A comparison of ambient measurements of NO_2, CO, $PM_{2.5}$, and O_3 during the COVID-19 pandemic with a climatological multiple linear regression model for various U.S. cities

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1. Introduction

- U.S. air quality monitoring network data are used to
    - inform the public of the extent and magnitude of pollution
    - evaluate the effectiveness of emission controls
    - constrain air quality models
- During the COVID-19 pandemic, state and local governments implemented lockdowns to reduce the spread of the disease, resulting in reduced traffic and on-road emissions beginning in Spring 2020
- We use measurements of NO_2, CO, $PM_{2.5}$, and O_3 and a multiple linear regression model to predict pollution levels, *controlled for meteorology*, in 9 U.S. cities and compare the model to observations to determine how emissions and atmospheric chemistry may have changed during the pandemic

2. Data

- Air quality monitoring data for CO, NO_2, O_3, and $PM_{2.5}$ were downloaded from the Environmental Protection Agency's Air Quality System (https://www.epa.gov/aqs)
    - when possible, the Core Based Statistical Area (CBSA) dataset is used, which includes multiple measurement sites
- Meteorological data were downloaded from NOAA's National Center for Environmental Information's Integrated Surface Data (ISD) for the nearest large airport (https://www.ncei.noaa.gov/pub/data/noaa/isd-lite/)
- The Stringency Index (SI) is used as a metric to determine the severity of the lockdowns (Hale et al., 2021)

3. Multiple Linear Regression (MLR) model

We use a multiple linear regression (MLR) model (similar to de Foy & Schauer, 2019) to account for decadal trends and meteorological factors

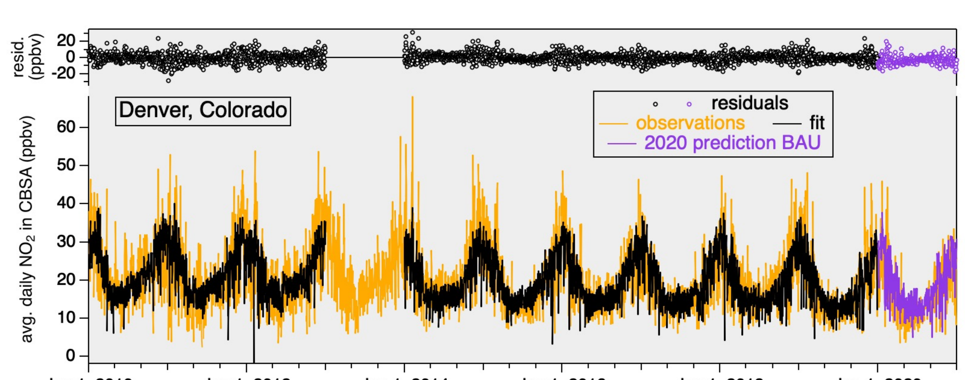
$$x_i = c_0 + c_1Y + c_2T + c_3P + c_4WS + c_5H + c_6WE + \epsilon$$

where x is a fit of daily max. 8-hr. O_3 (MDA8) or daily avg. CO, NO_2, or $\ln(PM_{2.5})$ for each month, i, from 2010–2019

Y is the year
T is the daily avg. temperature
P is the daily avg. precipitation
WS is the daily avg. wind speed
H is the daily avg. relative humidity
WE is 1 for weekend, 0 for weekday
and ϵ is the residual

Example:
Denver carbon monoxide

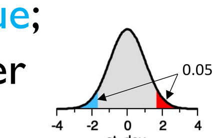
We use the model and 2020 meteorological data to predict NO_2, CO, $PM_{2.5}$, and O_3 in the absence of lockdowns

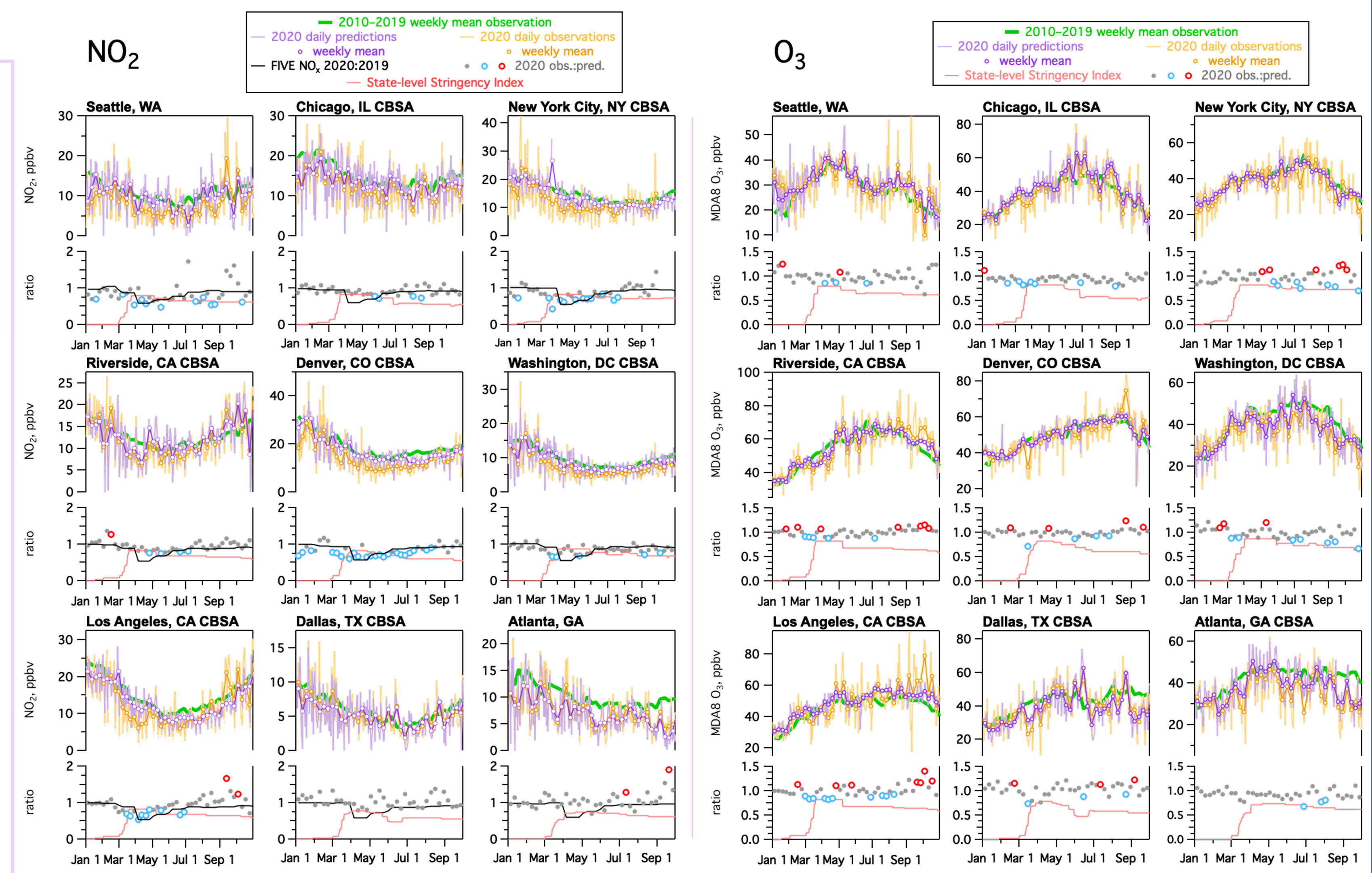


4. Comparison of measurements with modeled predictions in the absence of COVID for 2020

Observed and predicted NO_2 and O_3 are plotted for 9 U.S. cities, as are state-level stringency index, the FIVE inventory ratio of 2020 vs. 2019 for NOx (see panel 6 for details), and a ratio of the 2020 observed to predicted concentration.

A two-sided t-test was run each week. Using a 10% confidence interval, observations significantly lower than the predictions are plotted in blue; significantly higher in red.

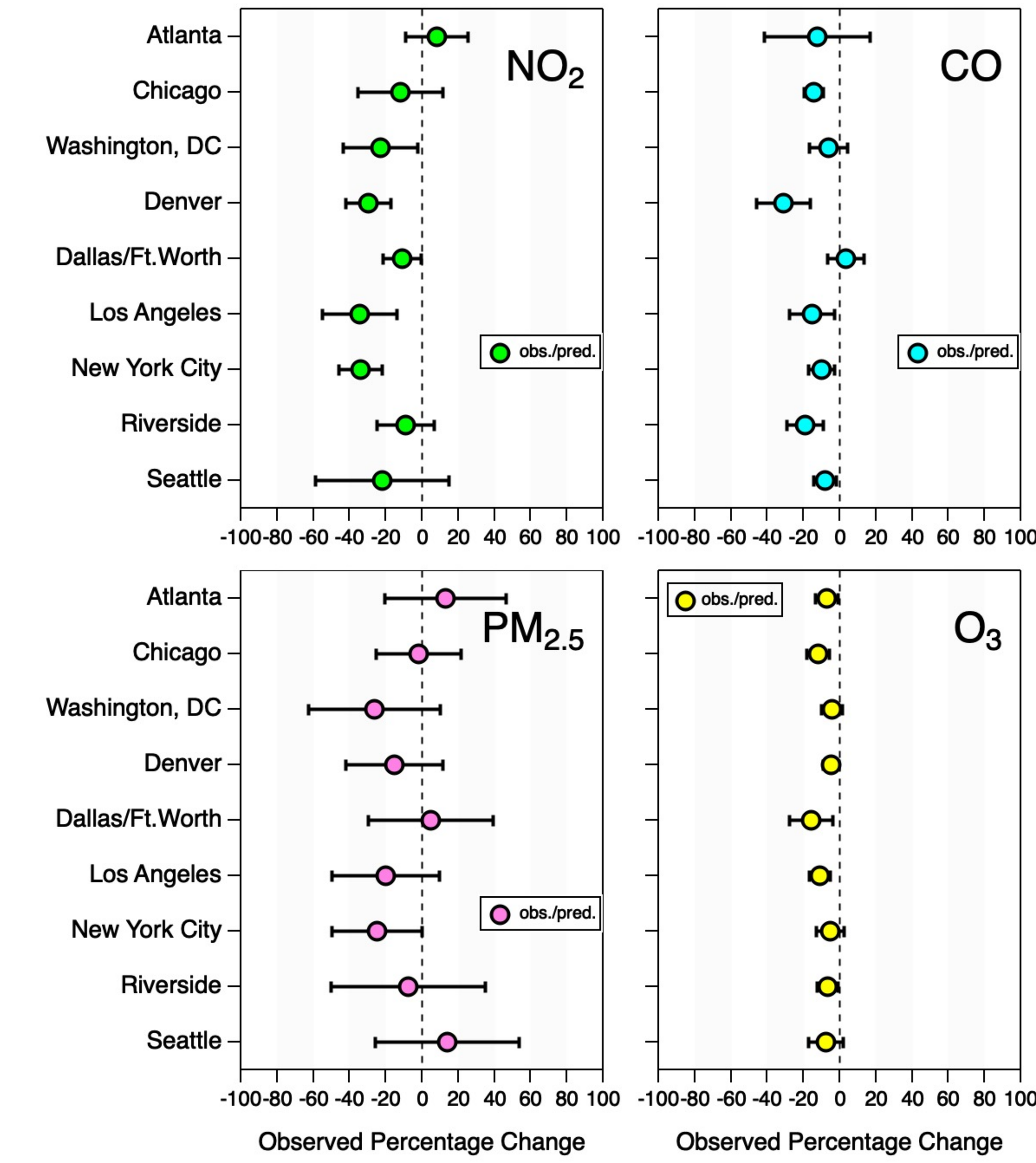




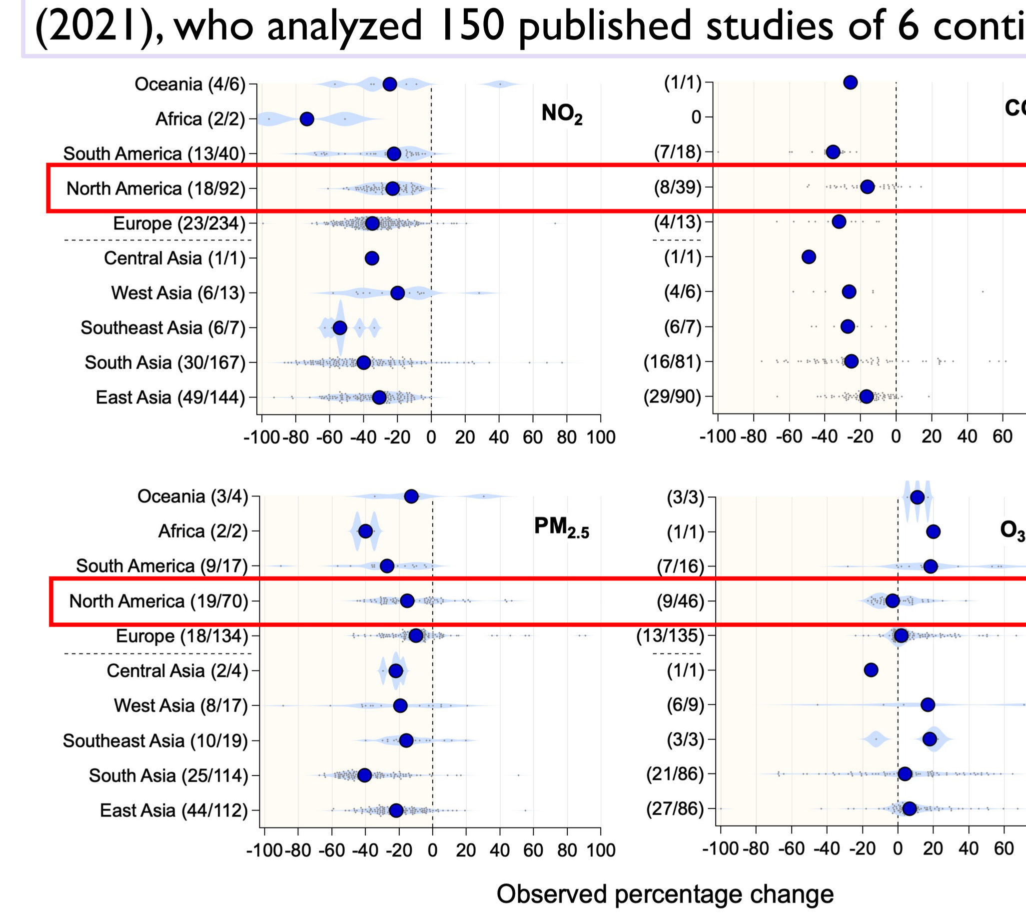
5. Model Results

Lockdown effects for all cities from March 29 – April 11:

- most cities experienced a decrease in NO_2 and CO
- many had decreases in $PM_{2.5}$; all cities had lower O_3
- avg. changes: NO_2 –18%, CO –13%, $PM_{2.5}$ –7%, O_3 –8%



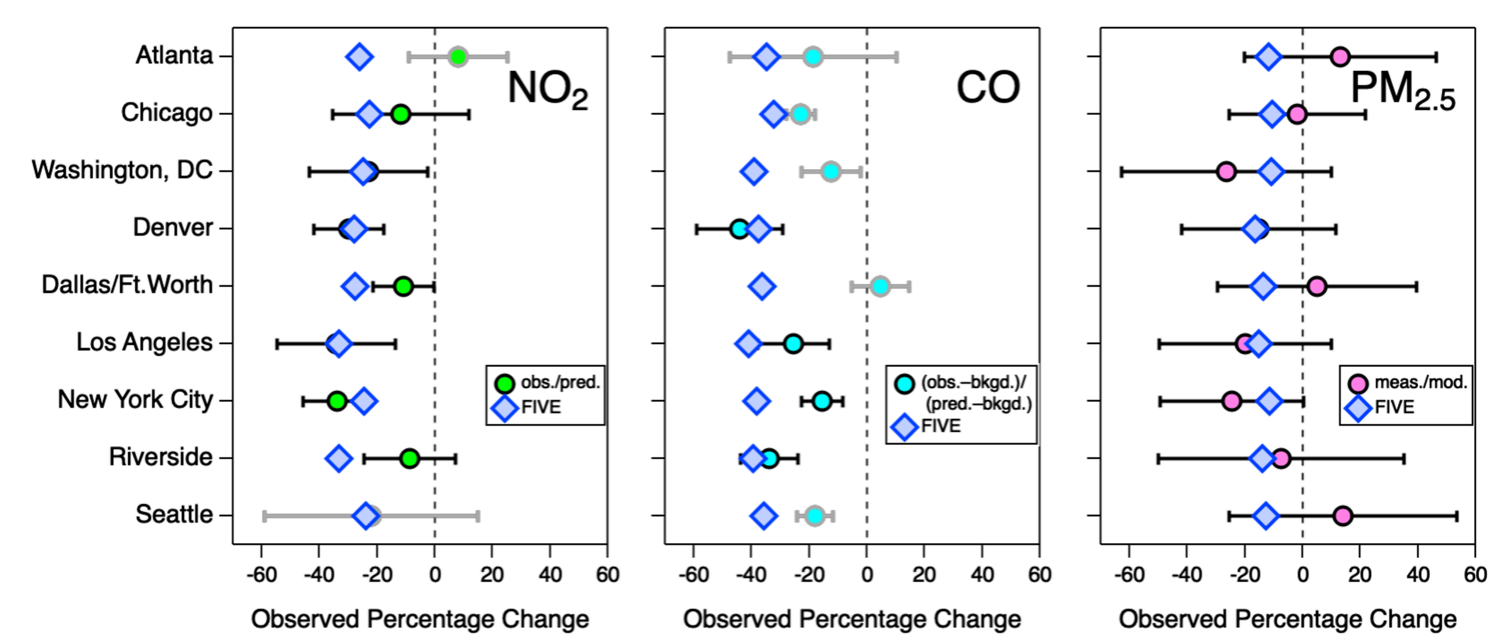
Consistent with North American results from Gkatzelis et al. (2021), who analyzed 150 published studies of 6 continents:



6. Comparison of Modeled Effects with Inventory

Comparison of observed/model-predicted ratios with ratios for 2020/2019 of a fuel-based primary emissions inventory, **FIVE** (Harkins et al., 2021), for March 29 – April 11. A CO background has been subtracted from the observed and predicted values for a comparison with emissions. Markers for cities with only one monitoring location are outlined in gray.

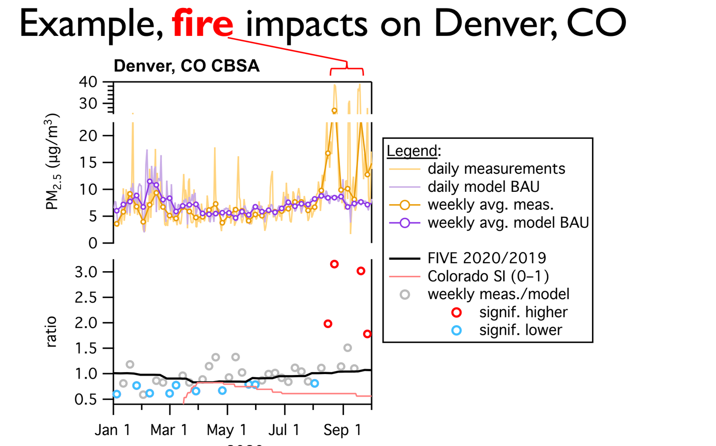
Reductions in emissions generally led to decreases in O_3 and $PM_{2.5}$. While the reasons for such decreases are not definitive, our model could help guide where the application of a more sophisticated chemistry model that relates NOx and VOC reductions to O_3 and PM formation may be of value to air quality managers.



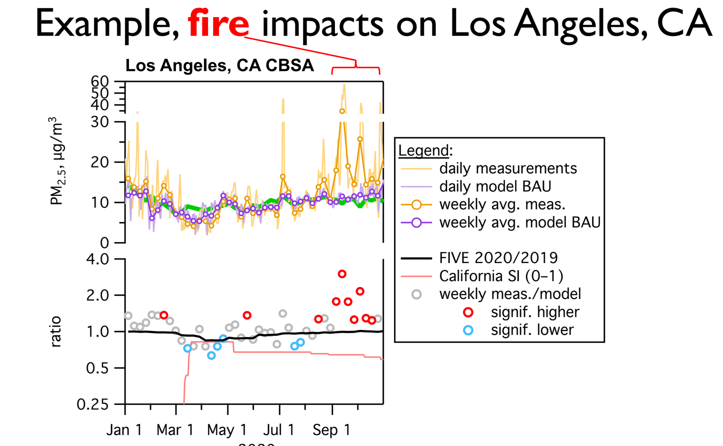
7. Conclusions and Future Work

- A multiple linear regression model that accounts for meteorology is used to determine daily lockdown effects for all cities
- Results are consistent with studies summarized by Gkatzelis et al. (2021) and mostly consistent with a fuel-based inventory (FIVE)
- Emissions reductions generally led to $PM_{2.5}$ and O_3 reductions, at least in the early springtime
- Model also shows impacts of **fire** and **dust** events often exceed those from COVID lockdowns (see examples to the right)
- Can compare directly with published studies of U.S. cities for any range of days
- Will analyze weekend regression results, e.g., NO_2 and O_3

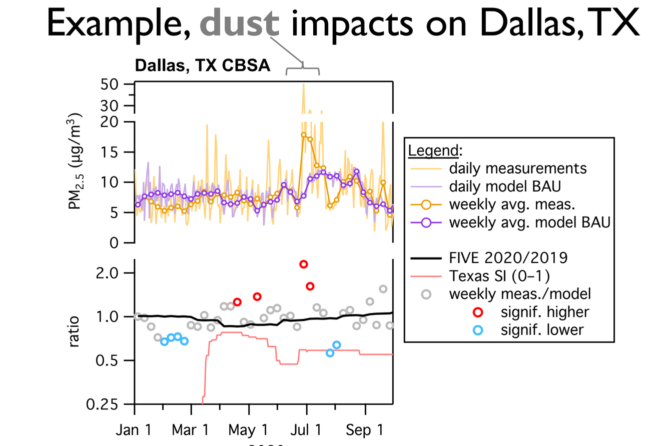
Example, **fire** impacts on Denver, CO



Example, **fire** impacts on Los Angeles, CA



Example, **dust** impacts on Dallas, TX



References

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