Quantifying the impacts of the COVID-19 lockdown on urban emissions across the Salt Lake Valley

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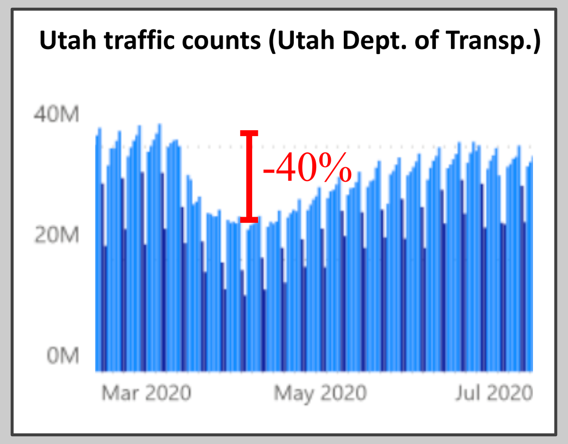
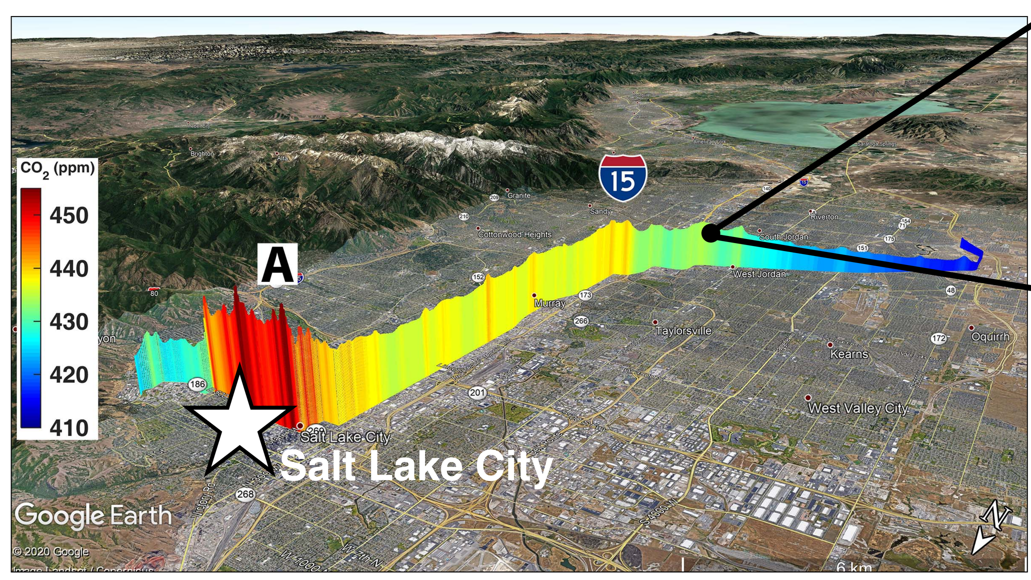
1. Motivation:

The COVID-19 pandemic resulted in a widespread lockdown during the spring of 2020. The Salt Lake Valley (SLV) observed a large decrease in anthropogenic emissions during the COVID-19 lockdown, which altered the urban atmospheric composition across the valley. During this time, the SLV saw an average decrease of 40% in traffic volume during the lockdown. The COVID-19 lockdown offered a unique opportunity to study how changes in human behavior can impact greenhouse gas (GHG) emissions and air quality.

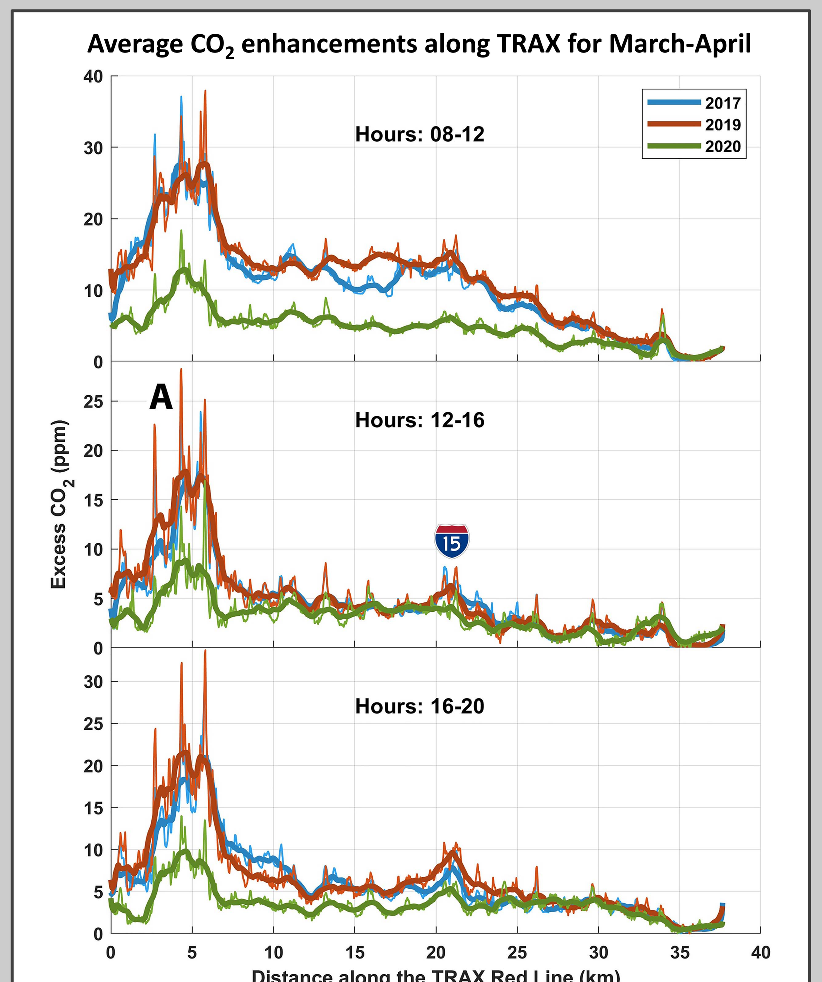


2. Observational Analysis



Map displaying CO_2 measurements collected by a LGR Ultraportable GHG Analyzer instrument mounted on the TRAX light-rail train.

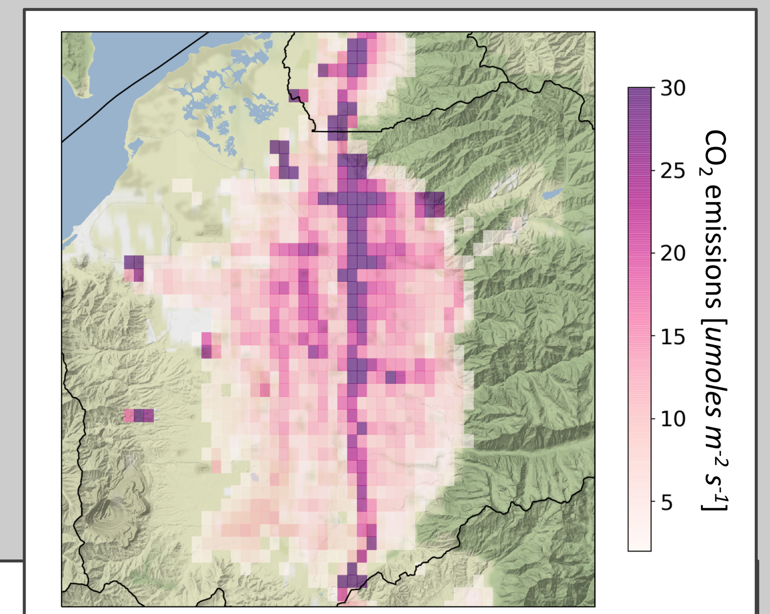
- Large decreases in CO_2 across much of the SLV in 2020 relative to non-COVID years (2017 & 2019)
- The largest differences in CO_2 were most evident during the early morning (8-12 LST) and across downtown Salt Lake City
- Preliminary results suggest that the COVID-19 had a large impact CO_2 emissions, which was potentially driven by changes in traffic activity
  - I-15 observed some of the largest differences in CO_2 as a percentage



CO_2 enhancements along the TRAX line averaged between March and April of 2017 (blue), 2019 (red), and 2020 (green). The starting distance starts in the NE corner of the SLV while the ending distance ends in the SW corner of the SLV.

3. Results:

An anthropogenic emissions inventory for CO_2 (VULCAN) was combined with an atmospheric transport model (WRF-STILT) to quantify discrepancies between emission inventory estimates during COVID and non-COVID years. Observations and model analyses were used to drive a Bayesian Inverse model to constrain urban emissions:

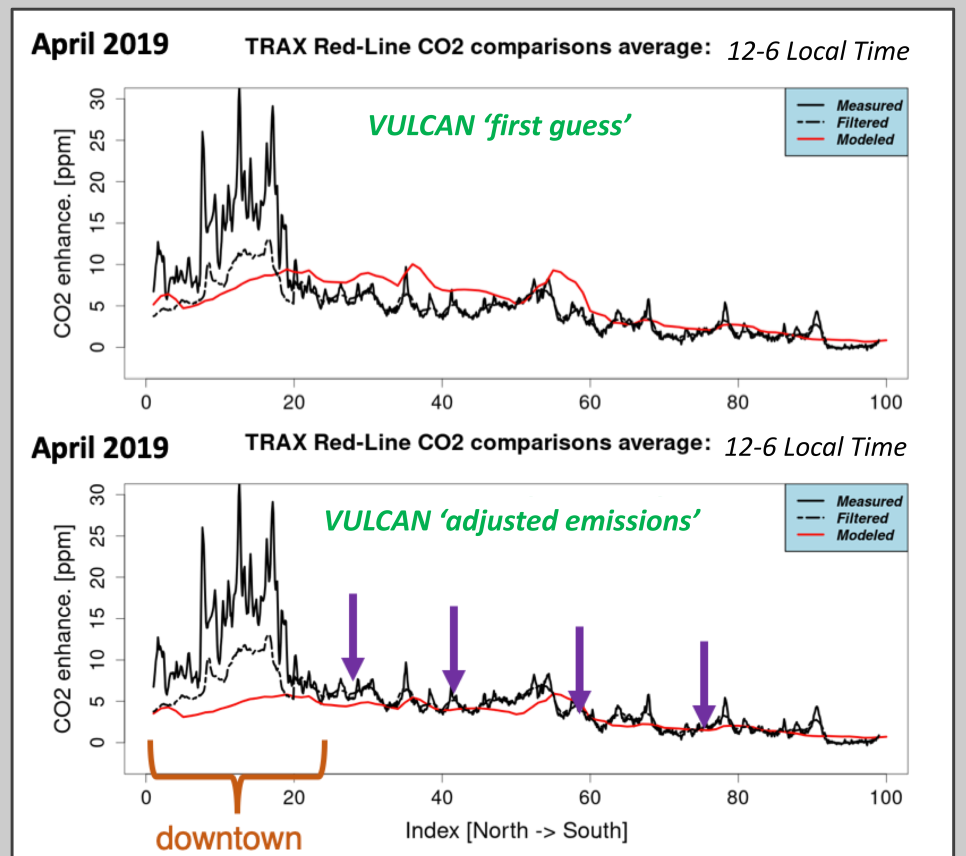


A map displaying VULCAN CO_2 emission estimates for the SLV during the spring of 2019.

$$\hat{s} = s_p + (HQ)^T (HQH^T + R)^{-1} (z - Hs_p)$$

Adjusted emissions; First guess emissions; Scaling that accounts for model uncertainties, first guess uncertainties, and the correlations of these uncertainties in time and space; Observed CO_2; Modeled predicted CO_2

*Equation for the Bayesian Inverse model use to constrain emissions. **H** describes the model-predicted spatiotemporal influence for each observation, **Q** characterizes the first guess emission uncertainty, and **R** describes uncertainties related to the atmospheric model and observations.*



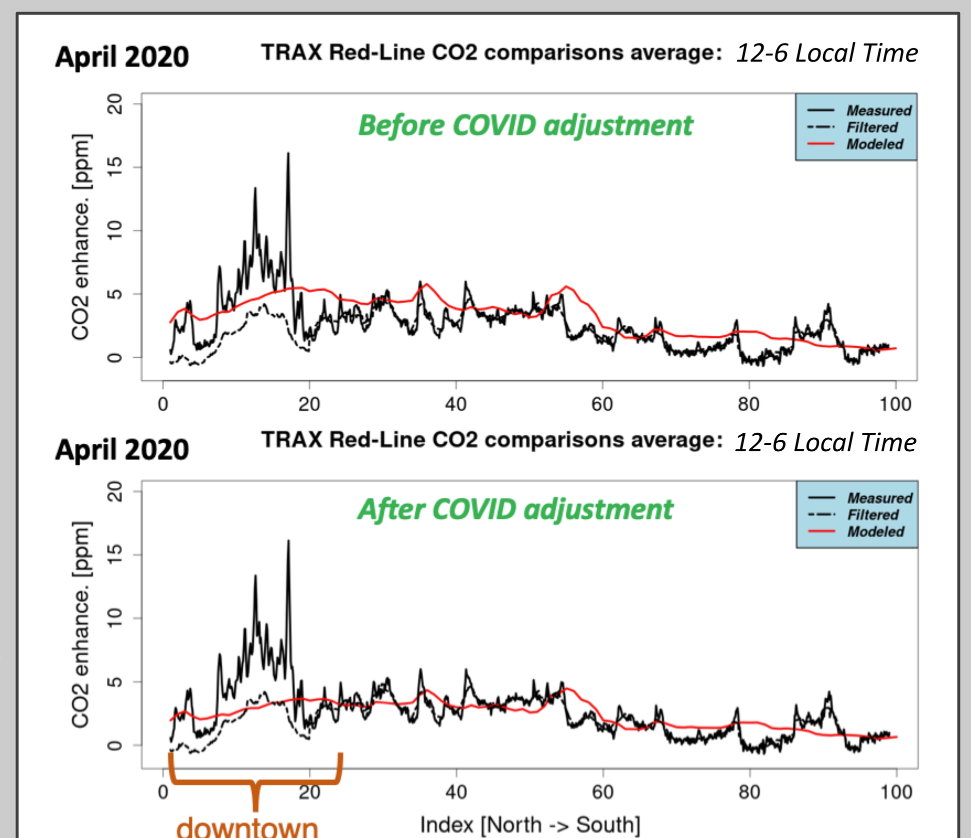
Simulated and observed CO_2 enhancements across the SLV where the simulation that used the first guess emissions is shown in the top panel and the simulation that used the adjusted emissions is shown in the bottom panel

Step 1: Correct inherent inventory errors for non-COVID year

- Objective of 2019 inverse analysis was to remove errors within our first guess emission inventory
  - Uncertainties at the city-scale can be large (> 30%)
- CO_2 emissions were overestimated by ~30% across the SLV during non-COVID years
- This analysis was used to re-scale VULCAN emissions before running an inverse model analysis for the COVID-19 lockdown in 2020

Step 2: Adjust emissions for COVID-19 lockdown period

- Modeled CO_2 enhancements overestimated, especially over northern half of the SLV when using our re-scaled VULCAN emissions inventory
  - Some overestimations over the southern part of the valley, but less pronounced
- Ran Bayesian Inverse analysis for 2020 to adjust emissions for COVID-19 lockdown
- Inverse analysis aligns modeled CO_2 enhancements more closely with observed concentrations

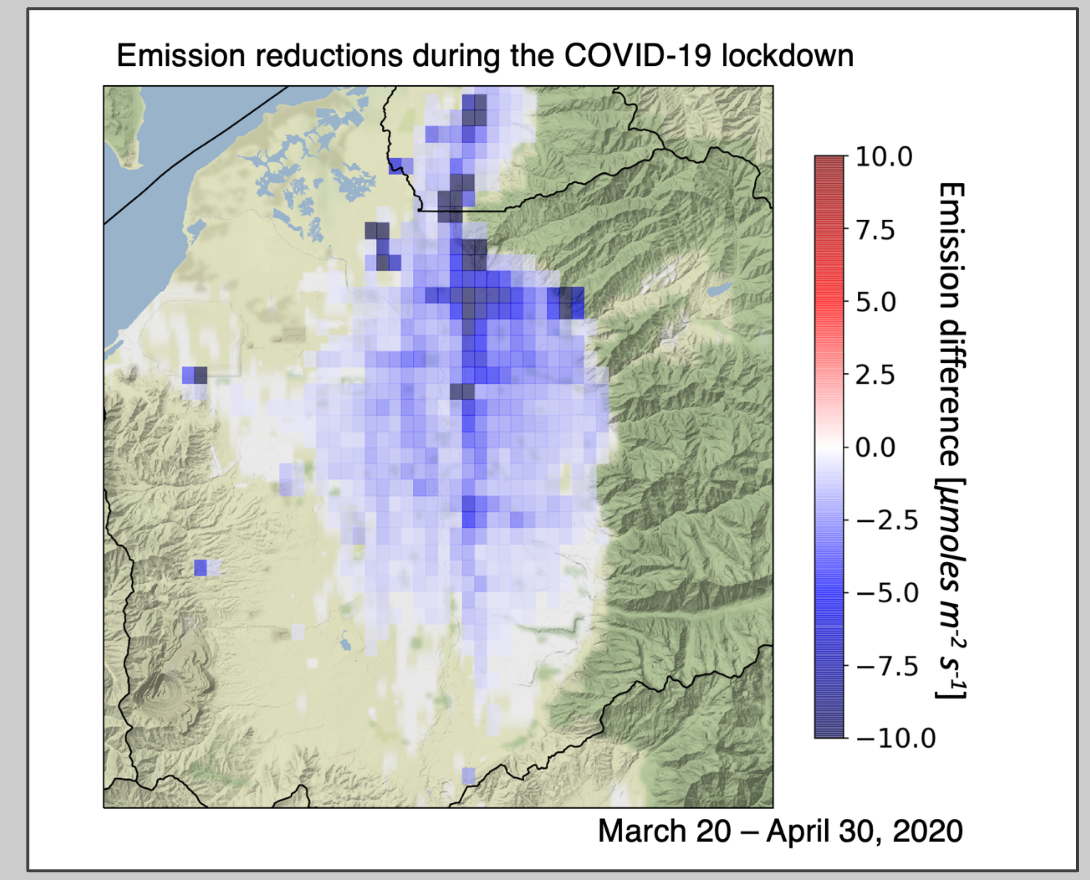


Simulated and observed CO_2 enhancements across the SLV where the simulation that used the non-COVID adjusted emissions is shown in the top panel and the simulation that used the COVID adjusted emissions is shown in the bottom panel

4. Conclusions

- Bayesian Inverse analysis for COVID-19 lockdown (March 20-April 30th) resulted in a 18% decrease in CO_2 emissions across the SLV
  - Emission adjustments confined to major roadways and towards the northern part of the SLV
- Emission reductions in agreement with back-of-the-envelope calculations where:

48% of the emissions in the SLV are from traffic
~40% reduction in traffic volume
= Expected decrease of 19% for CO_2 emissions



5. What's next?

- Large adjustments applied to point sources but are these adjustments real? For example, electricity power generation was likely flat during COVID-19
- Use CO_2 adjustments to correct emission estimates of co-emitted atmospheric pollutants ($PM_{2.5}$, CO, NO_x, VOCs)
- Can we use this framework to quantify the air quality benefits associated with reduced traffic emissions, *e. g., the electrification of SLV's vehicle fleet!*

Acknowledgements

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