Changes in NO_2 following the COVID-19 lockdowns: Disentangling anthropogenic changes from natural variability

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MARAMA Conference

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Thanks to: Susan Anenberg, Gaige Kerr, Zifeng Lu, Debora Griffin, Chris McLinden, Bryan Duncan

Support from: NASA Earth Sciences

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THE GEORGE WASHINGTON UNIVERSITY

NO_2 itself is a toxic pollutant!

Motivation

- NO_2 is a precursor to O_3 and $PM_{2.5}$
  - In most of Northeast US during summertime (outside of NYC area), as NO_2 ↓ then O_3 ↓ (but not linearly!)

- NO_X and its co-emissions (e.g., tailpipe VOCs) are responsible for ~20% of new pediatric cases of asthma in NYC and DC at current concentrations (which are well below the EPA NAAQS of 53 ppbv)
  - These are entirely preventable cases of asthma!

Jin et al., 2020 (https://pubs.acs.org/doi/10.1021/acs.est.9b07785)
Achakulwisut, et al., 2019 (https://thelancet.com/article/S2542-5196(19)30046-4/fulltext)

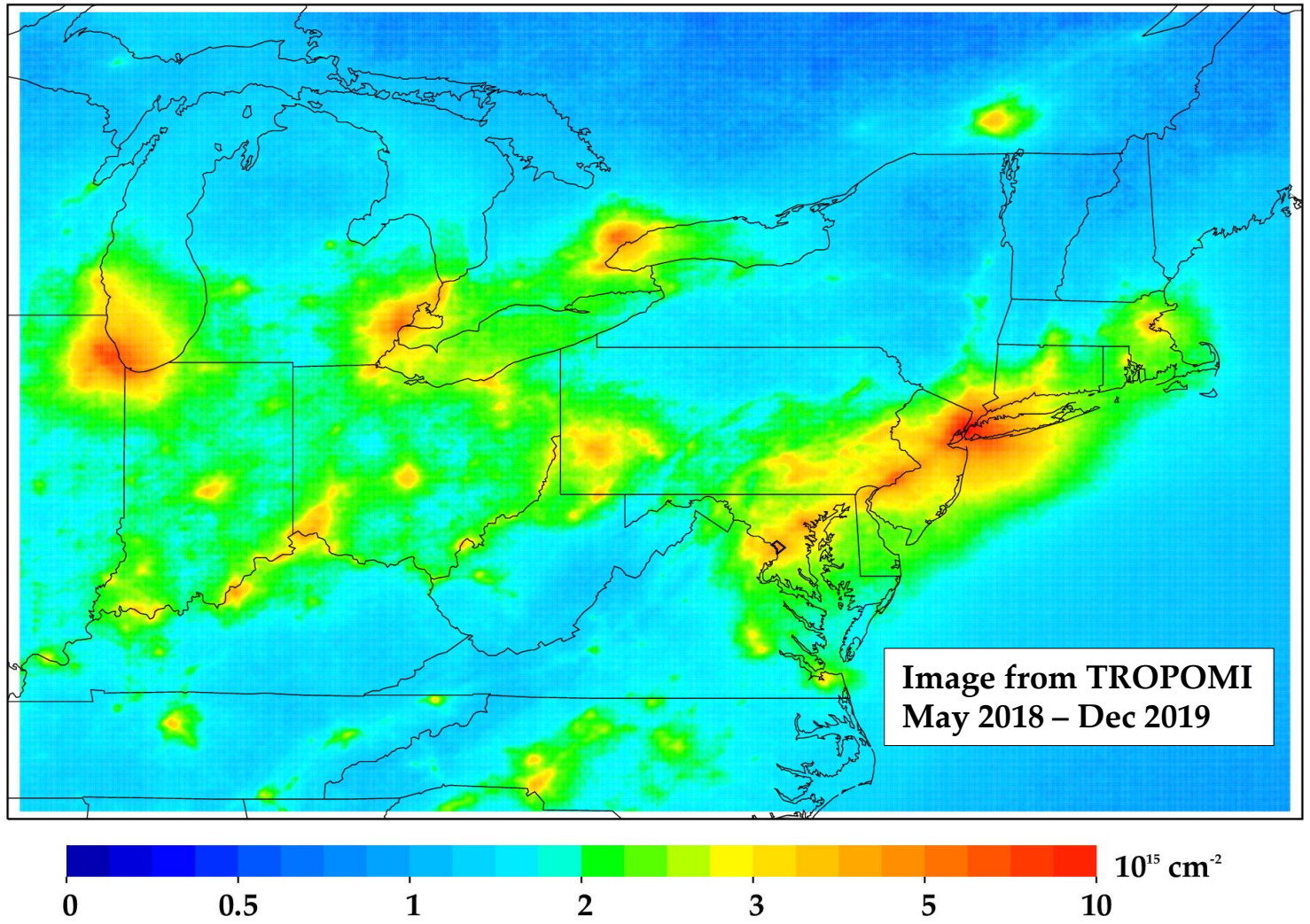
NO_2 as observed by satellite *pre-pandemic*

Pros:

- Satellites give full spatial coverage
- Can capture trends over time, using a single instrument
- Can validate or constrain model simulations

Cons:

- Measurement is once per day in the early afternoon
- Measurement is the amount in the vertical column of the atmosphere, but NO_2 mostly lives near surface



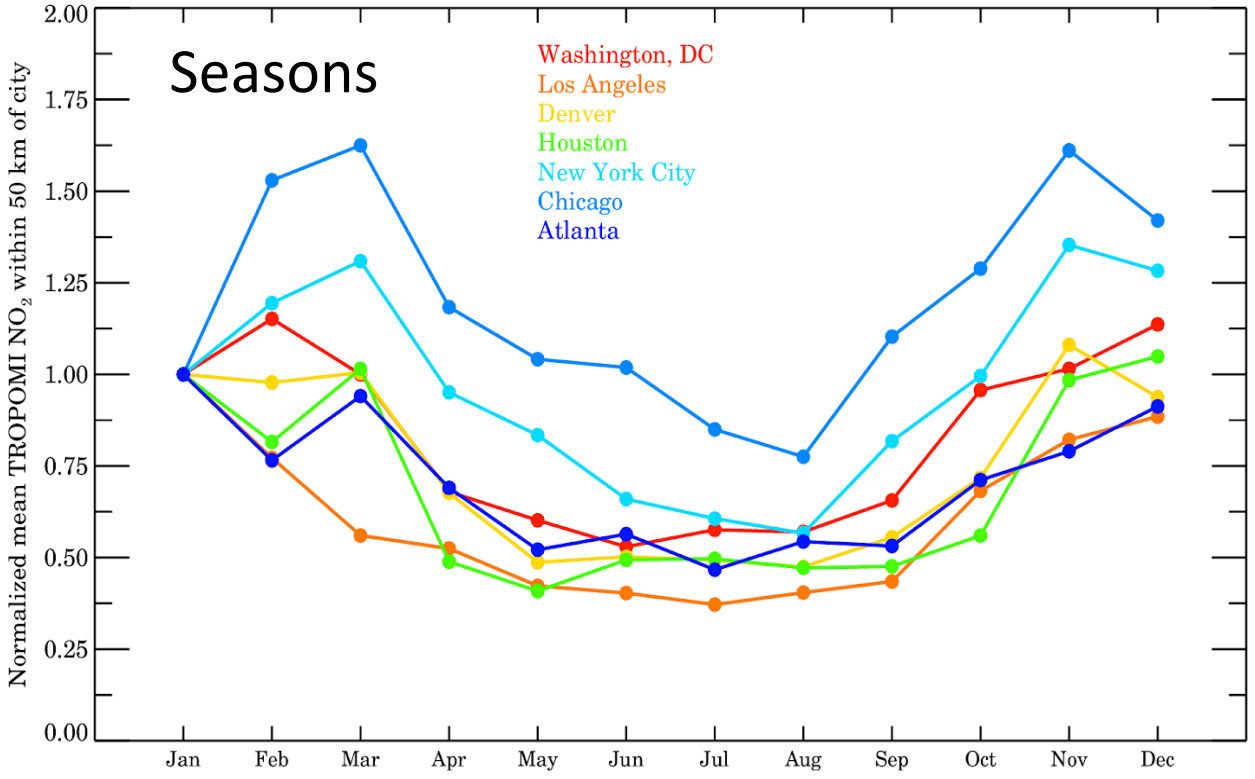
Units: Molecules per cm^2 – Red is larger, blue is smaller; Exponential colorbar

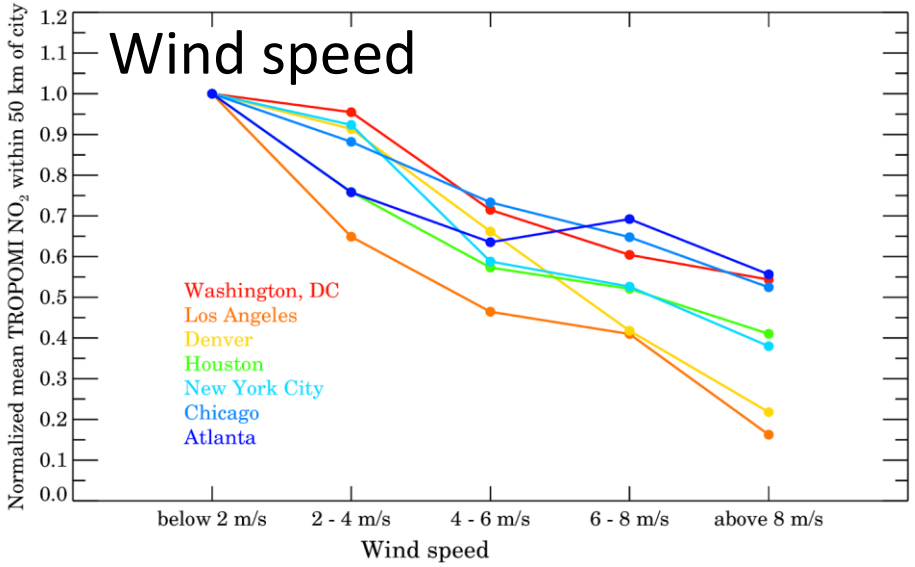
Worst NO_2 location by state, according to TROPOMI

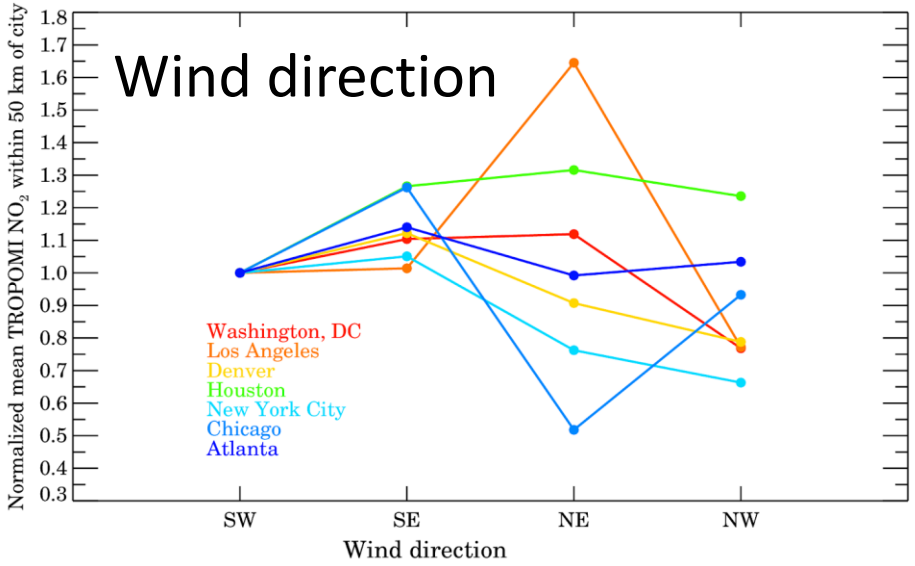
State	Lat	Lon	Value	Detailed location
CA	34.03	-118.18	1.41E+16	E Los Angeles, CA
NY	40.72	-73.97	1.13E+16	East River, Brooklyn, NY
NJ	40.69	-74.14	9.75E+15	Port Newark, NJ
IL	41.82	-87.77	7.31E+15	Cicero, Chicago, IL (near MDW)
WA	47.46	-122.26	6.90E+15	Tukwila, WA (SE Seatle)
IN	41.66	-87.47	6.28E+15	E Chicago, IN (Steel Mill)
UT	40.71	-111.9	6.18E+15	S Salt Lake City, UT
CO	39.76	-105.02	5.98E+15	Highland, Denver, CO
PA	39.95	-75.16	5.95E+15	Downtown Philadelphia, PA
AZ	33.47	-112.15	5.87E+15	Cuatro Palmas, Phoenix, AZ
MI	42.31	-83.11	5.74E+15	Detroit, MI
TX	29.74	-95.14	5.58E+15	Deer Park, Houston, TX
CT	41	-73.67	5.46E+15	Greenwich, CT
NV	36.1	-115.18	4.97E+15	Las Vegas Strip, Las Vegas, NV
MD	39.28	-76.6	4.94E+15	Port of Baltimore, Baltimore, MD
DC	38.89	-77.01	4.65E+15	Capitol Hill, Washington, DC
GA	33.64	-84.42	4.65E+15	Hartsfield Airport, Atlanta, GA
VA	38.88	-77.05	4.59E+15	Pentagon, Arlington, VA
DE	39.8	-75.37	4.34E+15	Claymont, Wilmington, DE
OR	45.52	-122.65	4.25E+15	Buckman, Portland, OR
KY	38.18	-85.73	4.21E+15	Louisville, KY (Airport)
OH	39.12	-84.54	4.20E+15	Cincinatti, OH
MA	42.37	-71.06	4.14E+15	Charlestown, Boston, MA (near BOS)
LA	29.93	-90.14	3.98E+15	Mississippi River, New Orleans, LA
NC	35.24	-80.85	3.76E+15	Catawba, NC (near Marshall Steam SPP)

State	Lat	Lon	Value	Detailed location
WV	38.94	-82.11	3.68E+15	Lakin, WV (near Gavin PP)
MO	38.68	-90.19	3.67E+15	Mississippi River, St Louis, MO
KS	39.12	-94.6	3.61E+15	Missouri River, Kansas City, KS
TN	36.16	-86.77	3.52E+15	Nashville, TN
FL	25.85	-80.34	3.40E+15	Medley, Miami, FL
WI	42.86	-87.82	3.40E+15	Oak Creek, WI (near Oak Creek PP)
MN	44.97	-93.24	3.28E+15	Mississippi River, Minneapolis, MN
AL	33.52	-86.82	3.21E+15	Fountain Heights, Birmingham, AL
RI	41.8	-71.41	2.88E+15	S Providence, RI
IA	41.25	-95.88	2.79E+15	Council Bluffs, IA
NE	41.25	-95.88	2.79E+15	Missouri River, Omaha, NE
OK	36.16	-96	2.64E+15	Tulsa, OK
WY	43.69	-105.32	2.52E+15	Thunder Basin Coal, WY
SC	32.88	-79.99	2.52E+15	N Charleston, SC
NM	35.11	-106.62	2.51E+15	Albuquerque, NM
AR	35.12	-90.1	2.46E+15	W Memphis, AR
ID	43.58	-116.23	2.30E+15	Boise, ID (Airport)
ND	47.35	-101.81	2.24E+15	Beulah, ND (near Dakota Gasification Co)
MT	45.86	-106.57	2.20E+15	Colstrip, MT (near Colstrip PP)
NH	42.94	-70.81	1.93E+15	Hampton, NH
ME	43.66	-70.29	1.90E+15	Portland, ME
MS	32.34	-90.19	1.77E+15	Jackson, MS
SD	43.6	-96.74	1.53E+15	N Sioux Falls, SD
VT	42.91	-73.18	1.49E+15	Wilmington, VT

Effects of seasonality and weather on NO_2







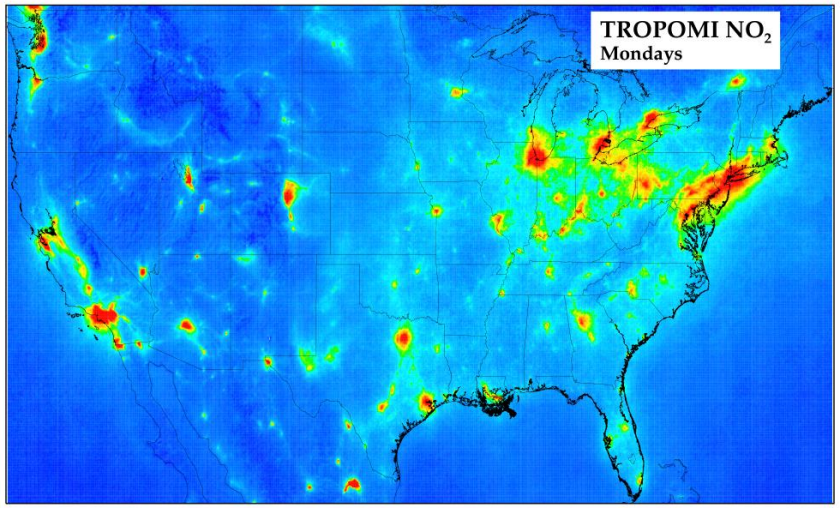
Goldberg et al. 2020
https://www.essoar.org/doi/10.1002/essoar.10503422.1

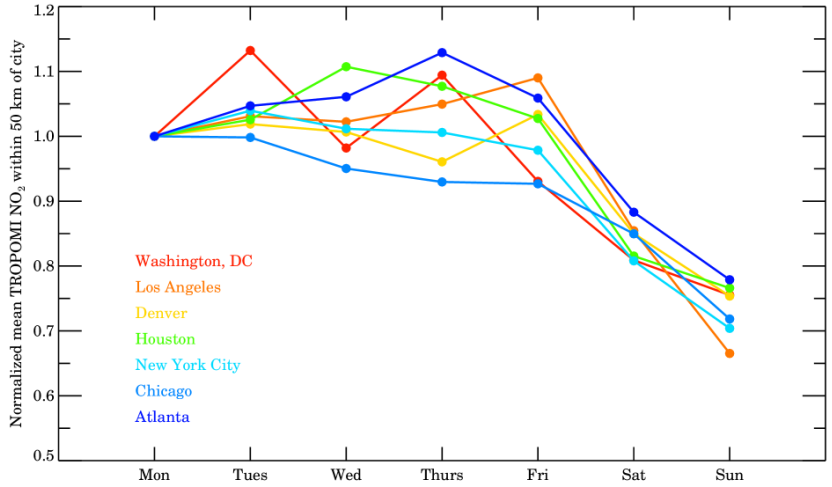
Anthropogenic effects: Weekday vs. weekend

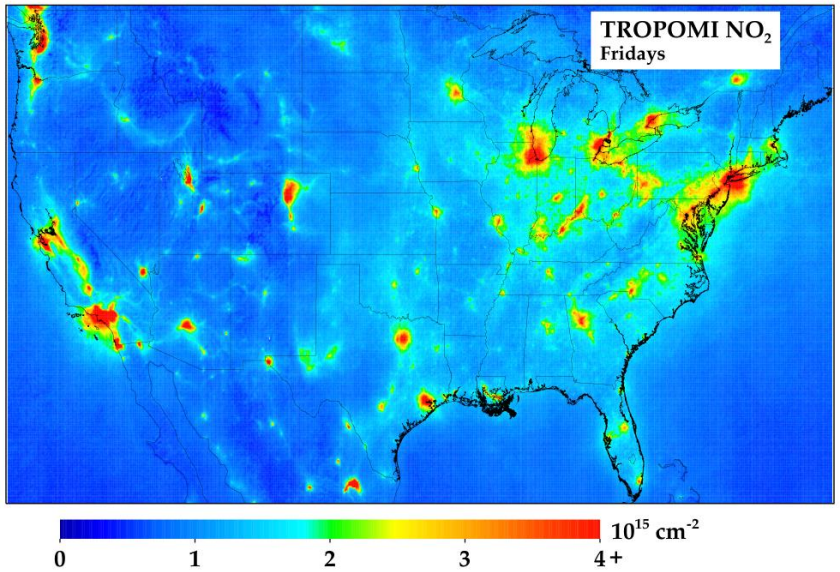
On Saturdays: 16% lower
On Sundays: 24% lower

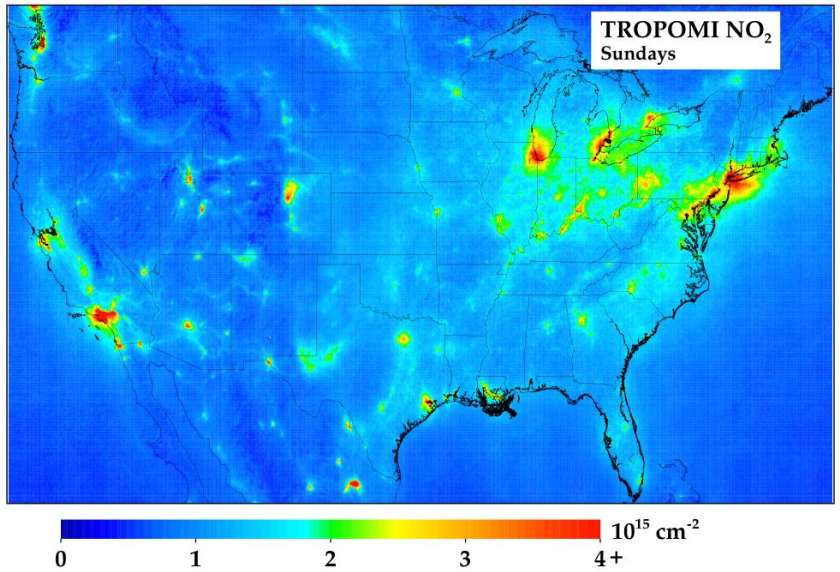
Some variability on weekdays, but no statistical difference between weekdays themselves

Weekday vs. weekend cycle of NO_2 pollution is “flatter” than 10-20 years ago





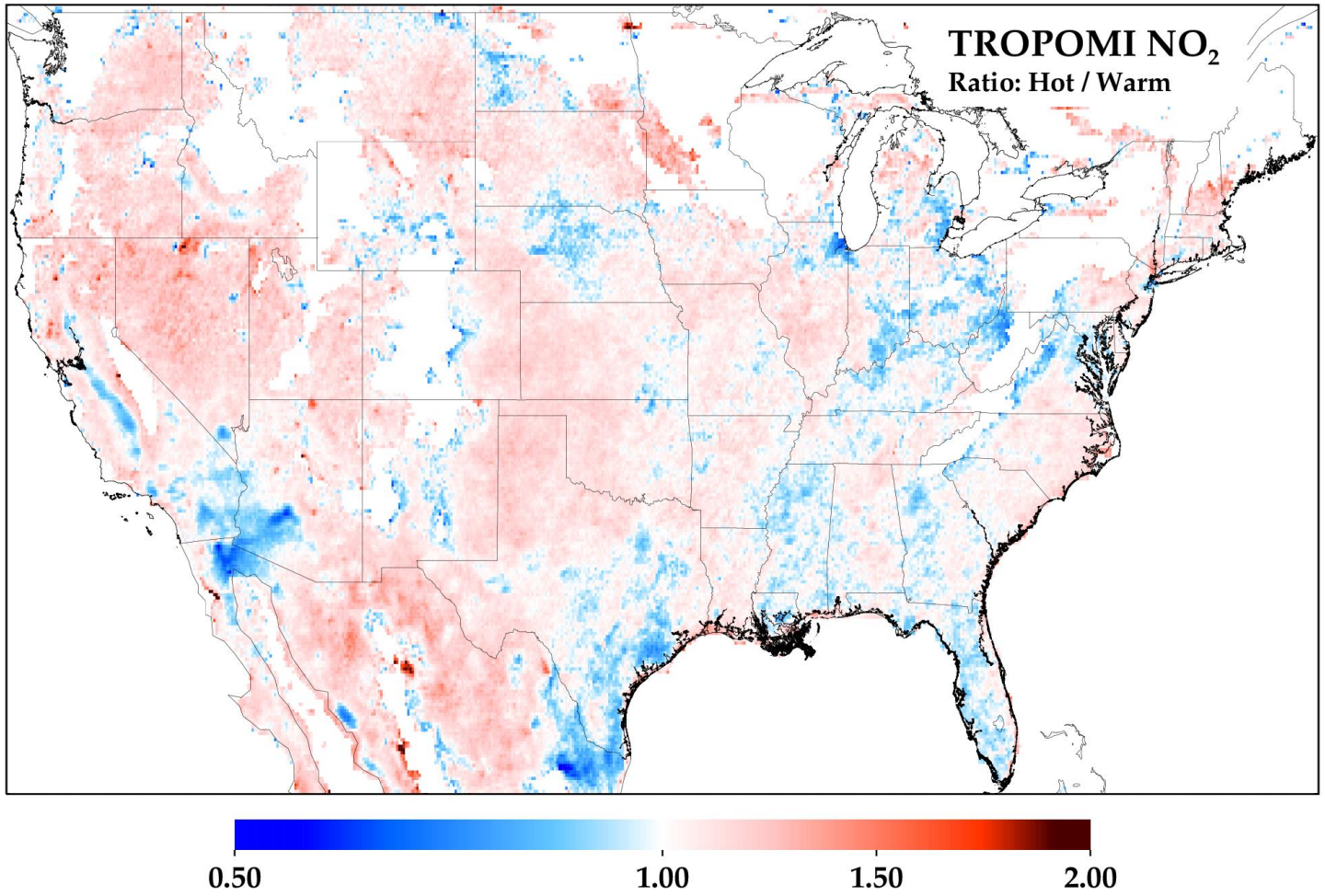




Anthropogenic + Natural effects: Hot vs. warm days

In most areas, NO_2 is larger on the hottest days as compared to seasonably warm days

- Often larger NO_X emissions on the hottest days
- Some chemical reactions yield more NO_2 on the hottest days, irrespective of NO_X emissions

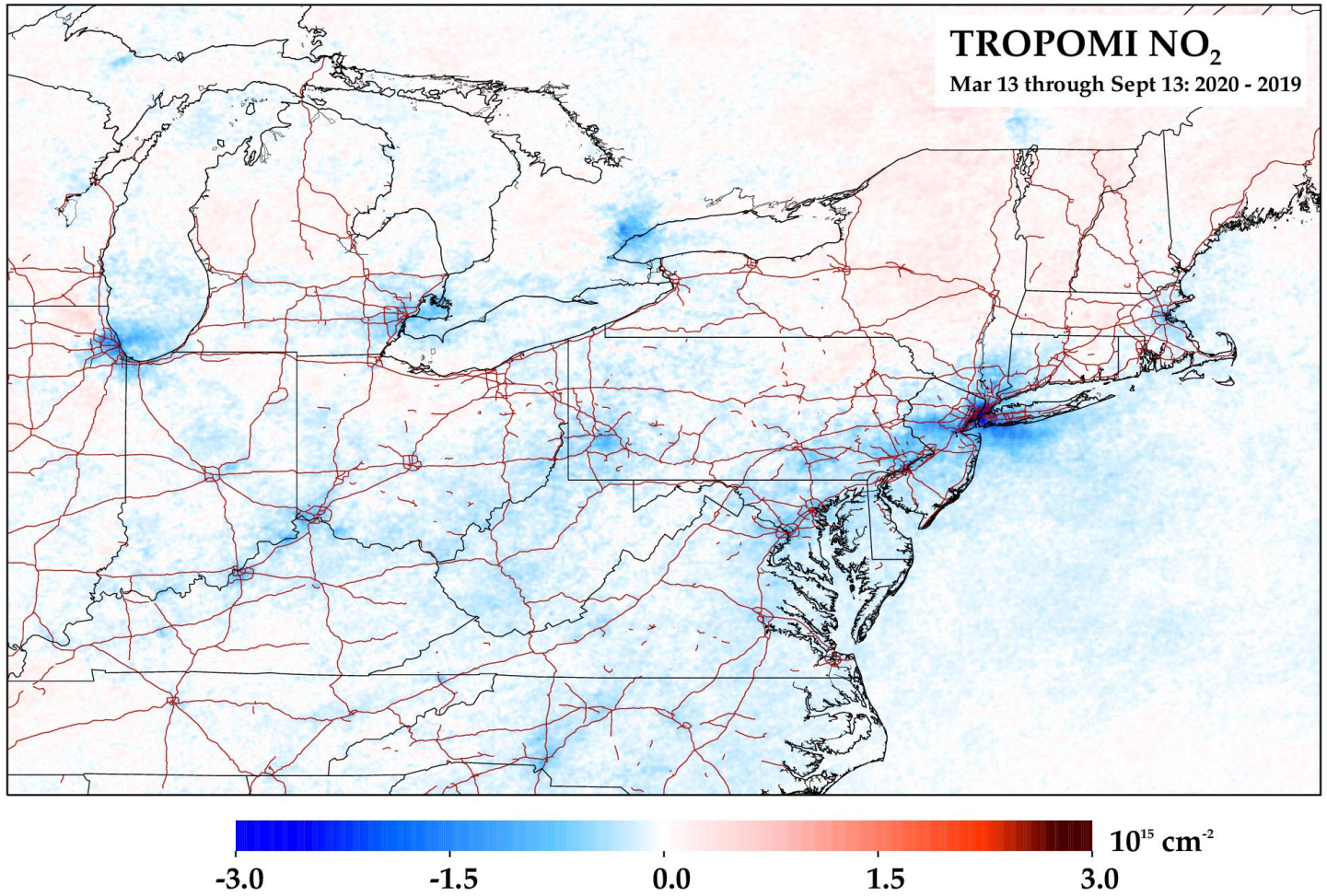


What can we learn from COVID-19 lockdowns?

1. What would NO_2 changes look like if meteorology was “normalized” out?

2. What does this reveal about environmental justice issues related to air quality?

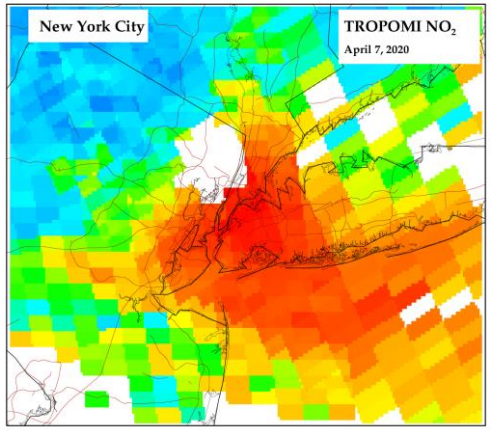
3. How did varying degrees of social distancing and urban transportation changes cause these NO_2 decreases?



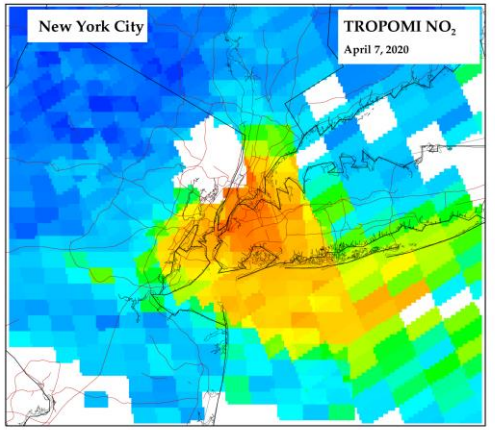
Methodology

1. Use 2018 & 2019 data to prepare analog relationships between TROPOMI NO_2 and weather parameters, such as wind speed, wind direction, sun angle, temperature, (and weekday-weekend effect)
2. Use those relationships to artificially scale TROPOMI NO_2 values on a day-by-day and city-by-city basis

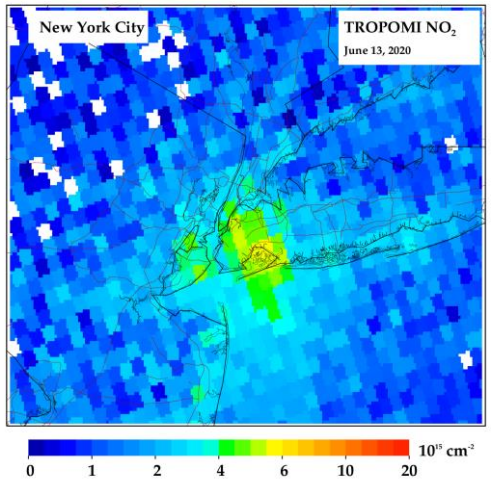
Tuesday
April 7, 2020
Stagnant



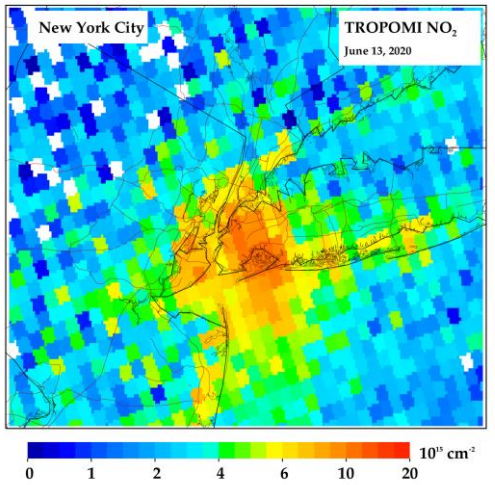
Multiply by scaling factor <1



Sunday
June 13, 2020
Windy



Multiply by scaling factor >1

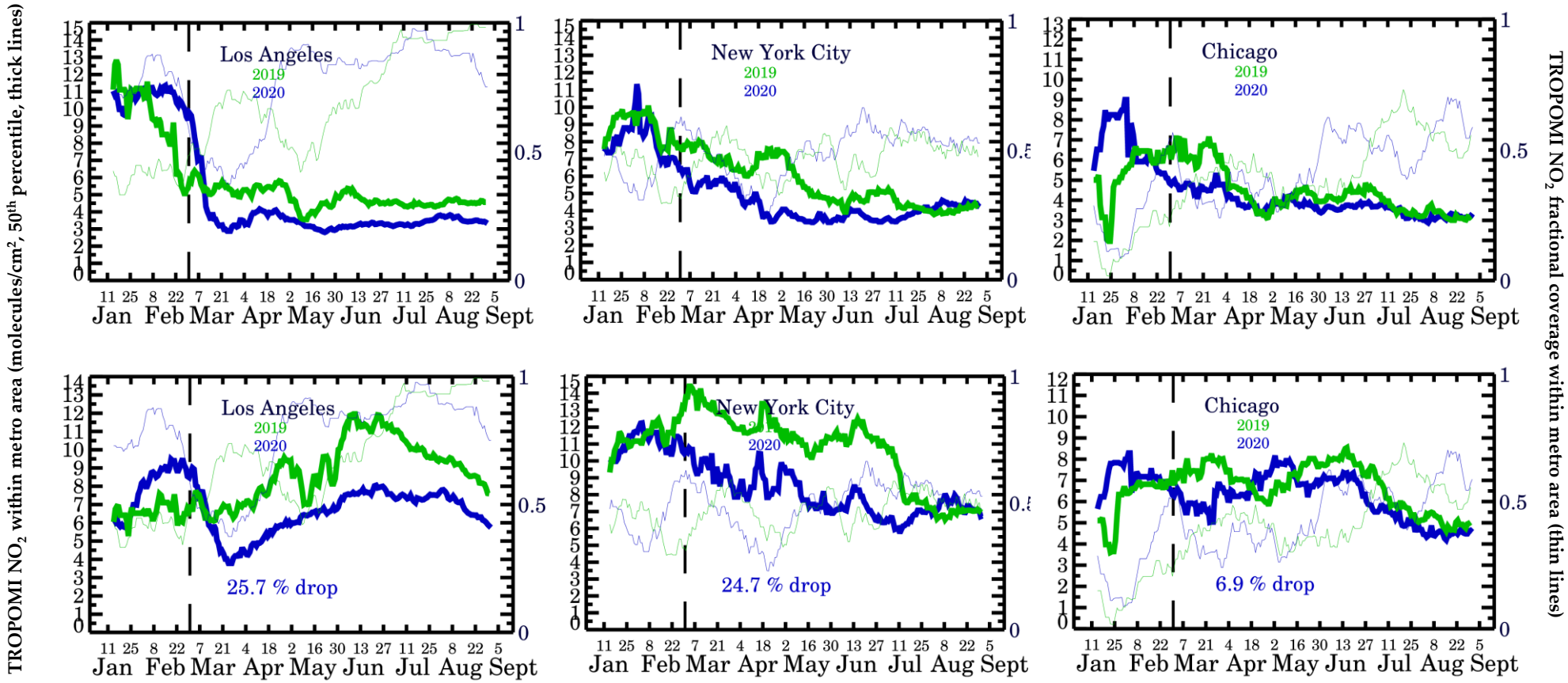


Closer to an apples-to-apples comparison

Disentangling the impact of the COVID-19 lockdowns on urban NO_2 from natural variability

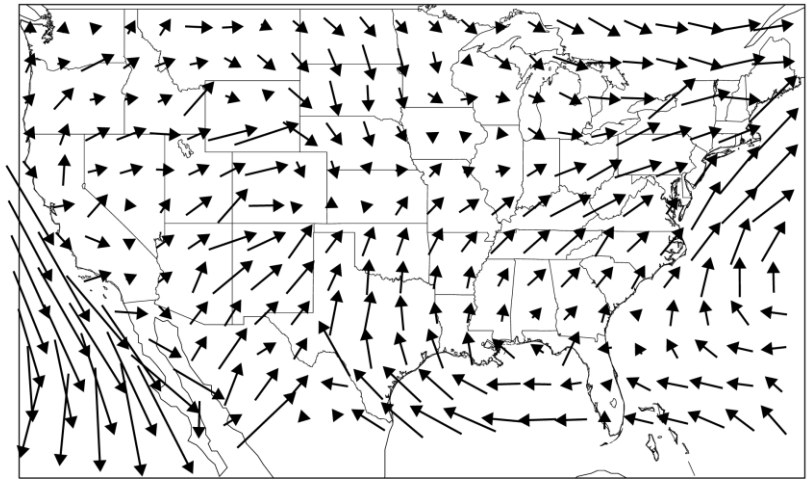
Column NO_2 trends by date, comparing 2020 to 2019.

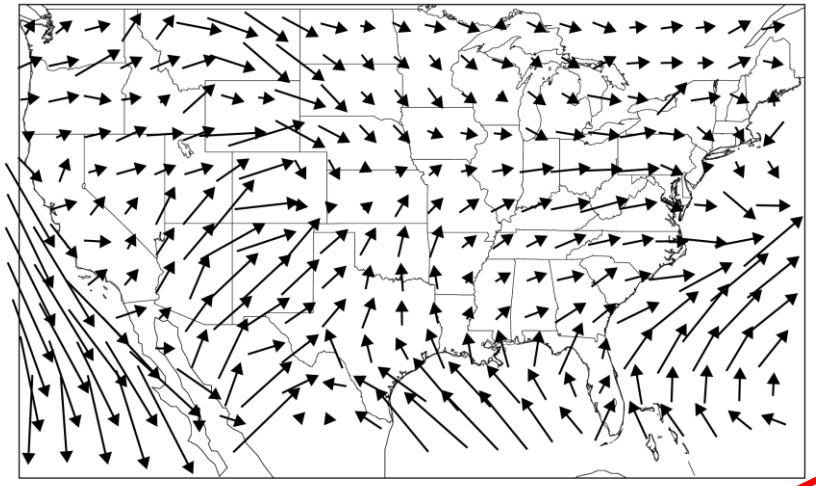
Column NO_2 by date, now "normalized" to account for meteorological differences between years.

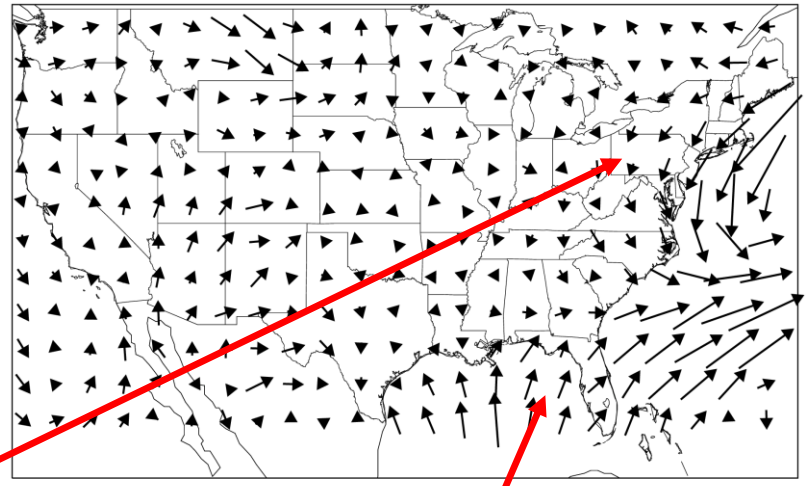


Thick lines are 28-day rolling medians of TROPOMI data within cities (approximately defined as 20 km radius of city)
Thin lines are 28-day rolling median of spatial coverage (i.e., Chicago has less coverage in Jan & Feb)

ERA5 Winds: Difference between 2019 & 2020 (March 15 – April 30)







- In Northeast US: Winds have a more northerly component in 2020 as compared to 2019
  - Northerly winds here = generally cleaner background
- In Florida: Winds have a more southerly component in 2020 as compared to 2019
  - Southerly winds here = generally cleaner background
- Elsewhere: Winds generally similar between years

Results

Examples:
Weather favorable for *smaller* NO_2 in Wash, DC
Weather favorable for *larger* NO_2 in Las Vegas

- **Method 0**
  TROPOMI NO_2 change 2020 only
  (Jan-Feb vs. Mar 15-Apr 30)
- **Method 1 – account for season**
  TROPOMI NO_2 2019 vs. 2020
  (Mar 15 – Apr 30)
- **Method 2 – account for season & meteorology**
  Normalize TROPOMI NO_2 by meteorology, 2019 v. 2020
  (Mar 15 – Apr 30)
- **Method 3 – account for season & meteorology**
  TROPOMI NO_2 vs. simulated "normal" times, 2020 only
  (Mar 15 – Apr 30)

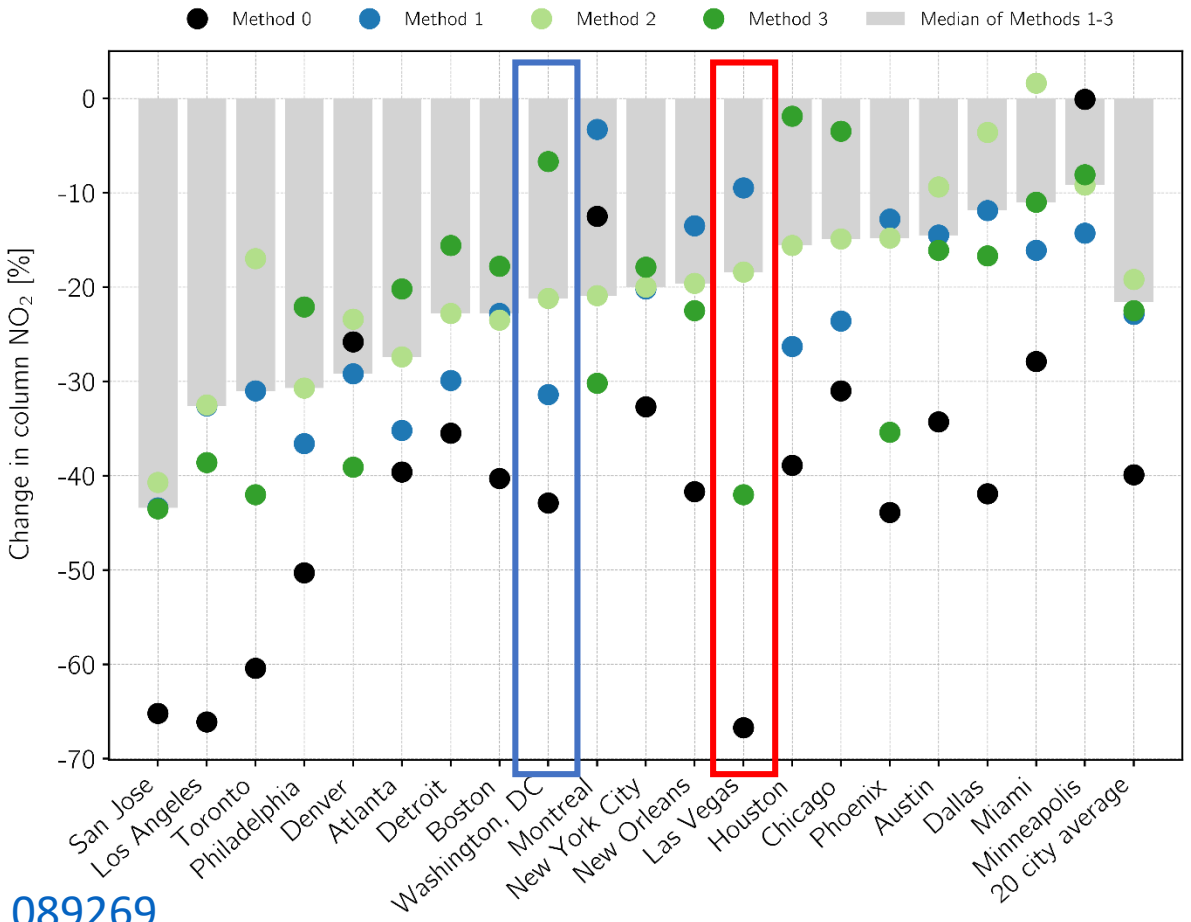
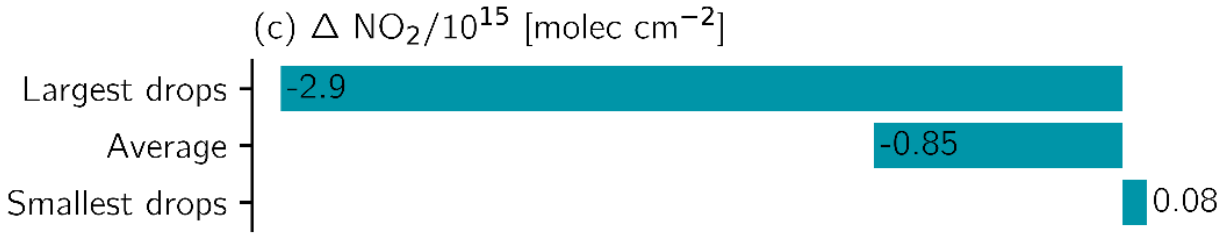
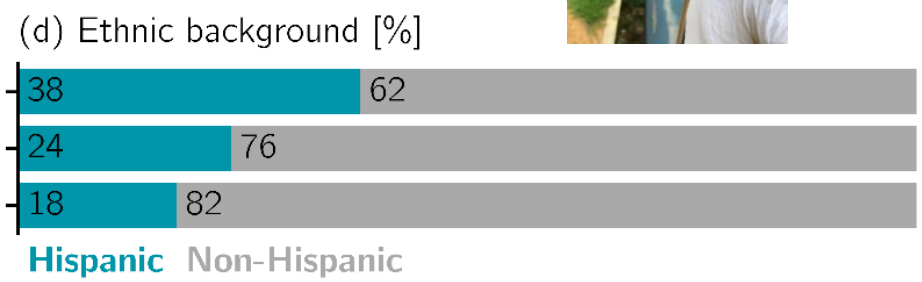


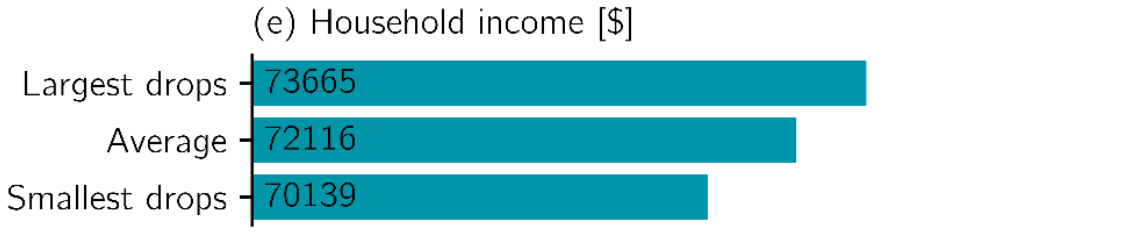
Figure created by Gaige Kerr

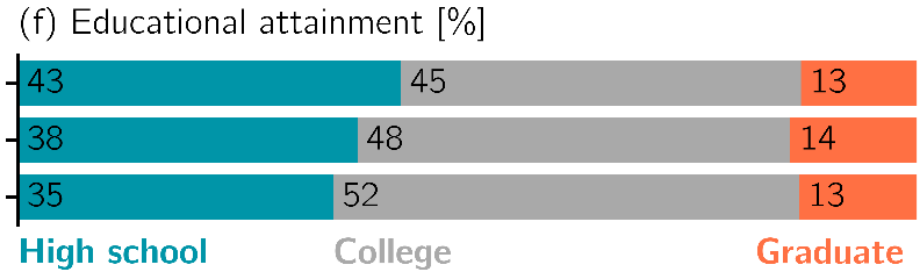
Goldberg et al., GRL 2020
https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2020GL089269

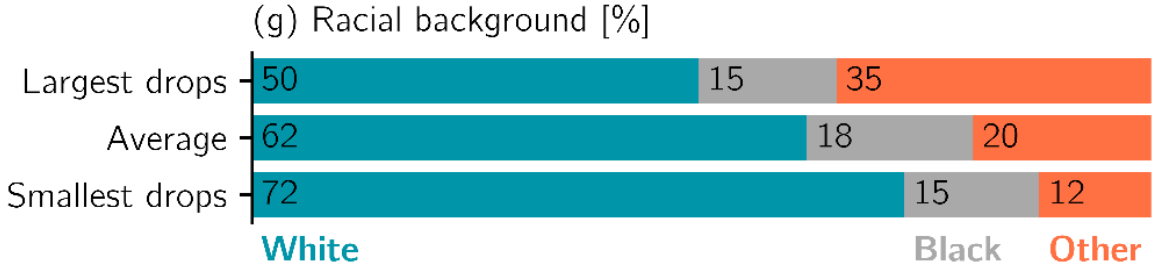
During COVID-19 precautions, less educated, minority communities experience the largest decreases in NO_2

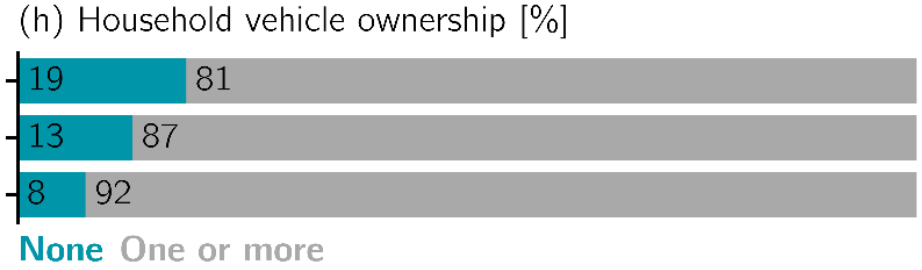












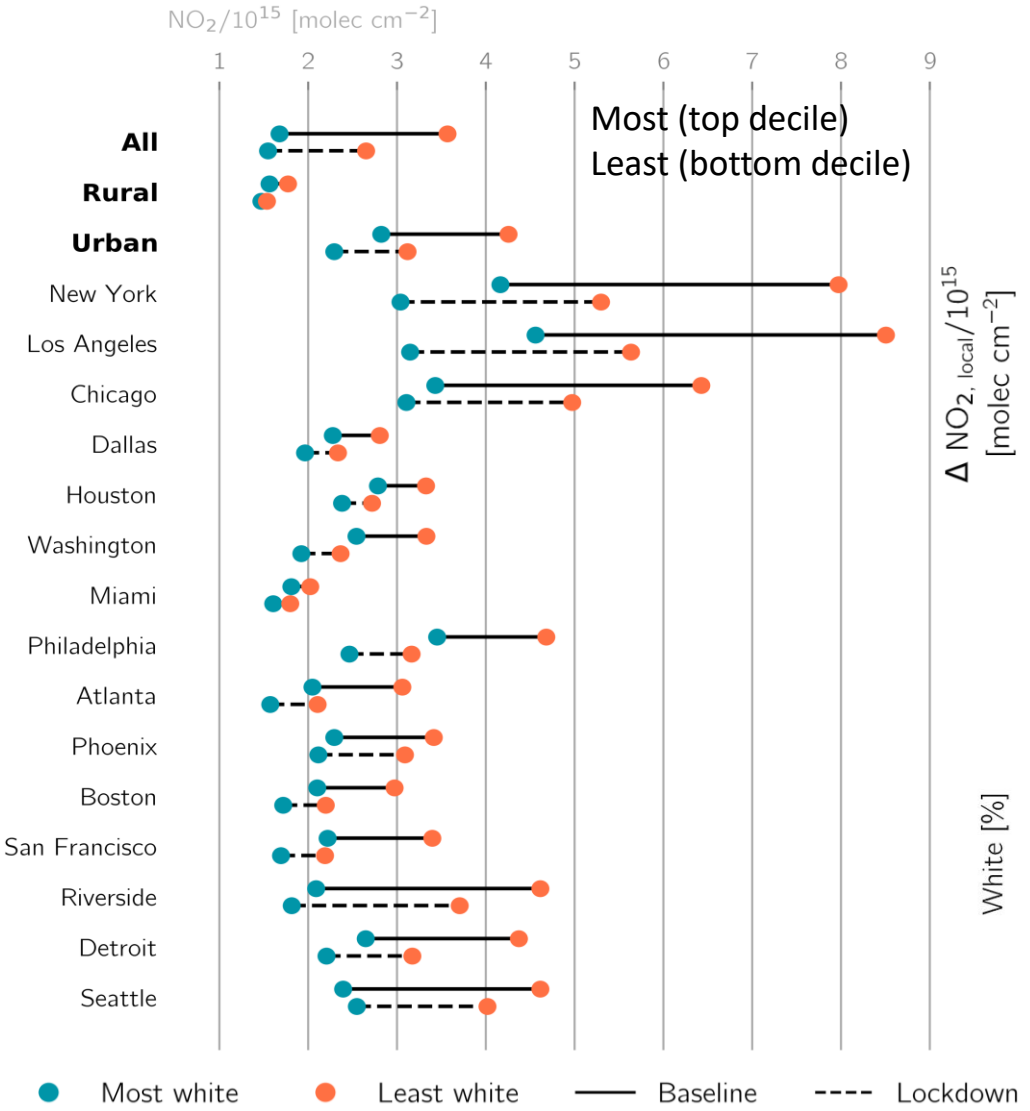
Baseline: 13 March – 13 June 2019
Lockdown: 13 March – 13 June 2020

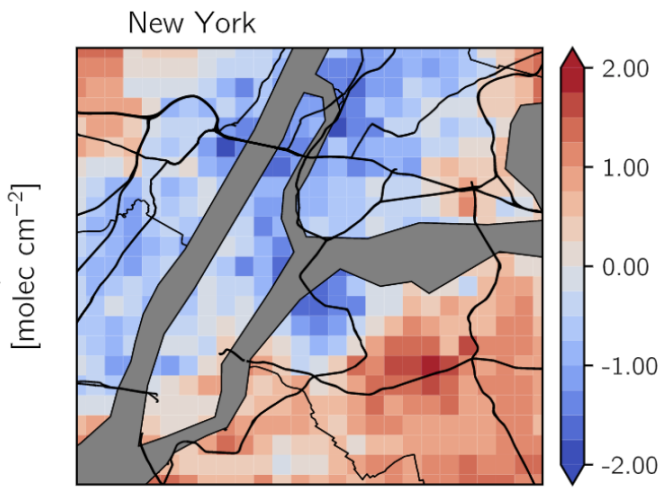
Largest gains (top decile in urban areas)
Average (middle decile in urban areas)
Smallest gains (bottom decile in urban areas)

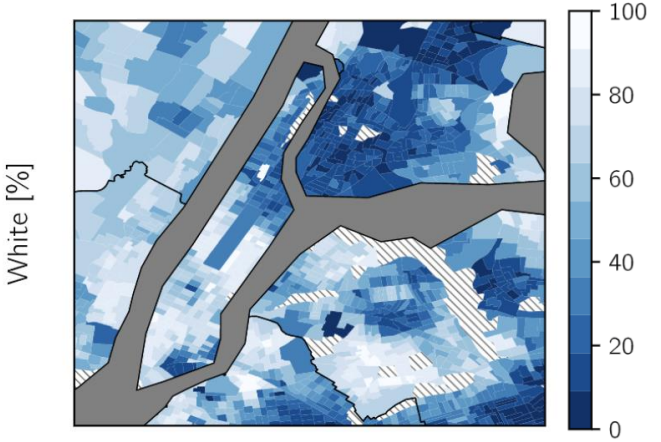
Kerr et al. submitted
https://www.essoar.org/doi/pdf/10.1002/essoar.10504561.2

Despite decreases for communities that are less white lockdowns did not eliminate disparities by race

- In many cities, the post-lockdown NO_2 amounts in the least white communities are still ~50% larger than the pre-lockdown NO_2 amounts in the most white communities
- Also holds for income and educational attainment







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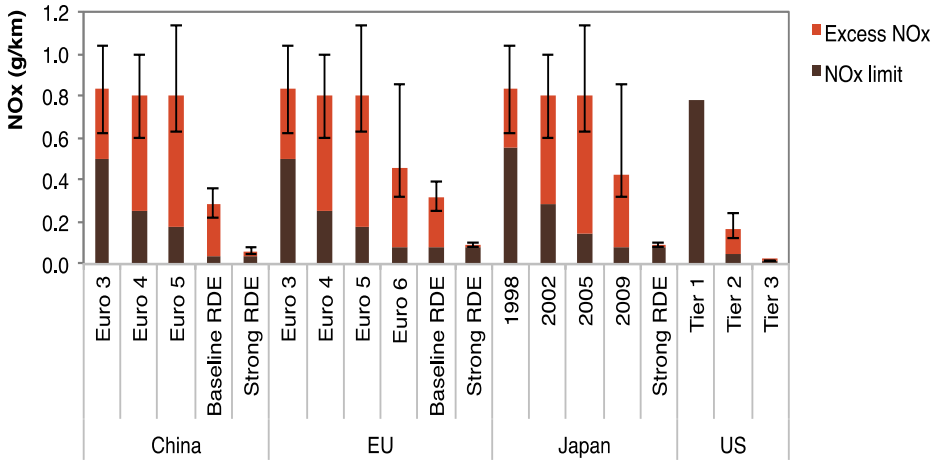
Policy implications

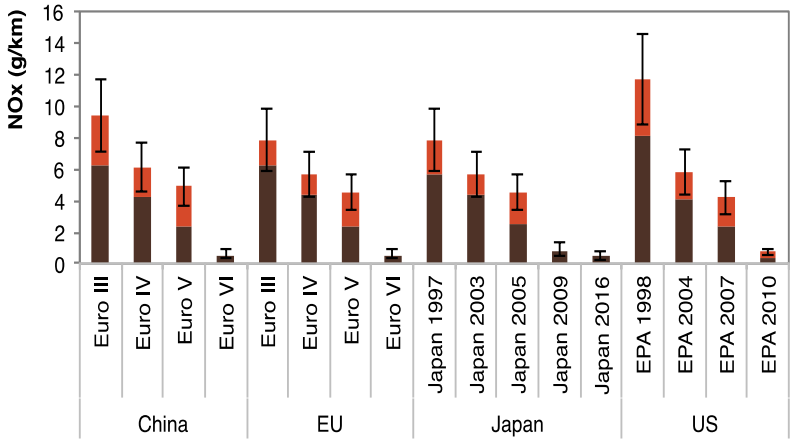
Future policies aimed at eliminating pollution disparities will need to look beyond reducing emissions from only passenger traffic and also consider other collocated sources of emissions such as heavy-duty trucks, power plants, and industrial facilities.

Emission factors

CARS



TRUCKS
(scale x10)



Anenberg et al., Nature, 2017

Conclusions

- NO_2 is a substantial contributor to pediatric asthma incidence globally and in the U.S., in addition to its role in O_3 and $PM_{2.5}$ formation.
- NO_2 drops attributed to COVID-19 lockdowns (anthropogenic forcing) ranged between 9.2% and 43.4% among 20 cities in North America, with a median of 21.6%.
- Meteorological patterns were favorable for low NO_2 in eastern U.S. in spring 2020, complicating comparisons with spring 2019.
  - Weather variations between years can cause NO_2 differences of ~15% over monthly timescales.
- Urban neighborhoods with a high percentage of racial and ethnic minorities and lower educational attainment experienced the largest reductions in NO_2 during lockdowns, but the lockdowns did not eliminate disparities.
  - In some cases, NO_2 in the most-white neighborhoods pre-pandemic was still lower than NO_2 in least-white neighborhoods post-pandemic.

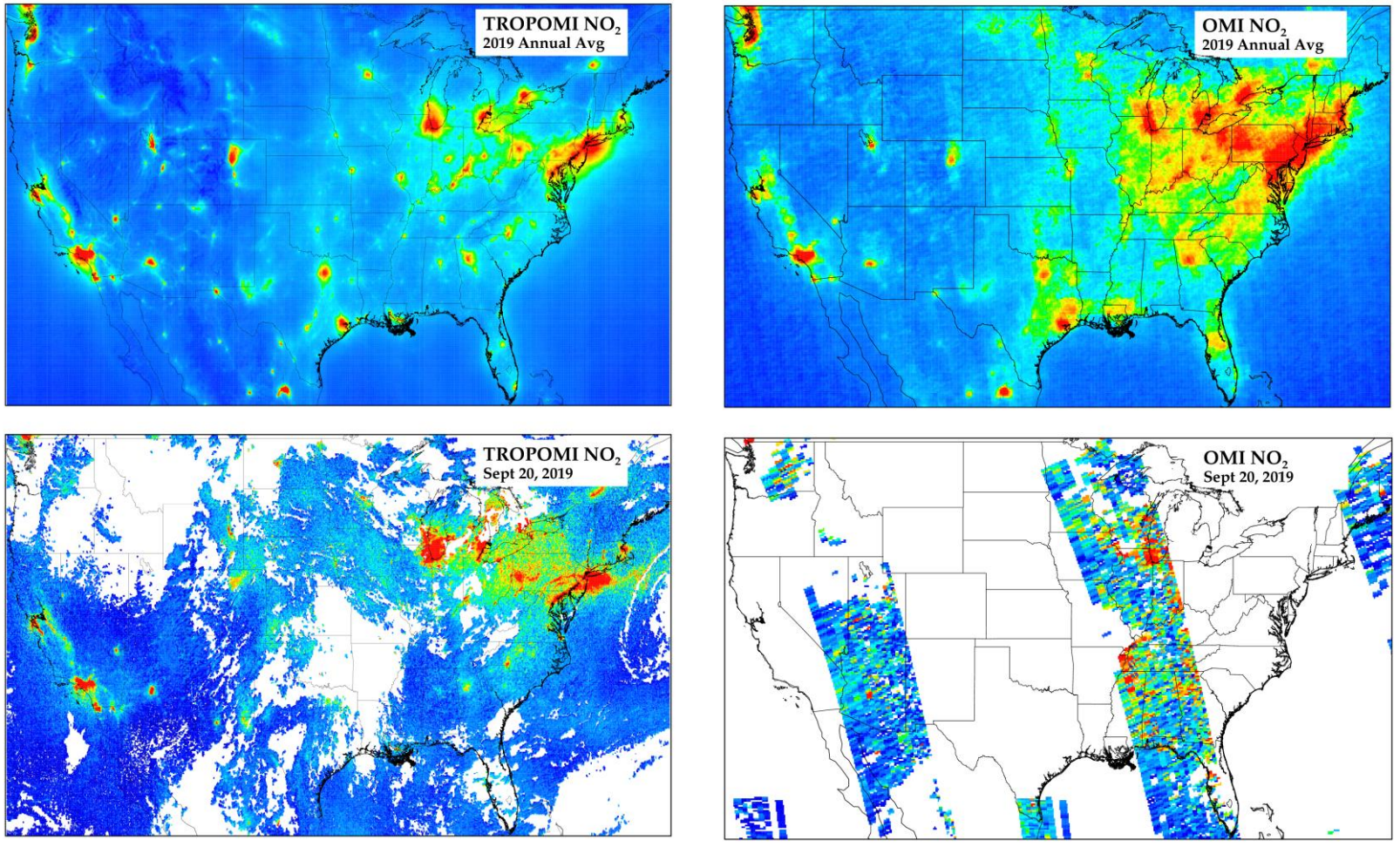
Manuscript/Publications

- Goldberg, D.L., S.C. Anenberg, Z. Lu, D.G. Streets, D. Griffin, C.A. McLinden (2020) Disentangling the impact of the COVID-19 lockdowns on urban NO_2 from natural variability. *Geophysical Research Letters*, https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2020GL089269
- Goldberg D.L., Anenberg S.C., Mohegh A., Lu Z., Streets D.G. TROPOMI NO_2 in the United States: A detailed look at the annual averages, weekly cycles, effects of temperature, and correlation with PM2.5. Pre-print, https://www.essoar.org/doi/abs/10.1002/essoar.10503422.1
- Kerr, G., Goldberg, D.L., S.C. Anenberg. COVID-19 lockdowns reveal pronounced disparities in nitrogen dioxide pollution levels. Pre-print, https://www.essoar.org/doi/abs/10.1002/essoar.10504561.2

Extra: TROPOMI NO_2 vs. OMI NO_2

TROPOMI NO_2

OMI NO_2



- Measurements are column contents; the amount of NO_2 between surface and ~12 km altitude
- Most (but not all) of NO_2 is near the surface in urbanized areas
- Units are molecules per cm^2; Red is high concentrations, Blue is low concentrations

- TROPOMI has less missing data & better spatial resolution

- OMI has larger values