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

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THE GEORGE WASHINGTON UNIVERSITY

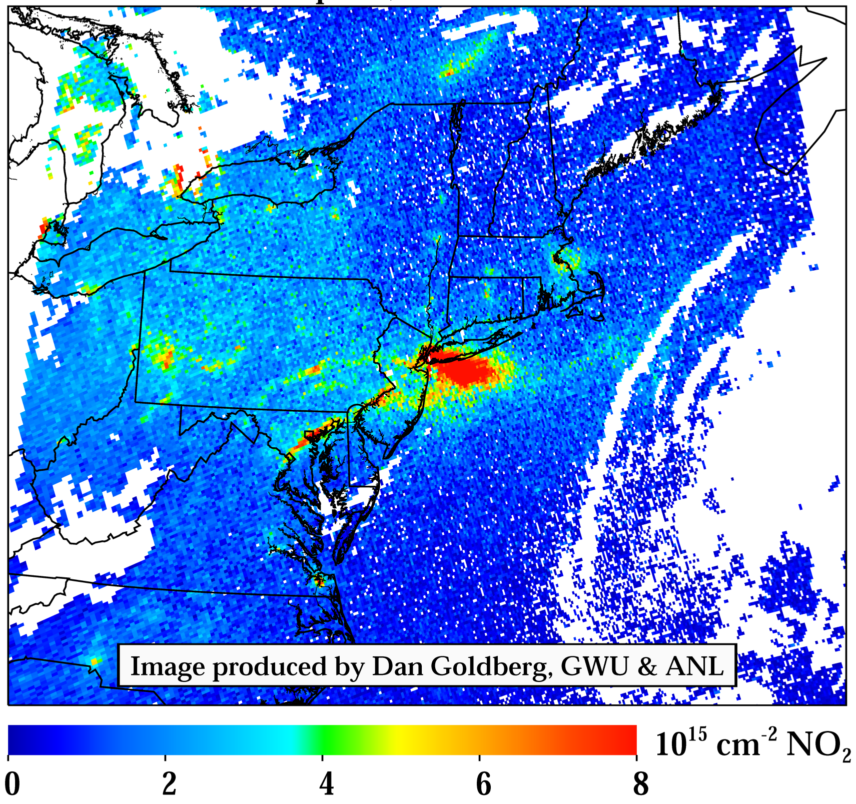
Manuscript/Publications

- 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

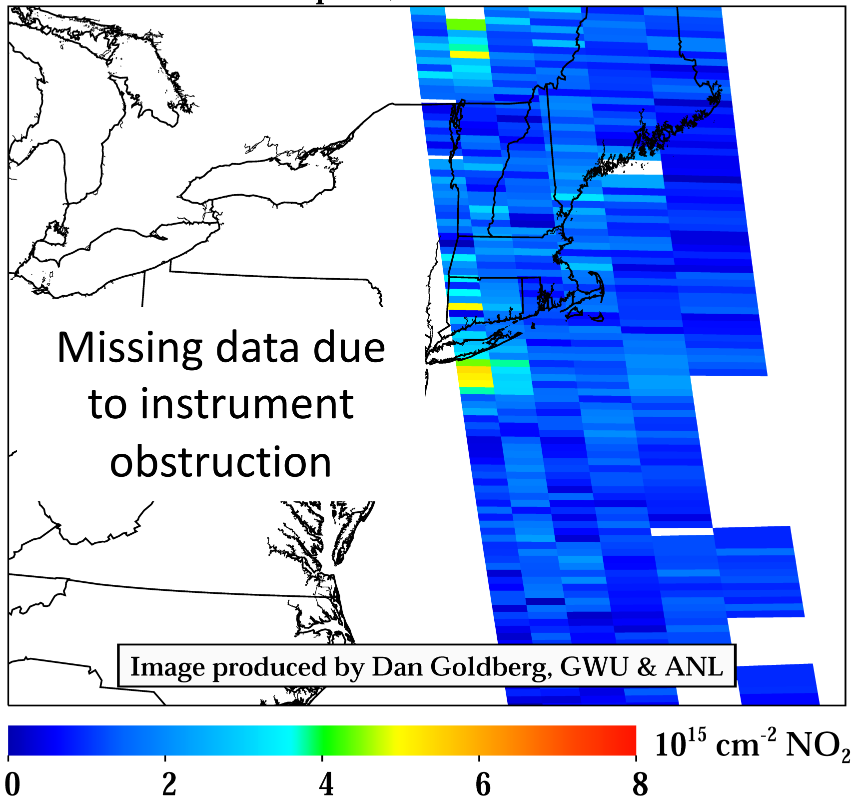
- Goldberg, D.L., S.C. Anenberg, Z. Lu, D.G. Streets, D. Griffin, C.A. McLinden (2020) Disentangling the impact of the COVID-19 lockdowns on urban NO_2 from natural variability. *Geophysical Research Letters*, https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2020GL089269

Single day of NO_2 from TROPOMI vs. OMI

NRT Tropomi NO_2 (Source: https://scihub.copernicus.eu/)
Sept 20, 2019 17:43Z

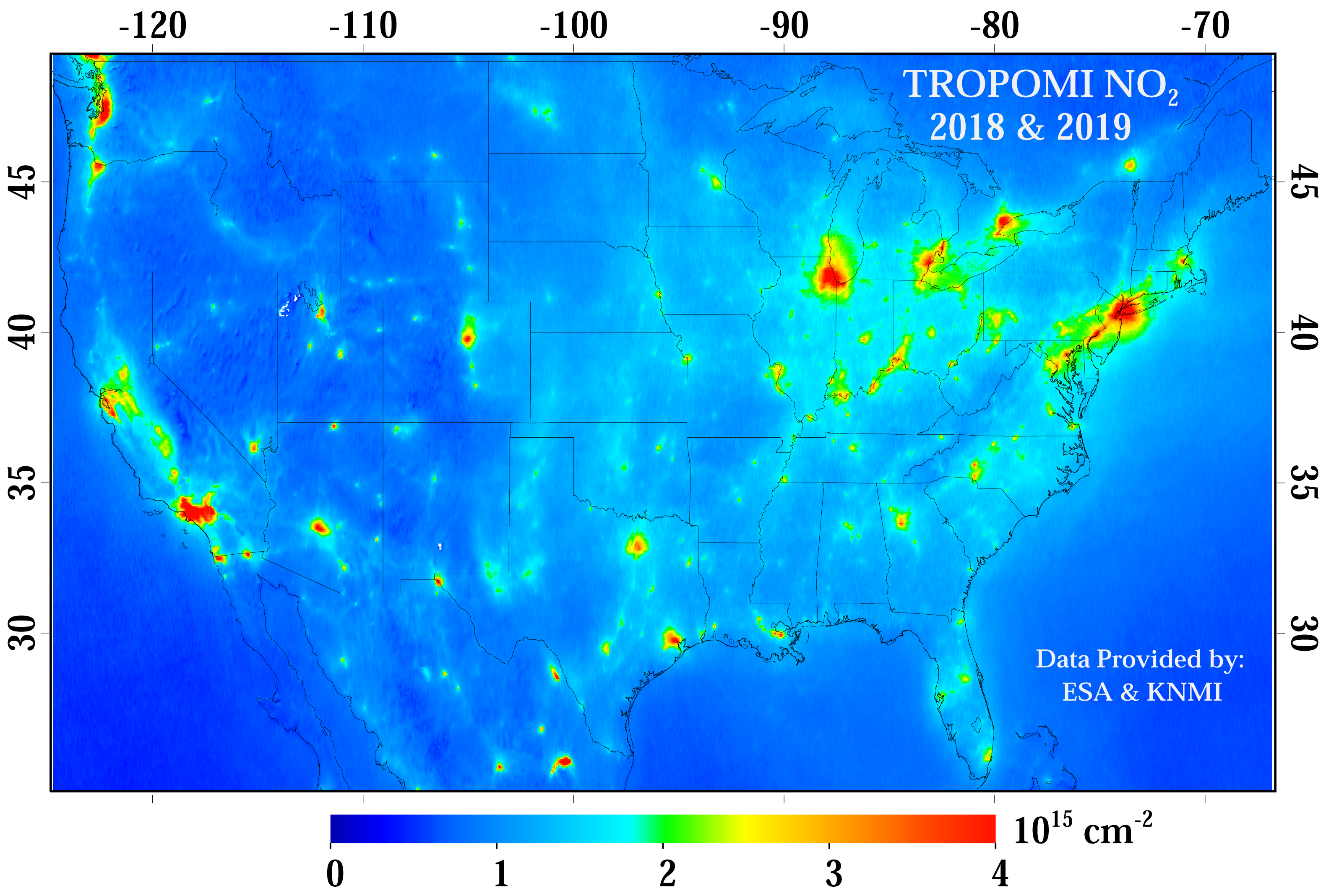


OMI NO_2 (Source: https://earthdata.nasa.gov/)
Sept 20, 2019 17:47Z



- 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

20-month average of NO_2 from TROPOMI



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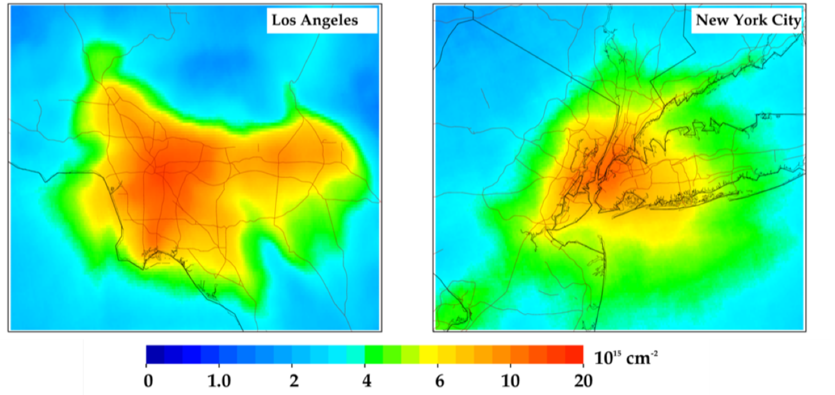
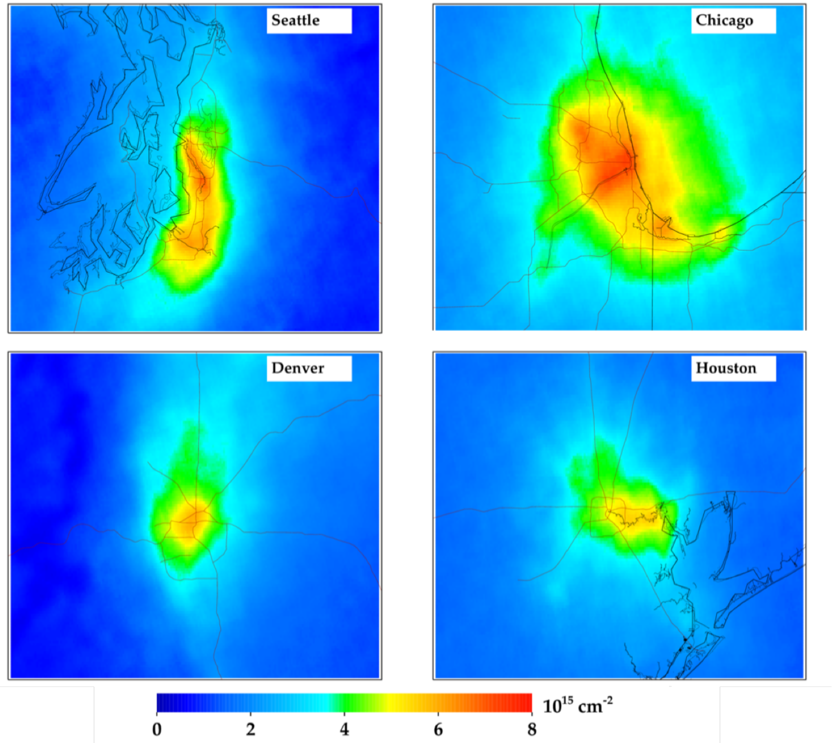
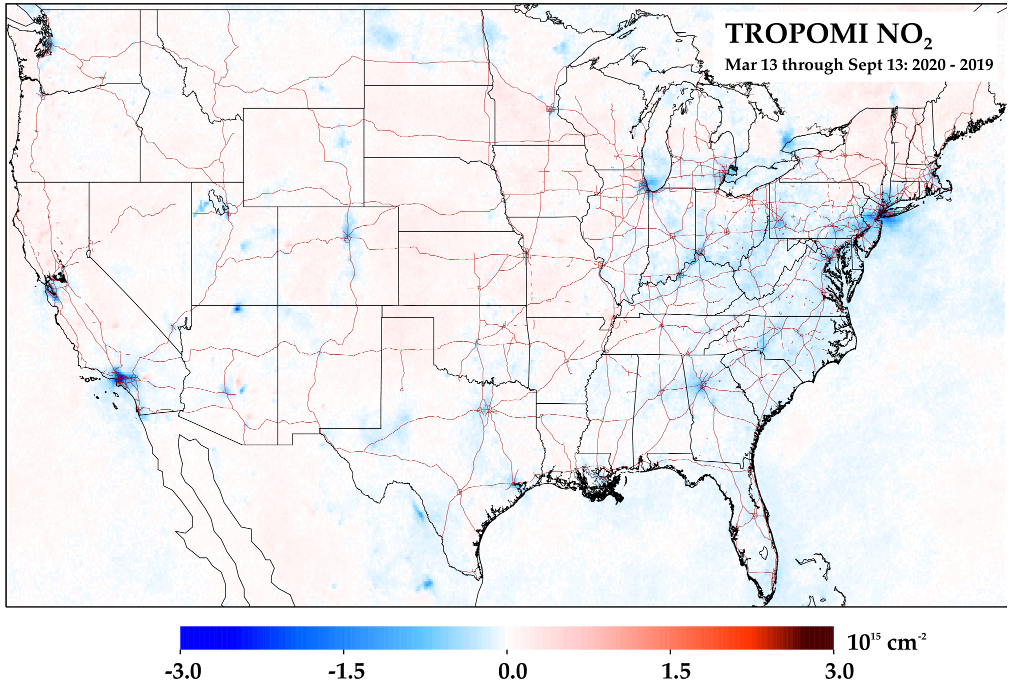


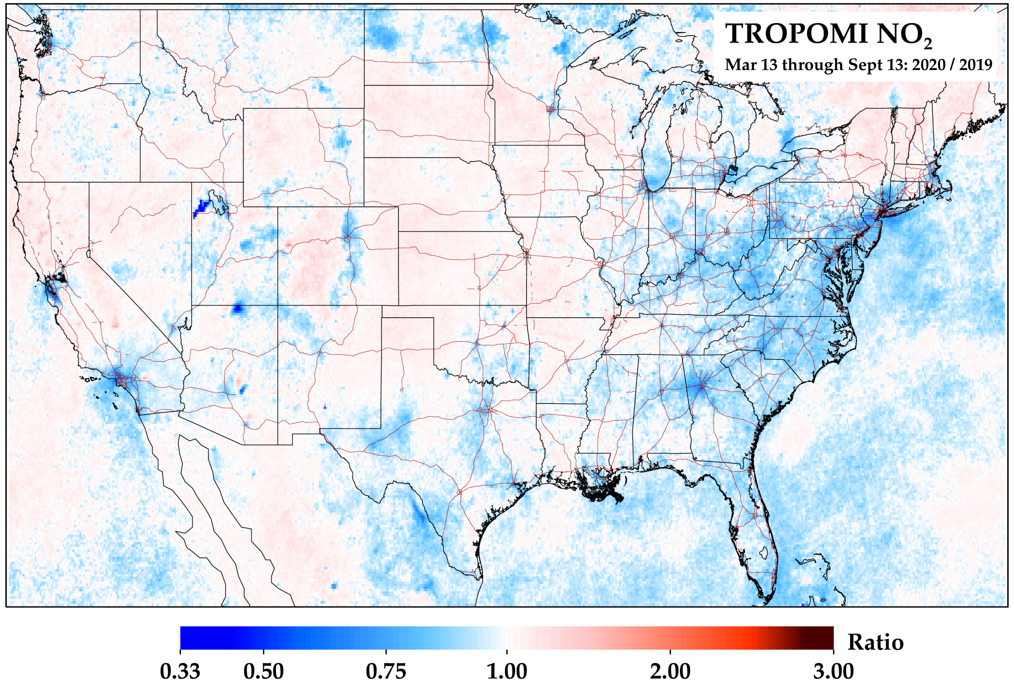


TROPOMI NO_2: Difference between 2019 vs. 2020 March 13 – Sept 13

Absolute Difference



Ratio



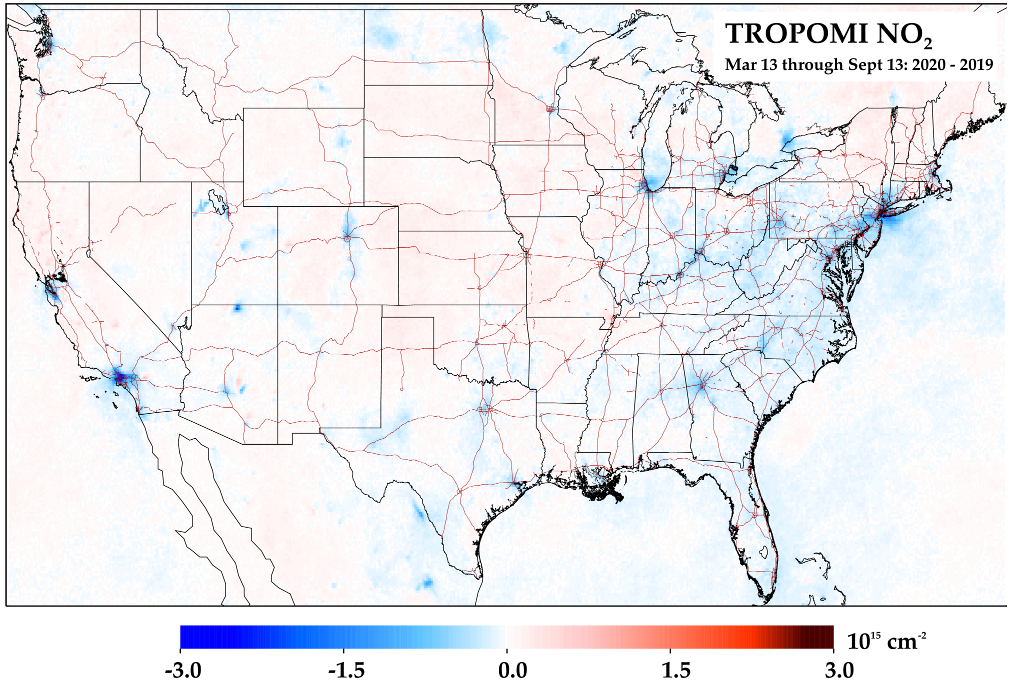

```
Percentage drops in each city
Austin:  -8.7%
Boston: -24.7%
Chicago: -18.7%
Seattle: -19.5%
Houston: -16.4%
Los Angeles: -30.0%
Montreal:   1.5%
New York City: -26.0%
Philadelphia: -21.6%
Portland: -10.1%
San Francisco: -11.3%
Toronto: -20.4%
Washington DC: -24.5%
Miami: -15.3%
Phoenix: -13.1%
Vancouver: -10.4%
New Orleans:  -0.7%
Atlanta: -26.5%
Dallas:  -7.9%
Detroit: -17.1%
Denver: -16.7%
Las Vegas: -11.8%
Minneapolis: -12.6%
San Jose: -33.6%
```

Varying changes in NO_2 across the US, which mostly align with social distancing stringency:

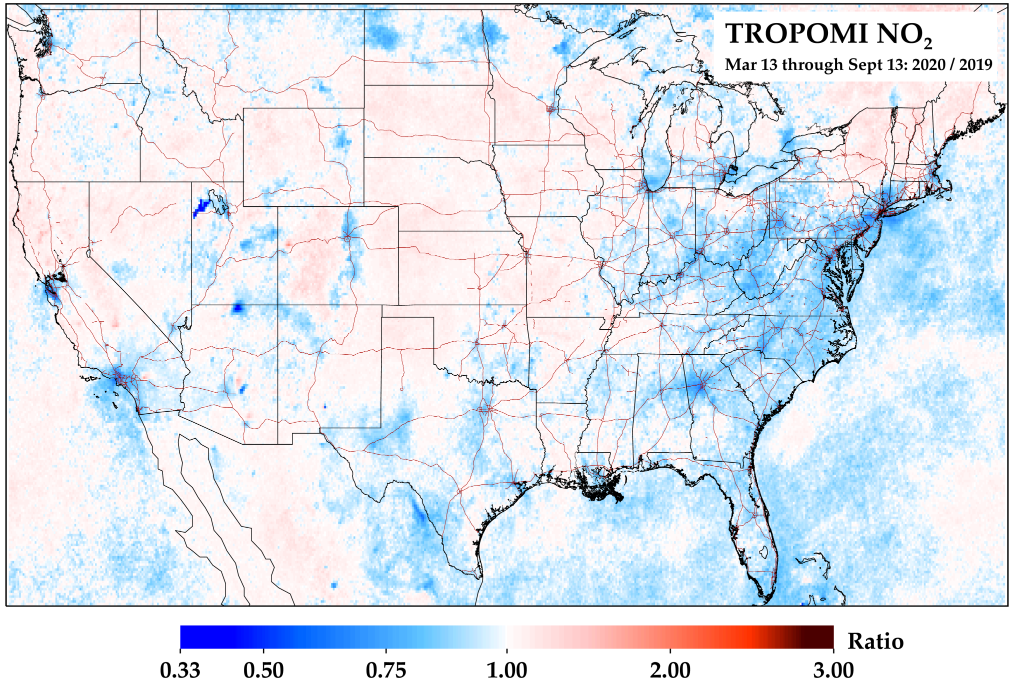
- Largest (by ratio) in Northeast US and California (20-30%)
- Smallest (by ratio) in Southern & Central US (5-15%)

TROPOMI NO_2: Difference between 2019 vs. 2020 March 13 – Sept 13

Absolute Difference



Ratio

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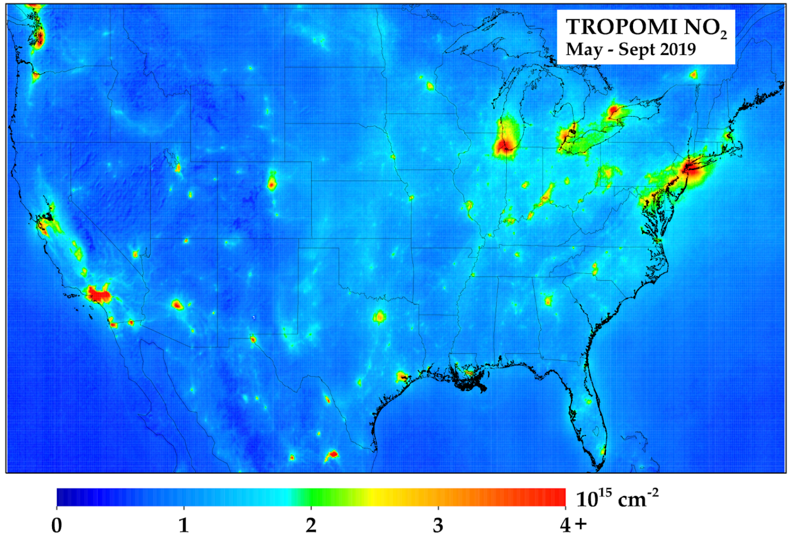
```

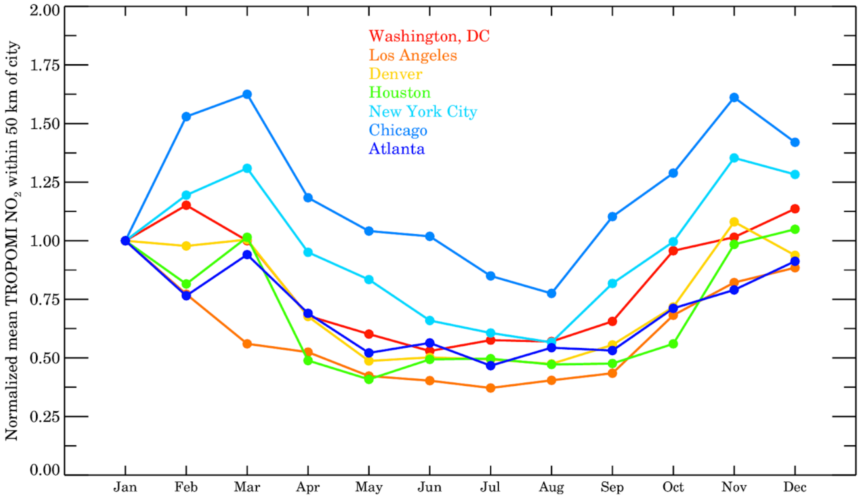
Once we have 6 months of data, effects of natural variability (i.e., meteorology) mostly "average out", but how can we identify changes in NO_2 attributed to anthropogenic causes if we only have 1 or 2 months worth of data?

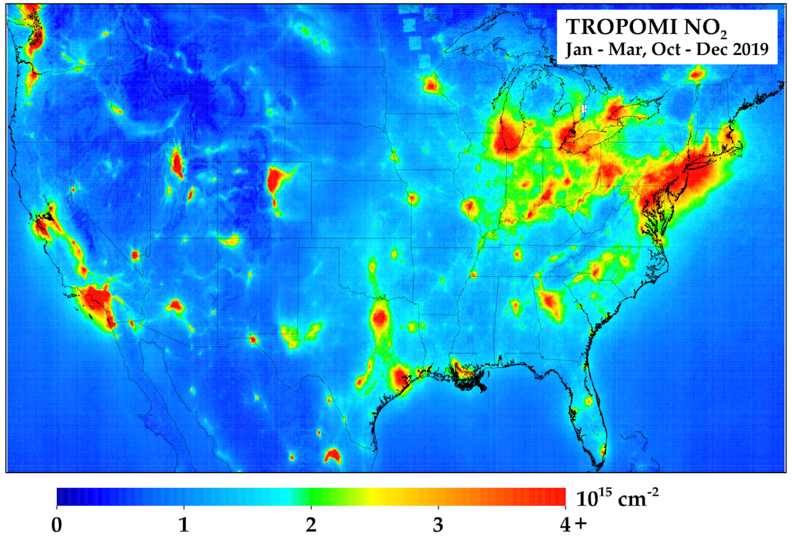
Isolating the anthropogenic signal using TROPOMI NO_2: Warm season vs. cold season

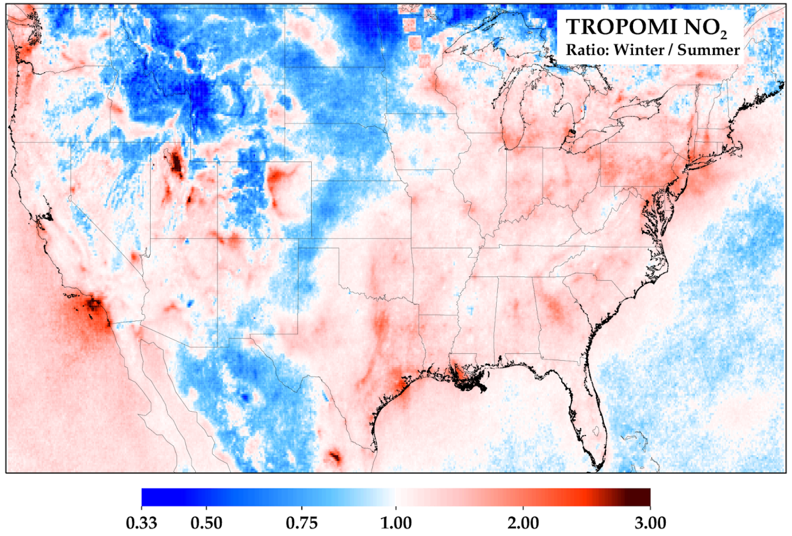
- NO_2 amounts are almost always less in urban areas during the summer as compared to winter. This is due to the shorter NO_2 lifetime during summer.

- If we were to directly compare February 2020 NO_2 concentrations to July 2020 NO_2 concentrations, a substantial fraction of the NO_2 change would be due to lifetime changes.



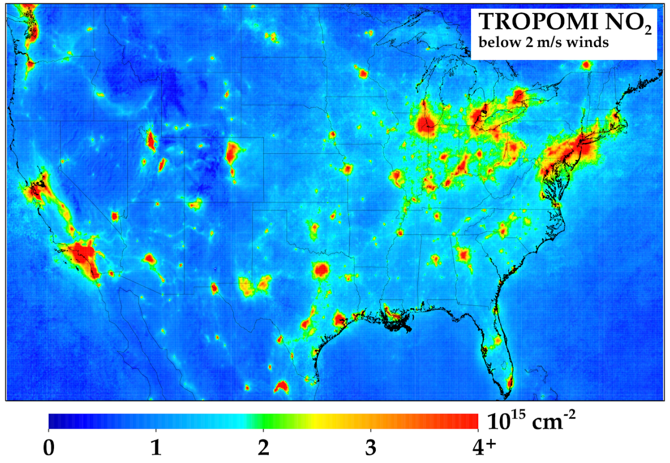


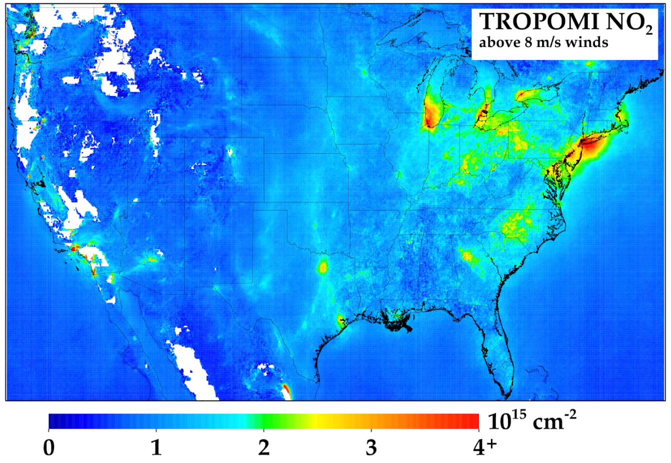


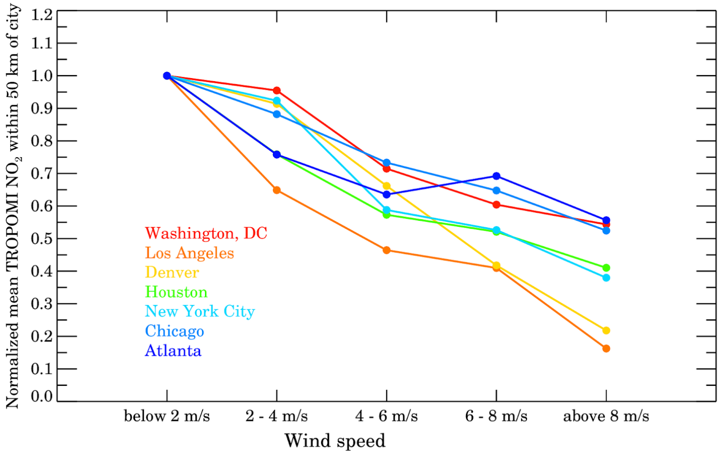


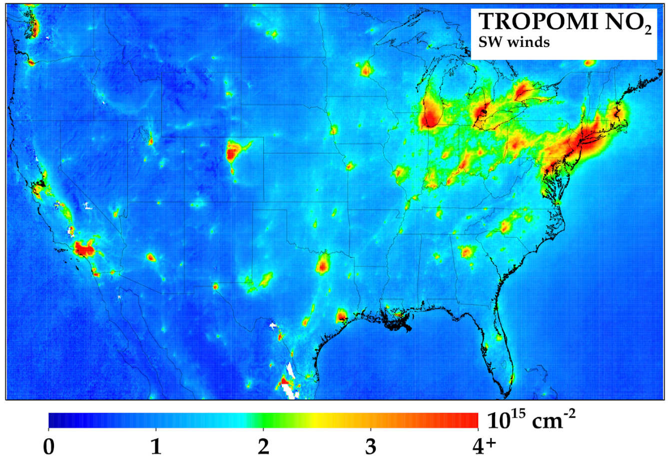
Isolating the anthropogenic signal using TROPOMI NO_2: Effects of wind speed & direction

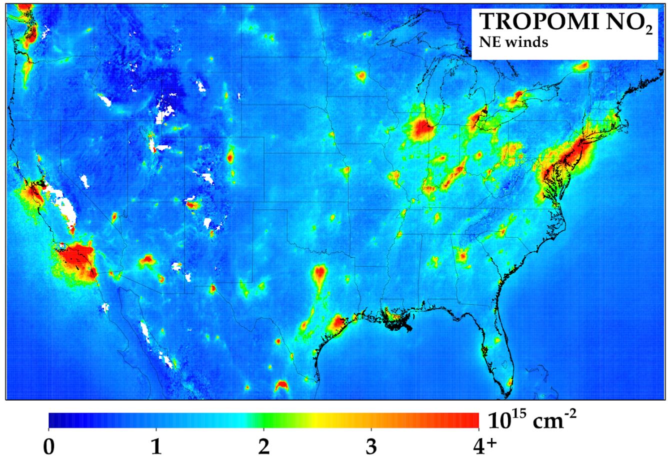
- Similarly, wind speed and direction can have dramatic effects on NO_2 concentrations in urban areas

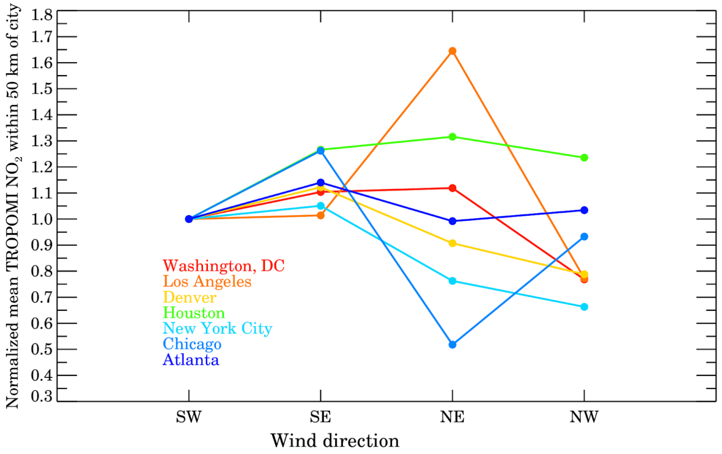




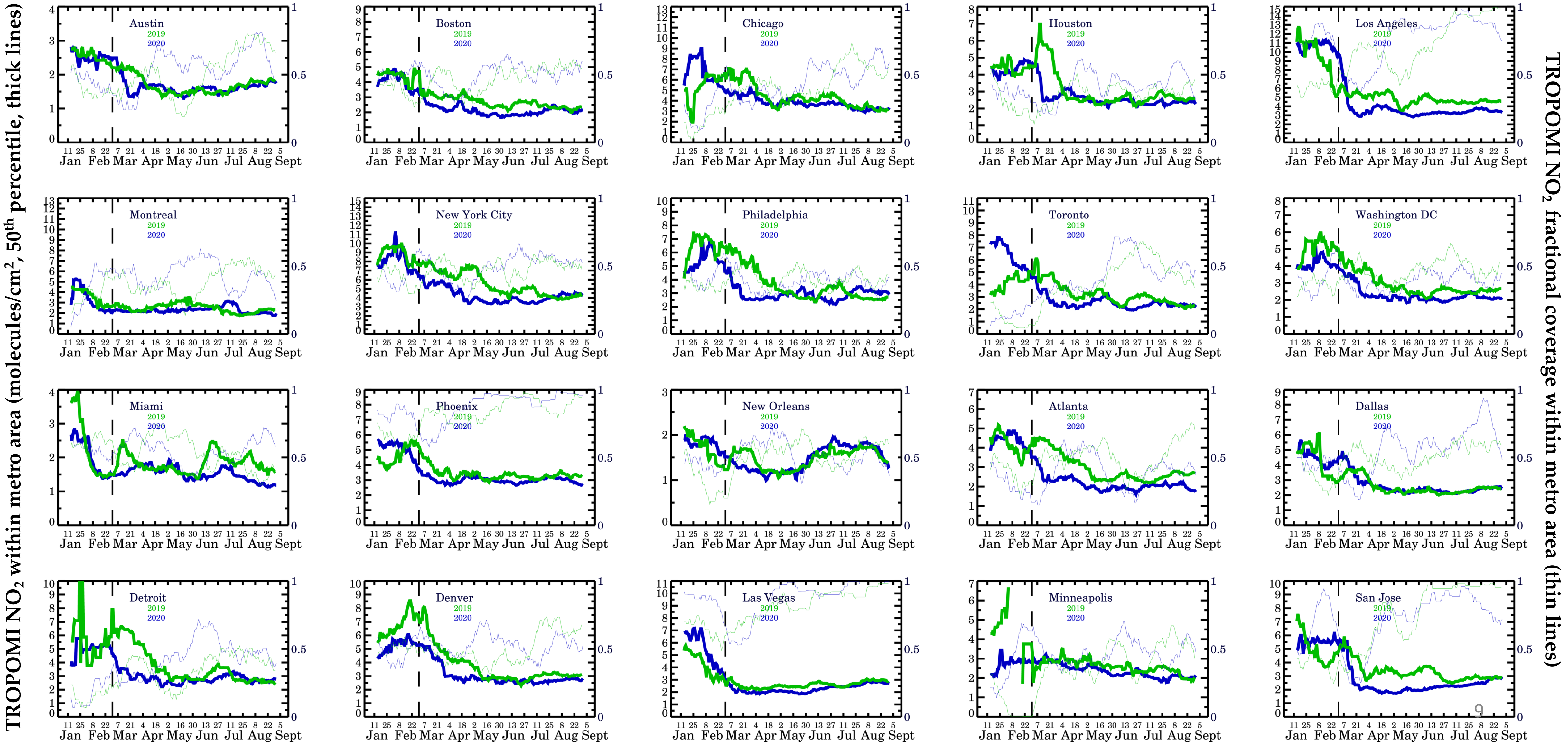




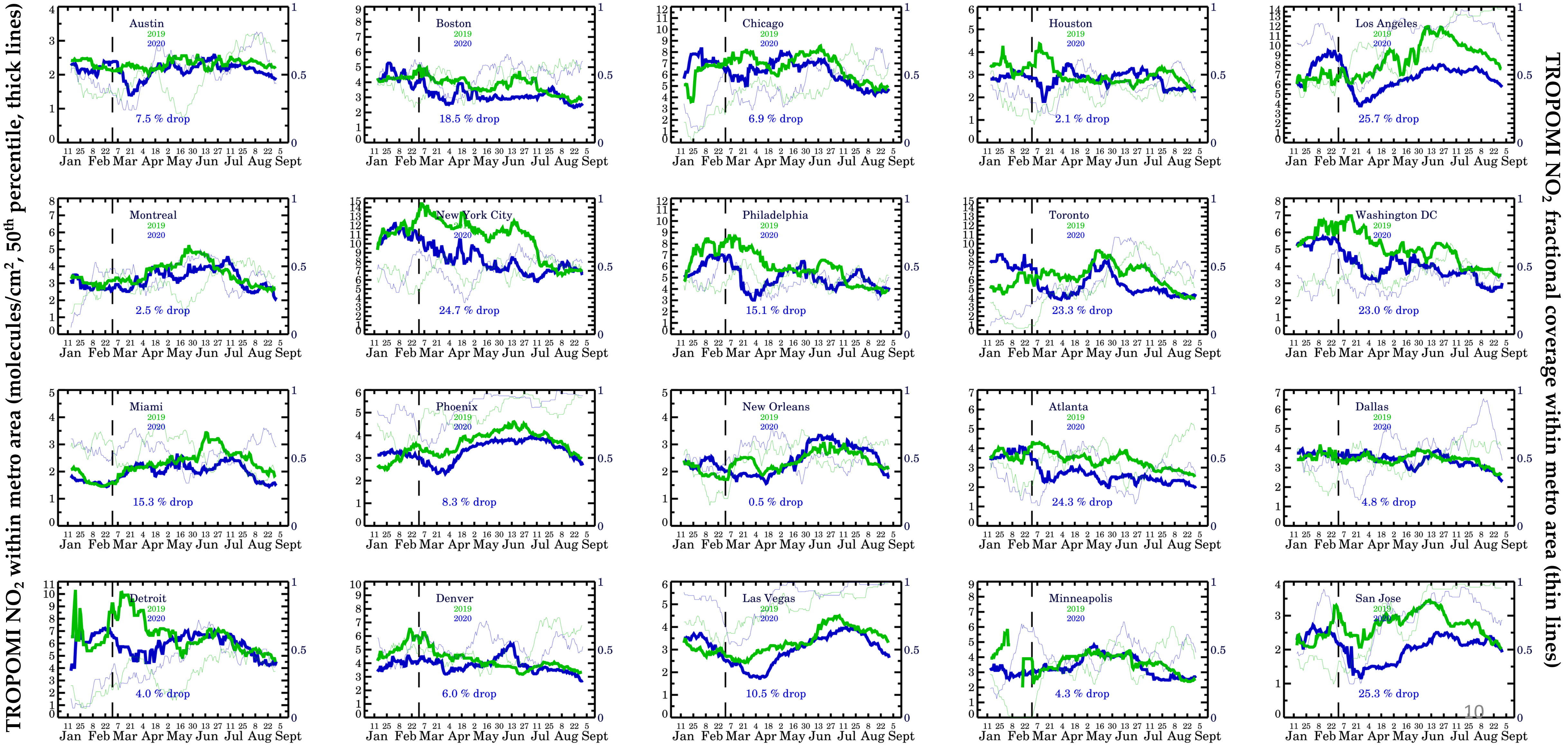




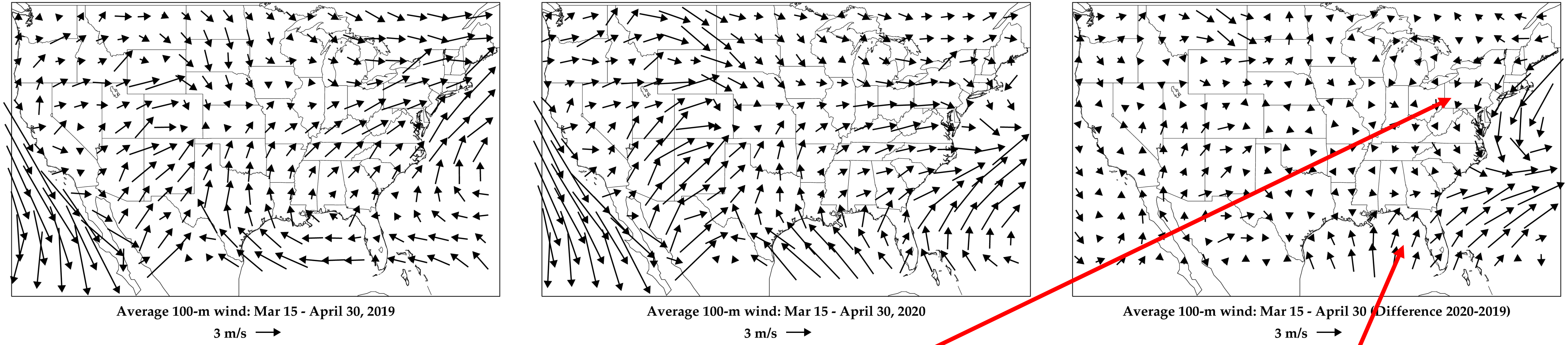
COVID-19: Recent changes in NO_2 as observed by TROPOMI, 28-day averages



COVID-19: Recent changes in NO_2 as observed by TROPOMI, 28-day averages, Normalized by meteorology



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

Estimated changes in anthropogenic NO_X due to COVID-19 precautions (*through April 30, 2020 only*)

Largest NO_2 drops in San Jose, Los Angeles, & Toronto

Smallest NO_2 drops in Dallas, Miami & Minneapolis

Weather favorable for lower NO_2 (e.g., winder): Washington DC & Miami

Weather favorable for larger NO_2 (e.g., stagnant): Montreal, New Orleans & Las Vegas

Table 1
Percentage Drop in Column NO_2 as Observed by TROPOMI

City name	Reference case Method 0: Δ between months 2020 only (January–February vs. 15 March to 30 April)	Account for solar zenith angle only Method 1: Δ between years 2019 vs. 2020 (15 March to 30 April)	Account for solar zenith angle and meteorology Method 2: Using ERA5 analogs to account for meteorology 2019 versus 2020 (15 March to 30 April)	Account for solar zenith angle and meteorology Method 3: Using GEM-MACH to infer NO_2, 2020 only (15 March to 30 April)	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%**

Conclusions

- 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.

Links to get started with satellite data:

To view daily satellite data:

- NASA World View (https://worldview.earthdata.nasa.gov/)
- NOAA Aerosol Watch (https://www.star.nesdis.noaa.gov/smcd/spb/aq/AerosolWatch/)
- EO Browser (https://apps.sentinel-hub.com/eo-browser/)

To download satellite data:

- NASA Earthdata (https://earthdata.nasa.gov/)
- Copernicus Scihub (https://s5phub.copernicus.eu/dhus/#/home)
- Netherlands Meteorological Institute (http://www.temis.nl/airpollution/no2.html)
- Google Earth Engine (https://developers.google.com/earth-engine/datasets/catalog/COPERNICUS_S5P_OFFL_L3_NO2)

To connect with the satellite community:

- NASA HAQAST (https://haqast.org/)
- NASA GSFC (https://airquality.gsfc.nasa.gov/news)