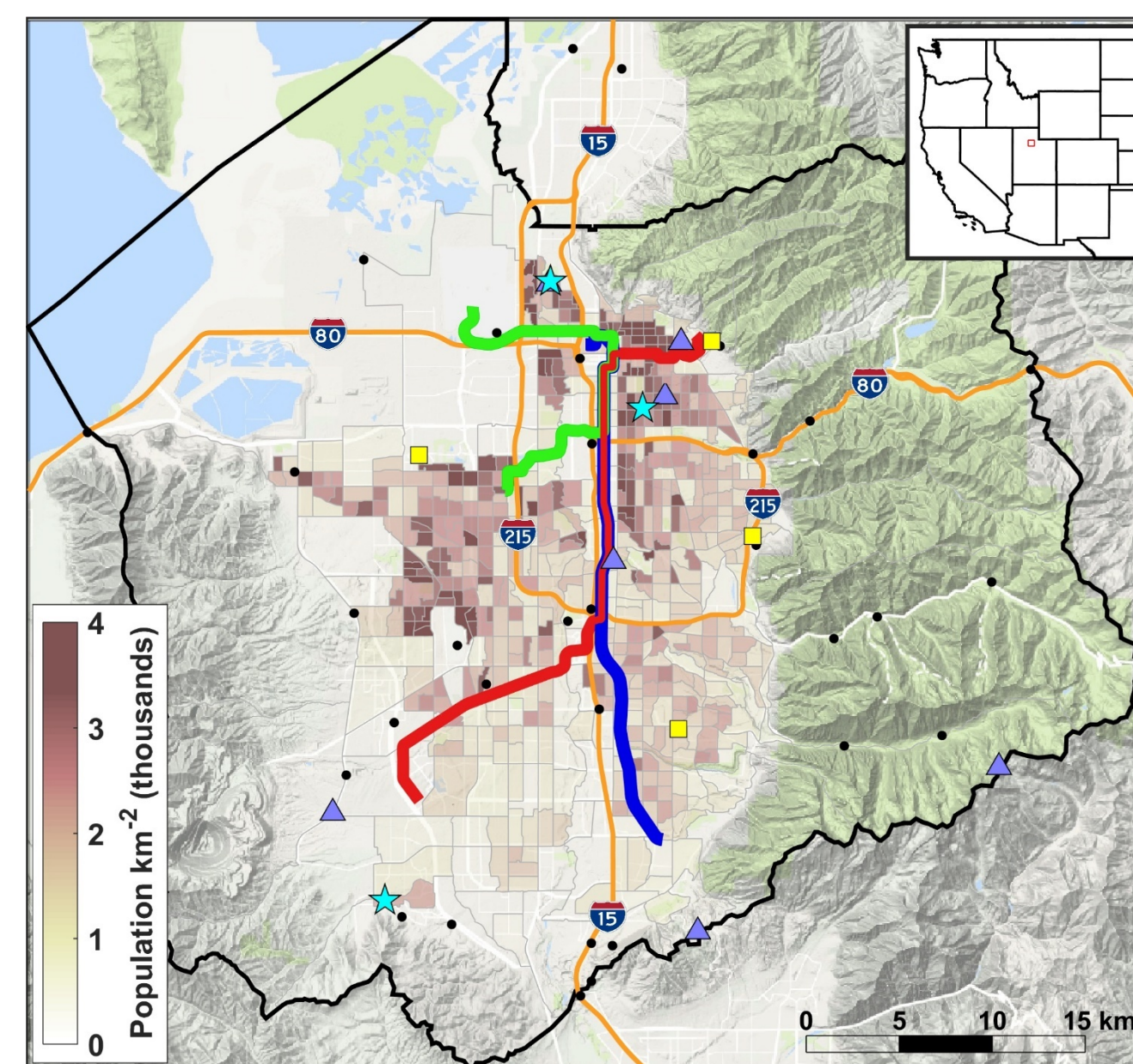


1. Introduction

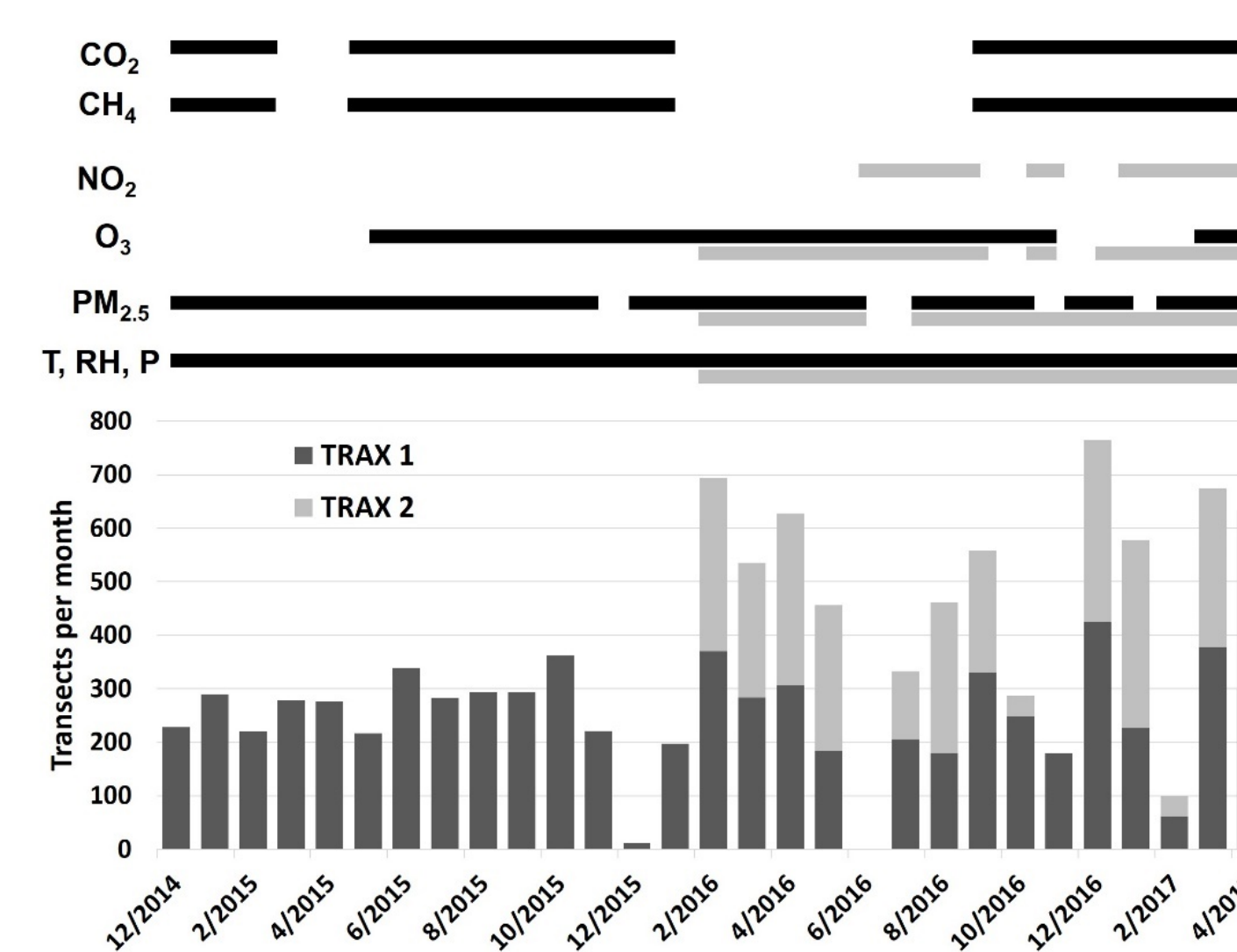
The locomotive industry plays an important role in the transport of people and products nationwide. Within locomotive rail yards, switch yard locomotives (“switchers”) are used to move freight trains around to facilitate the loading and unloading of cargo. Switchers have large diesel engines that are built to last a long time, but that also means that older diesel engines currently in operation lack modern pollution control technologies. Along Utah’s urbanized Wasatch Front the switchers are primarily older models that operate within Tier 0 or 0+ EPA emission standards that have high NO_x emissions. The TRAX based air quality measurement platform measures a suite of air pollutants and greenhouse gases (CO₂, CH₄, O₃, PM_{2.5}) and from June 2016-June 2017 the project was loaned a NO₂ analyzer from LGR to investigate the spatial patterns of NO₂ across the metropolitan area. The TRAX Green and Red lines travel adjacent to the Union Pacific rail yard in the central Salt Lake Valley and were thus fortuitously able to monitor emissions in this area.

2. Experimental Setup

- Operates on the Utah Transit Authority (UTA) TRAX light rail system:
- Red Line: traverses the entire Salt Lake Valley (northeast to southwest, including a symmetric elevation profile) at hourly intervals. Passes by the Univ. of Utah, through downtown, and out to the far margin of the city.
- Green Line: runs from the SLC airport to West Valley with two legs perpendicular to the dominant north-south transport providing plume characterization opportunities.

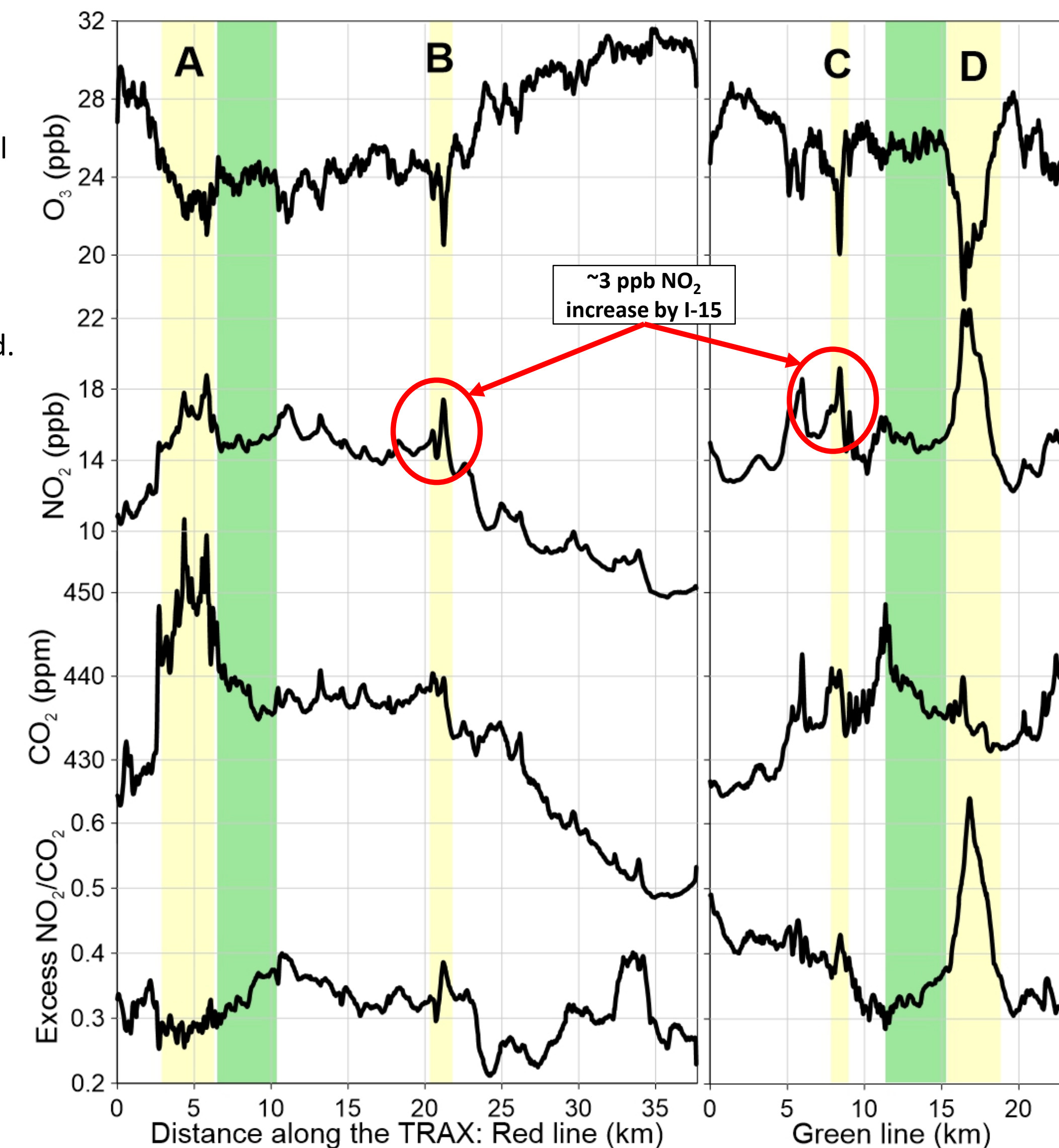


- Measures CO₂, CH₄, PM_{2.5}, O₃, and NO₂.
- Dec 2014 to present. 2nd rail car in Jan 2016.
- Sensors and sampling on roof, ~4m above ground.
- Upcoming Possibilities:
 - Expand this setup to additional rail cars to increase spatial & temporal coverage.

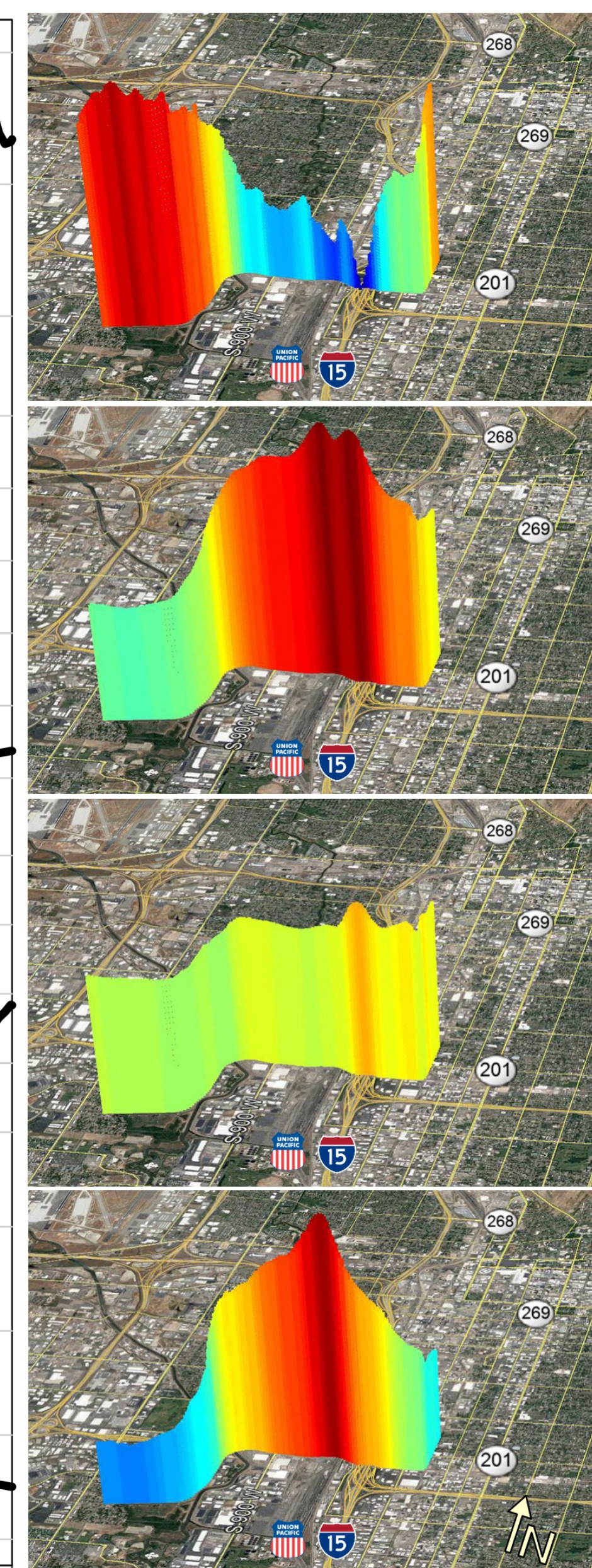
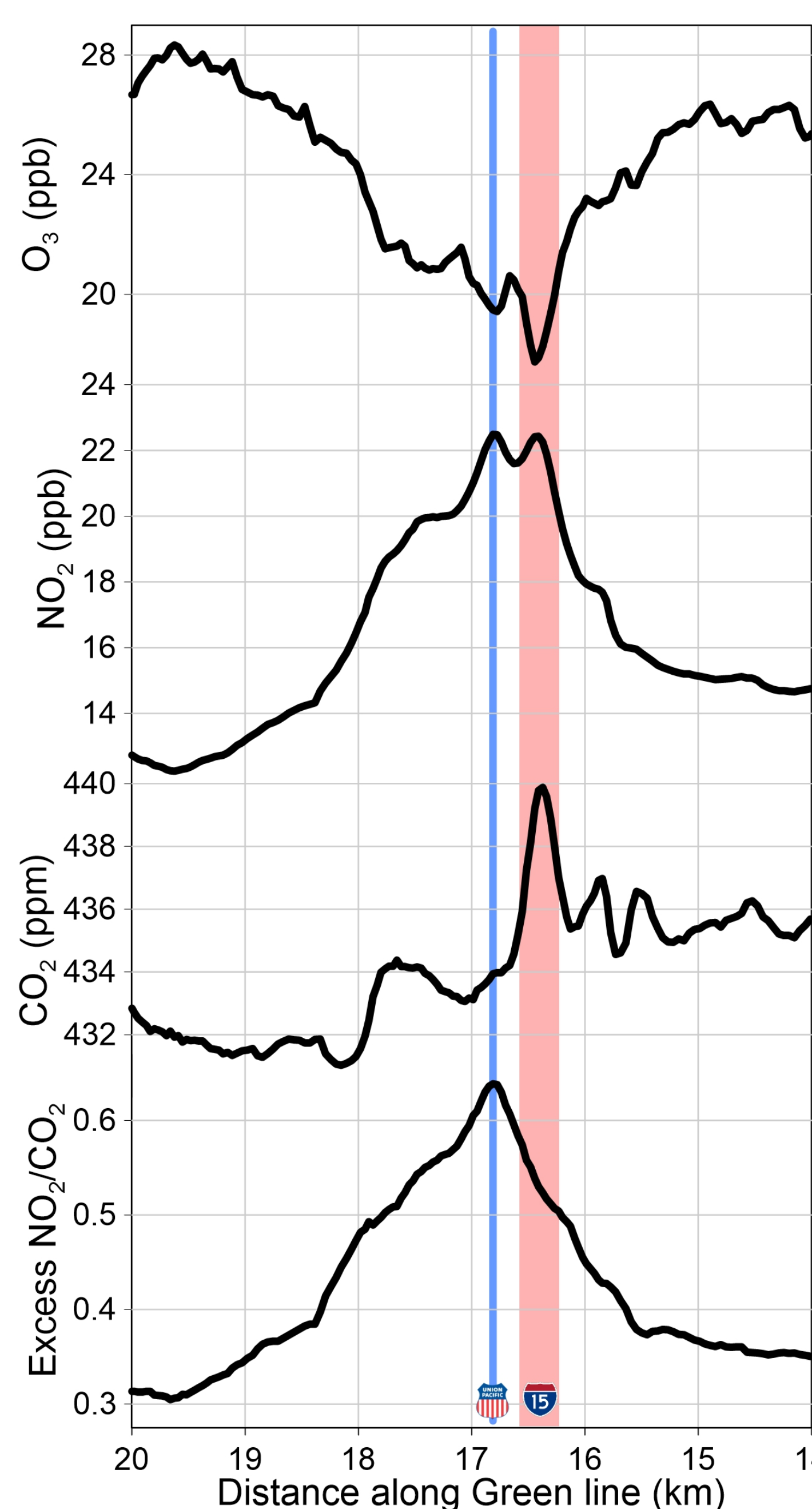


3. NO₂ Relationships

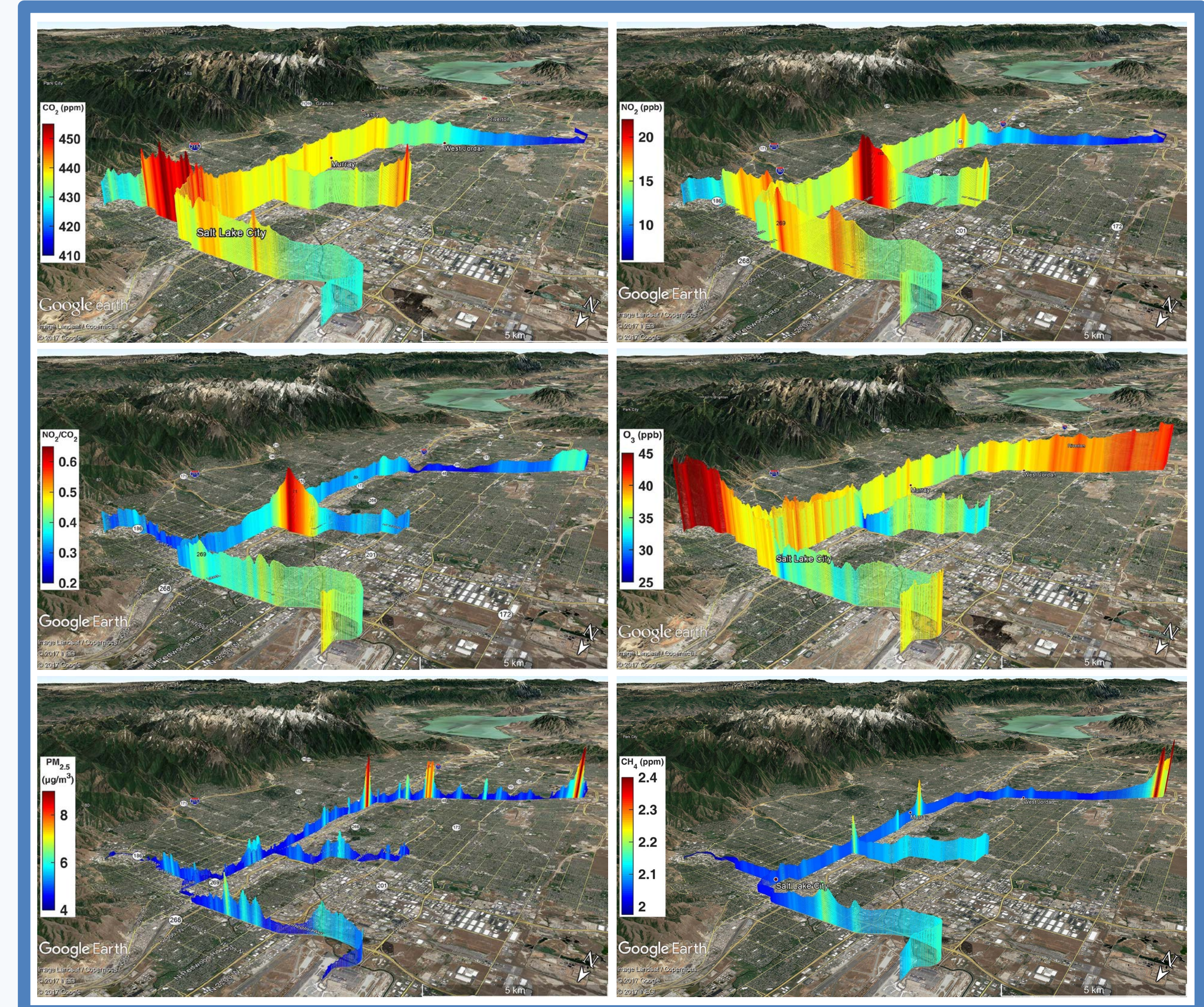
- CO₂ & NO₂ are co-emitted during fossil fuel combustion ($r = 0.83$).
- Elevated in the urban core where rail line is in the middle of traffic and along the whole urban corridor.
- Lower on the urban periphery.
- Local enhancement along every road.
- NO₂ & O₃ are related through atmospheric photochemistry ($r = -0.96$).
- Illustrates the complex signature of fossil fuel combustion on urban atmospheric composition & air quality.
- Green shading is where the Green & Red lines overlap.
- Yellow shading is notable regions where TRAX (left to right):
 - A. Is in the middle of traffic in downtown.
 - B. Crosses I-15 on the Red line.
 - C. Crosses I-15 on the Green line.
 - D. Crosses I-15 and goes by the Union Pacific rail yard.



4. Locomotive Switch Yard



- I-15 freeway interchange is adjacent to the locomotive switch yard complicating source identification.
- Proportional change in CO₂ and NO₂ by I-15 does not affect the excess NO₂/CO₂ ratio.
- The NO₂ emissions from I-15 are superimposed on a much larger NO₂ plume that is centered on the locomotive rail yard.
- The ~3 ppb NO₂ increase near I-15 superimposed on the larger plume is a similar magnitude as the two other locations where the train crosses I-15.
- The excess CO₂/NO₂ ratio is a fingerprint of different combustion sources. Diesel emissions emit more NO₂ relative to CO₂ that results in a higher ratio.



6. Conclusions & Future Directions

- Diesel locomotive “switcher” engines operate in rail yards to move rail cars around.
- Operate 24/7 during the winter & often idle.
 - Avoids difficult start-ups.
 - Prevents engine blocks from freezing in the winter.
- ~60 switchers in Utah, 49 operated by UPRR.
 - 30% of UPRR’s switchers are Tier 0 and 70% are Tier 0+ (Glade Sowards, UDAQ, personal communication).
- Replacing Tier 0+ with a Tier 4 switcher would reduce NO_x emissions by 89%.
- UDAQ analysis indicates an emissions reduction cost of \$3,412/ton (Peter Verschoor, UDAQ, personal communication).
 - Within range of reduction costs (\$238-6,560/ton) for area sources adopted by the Utah Air Quality Board, and well below that for large point sources.
 - States are prohibited from establishing emissions standards for locomotives in the Clean Air Act, but they can offer incentives to encourage clean tech upgrades.
- TRAX based measurements could be used to demonstrate improvements in air quality after upgrades were made.

Future Directions:

- Obtain a new NO₂ + NO analyzer for TRAX.
- Integrate observations into atmospheric chemistry model.
- Investigate differences between day and night measurements.
- Gain a better understanding of urban atmospheric chemistry and air quality exposure.
- Co-benefits of GHG and pollutant mitigation policies.



7. Salt Lake Measurement Programs

- (a) TRAX light rail network (<http://utahaq.chpc.utah.edu>)
- (b) Urban CO₂ network (<https://air.utah.edu>)
- (c) MesoWest (<http://mesowest.utah.edu>)
- (d) Utah Div. of Environmental Quality (<http://air.utah.gov/>)

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Real Time TRAX Data: