Disentangling the impact of the COVID-19 lockdowns on urban NO2 from natural variability

Feb 25th, 2021

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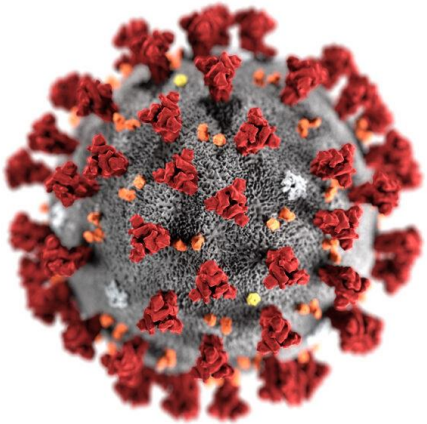
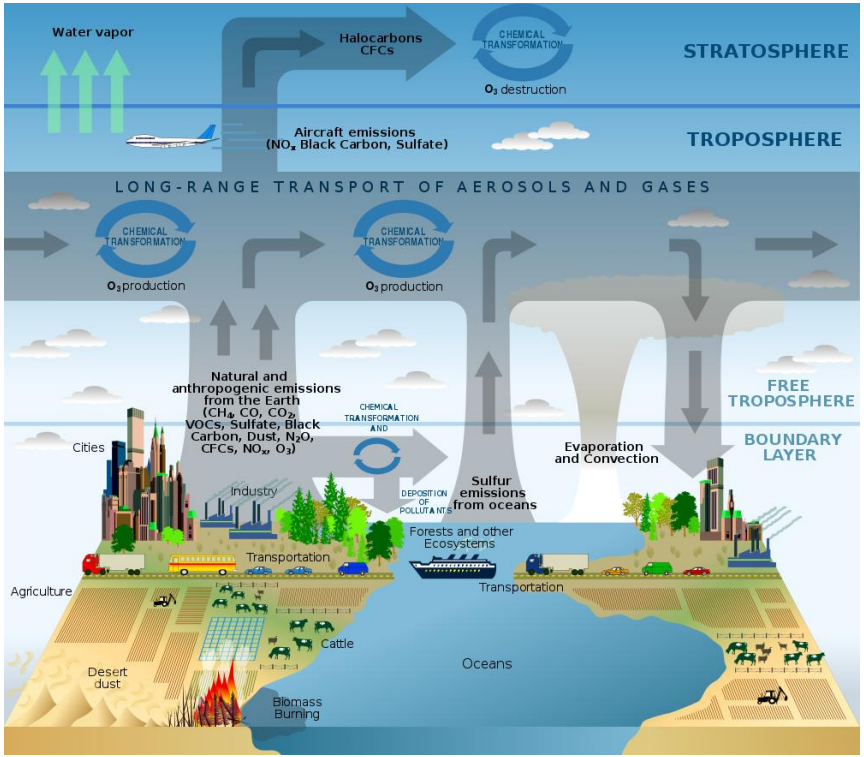
COVID-19 and Air Quality

- COVID-19 has resulted in wide scale changes in human behavior
- This has, in turn, has impacted traffic emissions.

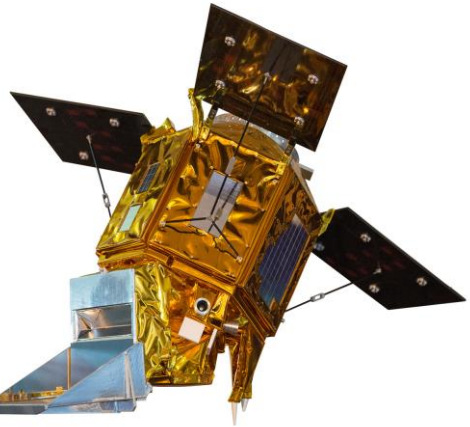


How much of the reduction in NO_2 is due to COVID-19 vs. seasonal impacts?

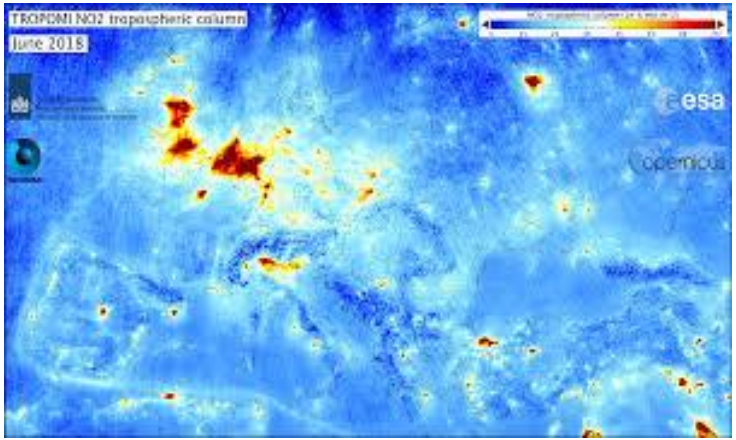
Methods



Atmospheric NO2 behaviour

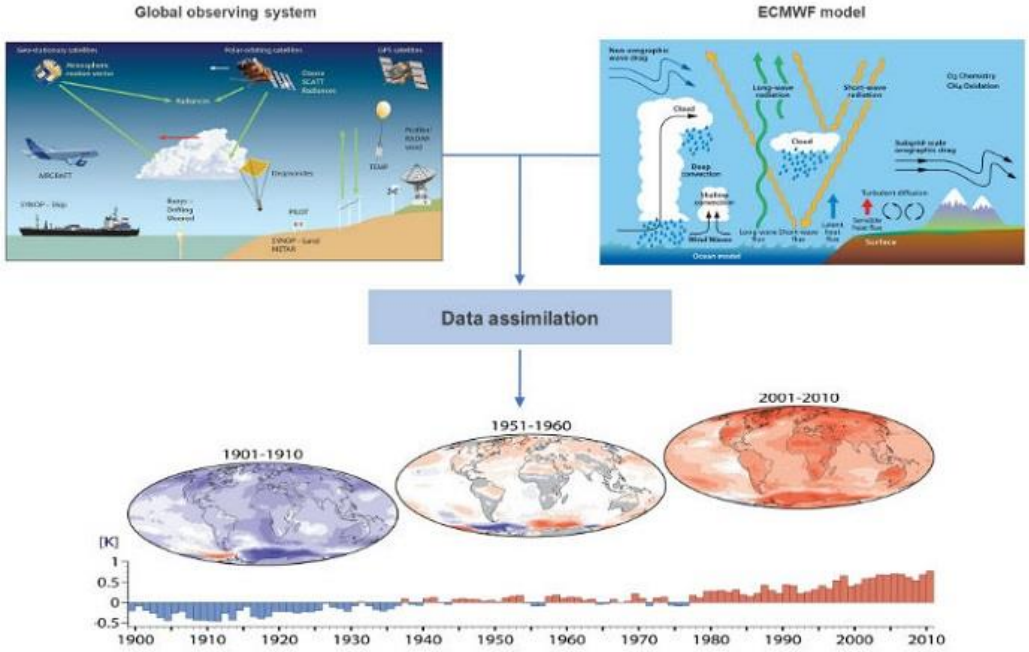


Sentinel-5P



Tropospheric NO2 from TROPOMI

Wind Data



opernicus
Europe's eyes on Earth

Climate
Change Service

Method 0 - The “Control” Method

Before COVID-19: Jan 1, 2020 – Feb 29, 2020

After COVID-19: March 15, 2020 – April 30, 2020

% Reduction = NO2 (Before COVID-19) – NO2 (After COVID-19)

Method 1: Same timeframe between 2019 and 2020

2019 period: March 15, 2019 – April 30, 2019

2020 period: March 15, 2020 – April 30, 2020

% Reduction = NO_2 (2019 period) – NO_2 (2020 period)

Method 2

Step 1

$$f_{sun-angle_n} = \frac{0.75 + 0.25 * cos\left[2\pi \frac{n+11}{365}\right]}{0.75 + 0.25 * cos\left[2\pi \frac{n_d+11}{365}\right]}$$

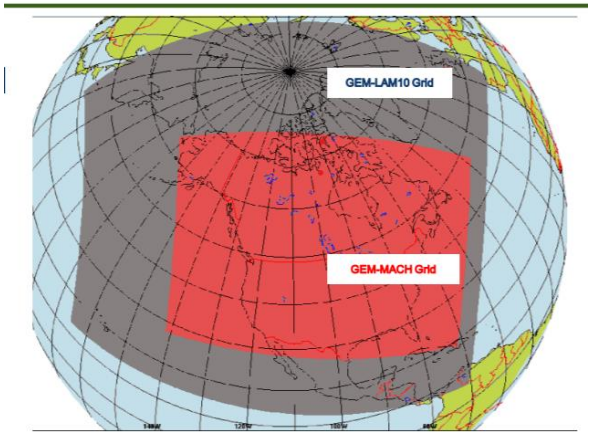
Step 2

$$f_{total_{n,i}} = \left[f_{sun-angle}\right]_n \left[f_{day-of-week}\right]_n \left[f_{wind-speed}\right]_{n,i} \left[f_{wind-dir}\right]_{n,i}$$

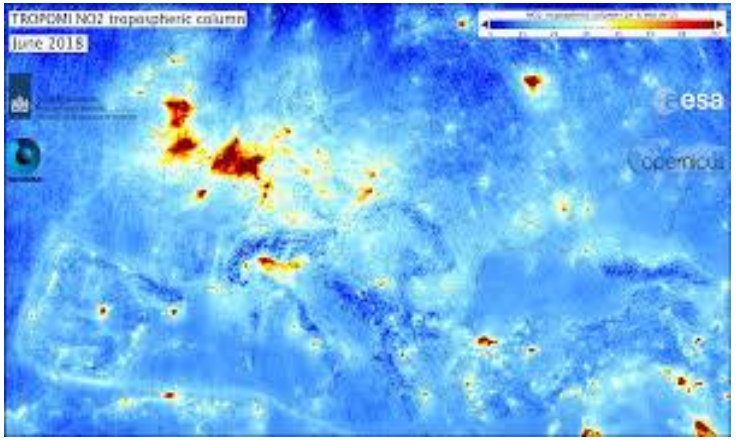
Step 3

$$\widehat{NO_2}_{n,i} = \frac{NO_{2_{n,i}}}{f_{total_{n,i}}}$$

Method 3



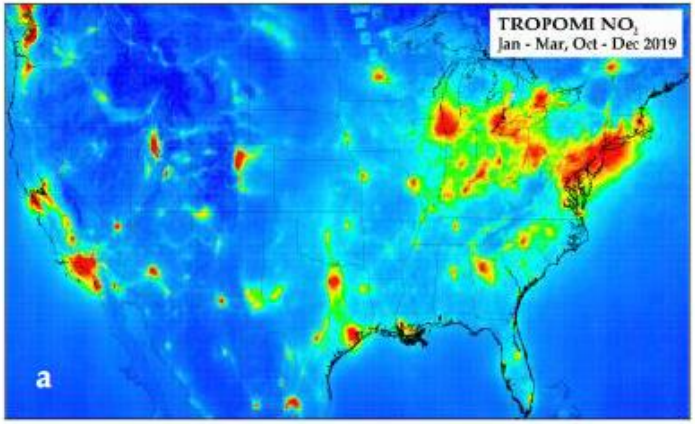
GEM-MACH run with no COVID-19 precautions in place

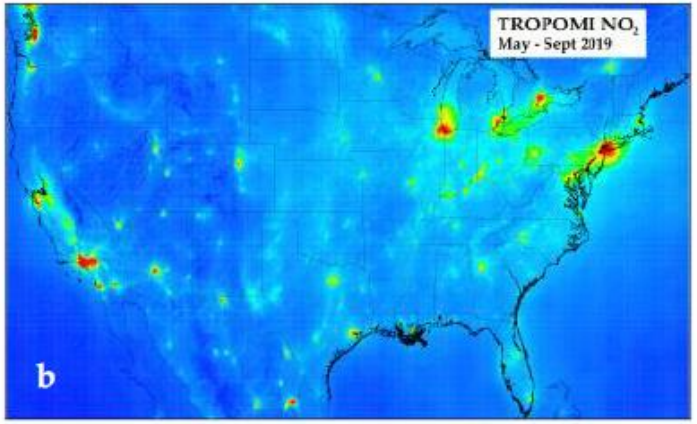


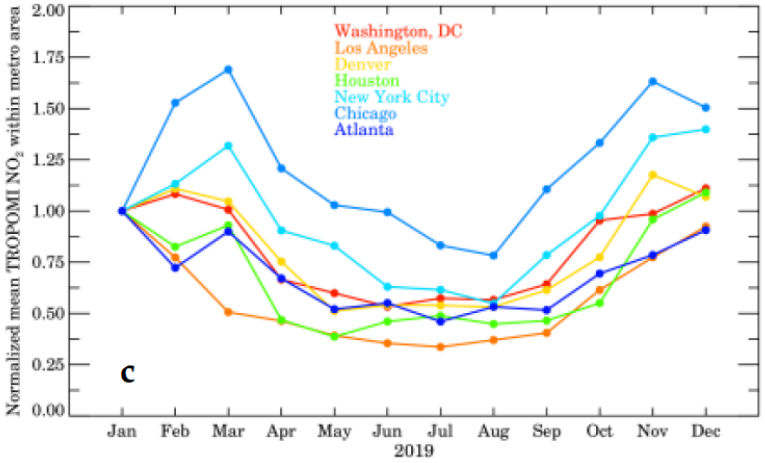
Tropospheric NO2 from TROPOMI

Results:
Impact of Meteorological Variables

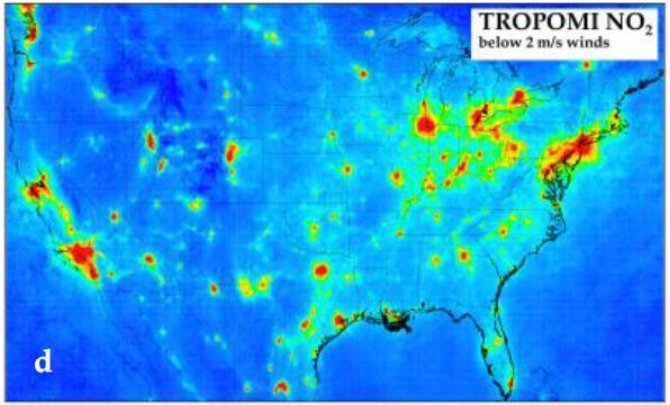
Impact of Sun Angle

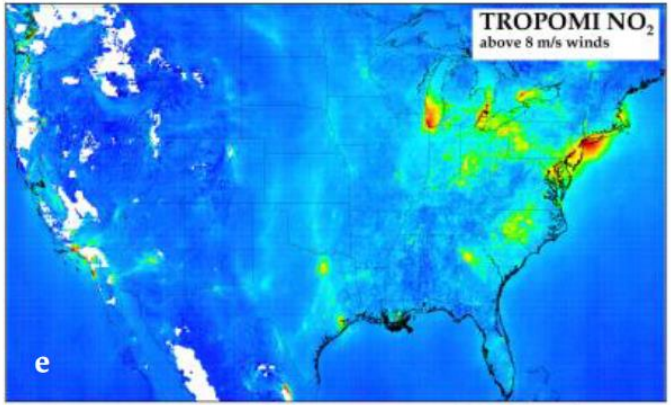


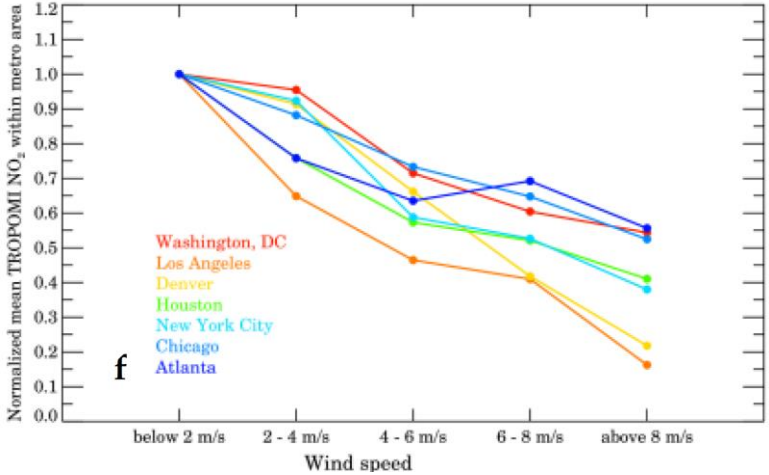




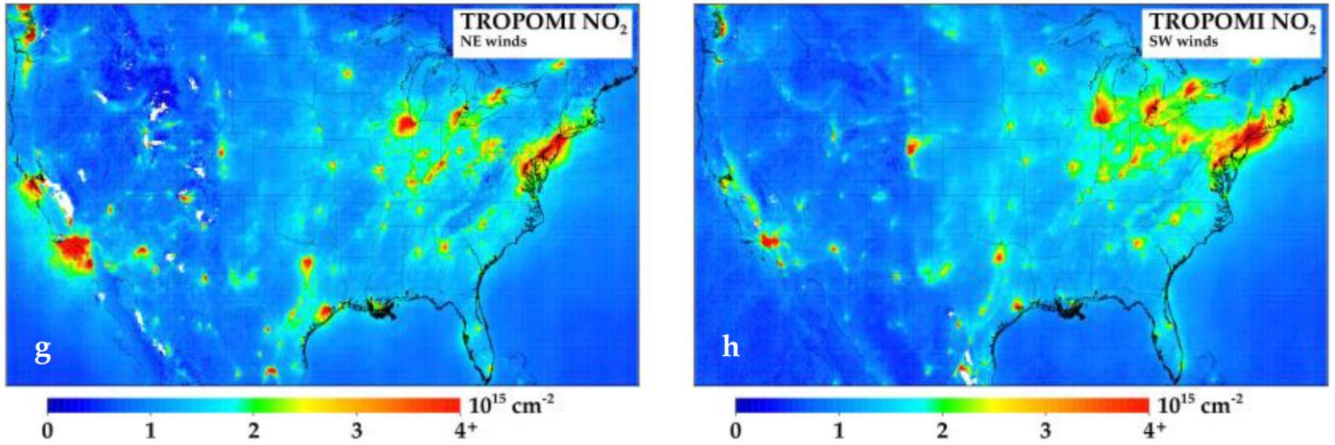
Impact of Wind Speed

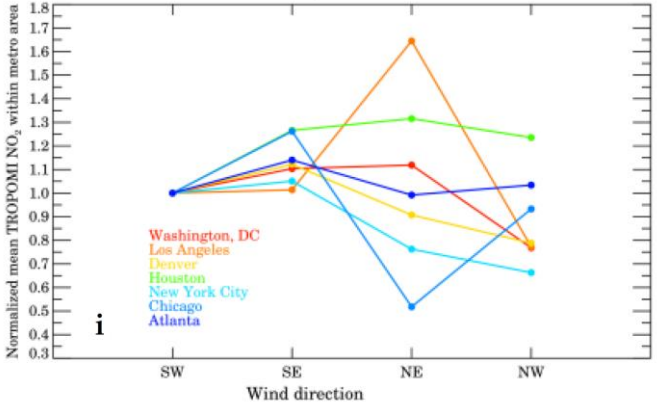






Impact of Wind Direction





Results for Methods 0 - 3

Comparison of results for each method

City Name	Reference case Method 0 Δ between months 2020 only (Jan-Feb vs. Mar 15 - Apr 30)	Account for sun-angle only Method 1 Δ between years 2019 vs. 2020 (Mar 15 - Apr 30)	Account for sun-angle & meteorology Method 2 Using ERA5 analogs to account for meteorology 2019 vs. 2020 (Mar 15 - Apr 30)	Method 3 Using GEM-MACH to infer NO2, 2020 only (Mar 15 - Apr 30)	*Mean of Methods 1-3*	*Median of Methods 1-3*
San Jose	65.2%	43.4%	40.7%	43.5%	42.5%	**43.4%**
Los Angeles	66.1%	32.6%	32.5%	38.6%	34.6%	**32.6%**
Toronto	60.4%	31.0%	17.0%	42.0%	30.0%	**31.0%**
Philadelphia	50.3%	36.6%	30.7%	22.1%	29.8%	**30.7%**
Denver	25.8%	29.2%	23.4%	39.1%	30.6%	**29.2%**
Atlanta	39.6%	35.2%	27.4%	20.2%	27.6%	**27.4%**
Detroit	35.5%	29.9%	22.8%	15.6%	22.8%	**22.8%**
Boston	40.3%	22.8%	23.5%	17.8%	21.4%	**22.8%**
Washington DC	42.9%	31.4%	21.2%	6.7%	19.8%	**21.2%**
Montreal	12.5%	3.3%	20.9%	30.2%	18.1%	**20.9%**
New York City	32.7%	20.2%	20.0%	17.9%	19.4%	**20.0%**
New Orleans	41.7%	13.5%	19.6%	22.5%	18.5%	**19.6%**
Las Vegas	66.7%	9.5%	18.4%	42.0%	23.3%	**18.4%**
Houston	38.9%	26.3%	15.6%	1.9%	14.6%	**15.6%**
Chicago	31.0%	23.6%	14.9%	3.5%	14.0%	**14.9%**
Phoenix	43.9%	12.8%	14.8%	35.4%	21.0%	**14.8%**
Austin	34.3%	14.5%	9.4%	16.1%	13.3%	**14.5%**
Dallas	41.9%	11.9%	3.6%	16.7%	10.7%	**11.9%**
Miami	27.9%	16.1%	-1.6%	11.0%	8.5%	**11.0%**
Minneapolis	0.1%	14.3%	9.2%	8.1%	10.5%	**9.2%**
Mean of each method	39.9%	22.9%	19.2%	22.5%	21.6%	**21.6%**

Method 1: Comparison between 2019 and 2020

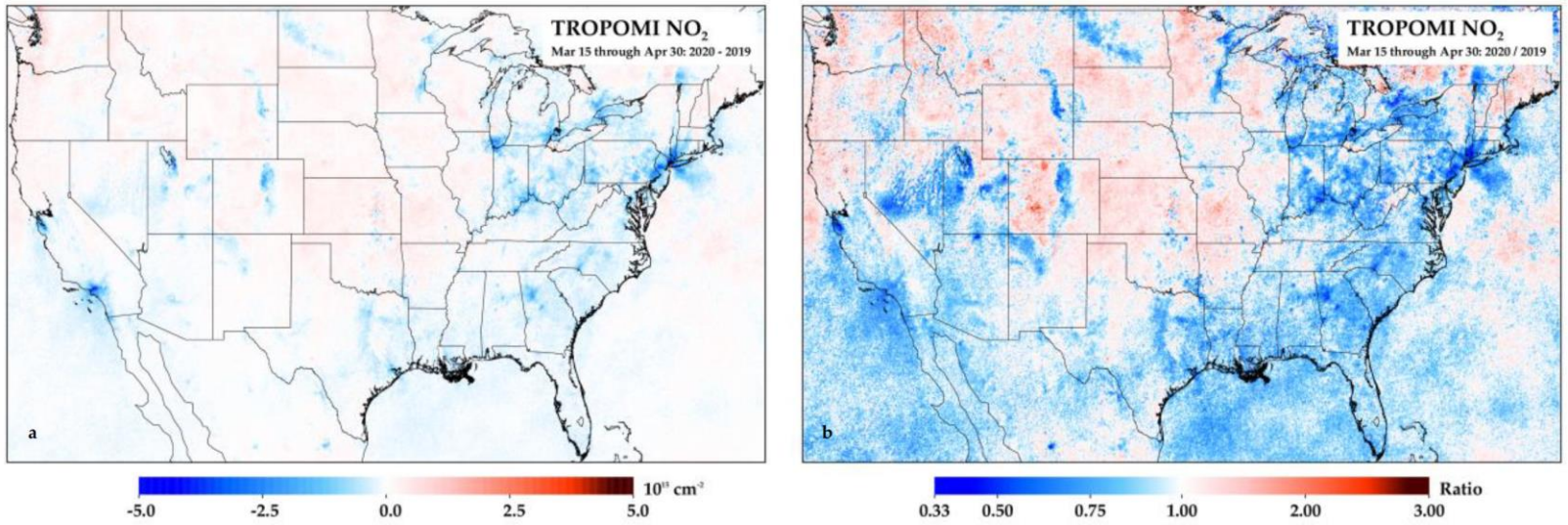


Figure 2. TROPOMI NO_2 differences between 2019 & 2020, using March 15 – April 30, 2020 as the post-COVID-19 period. Plots are showing (a) the absolute difference and (b) the ratio between years.

Method 2

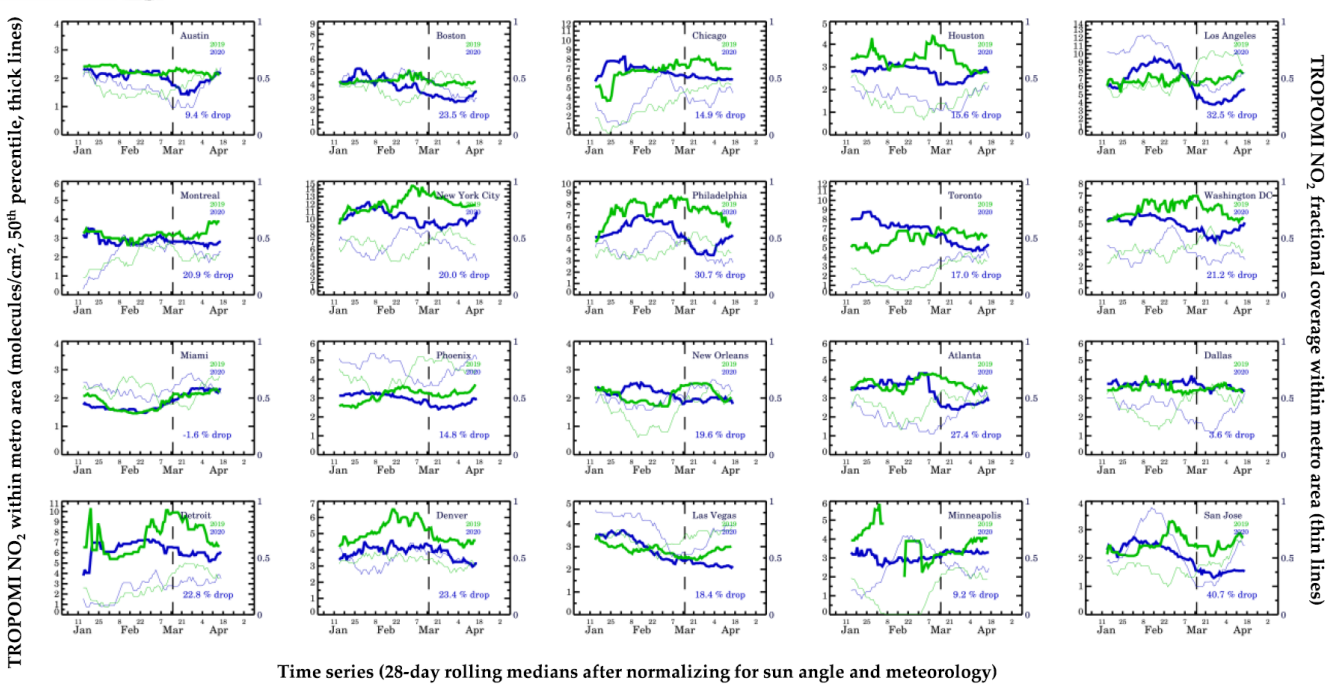


Figure 3. Trends in TROPOMI NO_2 since January 1 in 2019 and 2020 after accounting for meteorological variability and sun angle. The thick lines represent the 28-day rolling median value (50^{th} percentile) in a $0.4° \times 0.4°$ box centered on the city center for the largest cities (New York City, Los Angeles, Chicago, Toronto, Houston) and $0.2° \times 0.2°$ box in all other cities. The thin lines represent the fractional coverage (0 – 1) in the coincident spatiotemporal domain.

Method 3

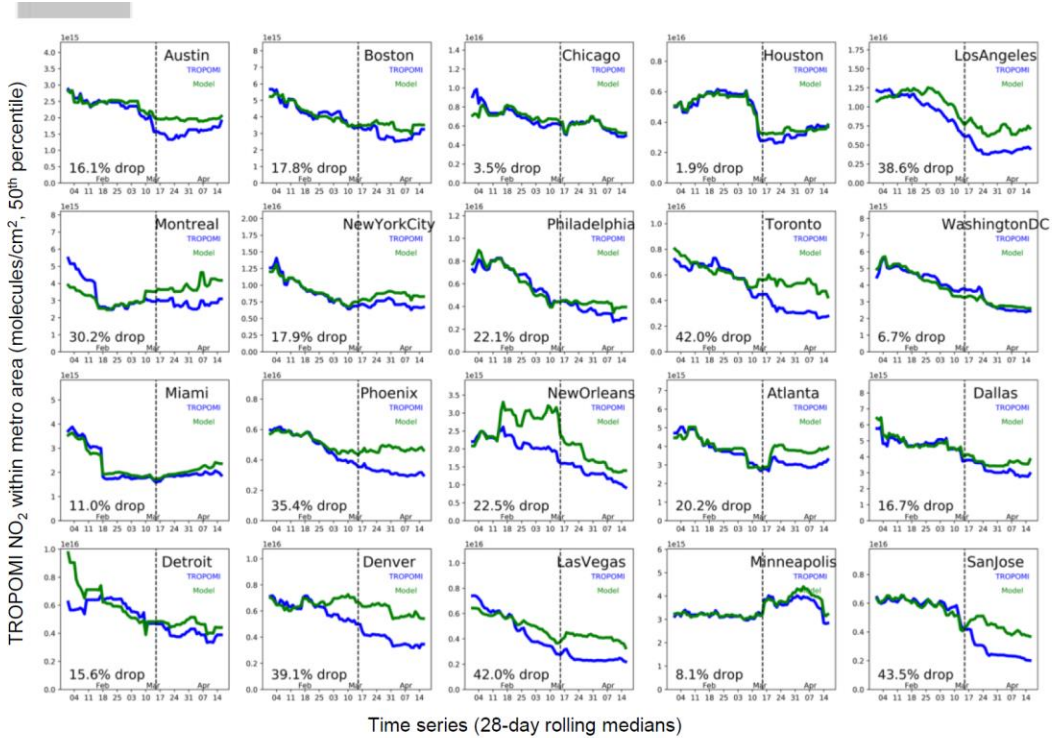


Figure 4. Trends in TROPOMI NO_2 since January 1, 2020. The actual observed columns are shown in black, while the "expected" columns - using GEM-MACH to infer NO_2 in the absence of lockdowns – is shown in blue. The lines represent the 28-day rolling median value (50^{th} percentile) in a $0.4° \times 0.4°$ box centered on the city center for the largest cities (New York City, Los Angeles, Chicago, Toronto, Houston) and $0.2° \times 0.2°$ box in all other cities.

Sources of Error

- TROPOMI underestimates NO2
- Clear-sky bias

Questions?

Vehicle Emission Inventory for the **Canada's Air Pollutant Emissions Inventory Report 2020**

ON-ROAD VEHICLES	
Description	On-road Vehicles include: Heavy-duty diesel vehicles, Heavy-duty gasoline trucks, Light-duty diesel trucks, Light-duty diesel vehicles, Light-duty gasoline trucks, Light-duty gasoline vehicles, Propane and natural gas vehicles, Motorcycles, and Tire Wear & Brake Lining.
General Inventory Method	Pollutant(s) Estimated: TPM, PM_{10}, $PM_{2.5}$, SO_x, NO_x, VOCs, CO, NH_3, Pb, Cd, Hg, dioxins/furans, B(a)p, B(b)f, B(k)f, I(cd)p Vehicle-specific activity (vehicle kilometres travelled) is multiplied by pollutant-specific emission factors in the MOVES model (version MOVES2014 was used for this submission). Refuelling VOC emissions are included in under Service Stations.
Activity Data	Data on the vehicle fleet (counts), defined by fuel type, model-year and gross vehicle weight rating, originate from DesRosiers Automotive Consultants (DAC 2014) and R. L. Polk & Co. (Polk & Co. 2013) for light- and heavy-duty vehicles, respectively. Motorcycle populations originate from the publication *Road Motor Vehicle, Trailer and Snowmobile Registration (registrations)* (Statistics Canada j, k). The *Annual Industry Statistics* report (MMIC 2013) is used to estimate the age distribution of motorcycles by model year which is applied to motorcycle populations obtained from Statistics Canada. The actual activity level is vehicle kilometres travelled (VKT). To arrive at estimates of VKT, vehicle counts are multiplied by mileage accumulation rates from Stewart-Brown Associates (Stewart-Brown 2012).
Emission Factors (EF)	Emission factors for on-road vehicles are embedded in the MOVES model. More information on MOVES is available online at www.epa.gov/otaq/models/moves/, in the U.S. EPA user guides (U.S. EPA 2012b, 2014b) and in U.S. EPA technical guidance document (U.S. EPA 2010b).