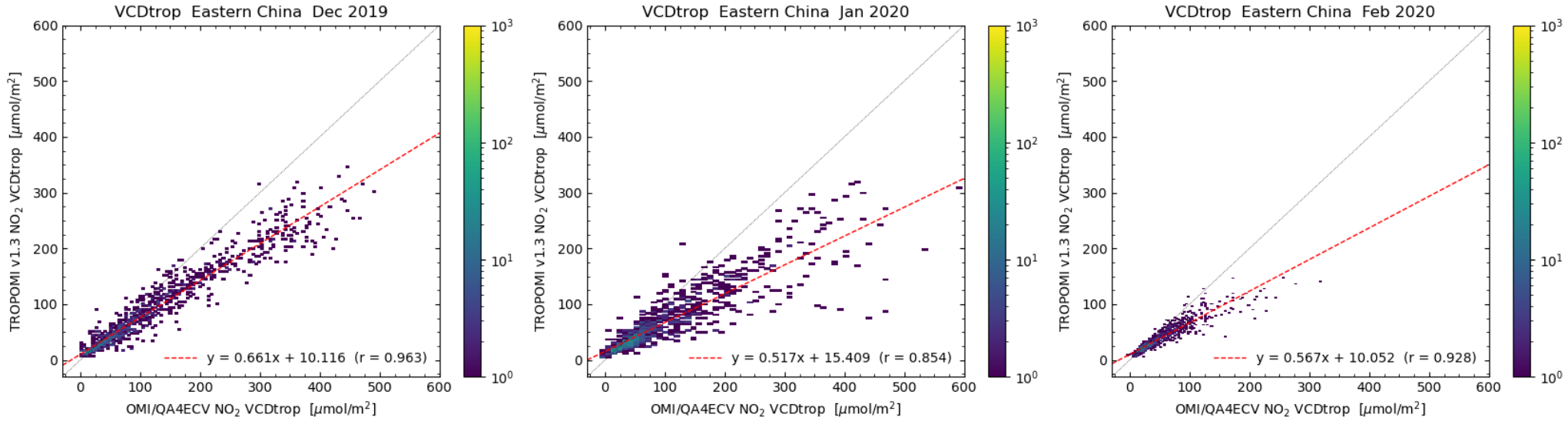
Differences megacities vs. coal powerplants



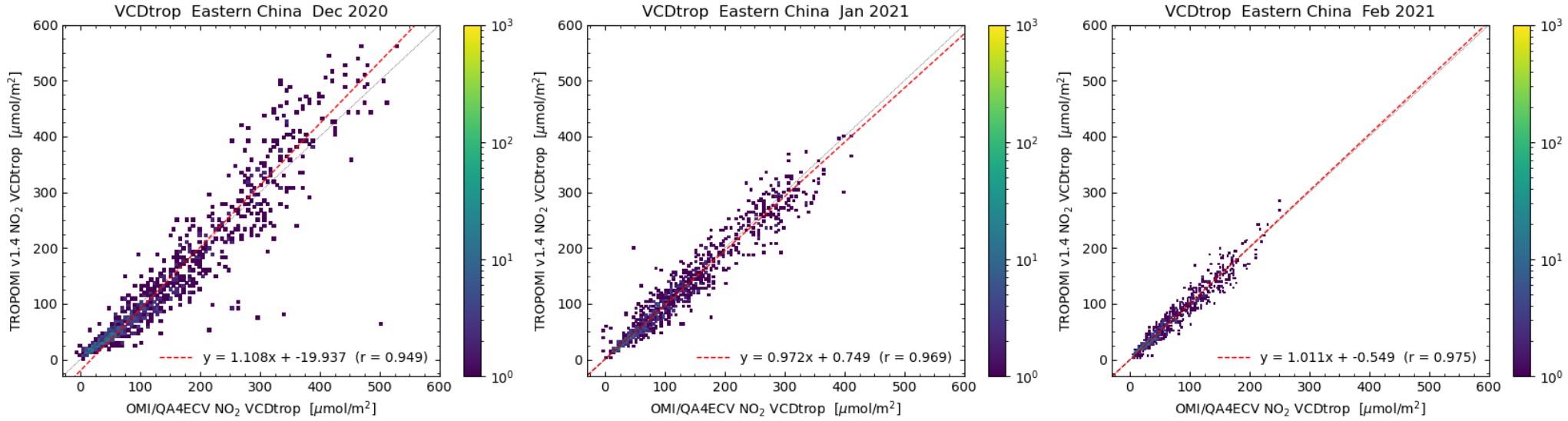
And what about 2021? Large change in NO2 product with v1.4

December | January | February

v1.3: 2019 / 2020

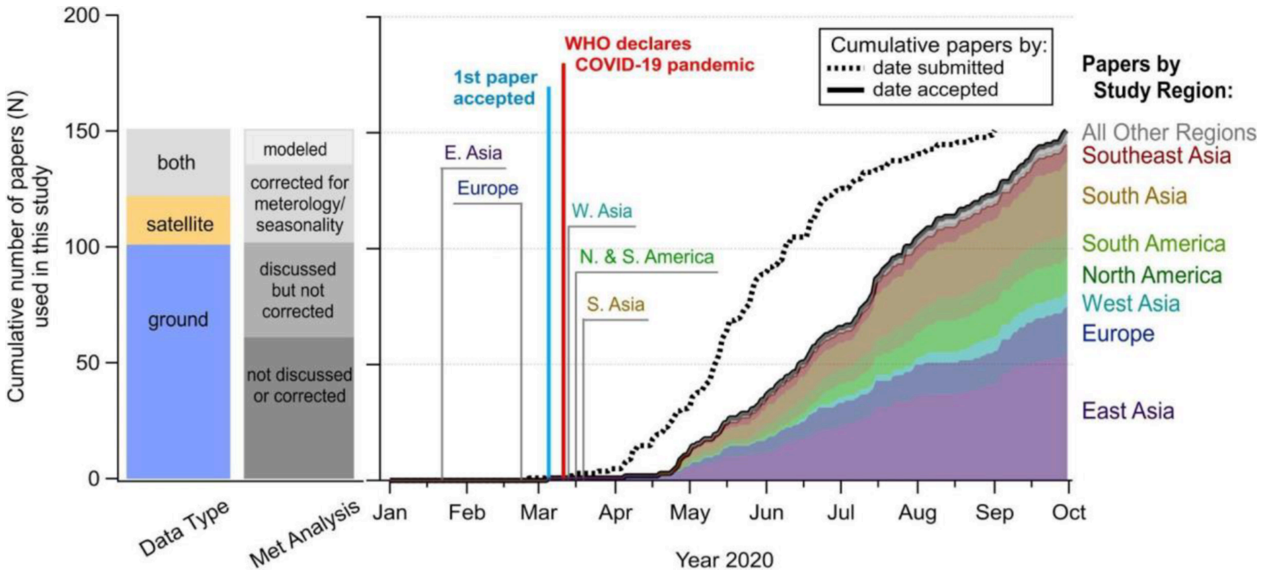


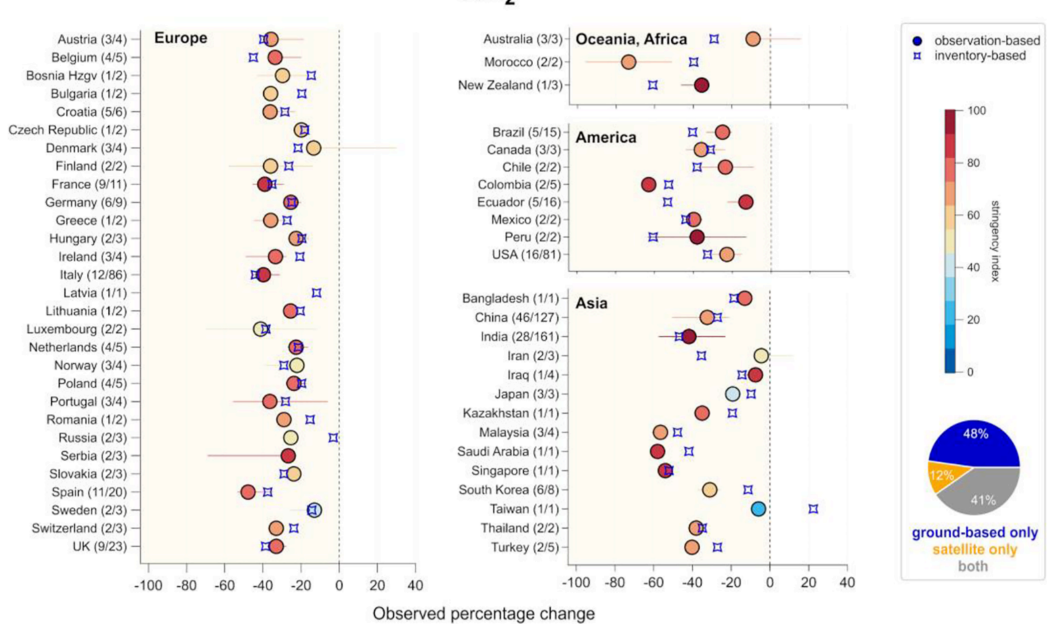
v1.4: 2020 / 2021



Jos van Geffen

Massive scientific attention for TROPOMI observations during COVID-19



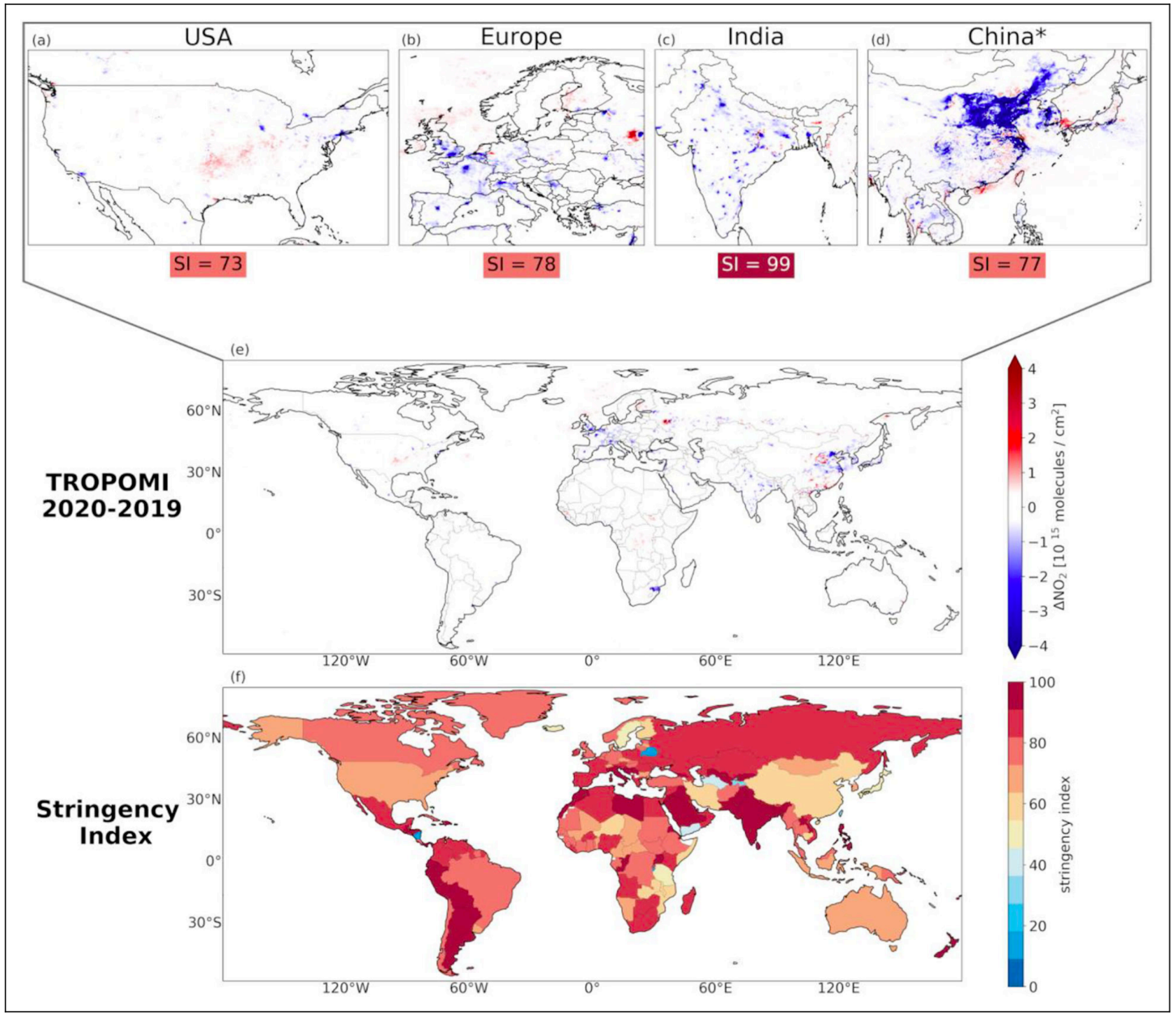


Review of 150 accepted papers until 1 October 2020:
about 50 papers make use of satellite data, mainly TROPOMI

Gkatzelis, et al; The global impacts of COVID-19 lockdowns on urban air pollution: A critical review and recommendations. https://doi.org/10.1525/elementa.2021.00176

Website with database of papers:
https://covid-aqs.fz-juelich.de

Gkatselis et al. review paper



Correcting for meteorological effects using CAMS-global reanalysis

Gkatzelis, et al;
The global impacts of COVID-19 lockdowns on urban air pollution:
A critical review and recommendations.
https://doi.org/10.1525/elementa.2021.00176

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