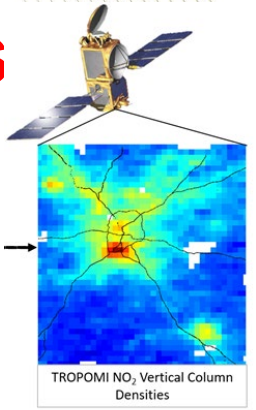
NASA HAQAST Tiger Team- Assessing Unconventional Oil and Gas Activity Impacts Using Earth Systems Observations and Models: A Glimpse of the Results & More to Come

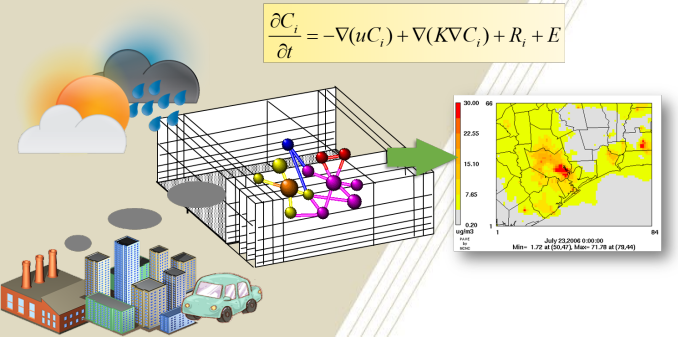


Ted Russell[1], Dan Goldberg[2], Jen Kaiser[1], Yongtao Hu[1], et al.

On behalf of the HAQAST Team

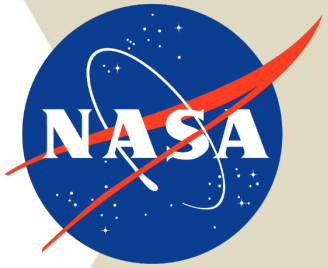
[1]GT, [2]GW

January 28th, 2025



Acknowledgements

Lots of Organizations and people have directly or indirectly contributed to this presentation (these are a few):



The HEI-Energy TRACER teams

The NASA HAQAST teams

But the opinions are all mine, and the views expressed are those of the presentor and do not necessarily represent the views of any of the organizations that have help formulate those views.

Outline

- Background
  - NASA HAQAST and Tiger Teams
- Objectives
  - Overall Tiger Team
    - Georgia Tech
    - George Washington
- Methods
  - Air quality modeling: CMAQ
  - Satellite data analysis: TROPOMI (TEMPO)
- Results
  - Vertical column density comparisons
  - Air quality impacts
- Summary
  - Input requested

Background

- NASA HAQAST: Health and Air Quality Applied Science **Teams**
  - Using earth systems products (satellite observations, air quality models,…) to address health and air quality
- The NASA HAQAST Program has a “Tiger Team” effort
  - A Tiger Team is a short-term, high-impact collaborative effort between HAQAST members and public stakeholders to identify and solve an immediate problem using NASA data and products. Each Tiger Team draws on the expertise of multiple HAQAST PIs to find the best, multifaceted solutions to pressing health and air quality issues.
  - If you are not familiar with HAQAST, I recommend going to: **https://haqast.org/**
- A group of us (next slide) proposed using our expertise to better understand oil and gas development impacts on air quality and light at night
  - Separate HAQAST Tiger Team meetings
  - This meeting is to talk directly with the TRACER and HEI stakeholders about what we have done and what are the most useful analyses we can do
- Specific objectives include making available to the HEI-funded investigators (and others) air quality relevant information, including
  - Modeled air quality impacts
  - Satellite-observed information relevant to environmental impacts from oil and gas operations (OGO) activities
  - Extend our understanding of UOGD impacts beyond what might be derived from the TRACER effort

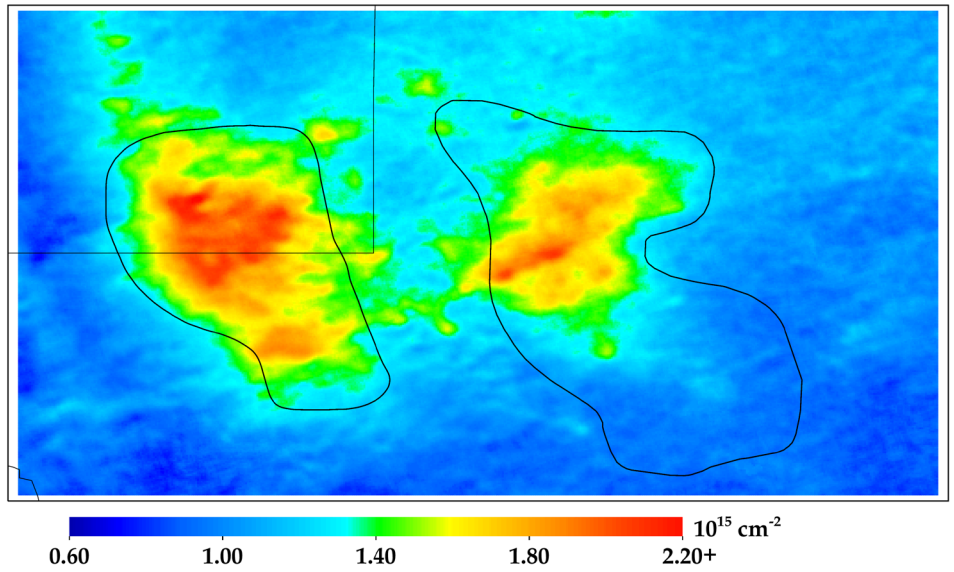
Tiger Team

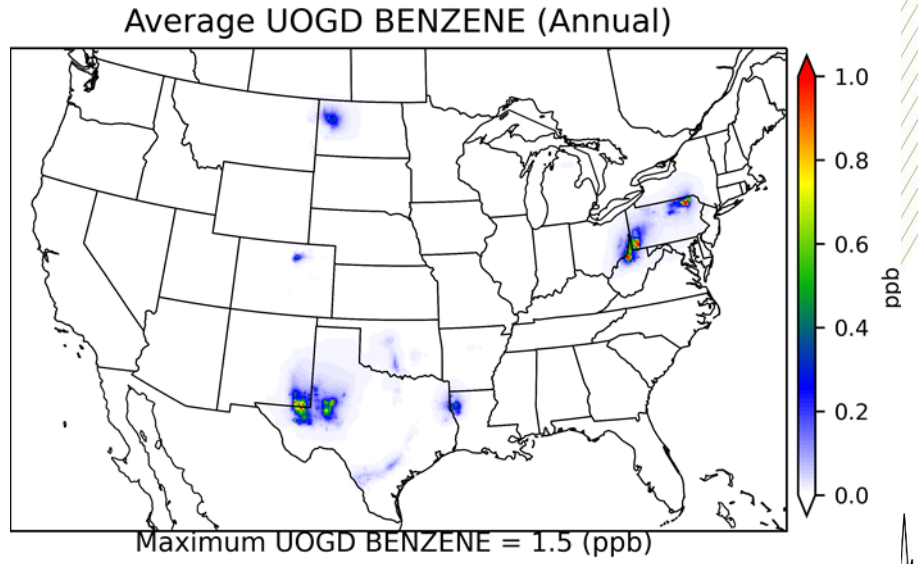
Focus	Key HAQAST personnel	Data/methods
NO_2 conc.	Anenberg, Goldberg, Russell	NO_2 datasets from TROPOMI, (potentially TEMPO); links with emission sources and air quality data
Light	Xiao, Qian	Light at night from VIIRS DNB
$PM_{2.5}$	Pierce, Holloway, Russell	AOD and aerosol optical properties from multiple instruments (MODIS, MAIA, etc.); Earth systems data sets, including emissions, CTM modeling
O_3, NO_2	Russell	Ground-based observations, CTM modeling
HCHO	Goldberg, Kaiser	HCHO datasets from TROPOMI, TEMPO
CH_4	Goldberg	CH_4 datasets from TROPOMI and GHGSat
Communications	Prados, Russell, Pierce	Communications with, internally, externally

UOGD Tiger Team Objectives

- **Objectives**
  - Assess the spatial footprint of UOGD operation impacts on air quality using earth systems observations (e.g., satellites) and models (in this case, CMAQ);
    - Assess the products of atmospheric transformations (e.g., formation of air toxics like HCHO, criteria pollutants such as O_3, as well as secondary aerosols).
- **Potential outcomes**
  - Satellite retrievals and air quality modeling results linking UOG operations to air quality
    - Spatial footprints
    - Trends

Permian basin as seen from TROPOMI: NO_2

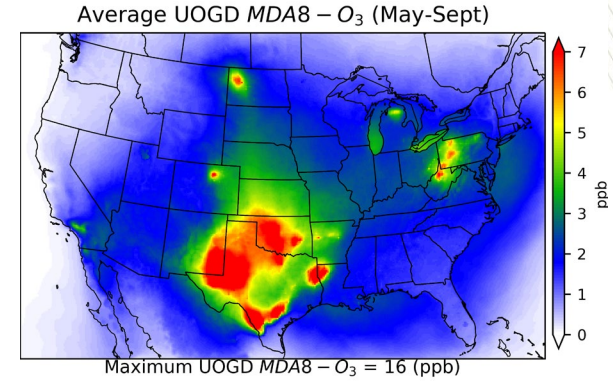


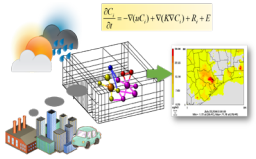


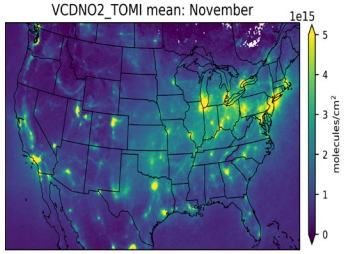
CMAQ simulated benzene

CMAQ, TEMPO and TROPOMI

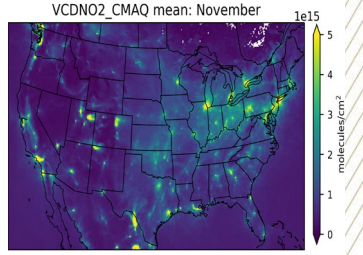
- **Approach**
  - CMAQ air quality modeling to link OG operations to air quality impacts around the US
    - Species: NO_2, ozone (O_3), PM2.5, HCHO, benzene other air toxics
  - Compare satellite observations (TROPOMI/TEMPO) of NO_2 (and HCHO) vertical column densities (**VCD**s) with CMAQ-modeled VCDs to identify potential emissions inventory biases
    - What is a VCD? Satellites observe the amount of a material in a column of air from the surface upwards: A VCD is how many molecules there are in that column (per area).
      - Models also simulate VCDs and can related VCDs to ground level concentrations
    - TROPOMI: an orbiting satellite given us one daytime observation per day
    - TEMPO: New, geosynchronous
      - You will be seeing much more in future
  - Use satellite observations over time to assess UOG-related emissions trends

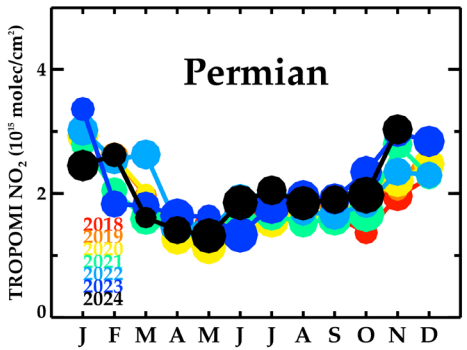






Vs.





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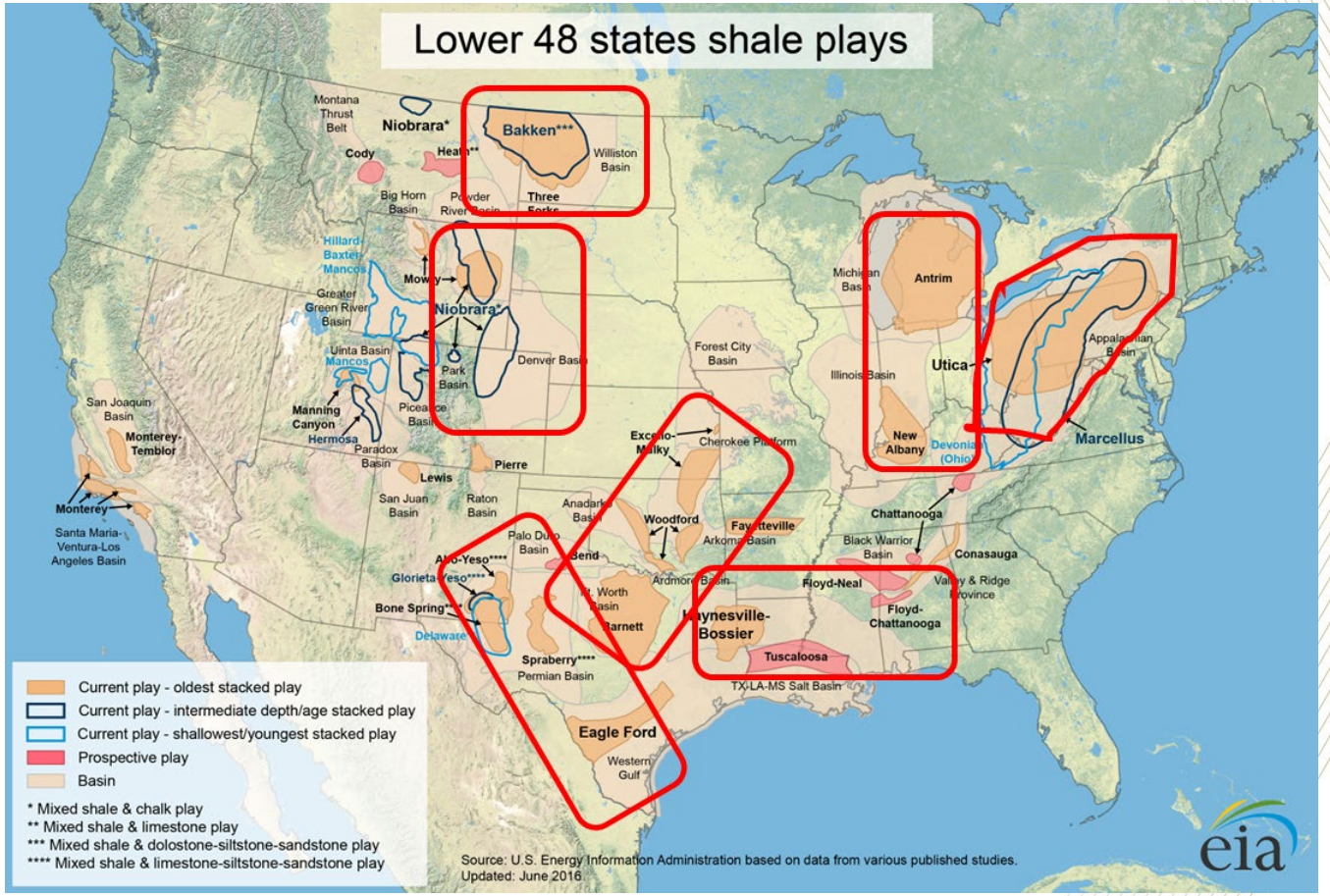
Oil and Gas Operations areas modeled using CMAQ

- Chose seven areas to model using CMAQ-ISAM
  - CMAQ: Widely used air quality model
    - Simulated June 2023-August 2024 (coinciding with TRACER experiments) (results available)
  - ISAM: Integrated Source Apportionment Model in CMAQ
  - Antrim+New Albany (ANA), Barnett+Woodford+Fayetteville (BFW), Bakken+Three Forks (BTF), Eagle Ford + Wolfcamp/Permian (EFW), Haynesville (HAY), Marcellus+Utica (MAU), Niobrara+Denver-Julesburg (NIO)
- ISAM provides how emissions from each area impact modeled species ozone, PM, HCHO, benzene,…)
  - Can differentiate between controlling species (VOCs vs. NOx)



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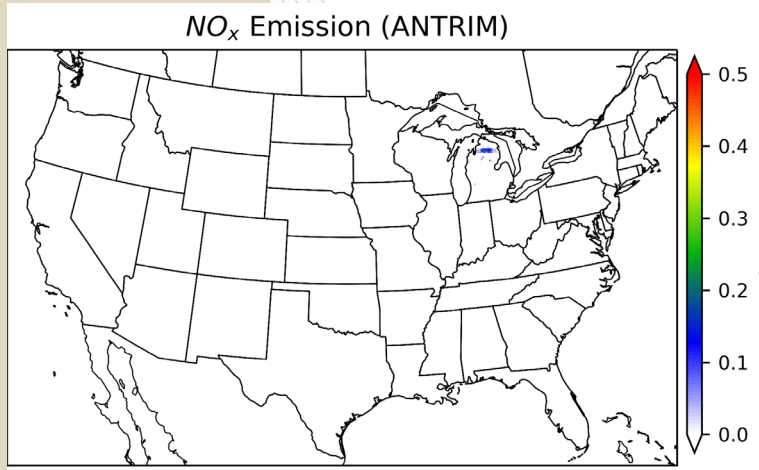
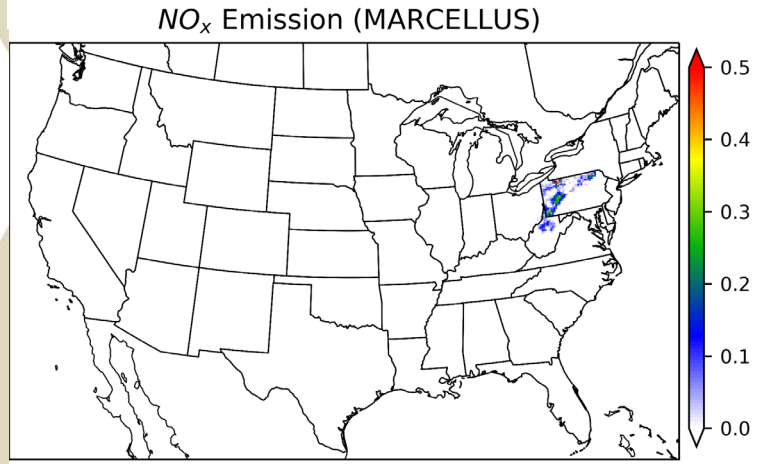
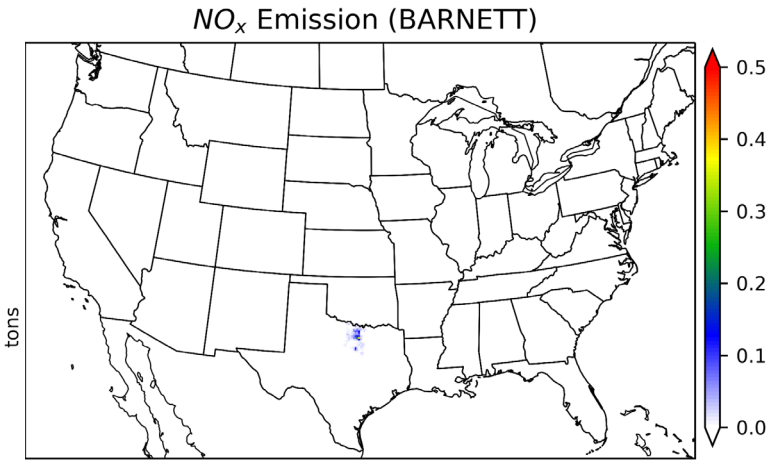
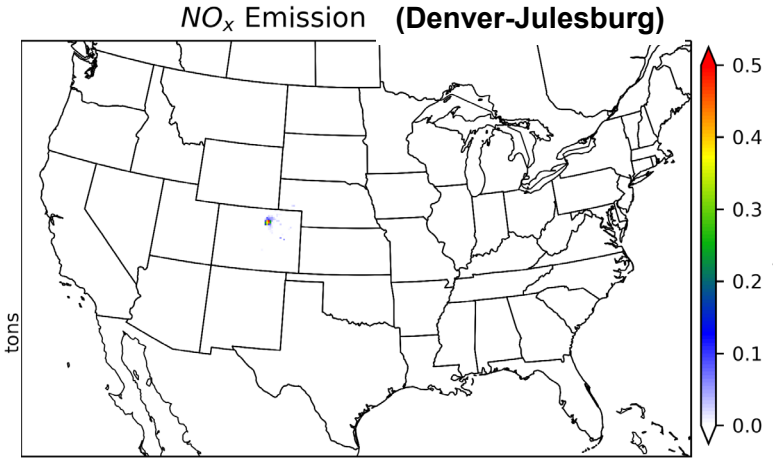
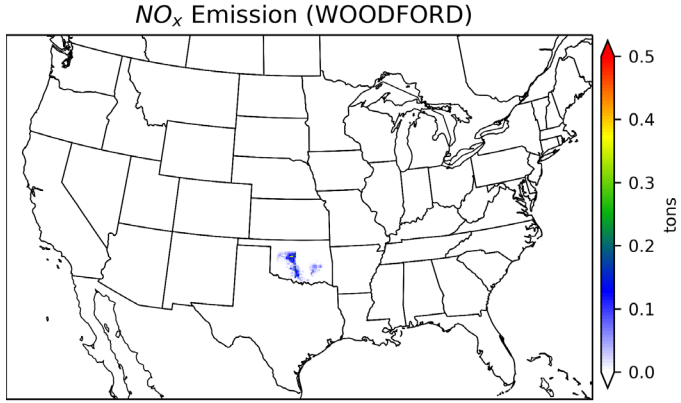
NOx emissions by play

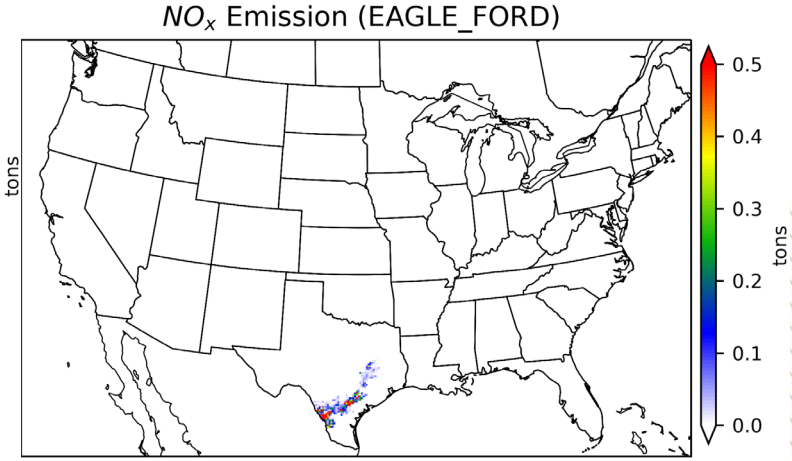


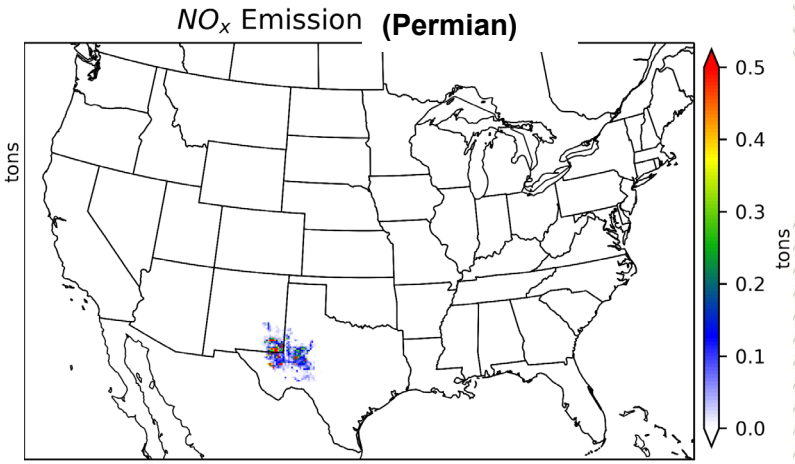












Also have VOCs, PM, SO2, air toxics,…

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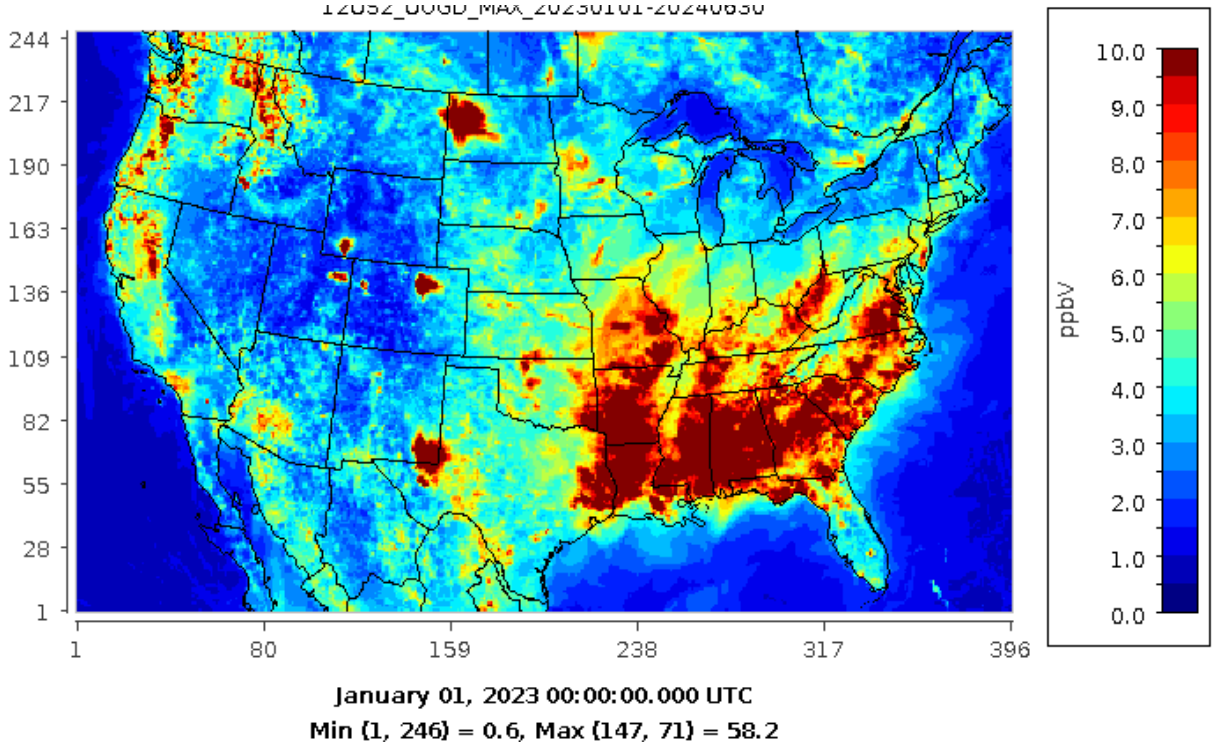
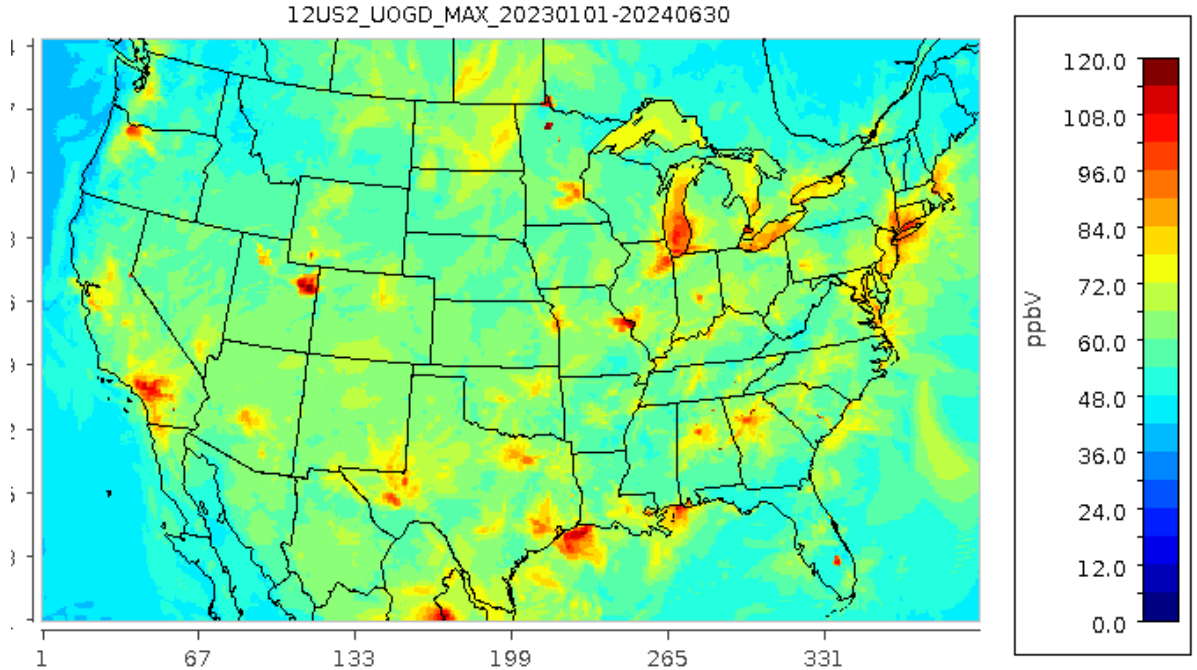
CMAQ Simulated Maximum Surface 1-hr Average Concentrations: 20230101-20240630

Maximum Formaldehyde



January 01, 2023 00:00:00.000 UTC
Min (1, 246) = 0.6, Max (147, 71) = 58.2

O3_MAX

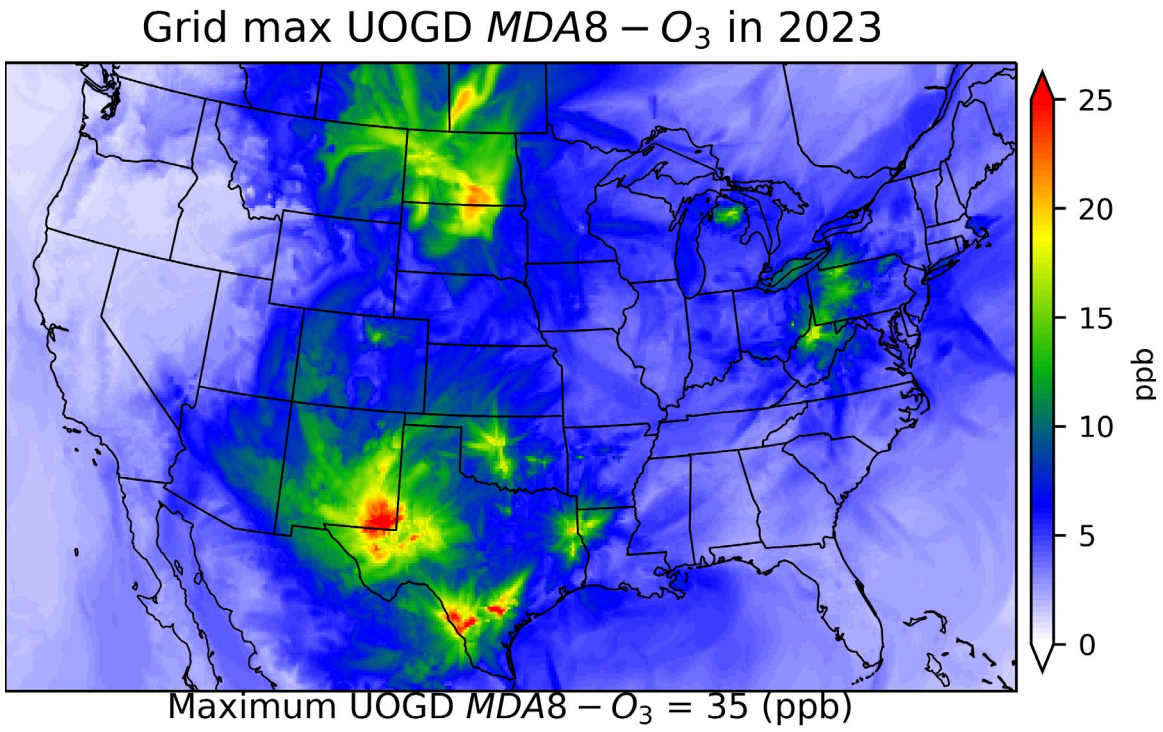


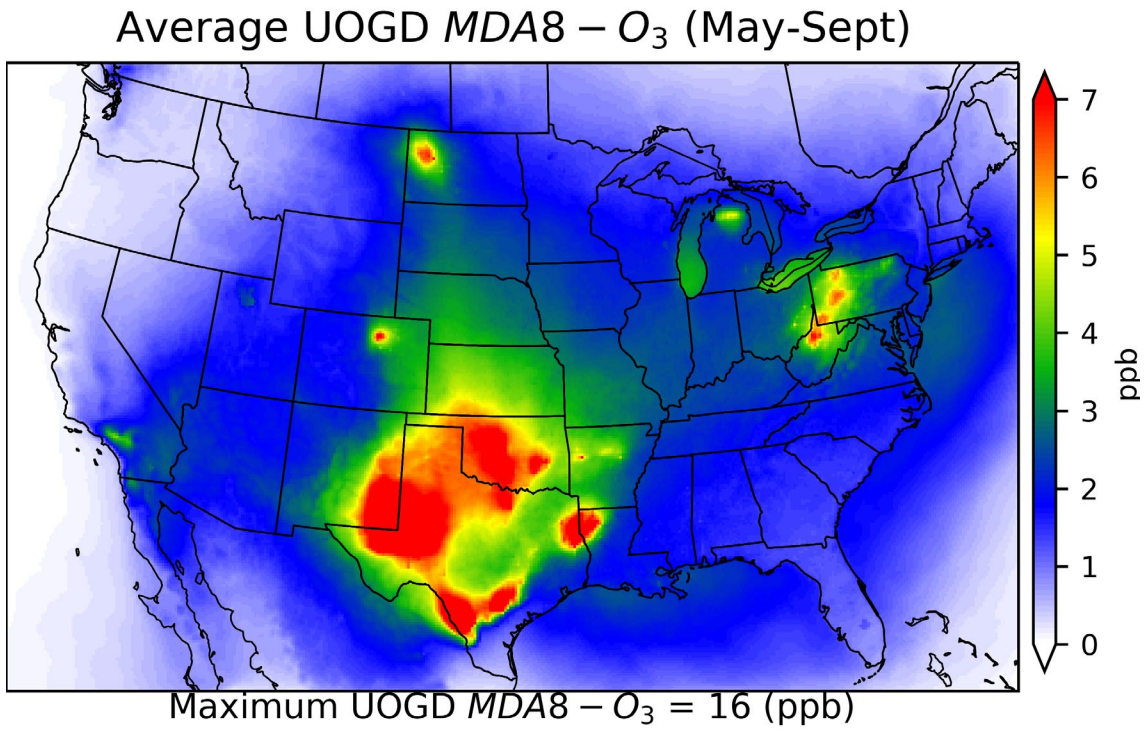
January 01, 2023 00:00:00.000 UTC
Min (21, 192) = 37.7, Max (213, 209) = 183.7

Oil and Gas specific impacts

- Used CMAQ-ISAM
  - Found some really interesting, long-distance impacts on ozone and NO2
- Additional analyses using CMAQ-DDM and brute force

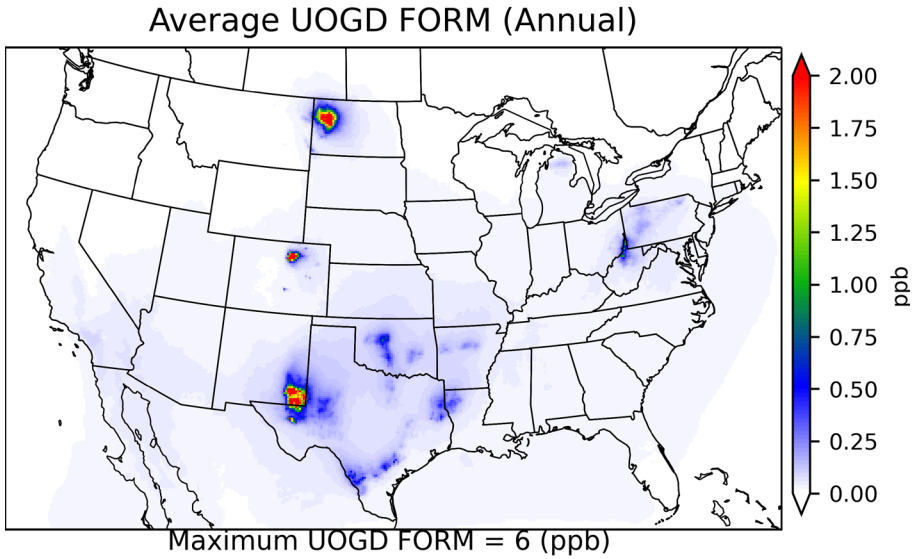
Grid Maximum and seasonal average MDA8 ozone impact

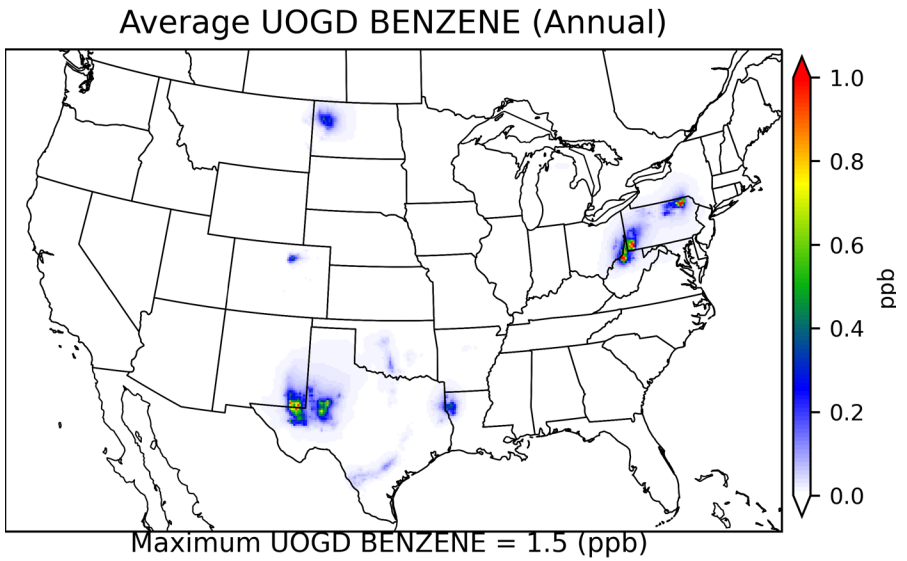


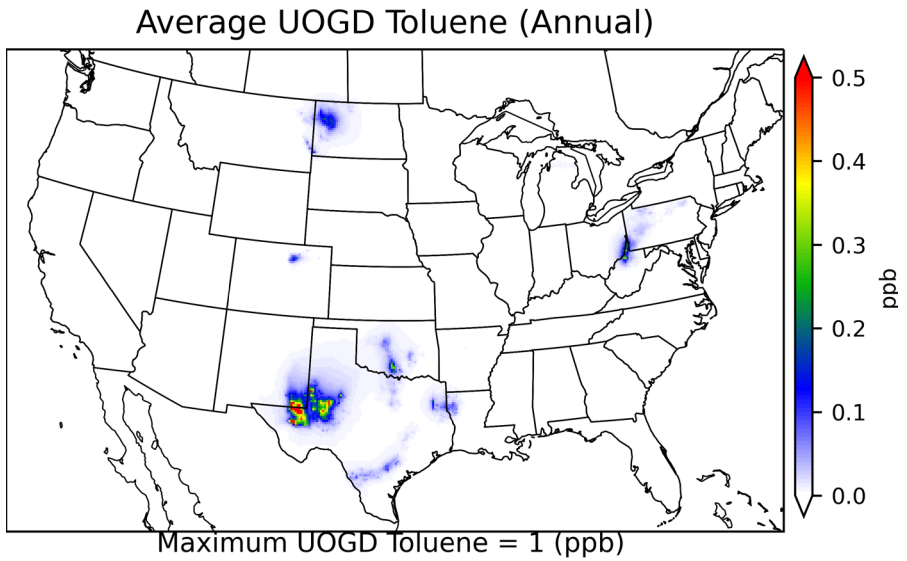


Results comparable to TRACER team observations

Other Pollutants: UOGD Impacts on formaldehyde, benzene and toluene

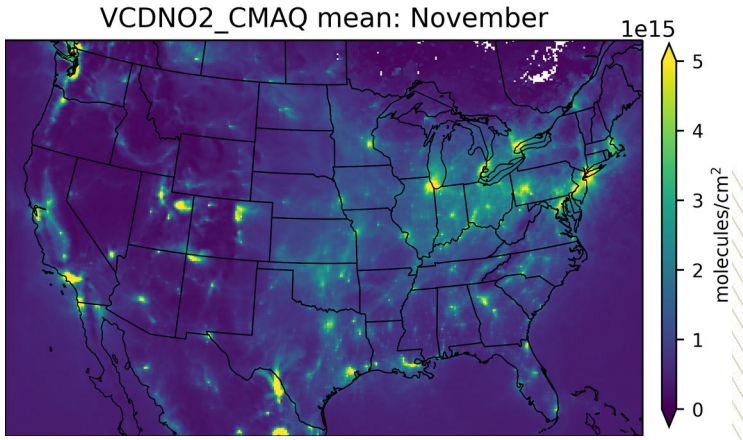


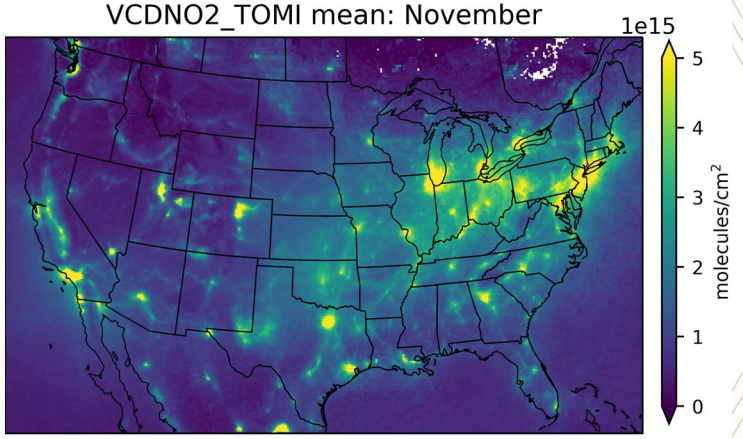


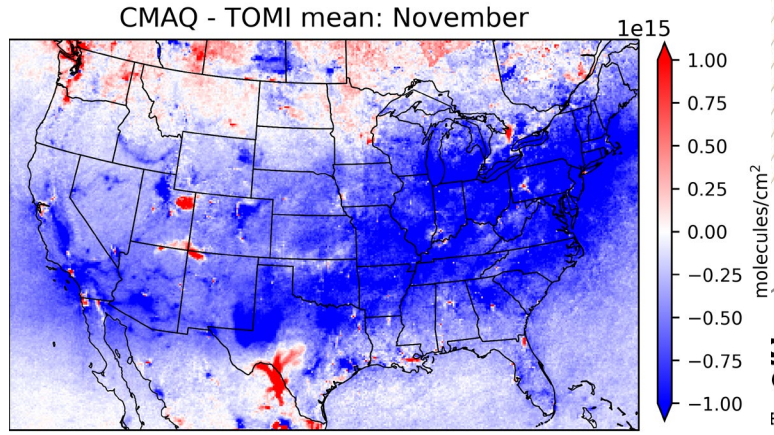


CMAQ-TROPOMI (and TEMPO) Comparisons

- Compare CMAQ vertical column densities (VCDs) with satellite-derived VCDs to identify areas where emissions estimates may be under or over estimated
  - NO_2, (HCHO…)
  - VCD: #molecules/cm^2 in a column from the surface upwards, i.e., amount of material per area, can be linked to emissions density
- CMAQ and TROPOMI have similar spatial trends, but…
  - Notable areas of CMAQ high bias (e.g., emissions overestimated)
    - Some cities, TX-Mexico border, Uinta
  - Low bias
    - Eastern US, DJ, Permian, CA Central Valley,…
  - West-to-east trend may have multiple causes (another story)



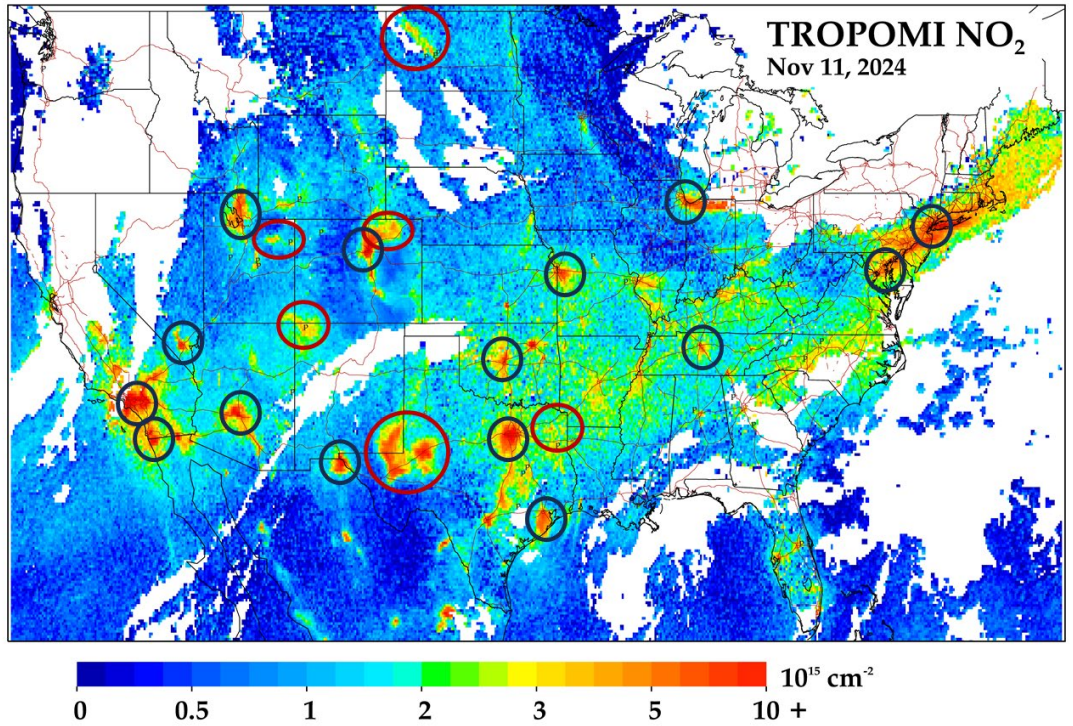




TROPOMI trend analyses (Dan Goldberg)

- Can use satellite observations for
  - Looking at spatial distribution of species in absence of direct measurements
  - Trend analysis
- TROPOMI provides multiple species associated with oil and gas activities
  - NO_2, CH_4, HCHO
    - HCHO secondary, often overwhelmed by atmospheric chemistry (but not always)
- TROPOMI has record of NO2 VCDs for use in trend analyses

A typical day of TROPOMI NO2 VCD retrievals



Black: Urban, Red: OG

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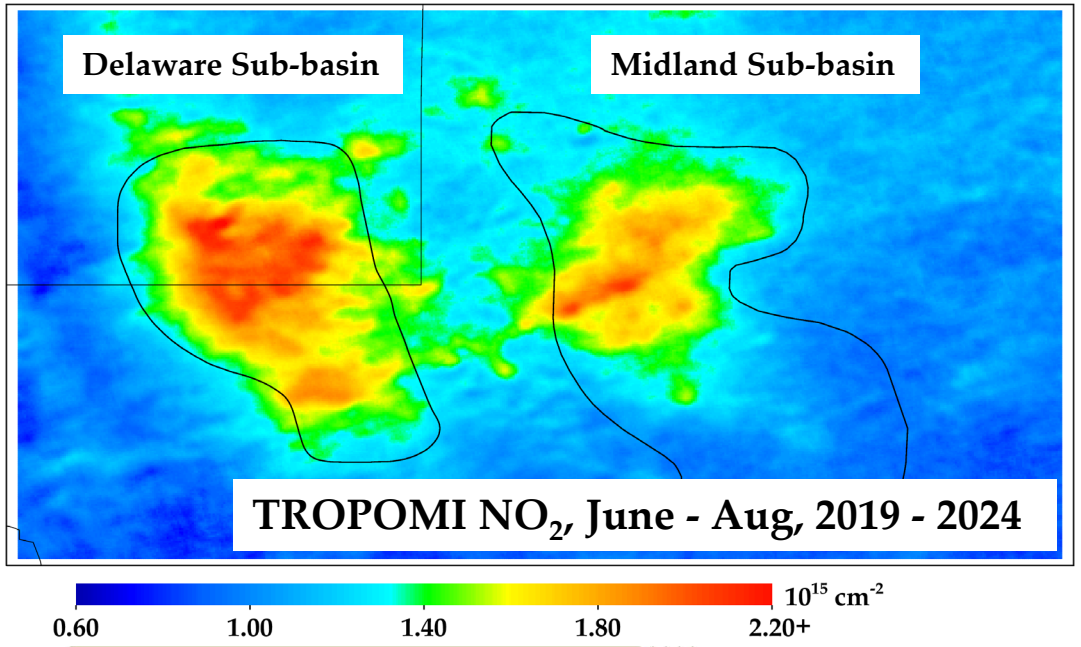
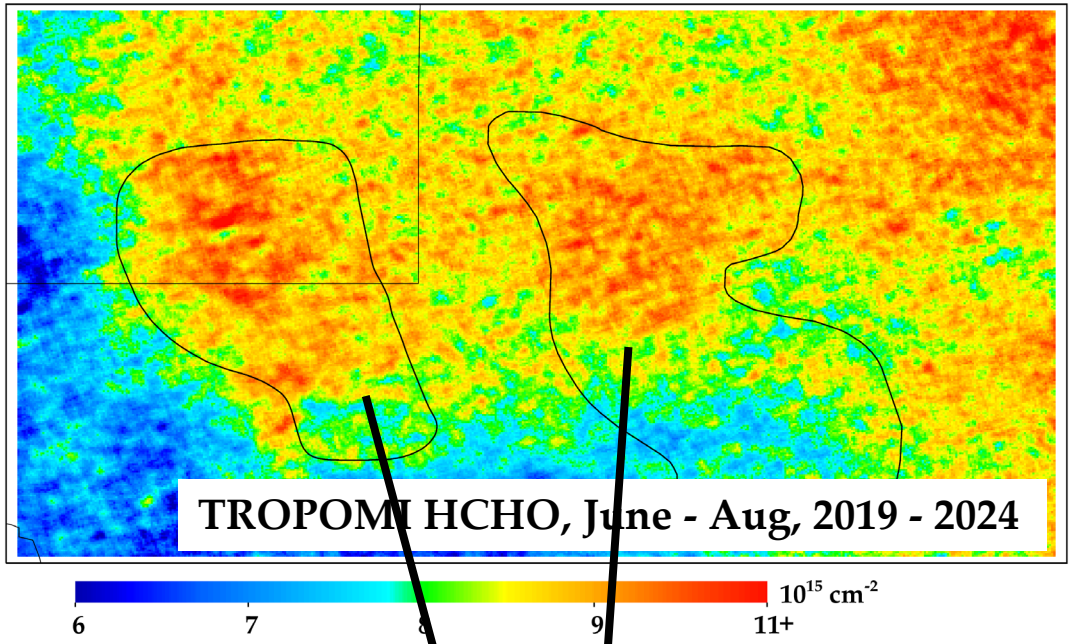
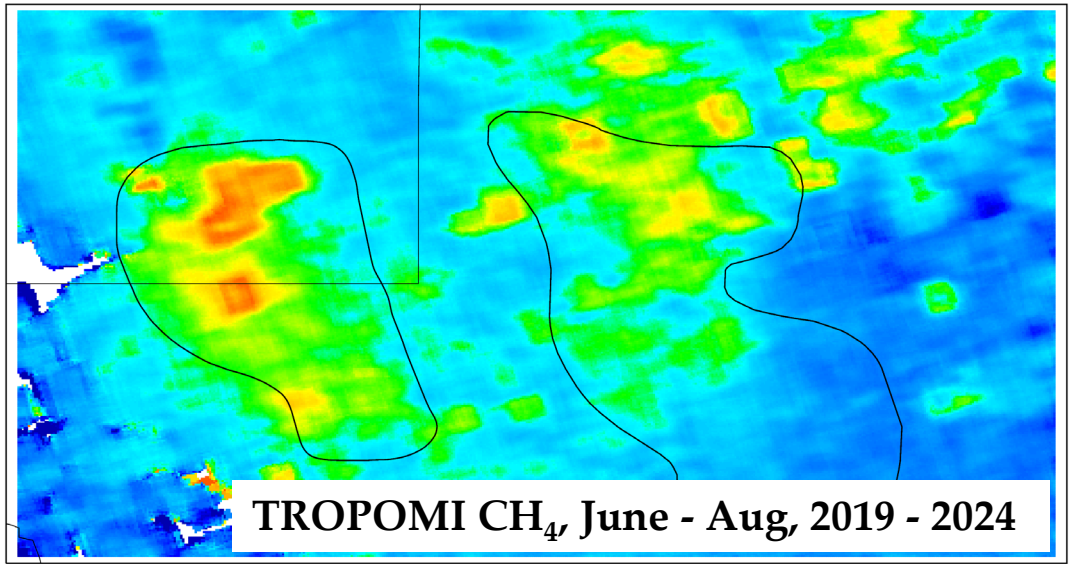
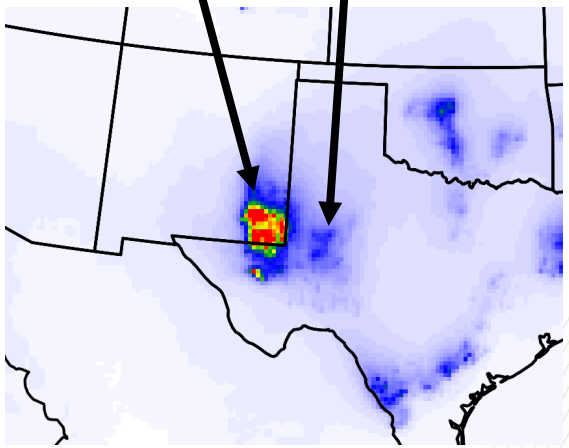
Permian basin as seen from TROPOMI: NO_2, HCHO & CH_4 VCDs









CMAQ HCHO from before

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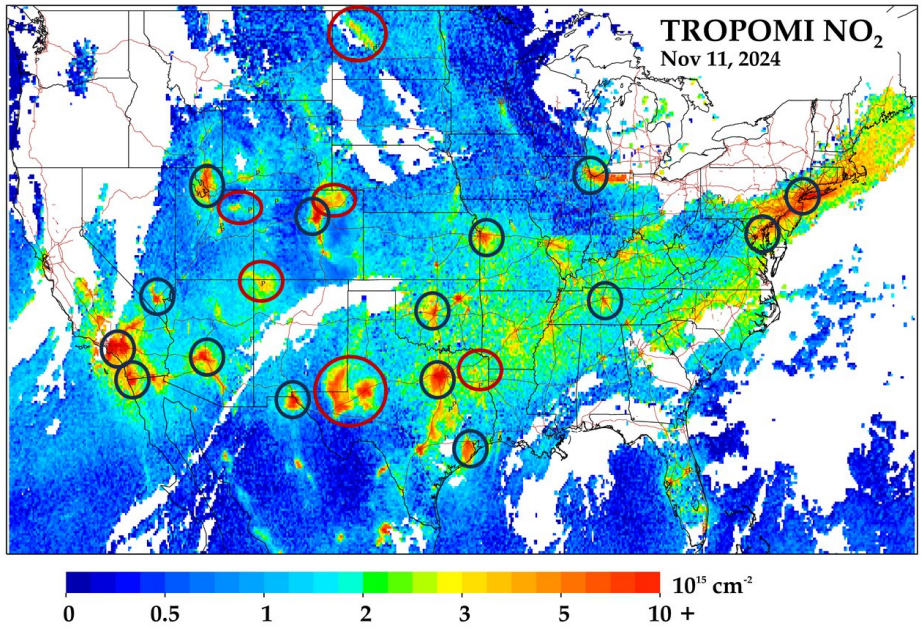
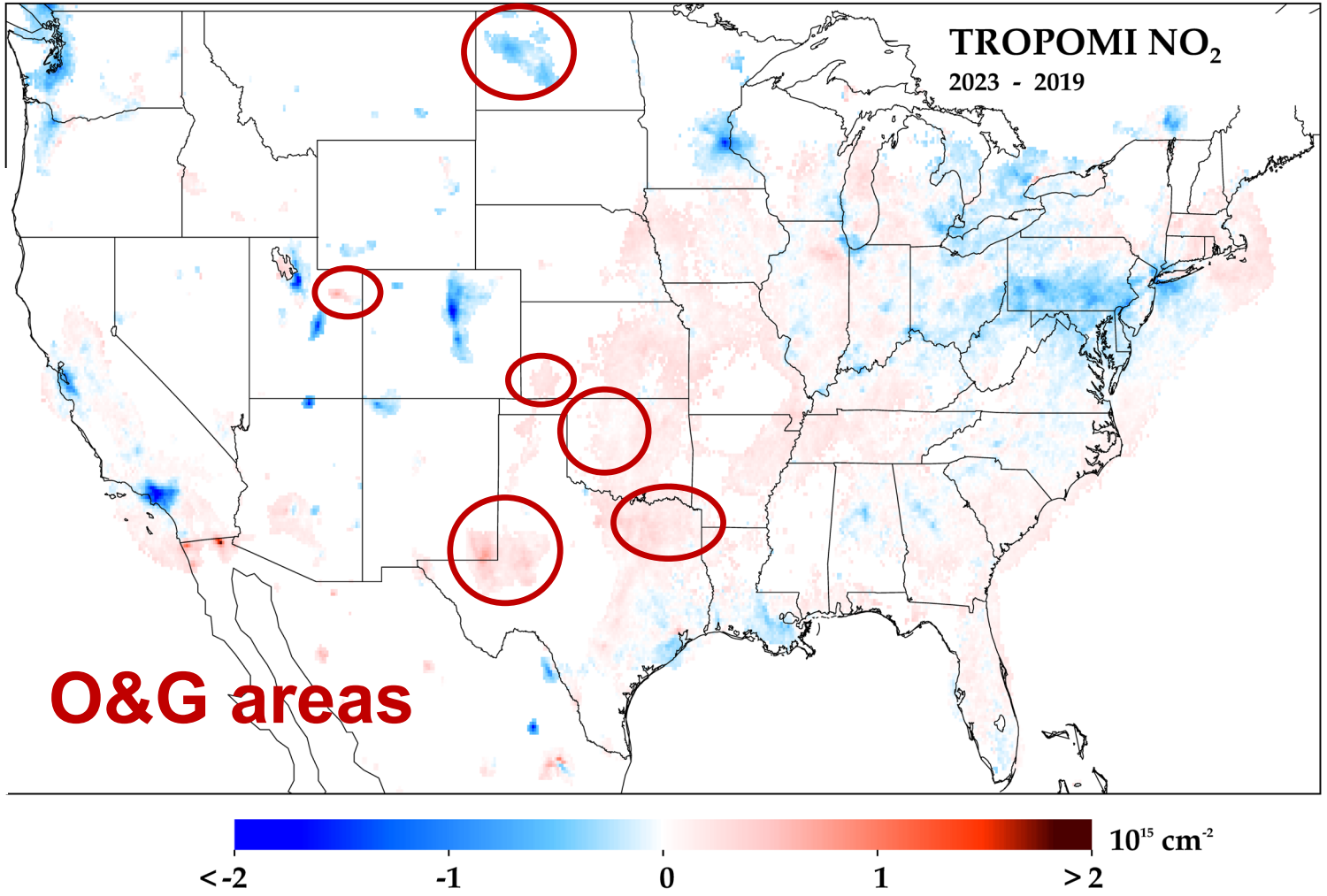
TROPOMI NO_2 : 2023 vs. 2019

- NO_2 decreases in major cities & near coal power plants
- NO_2 increases in many O&G regions and central US





Summary

- NASA Tiger Team using earth systems observations and models to better understand potential air quality impacts of UOGD emissions
  - CMAQ modeling generally agrees with satellite observations, but important areas of bias emerge
    - High and low
    - Basin differences and general trends
      - Analysis of differences continues
  - CMAQ modeling shows localized impacts on air toxics, ozone impacts more widespread
    - Shows elevated levels in basins, in line with observations and other modeling
  - Satellite trend analysis shows increasing impacts on NO2 VCDs over time in multiple basins
- Overall: Combining modeling and satellite observations linked to extend detailed observations taken by TRACER teams
  - Results available for others to use
- In the works
  - GT team plans to continue analysis over the coming year
    - Input and suggestions solicited
- Go to the HAQAST website (https://haqast.org/) for additional information
  - 1-pagers on various topics (including the ones above)