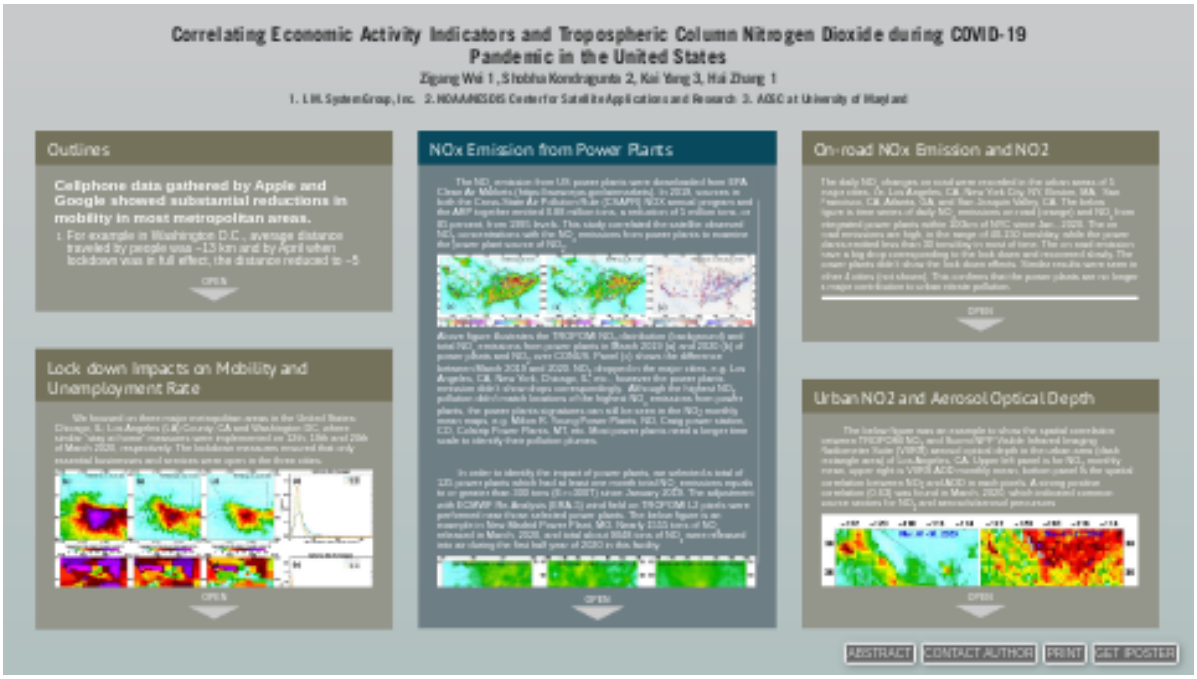
Correlating Economic Activity Indicators and Tropospheric Column Nitrogen Dioxide during COVID-19 Pandemic in the United States



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PRESENTED AT:

AGU FALL MEETING
Online Everywhere | 1–17 December 2020

OUTLINES

Cellphone data gathered by Apple and Google showed substantial reductions in mobility in most metropolitan areas.

1. For example in Washington D.C., average distance traveled by people was ~13 km and by April when lockdown was in full effect, the distance reduced to ~5 km. Consistent with reduced mobility, air quality as indicated by satellite observations decreased substantially.

Reductions in observed S5P TROPOMI NO_2 were between 20% to 45% between February and April 2020 depending on location and similar reductions in NO_2 amount in March and April 2020 compared to March and April 2019.

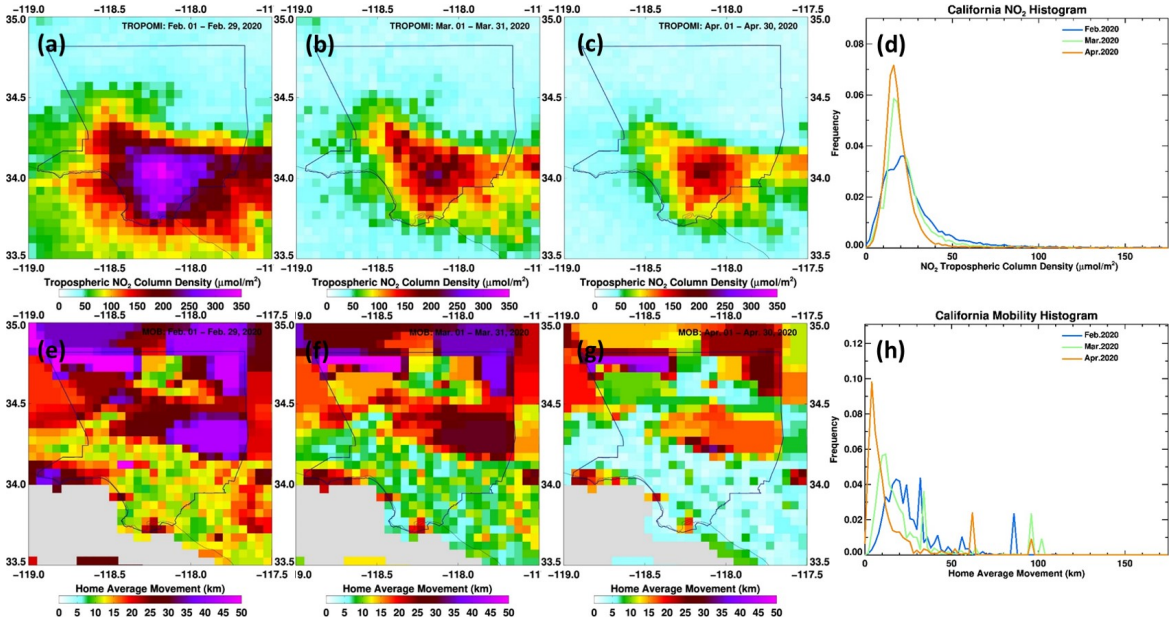
1. Changes in NO_2 across the continental U.S. between 2020 and 2019 correlated well with:

- Mobility
- Unemployment rate
- Power plant emissions
- On-road emissions

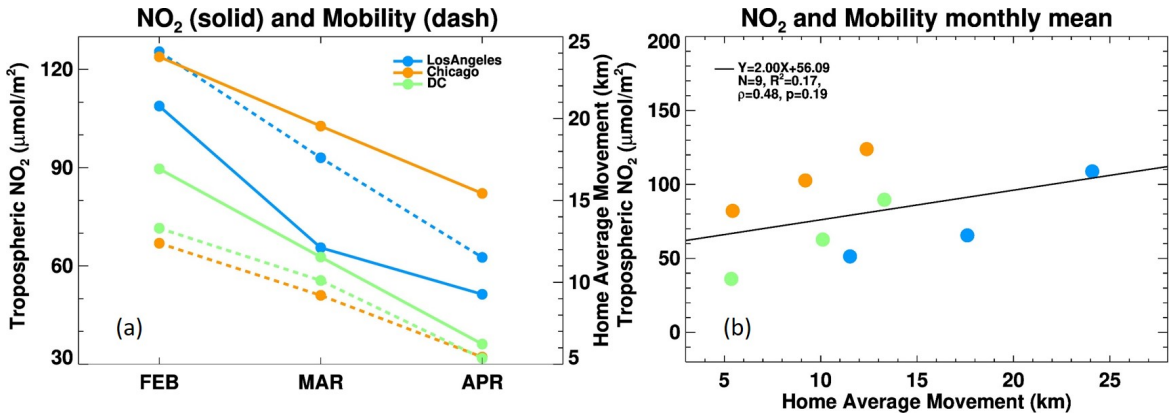
NO_2 and aerosol optical depth correlated positively near major cities indicating source sector

LOCK DOWN IMPACTS ON MOBILITY AND UNEMPLOYMENT RATE

We focused on three major metropolitan areas in the United States: Chicago, IL; Los Angeles (LA) County, CA and Washington DC, where similar “stay at home” measures were implemented on 12th, 19th and 20th of March 2020, respectively. The lockdown measures ensured that only essential businesses and services were open in the three cities.

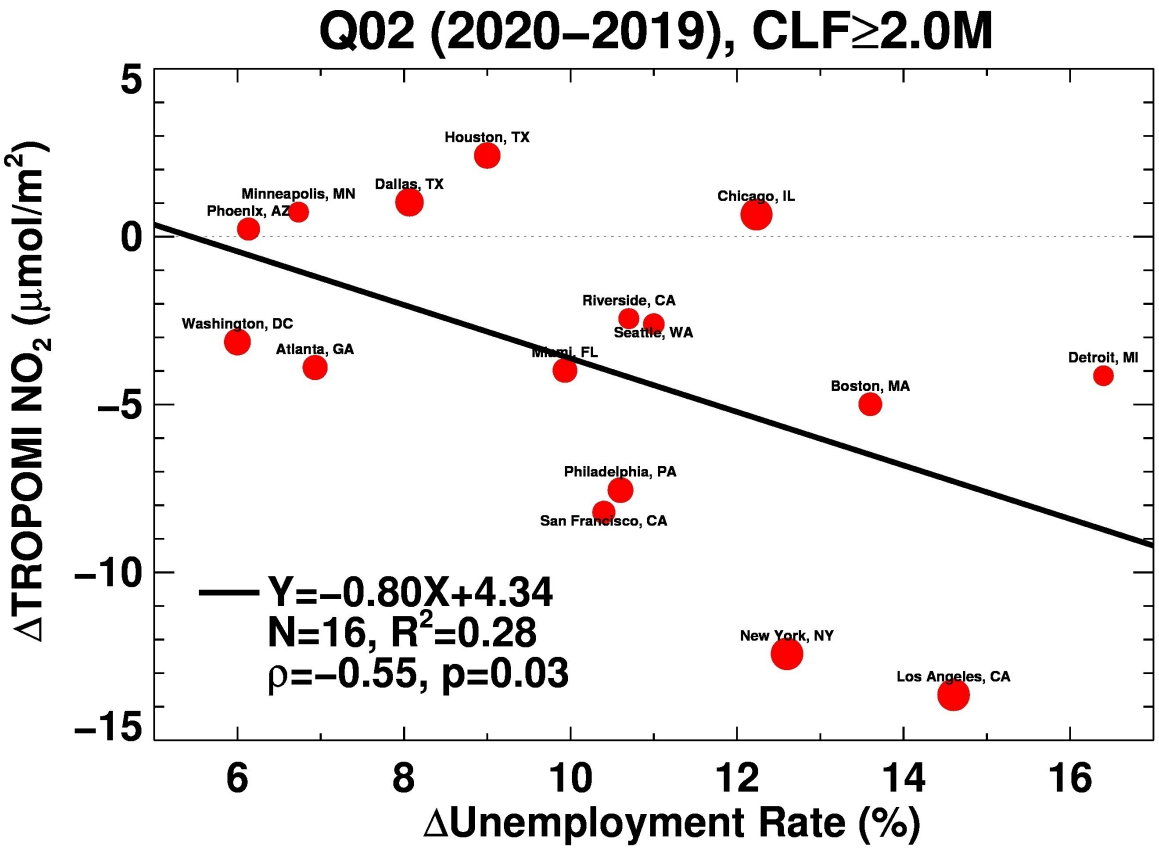


Above figure shows the trend of distributions of TROPOMI NO_2 and mobility in Los Angeles county. The NO_2 trends in Los Angeles county showed a large reduction in the monthly average tropospheric column NO_2 from February to April as shown in panel a, b and c. The width of NO_2 histograms (Panel d) keep shrinking, which means the number of high polluted pixels were decreasing. The monthly mean in the county (blue polygons) dropped total about 52.8% in 2020. Comparing with the same period of last year, the lock down effects accounted for about 23.2% of the drop, the rest can contributed to seasonal and other changes. The mobility has similar trends since the lock down as shown in panel e, f, g, and h. The monthly average mobility decreased by 52% from February to April in the whole Los Angeles county.



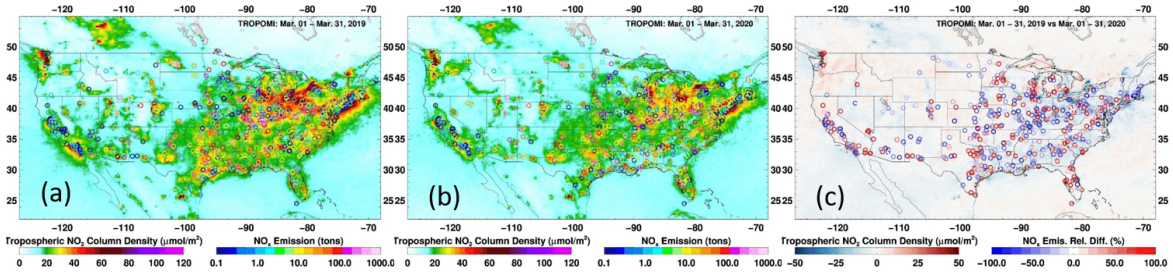
In D.C. and Chicago metropolitan area, more than a half decreasing trend can be seen in Mobility, too, as show in panel a of above figure (left y-axis is for NO_2. right y-axis is for NO_x The NO_2 had about 59% and 33% drops in these two metropolis. Panel (b) shows the overall correlation coefficient can be up to 0.48 between the monthly averaged NO_2 and home averaged movement in the 3 metropolitan areas. Due to the small number of sample and seasonal effects, the significance was low.

The lockdown deeply impacted the unemployment rate in the United States. The Local Area Unemployment Statistics (LAUS) program is a federal-state cooperative effort in which monthly estimates of total employment and unemployment are prepared for over 7,500 areas including metropolitan areas. According to the LAUS data, the lockdown caused the unemployment increased significantly since March 2020. The Changes in unemployment rates and NO_2 column values between 2020 (COVID-19) and 2019 (Business as Usual) for the average of April, May and June were computed for 16 large metropolitan areas where the civilian labor force >= 2 million. A negative correlation was seen in below figure, the correlation coefficients was up to -0.55, p-value=0.03.



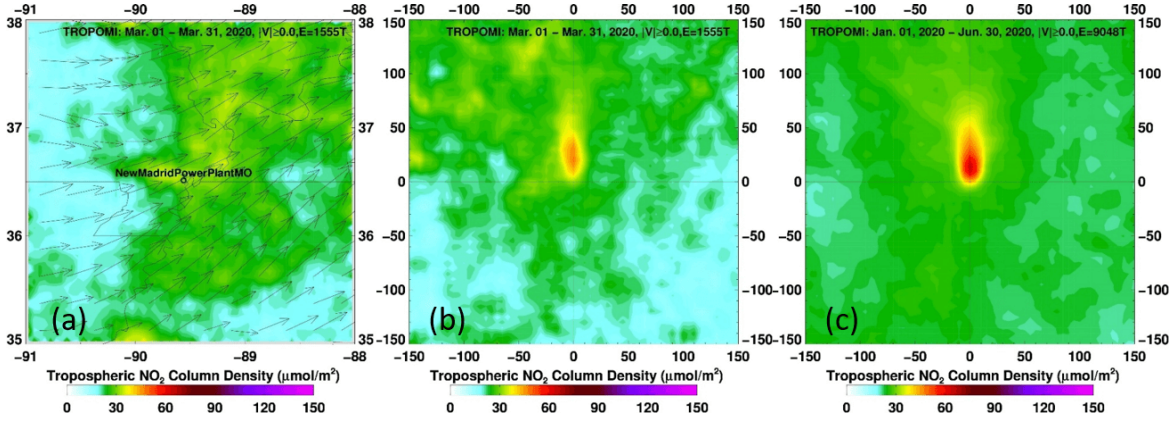
NOX EMISSION FROM POWER PLANTS

The NO_x emission from US power plants were downloaded from EPA Clean Air Markets (https://www.epa.gov/airmarkets). In 2019, sources in both the Cross-State Air Pollution Rule (CSAPR) NOX annual program and the ARP together emitted 0.88 million tons, a reduction of 5 million tons, or 85 percent, from 1995 levels. This study correlated the satellite observed NO_2 concentrations with the NO_x emissions from power plants to examine the power plant source of NO_2.

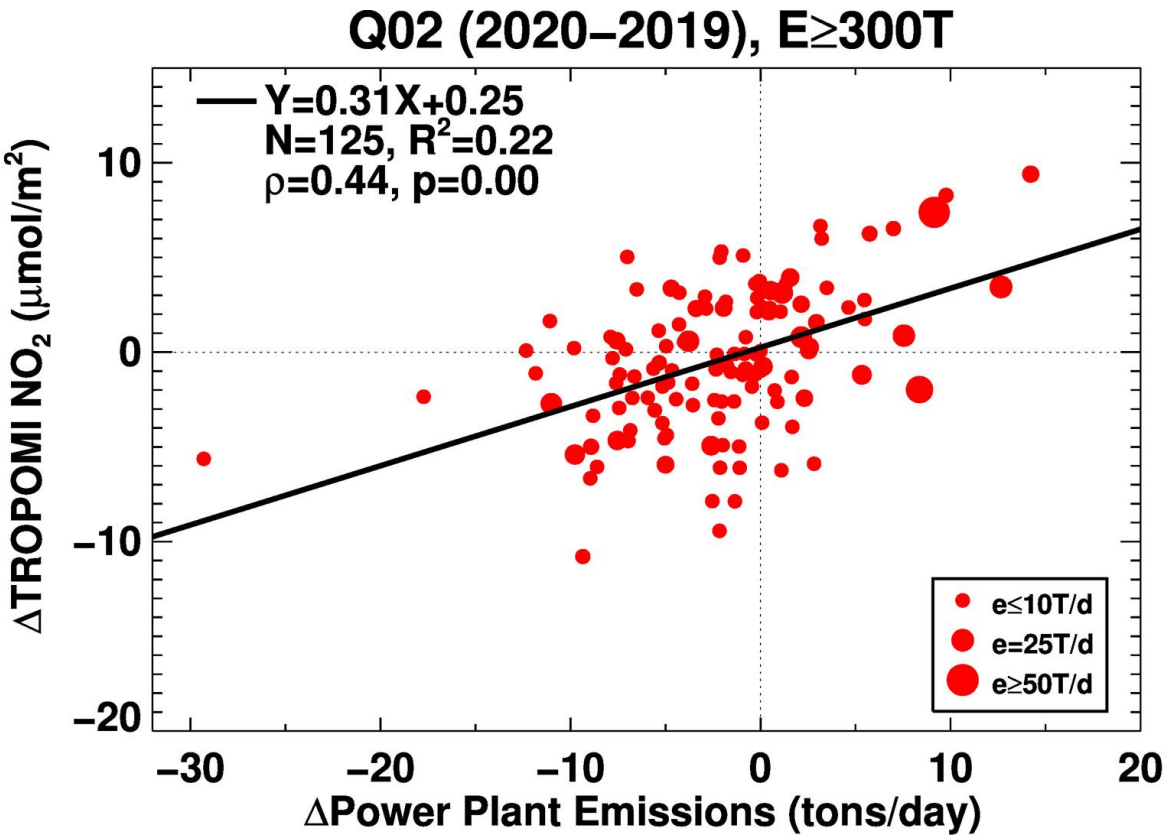


Above figure illustrates the TROPOMI NO_2 distribution (background) and total NO_x emissions from power plants in March 2019 (a) and 2020 (b) of power plants and NO_2 over CONUS. Panel (c) shows the difference between March 2019 and 2020. NO_2 dropped in the major cities, e.g. Los Angeles, CA, New York, Chicago, IL, etc., however the power plants emission didn't show drops correspondingly. Although the highest NO_2 pollution didn't match locations of the highest NO_x emissions from power plants, the power plants signatures can still be seen in the NO_2 monthly mean maps, e.g. Milton R. Young Power Plants, ND, Craig power station, CO, Colstrip Power Plants, MT, etc. Most power plants need a longer time scale to identify their pollution plumes.

In order to identify the impact of power plants, we selected a total of 125 power plants which had at least one month total NO_x emissions equals to or greater than 300 tons (E>=300T) since January 2019. The adjustment with ECMWF Re-Analysis (ERA-5) wind field on TROPOMI L2 pixels were performed near those selected power plants. The below figure is an example in New Madrid Power Plant, MO. Nearly 1555 tons of NO_x released in March, 2020, and total about 9048 tons of NO_x were released into air during the first half year of 2020 in this facility.

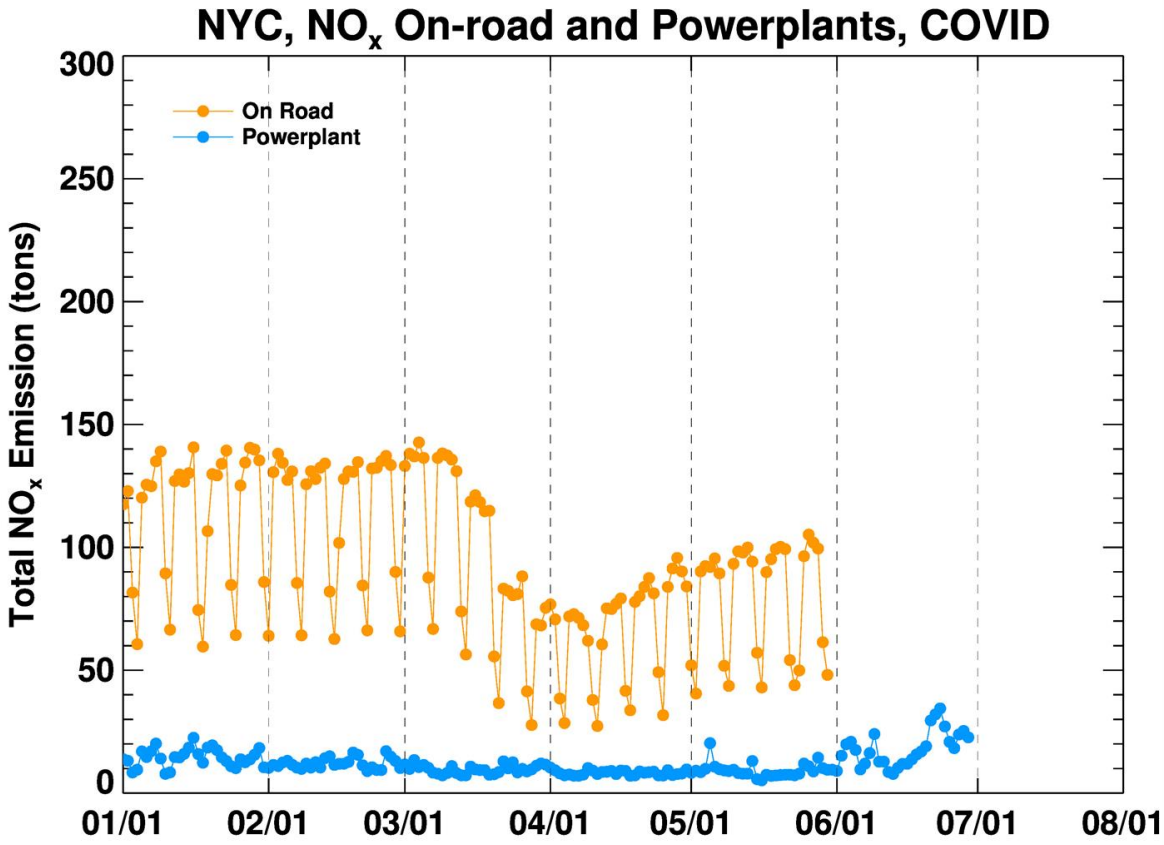


The panel (a) in above figure illustrates the TROPOMI monthly gridded (0.05^ox0.05^o) NO_2 tropospheric column before adjustment in March, 2020, the black arrows are averaged wind vectors within 100hPa above the surface. A clear pollution pattern can be seen near the facility after adjustment in panel (b) (5kmx5km resolution). The plume is even more obvious with oversampling for half year time scale as shown in panel (c). We calculated the NO_2 average in the rectangle box, i.e. upwind 5km, down wind 25km and 10km in cross wind directions, and correlated the averaged NO_2 with the daily averaged NO_x emission. The correlation study was carried on the NO_2 changes and NO_x changes according to the 125 power plants in the Quarter 2 from 2019 to 2020. The blow scatter plots showed the overall correlation can be up to 0.44.

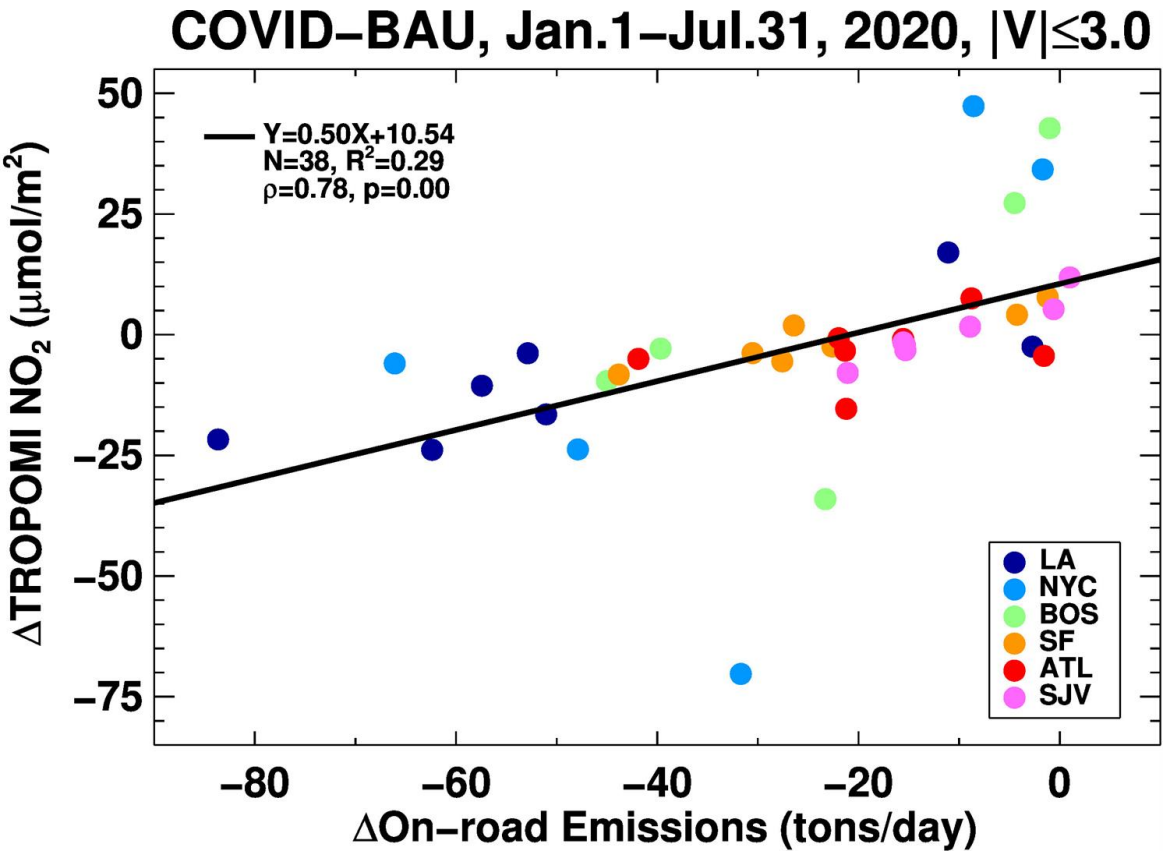

Q02 (2020–2019), E≥300T
Y=0.31X+0.25
N=125, R²=0.22
ρ=0.44, p=0.00
ΔTROPOMI NO₂ (μmol/m²)
ΔPower Plant Emissions (tons/day)
e≤10T/d
e=25T/d
e≥50T/d
10
0
−10
−20
−30
−20
−10
0
10
20

ON-ROAD NOX EMISSION AND NO2

The daily NO_x changes on road were recorded in the urban areas of 5 major cities, i.e. Los Angeles, CA, New York City, NY, Boston, MA, San Francisco, CA, Atlanta, GA, and San Joaquin Valley, CA. The below figure is time series of daily NO_x emissions on road (orange) and NO_x from integrated power plants within 100km of NYC since Jan., 2020. The on road emissions are high, in the range of 40-150 tons/day, while the power plants emitted less than 30 tons/day in most of time. The on road emission have a big drop corresponding to the lock down and recovered slowly. The power plants didn't show the lock down effects. Similar results were seen in other 4 cities (not shown). This confirms that the power plants are no longer a major contribution to urban nitrate pollution.

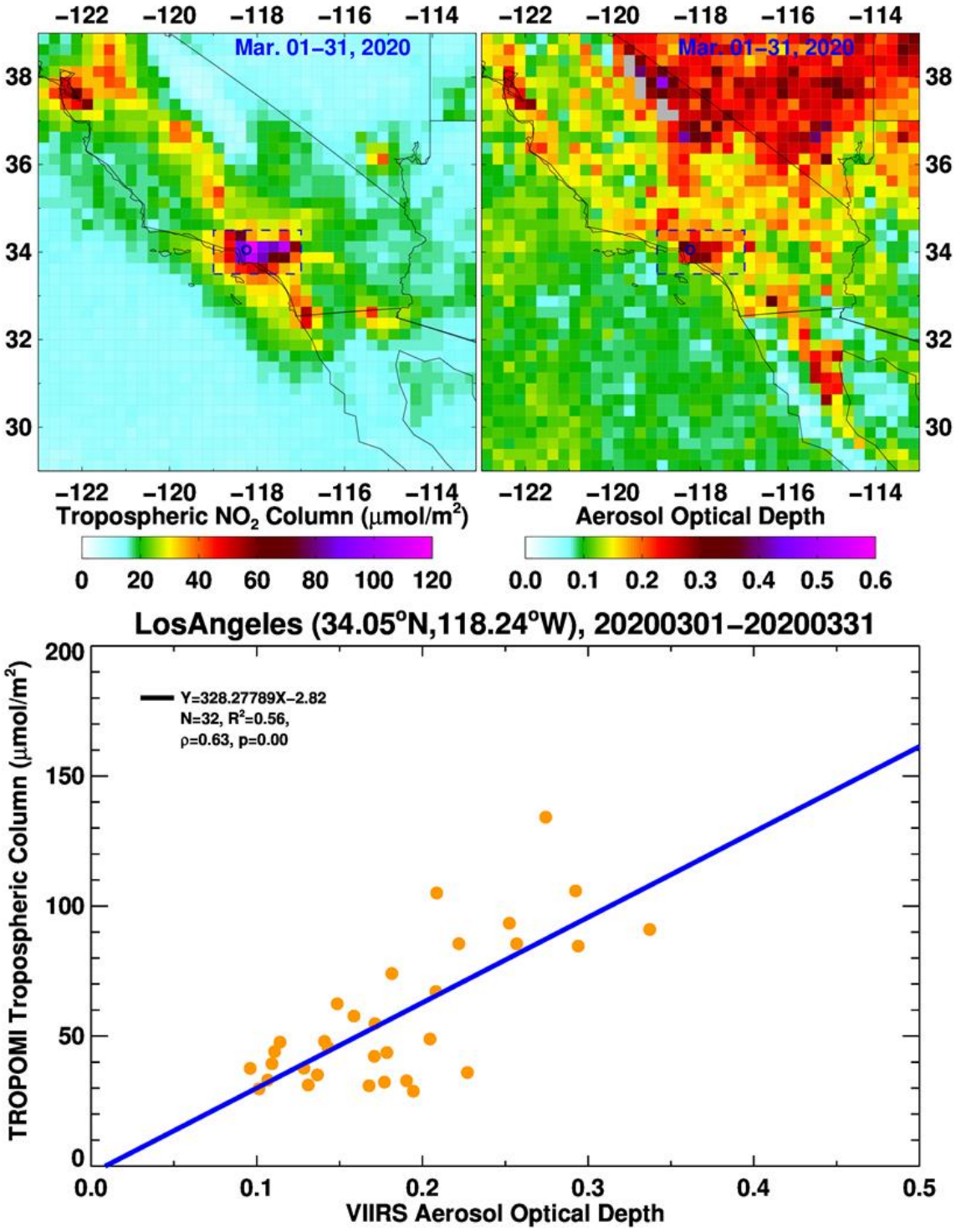


The TROPOMI NO_2 data was adjusted with ERA-5 wind around the city centers as we did for power plants, but the rectangle box was 50km in up-wind and cross wind directions and 100km in the down-wind direction from city center. In order to remove the seasonal signals, we took the monthly average differences of observations of 2020 (COVID) and Business As Usual (BAU) for NO_2 and NO_x on road time series. We also limited the wind speed less than 3m/s. The below figure showed the changes in tropospheric NO_2 column due to COVID-19 shutdown correlate well with NOx emissions changes, the correlation was up to 0.78, which is much bigger than power plant emissions due to COVID-19 lockdown.


COVID–BAU, Jan.1–Jul.31, 2020, |V|≤3.0
Y=0.50X+10.54
N=38, R²=0.29
ρ=0.78, p=0.00
ΔTROPOMI NO₂ (μmol/m²)
ΔOn–road Emissions (tons/day)
50
25
0
–25
–50
–75
–80
–60
–40
–20
0
LA
NYC
BOS
SF
ATL
SJV

URBAN NO2 AND AEROSOL OPTICAL DEPTH

The below figure was an example to show the spatial correlation between TROPOMI NO_2 and Suomi NPP Visible Infrared Imaging Radiometer Suite (VIIRS) aerosol optical depth in the urban area (dash rectangle area) of Los Angeles, CA. Upper left panel is for NO_2 monthly mean, upper right is VIIRS AOD monthly mean, bottom panel is the spatial correlation between NO_2 and AOD in each pixels. A strong positive correlation (0.63) was found in March, 2020, which indicated common source sectors for NO_2 and aerosols/aerosol precursors



Conculsion and Discussion

1. Lockdown significantly decreased the mobility in the major metropolis areas in the U.S. This led to reduced NO_x emissions that was well observed by S5P TROPOMI
2. Air quality in the U.S. improved due to reduced NO_x emissions due to partial lockdown in some states (e.g., CA, MD, NY, etc.)
3. Changes in on-road NO_x emissions and power plant emissions correlate well with satellite observations of NO_2
4. This study showed that power plant emissions are no longer the main source of NO_x in the urban areas.
5. As unemployment rate increases tropospheric NO_2 decreases in the huge metropolitan areas.

ABSTRACT

Most countries around the world took actions to control COVID-19 spread that included social distancing, limiting air and ground travel, closing schools, suspending sports leagues, closing factories etc., leading to economic shutdown. The reduced traffic and human movement compared to Business as Usual (BAU) scenario was tracked by Apple and Android cellphone use; the data showed substantial reductions in mobility in most metropolitan areas. For example in Washington D.C., average distance traveled by people was ~17 km and by April when lockdown was in full effect, the distance reduced to ~6 km. Consistent with reduced mobility, air quality as indicated by satellite observations decreased substantially. Granted that year to year variability in weather patterns can have influence on observed NO2 and aerosol concentrations, but the drop in tropospheric nitrogen dioxide (NO2) observed by Sentinel 5P Tropospheric Ozone Monitoring Instrument (TROPOMI) and Suomi NPP Ozone Mapping Profiling Suite (OMPS) observations of NO2 was significant; reductions in observed NO2 were between 15% to 50% between February and April 2020 depending on location and similar reductions in NO2 amount in March and April 2020 compared to March and April 2019. Further, the changes in NO2 across the continental U.S. between 2020 and 2019 correlated well with on-road emissions but did not correlate with changes in emissions from power plants. These findings confirm that power plants are no longer the major source of NO2 in the United States. We also found positive correlation between NO2 and Suomi NPP Visible Infrared Imaging Radiometer Suite (VIIRS) aerosol optical depth measurements in these urban regions indicating common source sectors for NO2 and aerosols/aerosol precursors.