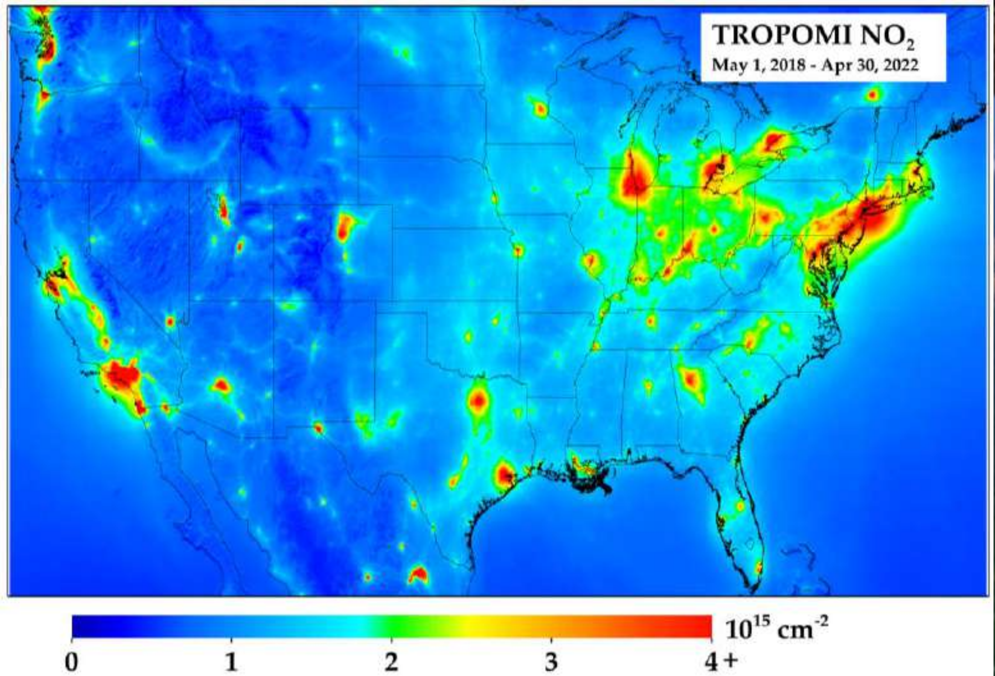
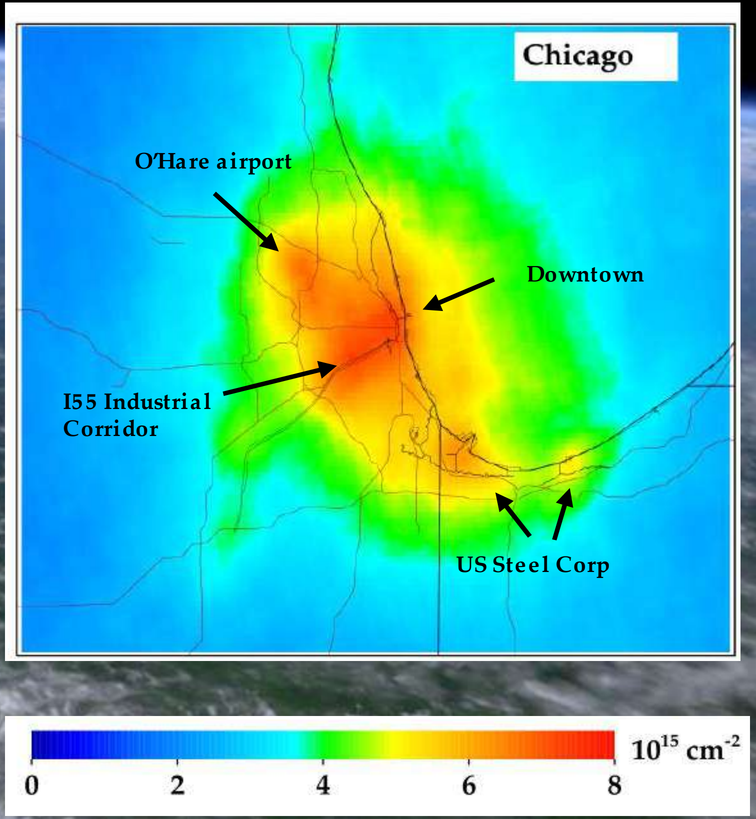
Policy and Health Relevant Applications of TROPOMI NO_2 in the United States

By: Dan Goldberg, PhD
George Washington University

Sentinel-5P Mission: 5 years anniversary
Tuesday 11 October 2022





Milken Institute School of Public Health
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ESA: TROPOMI on the Sentinel 5 Precursor Satellite

Thank you Sentinel-5P Operational Science Team!

Instrument has been ***extremely*** useful and reliable from an end-user standpoint


Dr. Maria Tzortziou


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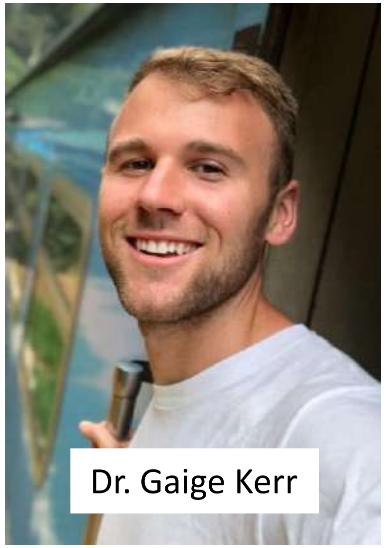
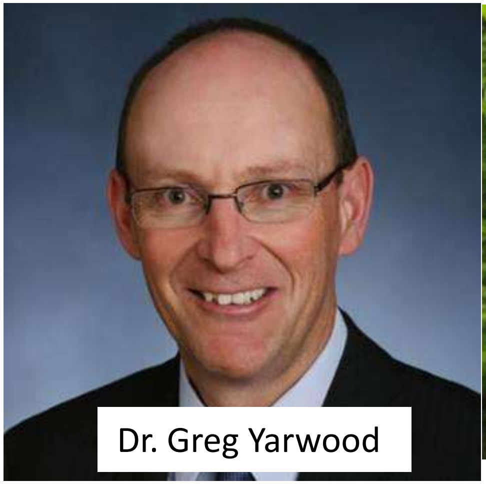
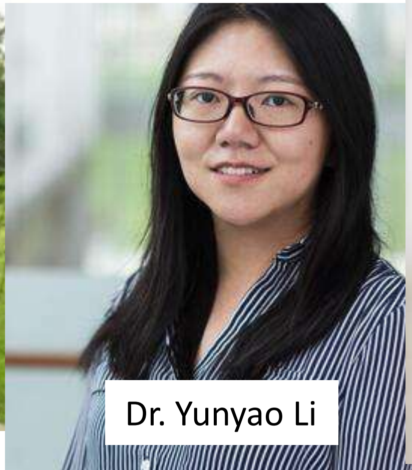

Dr. Gaige Kerr


Dr. Susan Anenberg


Dr. Tracey Holloway


Dr. Greg Yarwood


Dr. Ben de Foy


Dr. Yunyao Li


Dr. Daniel Tong


Nigel Martis


Perrin Krisko

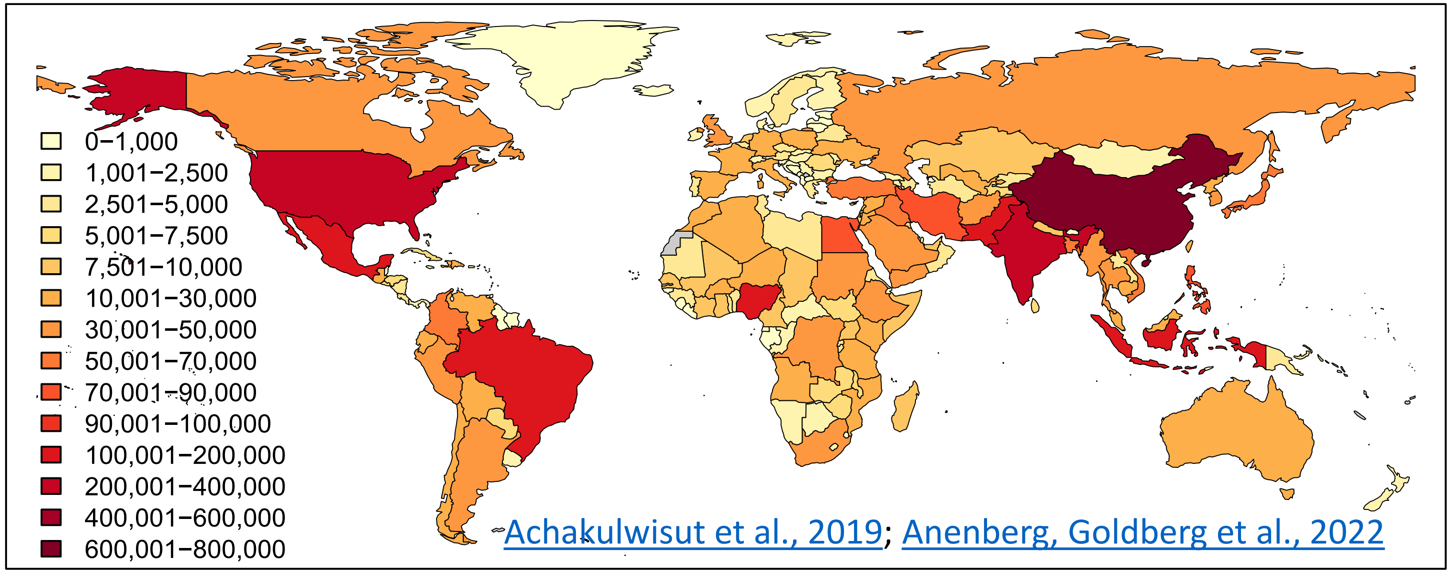
Health effects of NO_2

- Impairs cardiovascular function leading to potential cardiovascular diseases and premature mortality

- Causes and exacerbates asthma

In 2019, 1.8 million (95% CI 0.9 - 2.8) children developed asthma due to NO_2 pollution, responsible for 16% of all asthma

(a) Number of new asthma cases due to NO_2 exposure



Achakulwisut et al., 2019; Anenberg, Goldberg et al., 2022

- Co-emitted with other harmful pollutants (diesel PM, VOC air toxics, heavy metals, etc.)

- Inequitably distributed across the urban landscape; racialized, marginalized, and minoritized communities experience worse NO_2

Motivation

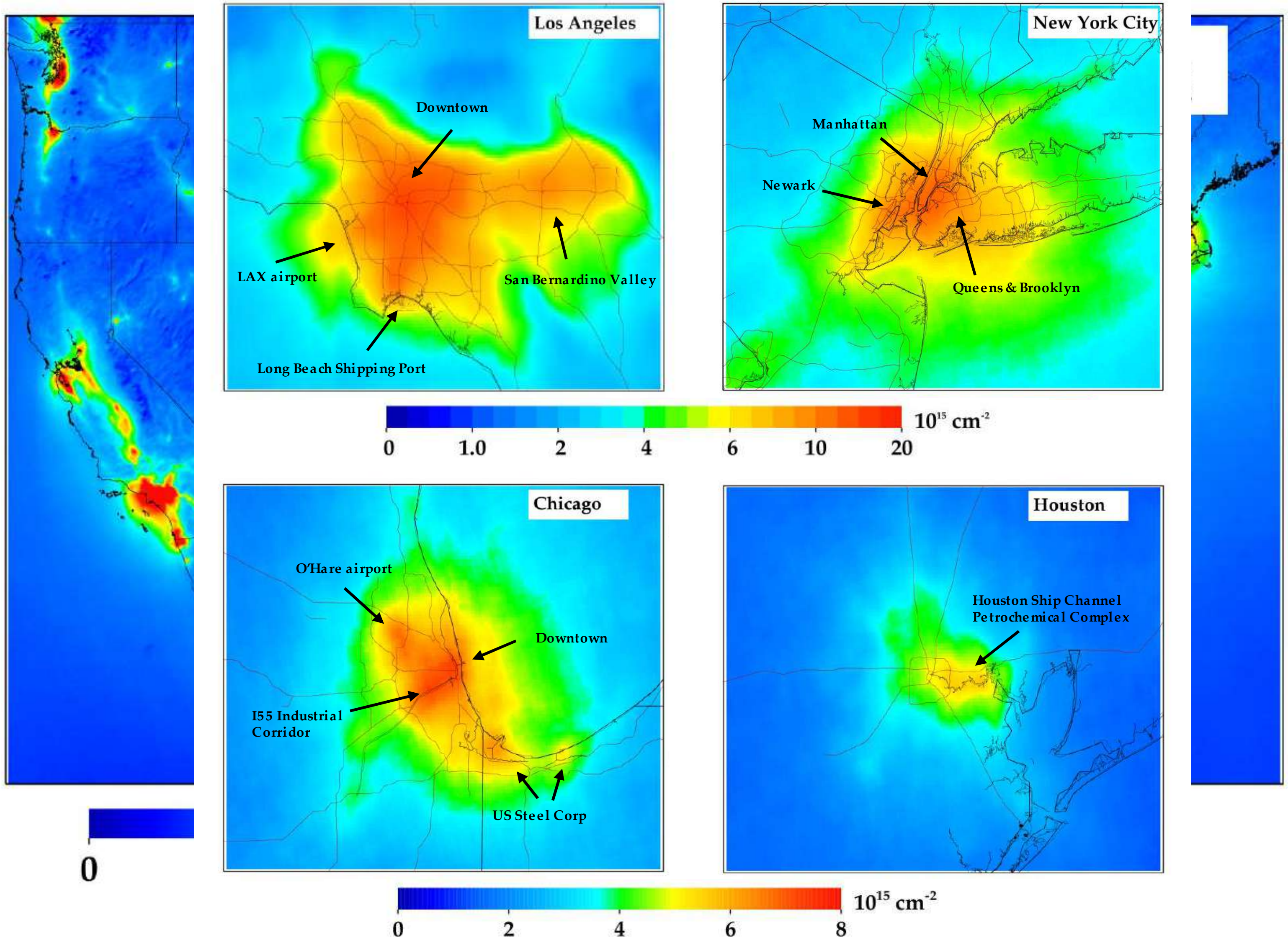
Improved spatial resolution of TROPOMI now allows us to assemble information at the local scale (~1 km).

Questions:

- Can we use TROPOMI data to differentiate NO_X emissions from highways, ports, airports, and large points sources within a metropolitan area?

- Can we use TROPOMI data to diagnose environmental justice issues within urban areas (e.g., NO_2 in poorer neighborhoods) without the use of an additional model?

4-year average of TROPOMI NO_2 at 0.01° × 0.01°

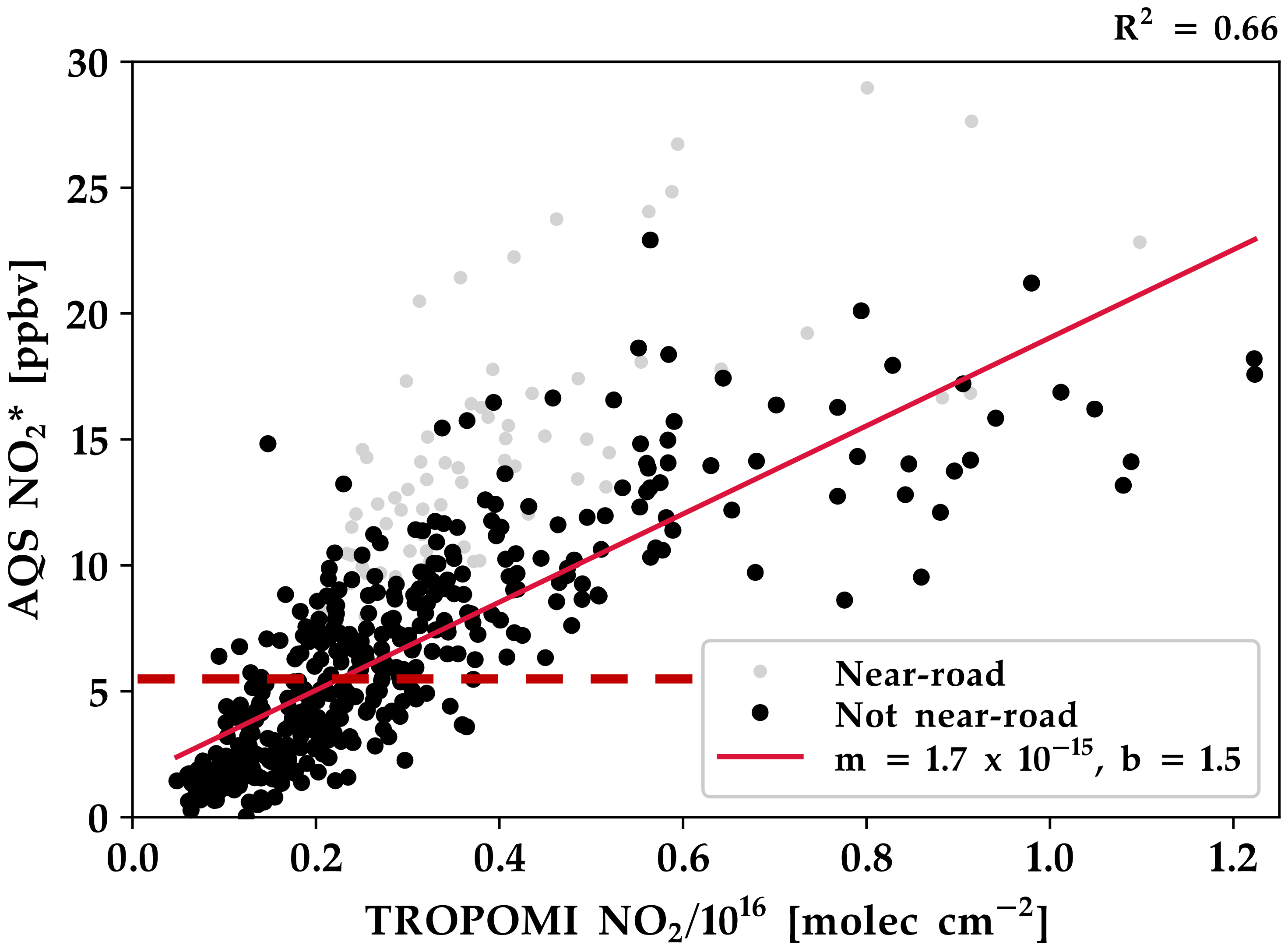


US areas with "worst" NO_2

State	Lat	Lon	Value	Detailed location
CA	34.03	-118.18	1.41E+16	E Los Angeles, CA
NY	40.72	-73.97	1.13E+16	East River, Brooklyn, NY
NJ	40.69	-74.14	9.75E+15	Port Newark, NJ
IL	41.82	-87.77	7.31E+15	Cicero, Chicago, IL (near MDW)
WA	47.46	-122.26	6.90E+15	Tukwila, WA (SE Seatle)

Goldberg et al., 2021a

TROPOMI NO_2: Great correlation with surface measurements



- $R^2 = 0.66$; great correlation between satellite and surface monitors

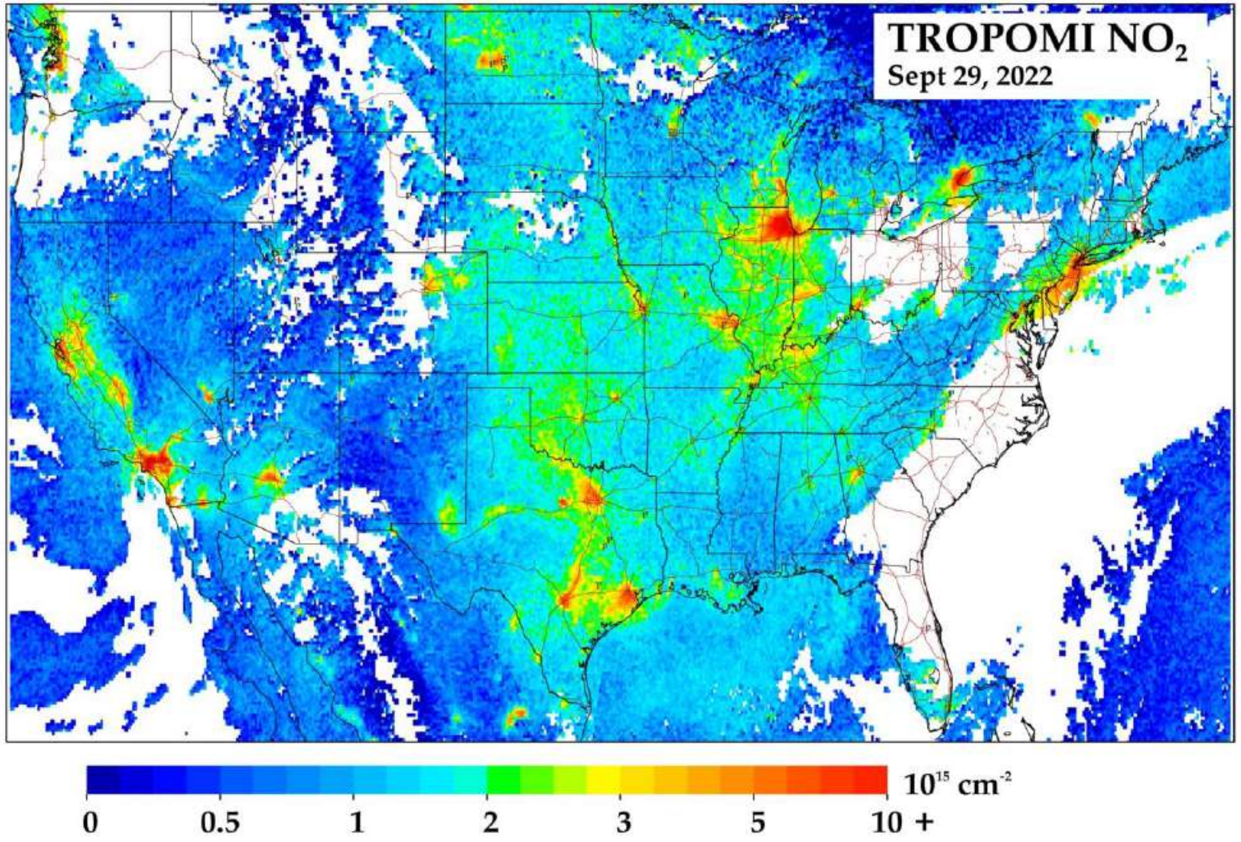
- WHO (health) guideline: 5.3 ppb
- EPA standard: 53 ppb

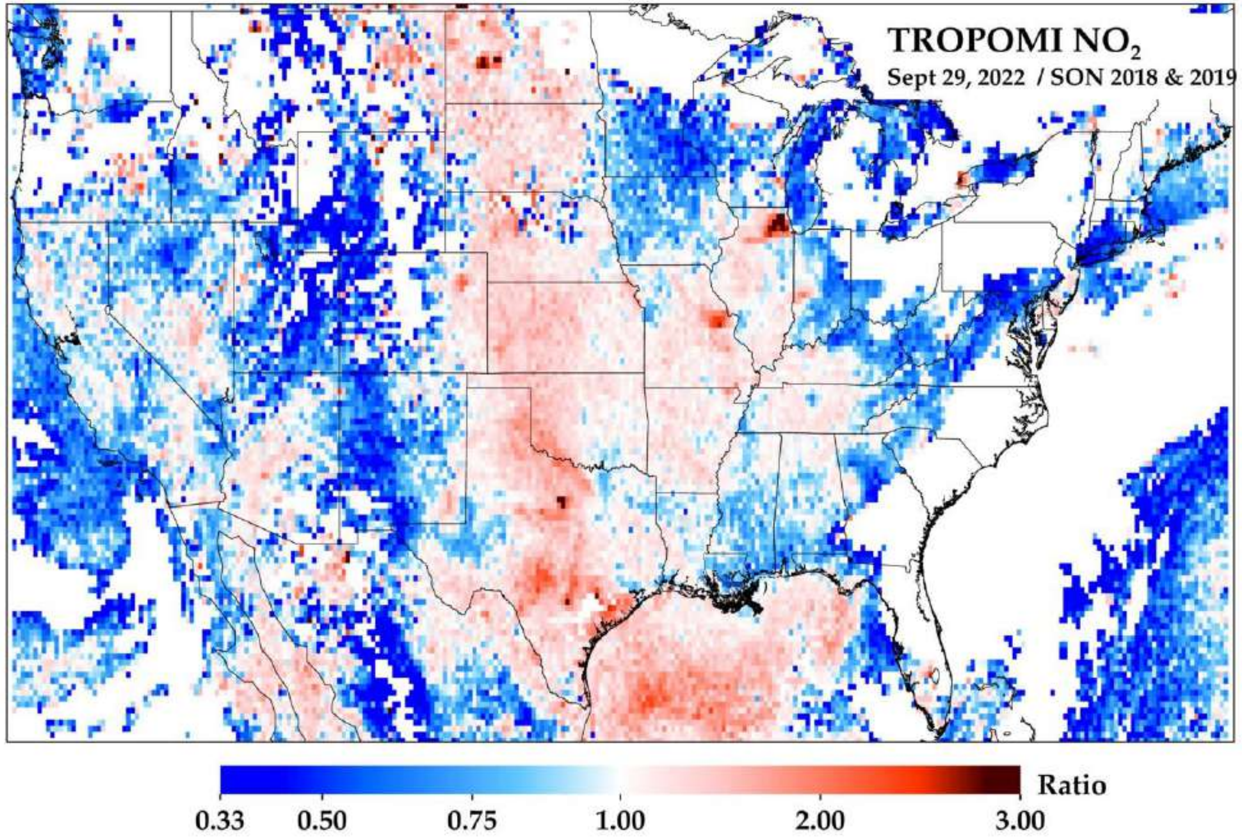
- 0.2×10^{16} molec $cm^{-2} \approx 5$ ppb NO_2
- 0.5×10^{16} molec $cm^{-2} \approx 10$ ppb NO_2
- 1.0×10^{16} molec $cm^{-2} \approx 18$ ppb NO_2

Goldberg et al., 2021a

Near-real-time images of TROPOMI NO_2

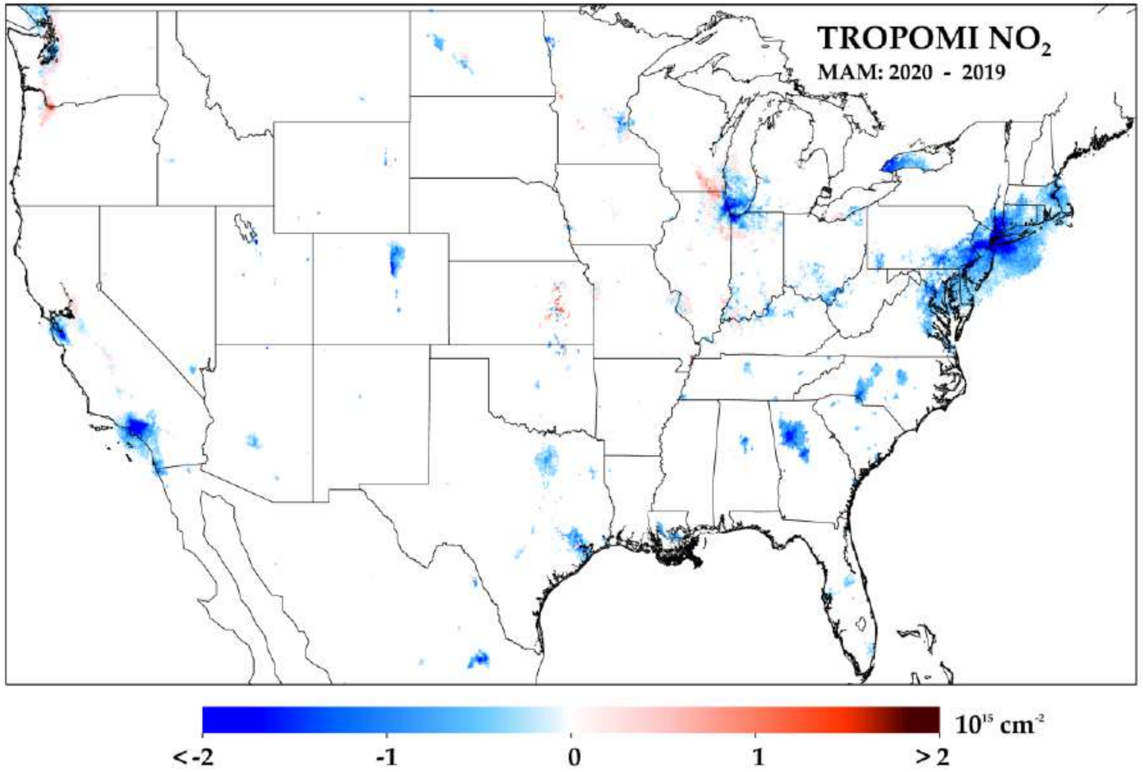
tropomino2.us





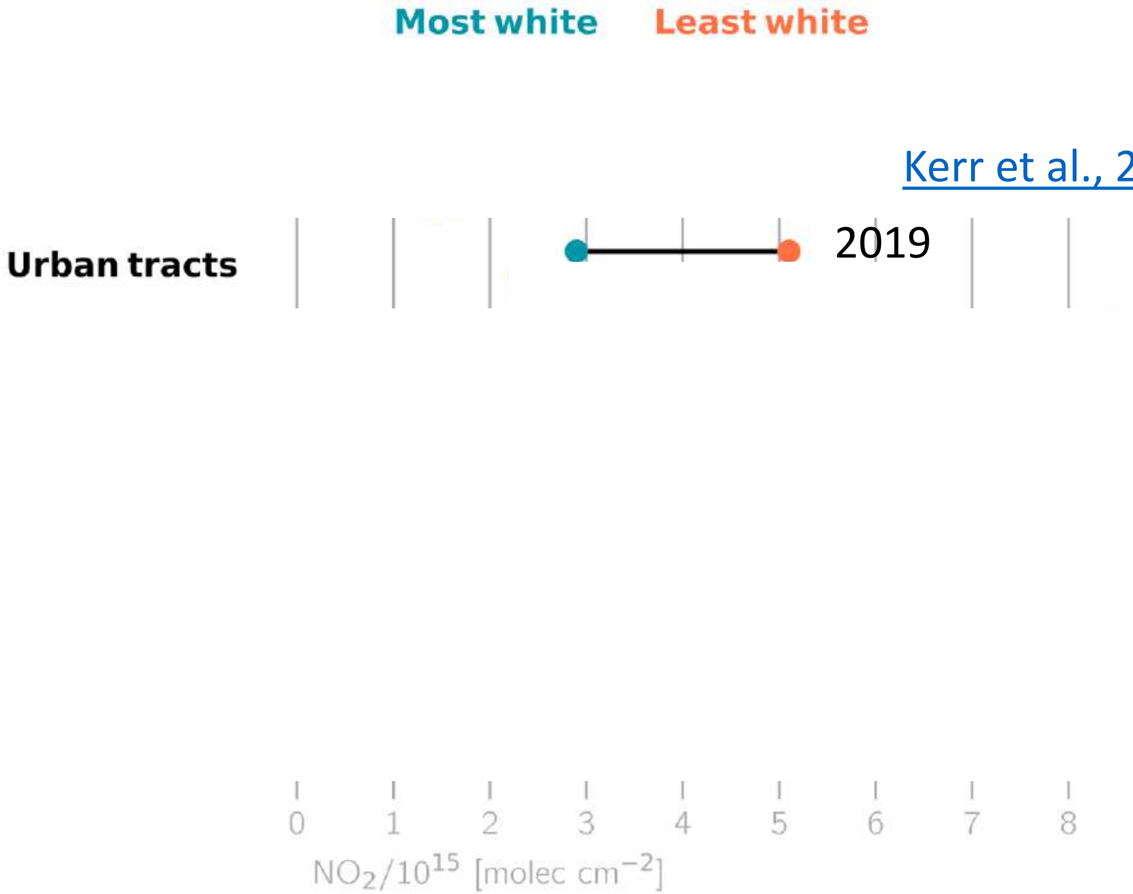
Pandemic temporarily reduced NO_2 concentrations, but did not eliminate NO_2 disparities

Spring 2020



NO_2 drops in most major US cities (as expected)

Values in rural areas are filtered out to highlight changes near cities



[Kerr et al., 2021]

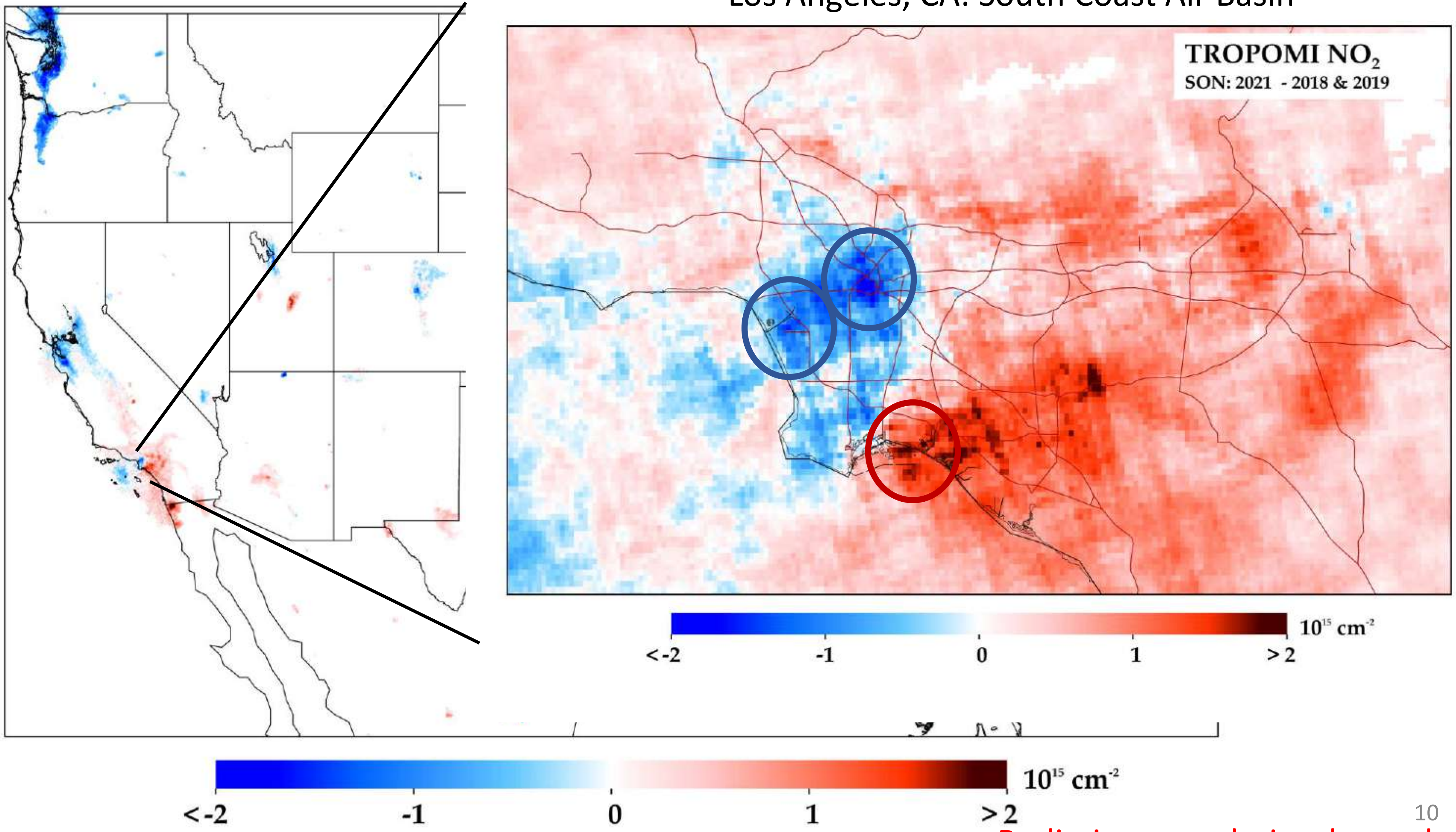
NO_2 in least white communities during the pandemic exceeded levels in most white areas prior to the pandemic.

TROPOMI NO_2: Rapidly assessing changes after COVID-19 Difference between 2018 & 2019 vs. 2021

Fall 2021

Values < 2 × 10^{15} are filtered out to highlight changes near cities

Los Angeles, CA: South Coast Air Basin



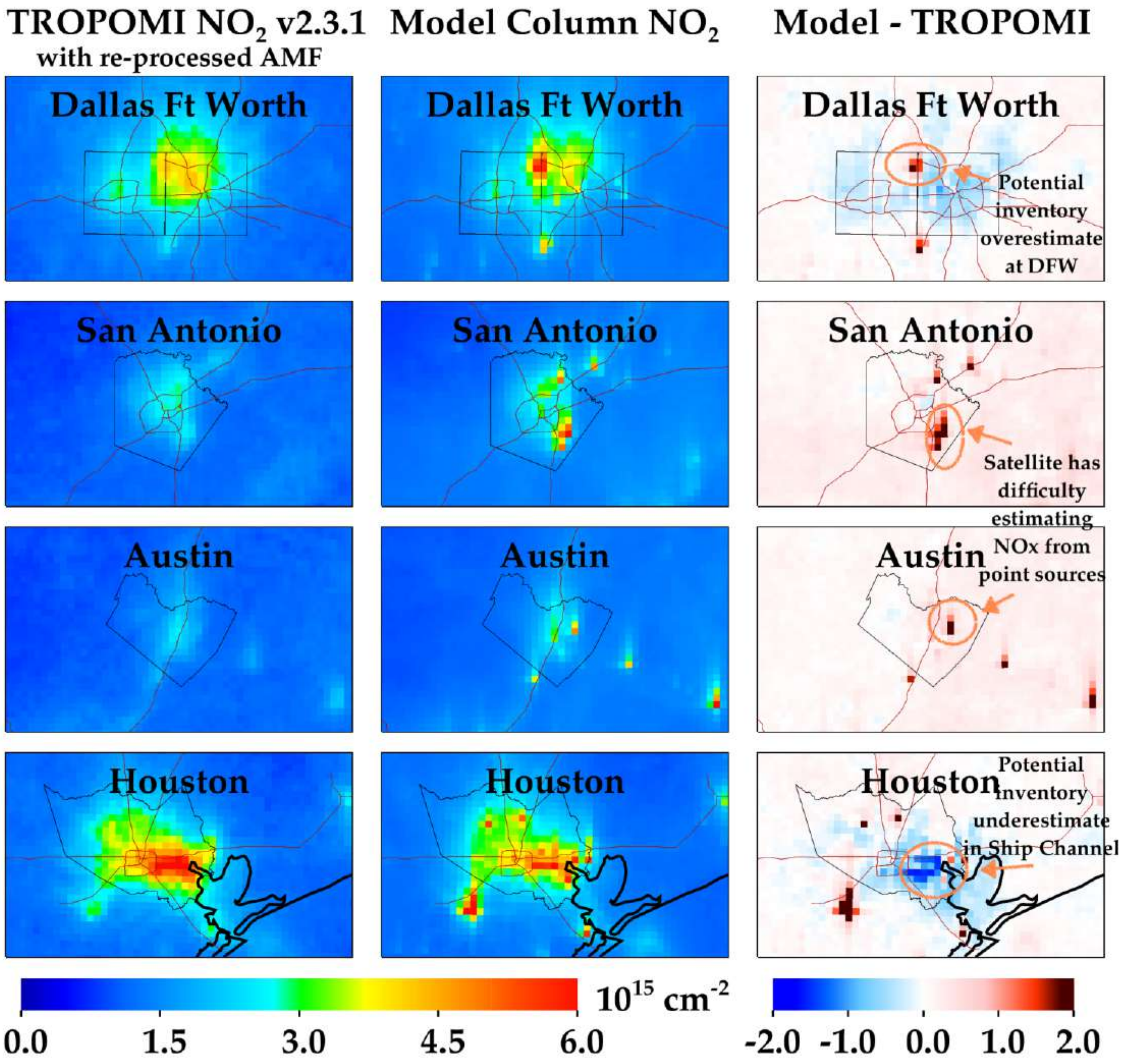
Preliminary analysis, please do not cite

New paper published in *Atmospheric Chemistry and Physics*

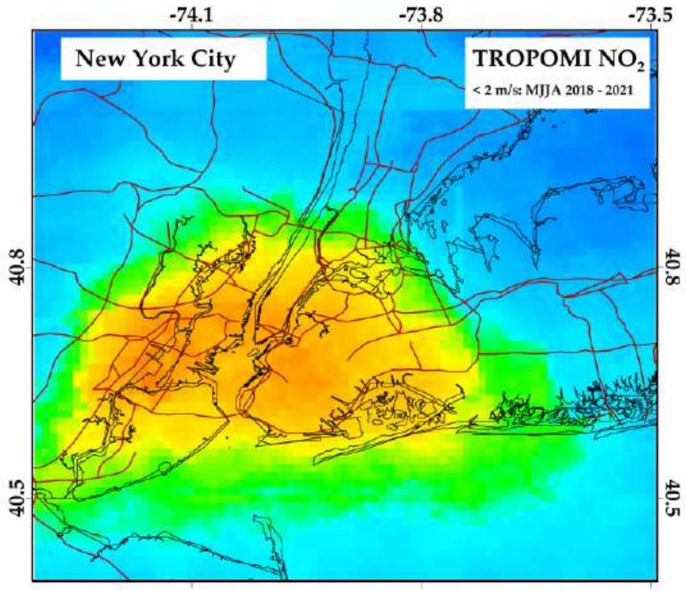
[Goldberg et al., 2022]

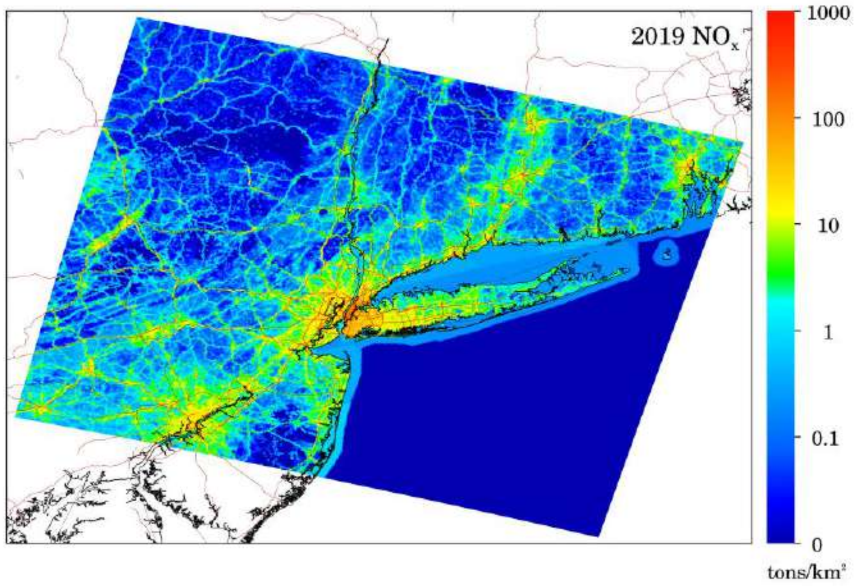
Also see [Twitter thread] for summary

- Satellite and inventory NOx emissions generally agree within 20% in Texas
- Worse agreement near point sources

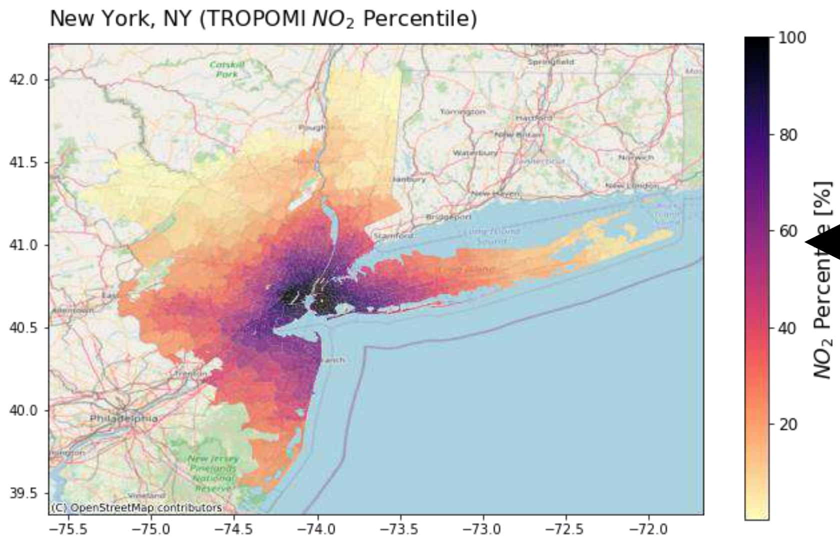


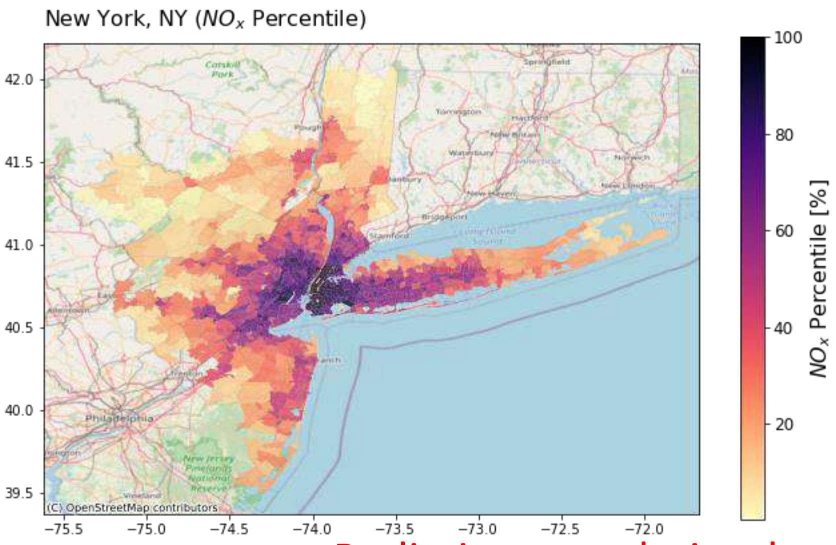
TROPOMI NO_2 vs. Gridded Emissions Inventory (1 km)





From: EPA National Emissions Inventory & Dr. Daniel Tong





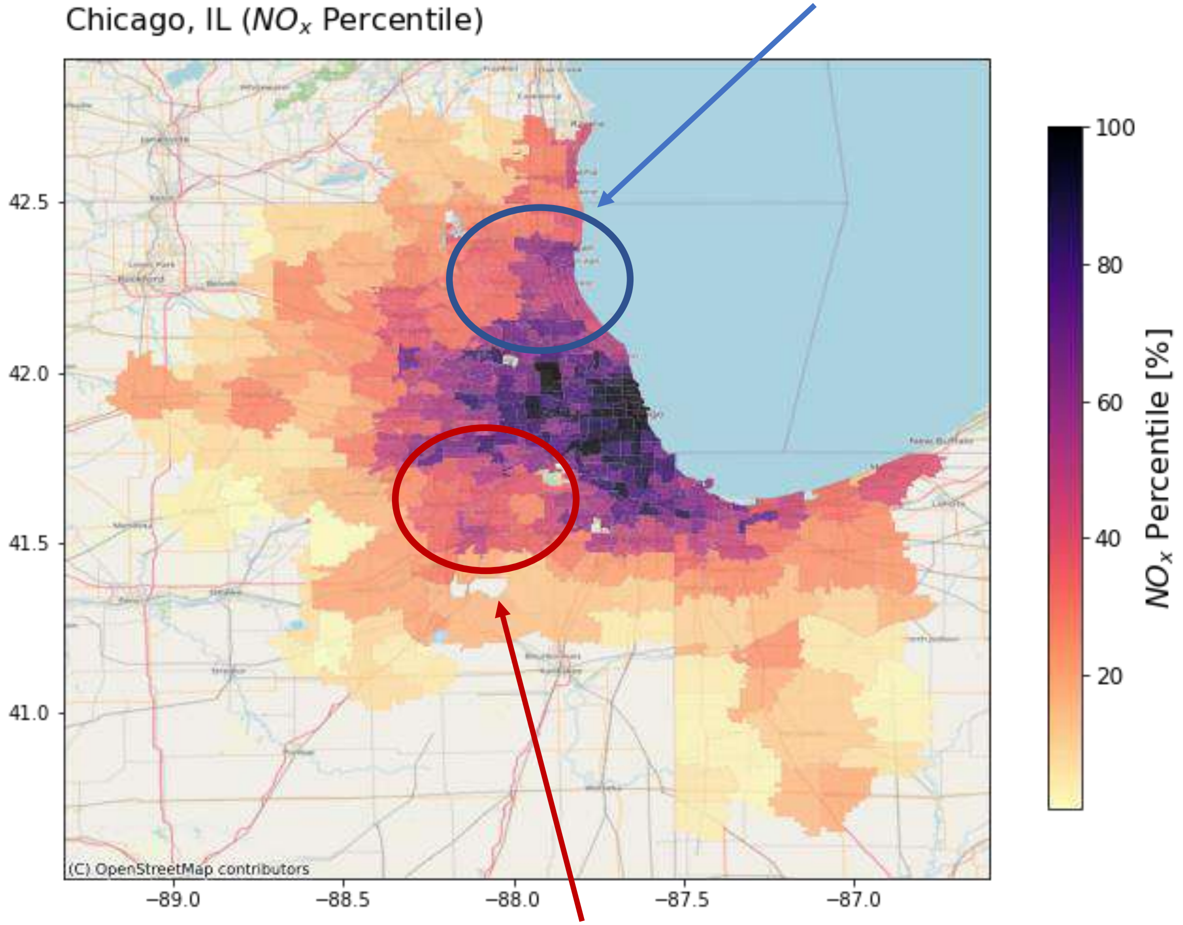
Preliminary analysis, please do not cite

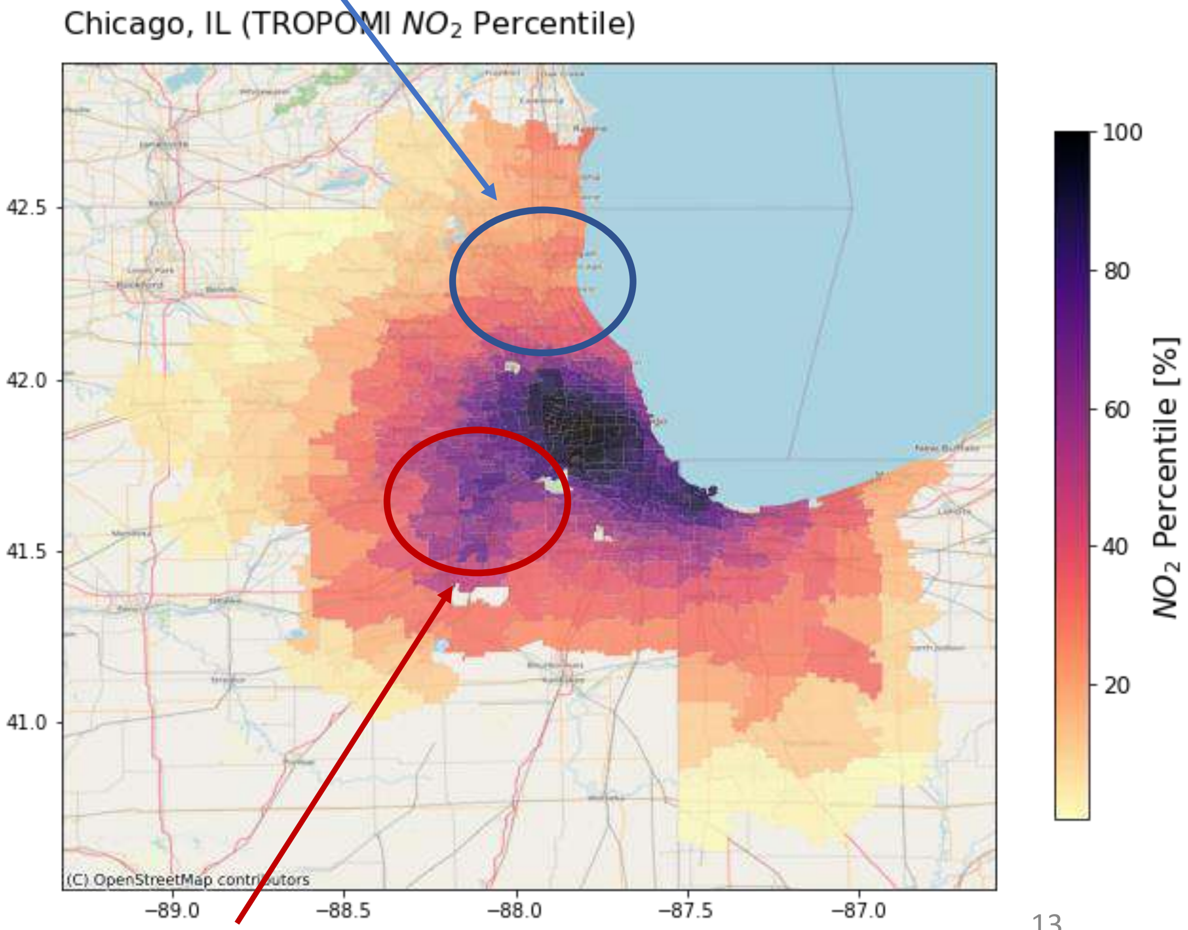
Urban NOx comparison

NOx inventory percentile

Inventory may be overestimating NOx emissions in a wealthy neighborhood

NO_2 satellite percentile





Inventory may be underestimating NOx emissions in neighborhood with many warehouses

Preliminary analysis, please do not cite

Conclusions

- Near-real-time daily TROPOMI NO_2 images are available (tropomino2.us)
- Tracking seasonal NO_2 in near-real-time (pre vs. post-COVID)
  - Urban NO_2 in East Coast cities dropped between 20 - 30% during Spring 2020
  - *Potential* "super-recovery" of urban NO_2 in *some cities*
- Under the right conditions, satellite NO_2 can be compared directly to NO_X emissions on annual timescales
  - NOx emissions in most US cities (pre-COVID) when aggregated to the full metropolitan area are comparable to NOx inventory estimates
  - Generally excellent *spatial* correlation between satellite and inventory
  - Some areas of improvement of the spatial allocation may be needed, especially if high-resolution is requested: EJ communities (near warehouses, ports, industrial areas, etc.)

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Recently published papers using TROPOMI NO_2 and OMI NO_2 data

- **Goldberg, D. L.,** M. Harkey, L. Judd, B. de Foy, J. Johnson, G. Yarwood, T. A. Holloway (2022) Evaluating NO_x emissions and their effect on O_3 production in Texas using TROPOMI NO_2 and HCHO. *Atmos. Chem. Phys.*, 22, 10875–10900, https://doi.org/10.5194/acp-22-10875-2022

- **Kerr**, G.H., D.L. **Goldberg**, K.E. Knowland, C.A. Keller, D. Oladini, I. Kheirbek, L. Mahoney, Z. Lu, S.C. **Anenberg** (2022) Diesel passenger vehicle shares influenced COVID-19 changes in urban nitrogen dioxide air pollution. *Environmental Research Letters*, doi: https://doi.org/10.1088/1748-9326/ac7659.

- Tzortziou, M., Kwong, C. F., **Goldberg, D. L.**, Schiferl, L., Commane, R., Abuhassan, N., et al. (2022). Declines and peaks in NO2 pollution during the multiple waves of the COVID-19 pandemic in the New York metropolitan area. *Atmospheric Chemistry and Physics,* https://doi.org/10.5194/acp-22-2399-2022.

- Jing, P., & **Goldberg, D. L.** (2022). Influence of conducive weather on ozone in the presence of reduced NOx emissions: A case study in Chicago during the 2020 lockdowns. *Atmospheric Pollution Research*, *13*(2), 101313. https://doi.org/10.1016/J.APR.2021.101313.

- **Anenberg**, S.C., A. **Mohegh**, D.L. **Goldberg**, G.H. **Kerr**, M. Brauer, K. Burkart, P. Hystad, A. Larkin, S. Wozniak, L. Lamsal (2022) Long-term trends in urban NO2 concentrations and associated pediatric asthma cases: estimates from global datasets. *Lancet Planetary Health*, https://doi.org/10.1016/S2542-5196(21)00255-2. (Anenberg and Mohegh contributed equally)

- **Goldberg**, D.L., S.C. **Anenberg**, L.N. Lamsal, Z. Lu, E.E. McDuffie, S.J. Smith, D.G. Streets (2021) Urban NOx emissions around the world declined faster than anticipated between 2005 and 2019. *Environmental Research Letters,* https://doi.org/10.1088/1748-9326/ac2c34. Supplementary

- **Goldberg**, D.G.,**C. Anenberg,** G.H. **Kerr**, Z. Lu, D.G. Streets (2021) TROPOMI: A revolutionary new satellite instrument measuring NOx air pollution. *EM Magazine*, September 2021.

- **Kerr**, G.H., D.L. **Goldberg**, S.C. **Anenberg** (2021) COVID-19 lockdowns reveal persistent disparities in nitrogen dioxide pollution levels. *Proceedings of the National Academy of Sciences*, https://doi.org/10.1073/pnas.2022409118.

- Kondragunta, S., Wei, Z., McDonald, B. C., **Goldberg, D. L.** and Tong, D. Q. (2021) COVID-19 Induced Fingerprints of a New Normal Urban Air Quality in the United States, J. *Geophys. Res. Atmos.*, e2021JD034797, doi:10.1029/2021JD034797.

- **Goldberg**, D., S. **Anenberg**, G.H. **Kerr**, A. **Mohegh**, Z. Lu, D.G. Streets (2021) TROPOMI NO2 in the United States: A detailed look at the annual averages, weekly cycle, effects of temperature, and correlation with surface NO2 concentrations. *Earth's Future*, https://doi.org/10.1029/2020EF001665.

- **Mohegh**, A., D. **Goldberg**, P. Achakulwisut, S.C. **Anenberg** (2020) Sensitivity of estimated NO2-attributable pediatric asthma incidence to grid resolution and urbanicity. *Environmental Research Letters*, doi: 10.1088/1748-9326/abce25.

- **Goldberg**, D.L., S.C. **Anenberg**, D. Griffin, C.A. McLinden, Z. Lu, D.G. Streets (2020) Disentangling the impact of the COVID-19 lockdowns on urban NO2 from natural variability. *Geophysical Research Letters*, https://doi.org/10.1029/2020GL089269.

- **Goldberg, D. L.,** Z. Lu, T. Oda, L. N. Lamsal, F. Liu, D. Griffin, C. A. McLinden, N. A. Krotkov, B. N., Duncan, D. G. Streets (2019), Exploiting OMI NO_2 satellite observations to infer fossil-fuel CO_2 emissions from U.S. megacities, *Sci. Tot., Environ*., 695, 133805, https://doi.org/10.1016/j.scitotenv.2019.133805.

- **Goldberg, D. L.,** Lu, Z., Streets, D. G., de Foy, B., Griffin, D., McLinden, C. A., Lamsal, L. N., Krotkov, N. A. and Eskes, H. (2019) Enhanced Capabilities of TROPOMI NO_2 : Estimating NOx from North American Cities and Power Plants, *Sci. Technol.,* acs.est.9b04488, doi:10.1021/acs.est.9b04488.

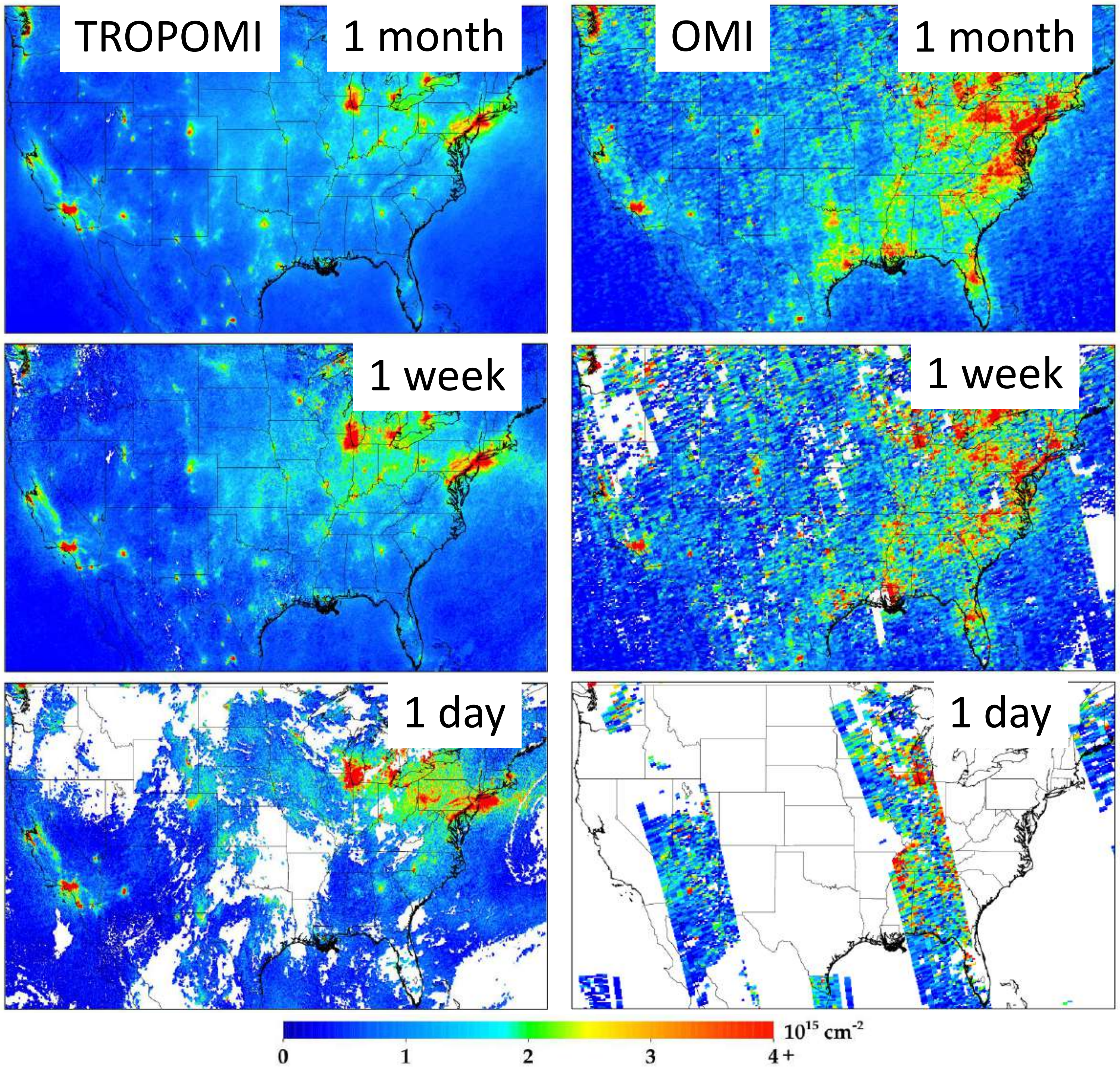
New technology vs. Older technology

Left column – **TROPOMI**: Launched Fall 2017; 5.5 x 3.5 km^2 spatial resolution

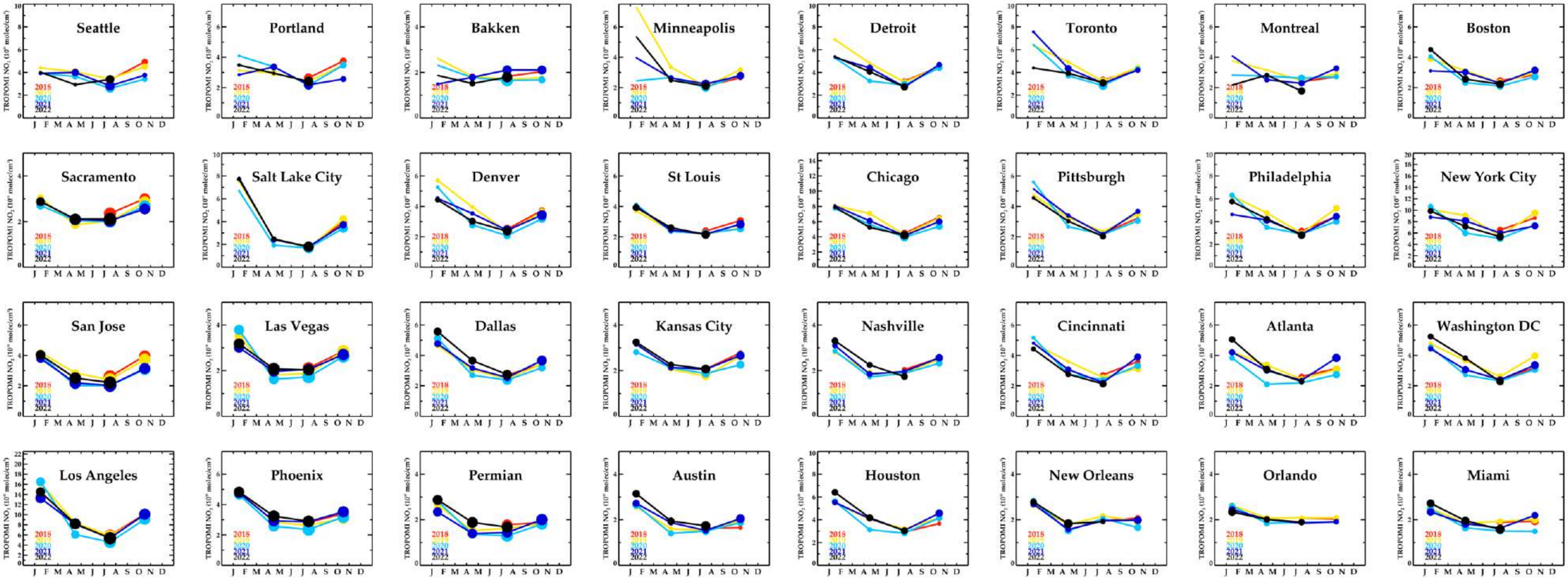
Right column: **OMI**: Launched Summer 2004; 24 x 13 km^2 spatial resolution

Higher spatial resolution and less instrument noise with TROPOMI, which comes at expense of having a shorter data record (only since 2018)

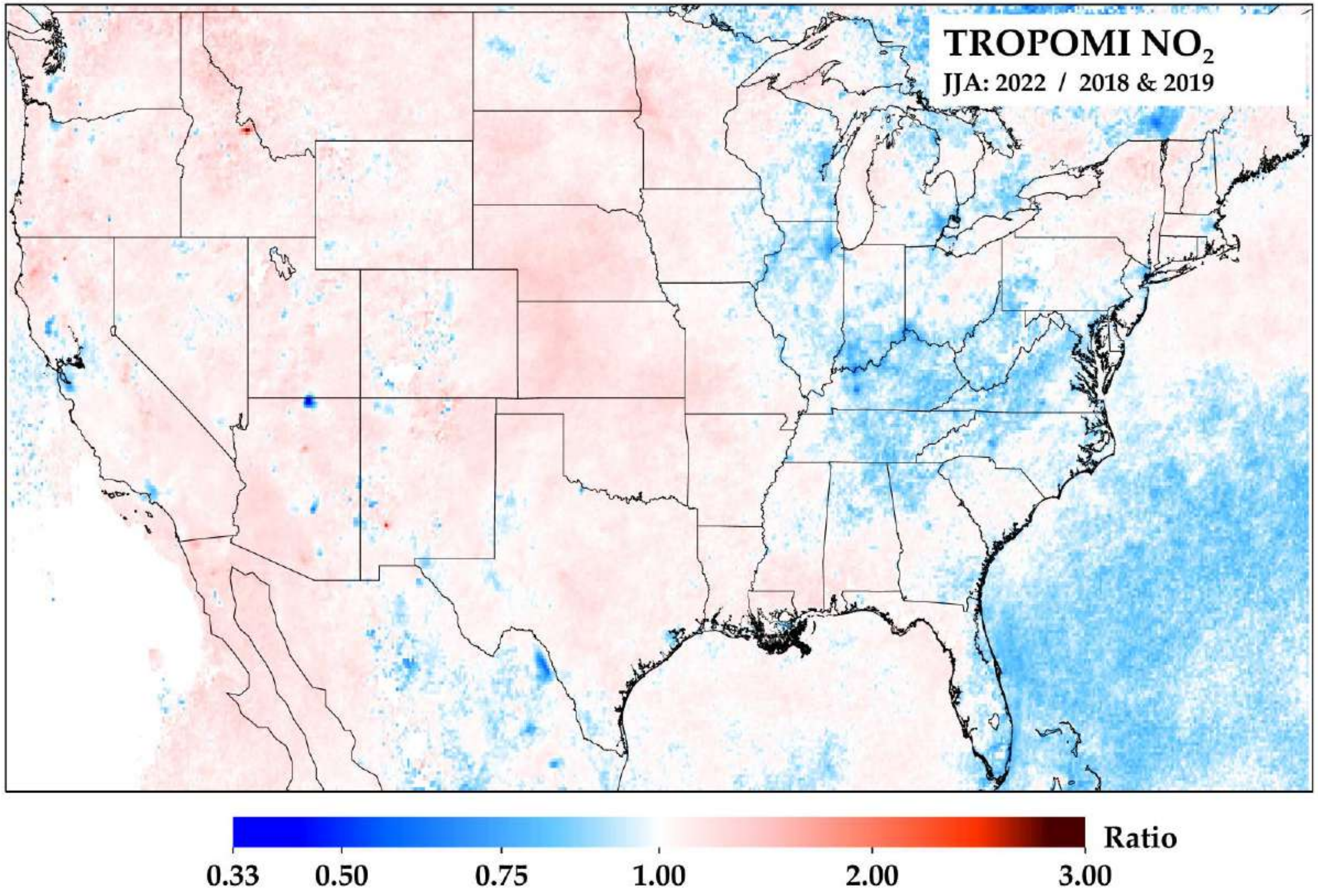
Goldberg et al., 2021a



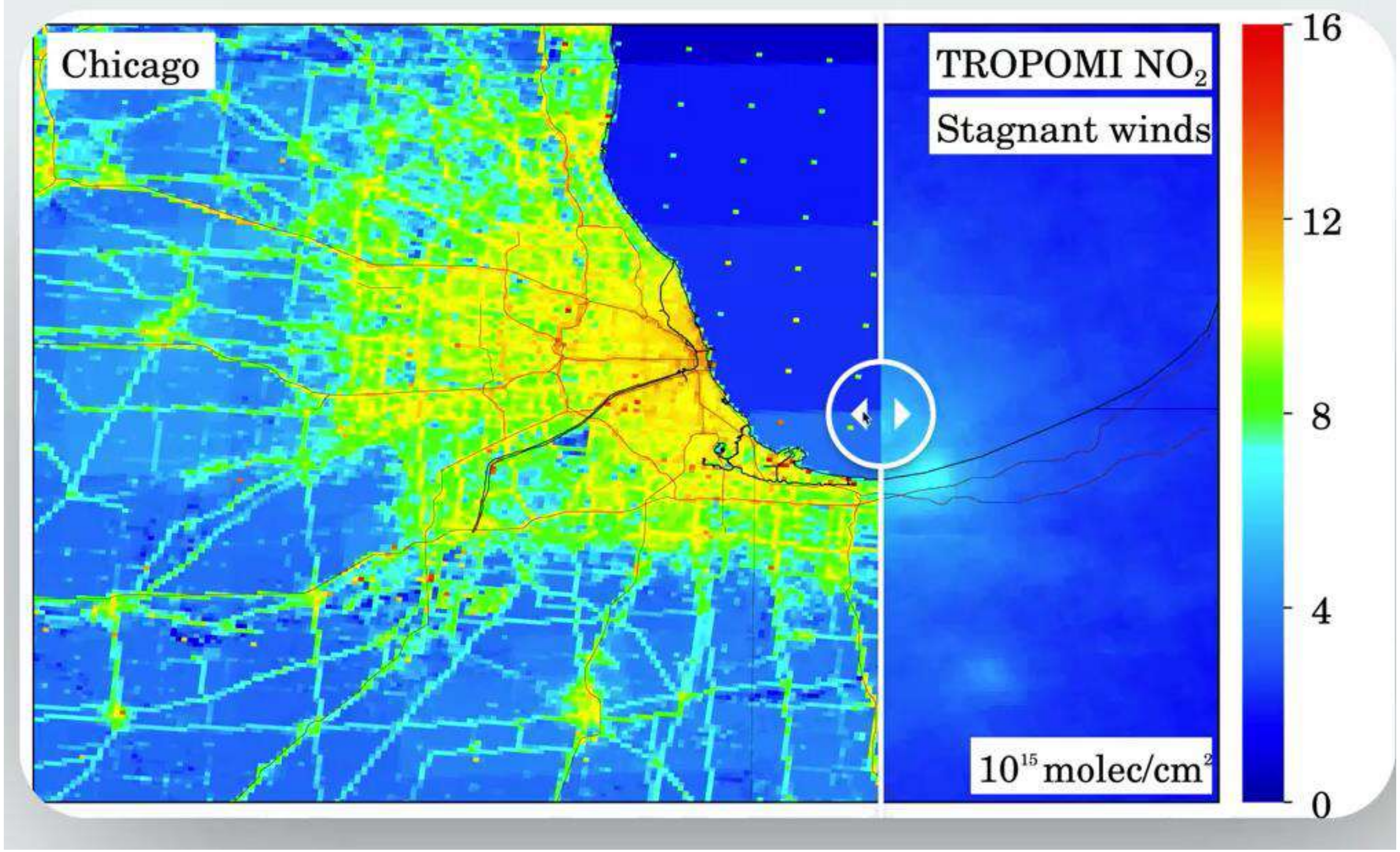
TROPOMI NO_2: Rapidly assessing changes after COVID-19 Difference between 2018 vs. 2019 vs. 2020 vs. 2021 vs. 2022



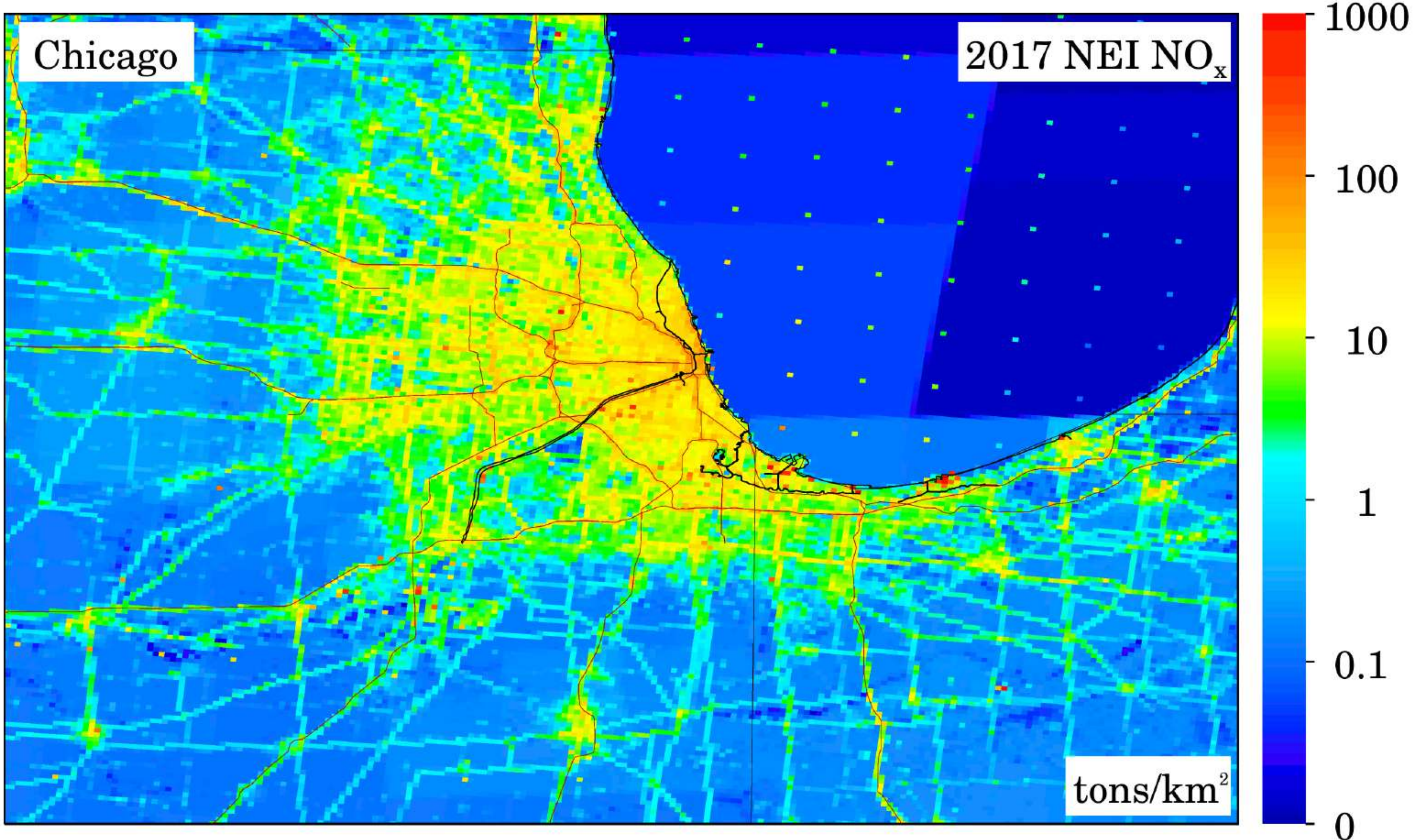
TROPOMI NO_2: Rapidly assessing changes after COVID-19
Difference between 2018 vs. 2019 vs. 2020 vs. 2021 vs. 2022

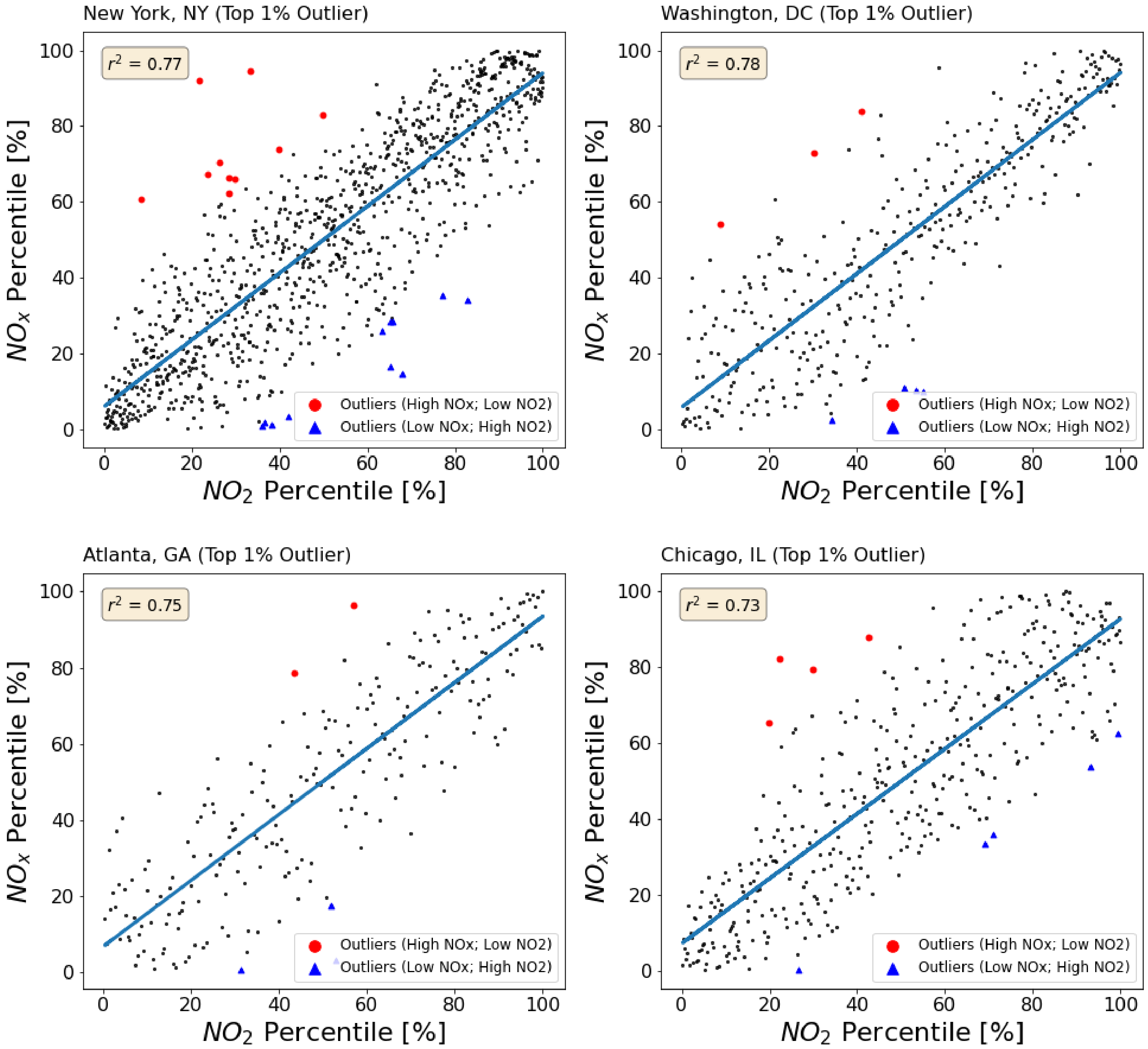


Urban NOx comparison



Urban NOx comparison (Back-up)





Great agreement between TROPOMI NO_2 and the spatial allocation of the NEI NOx emissions inventory ($r^2 > 0.7$)

Red = potential NOx inventory overestimate OR satellite has difficulty observing source

Blue = potential NOx inventory underestimate OR NO_2 outflow from nearby source

Many of the "red" points are locations of point sources, and some of the "blue" points are locations with no/little emissions, but nearby very large emission sources (e.g., Central Park in NYC)

Sector-inventory of NOx emissions