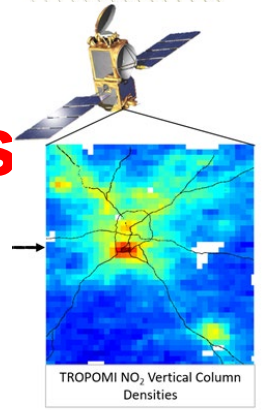
NASA HAQAST Tiger Team- Assessing Unconventional Oil and Gas Activity Impacts Using Earth Systems Observations and Models

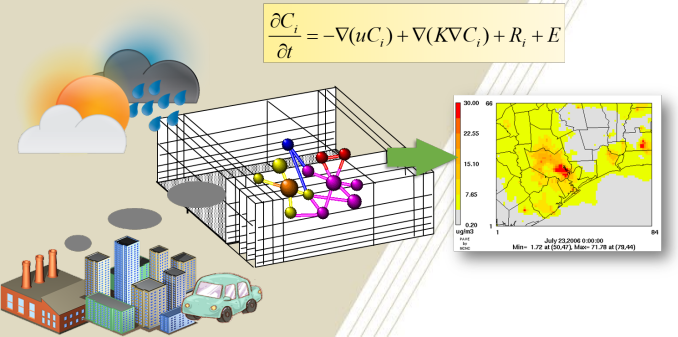


Ted Russell[1], Dan Goldberg[2], Jen Kaiser[1], Yongtao Hu[1], et al.

On behalf of the HAQAST Team

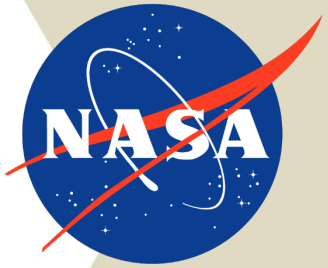
[1]GT, [2]GW

May 5th, 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

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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

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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.
- A group of us 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 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
- **Love to talk to you more about this program…**
  - Also, If you are not familiar with HAQAST, I recommend going to: **https://haqast.org/**

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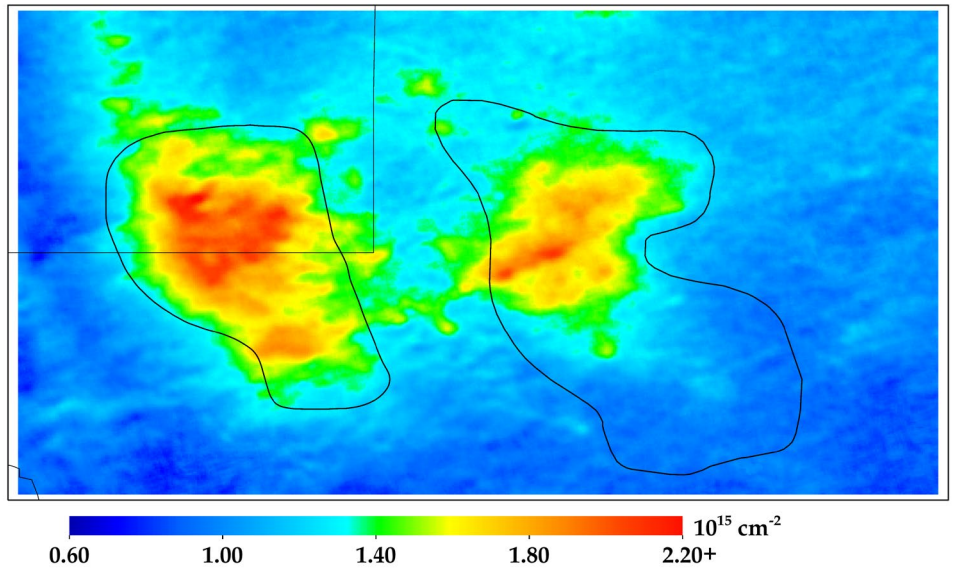
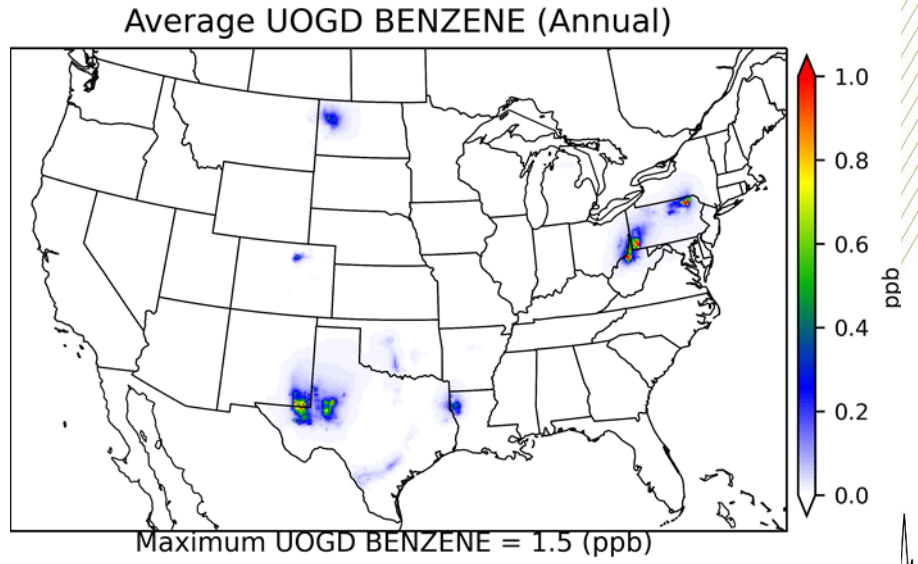
UOGD Tiger Team Objectives

- **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

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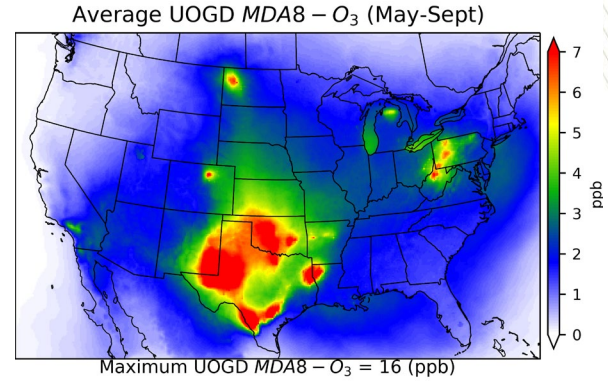
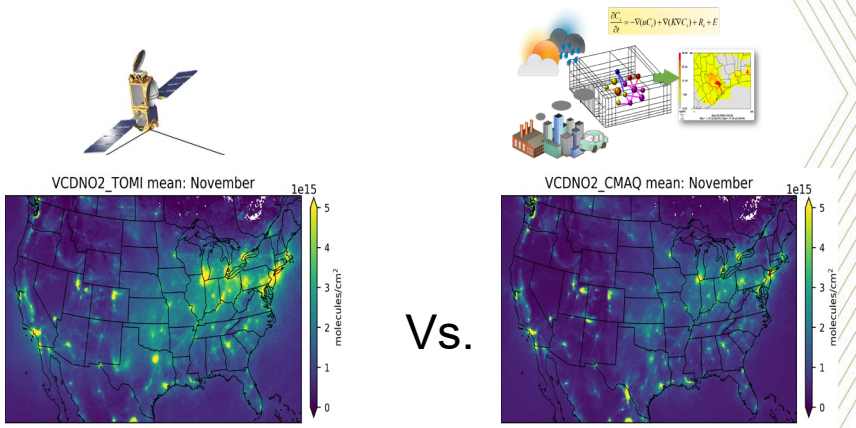
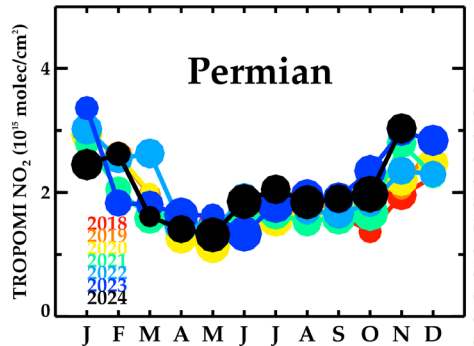
CMAQ, TEMPO and TROPOMI

- **Approach**
  - Compare ground (TRACER and routine) and satellite observations (TROPOMI/TEMPO) with air quality modeling results in oil and gas areas
    - Satellites: 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).
      - TROPOMI: an orbiting satellite given us one daytime observation per day
      - TEMPO: New, geosynchronous
        - You will be seeing much more in future
    - Ground-based ozone, NO2, HCHO, benzene
      - Focus on benzene (identified as air toxic of most concern) and ozone
    - 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
  - Use satellite observations over time to assess UOG-related emissions trends







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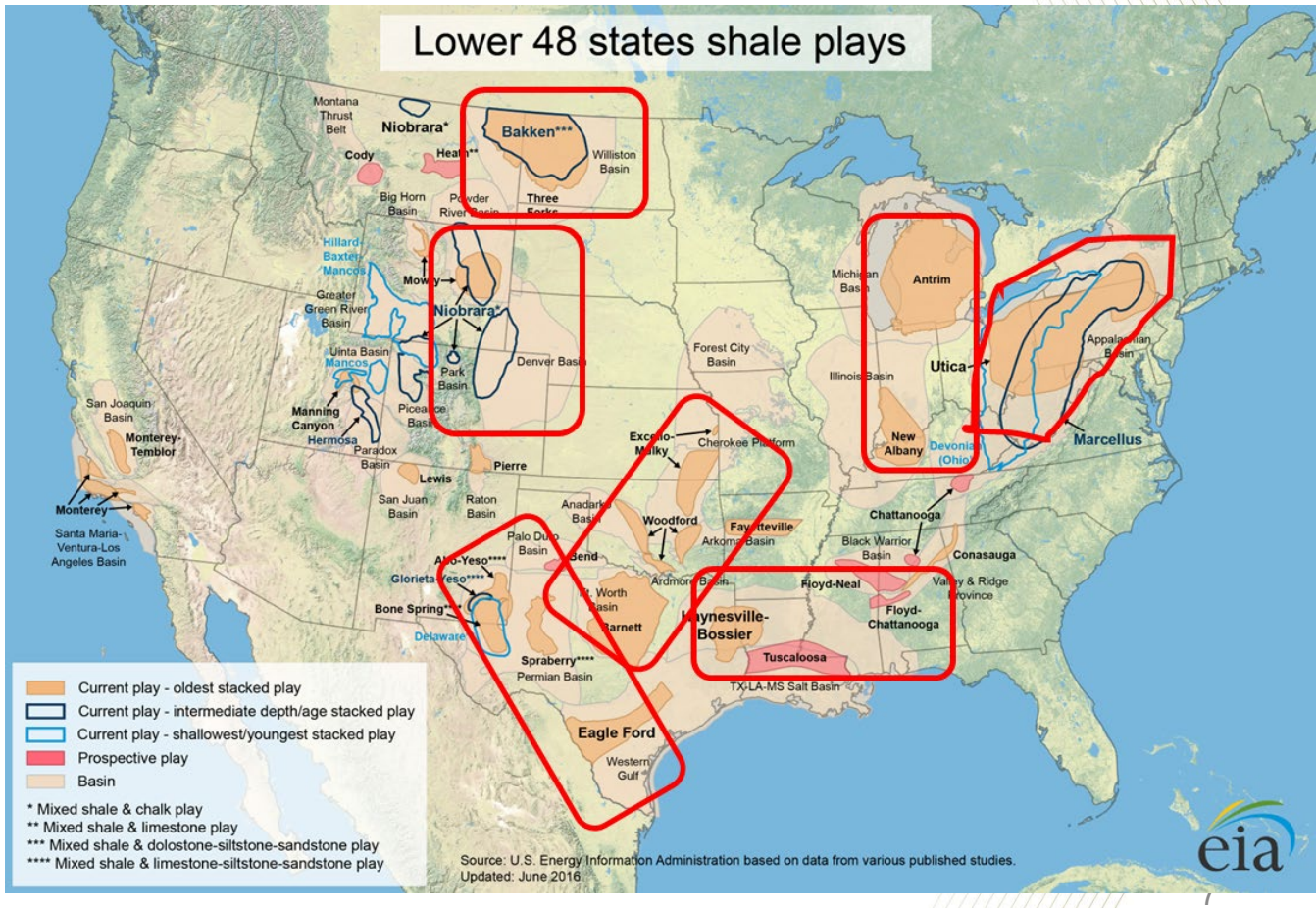
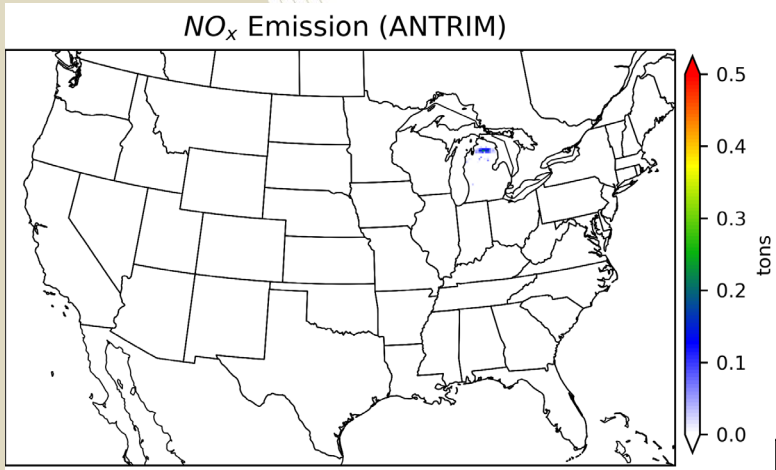
Oil and Gas Operations areas modeled using CMAQ

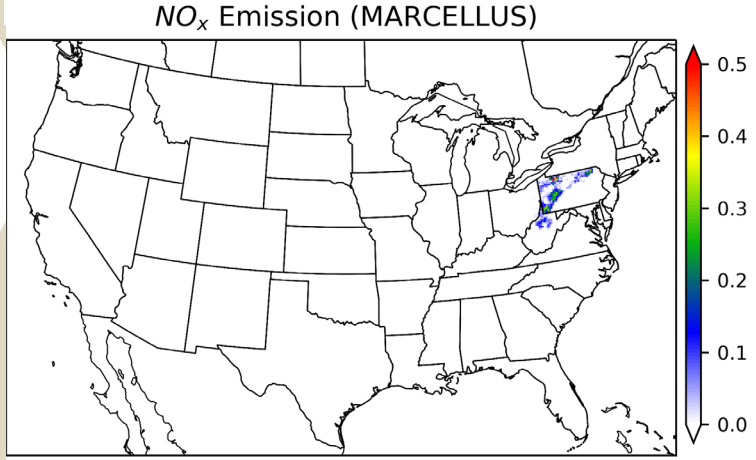
- CMAQ applied nationally+
  - CMAQ: Widely used air quality model
  - Simulated June 2023-August 2024 (coinciding with TRACER experiments) (results available)
- Chose seven areas to model using CMAQ-ISAM
  - ISAM: Integrated Source Apportionment Model in CMAQ
    - ISAM provides how emissions from each area impact modeled species ozone, PM, HCHO, benzene,…)
    - Can differentiate between controlling species (VOCs vs. NOx)

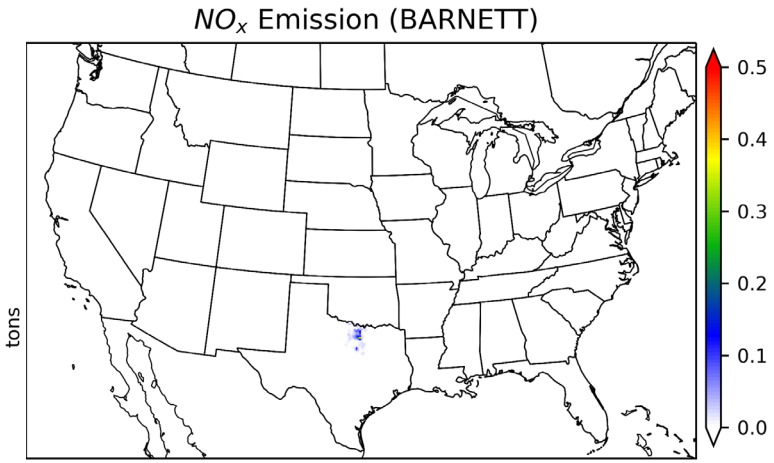


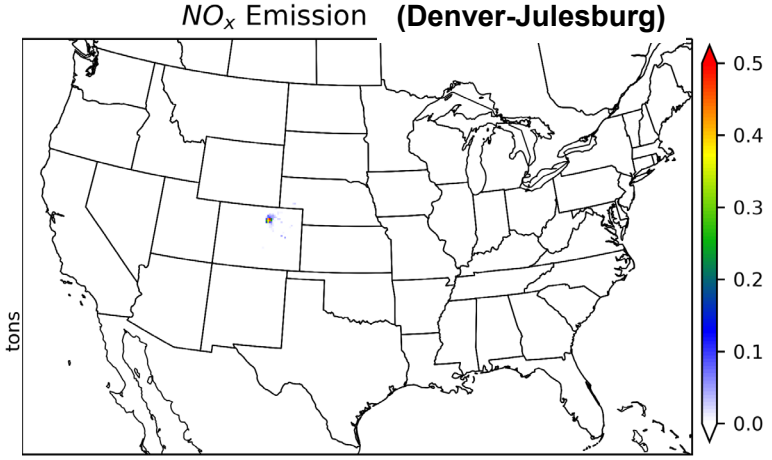
Antrim+New Albany (ANA), Barnett+Woodford+Fayetteville (BFW), Bakken+Three Forks (BTF), Eagle Ford + Wolfcamp/Permian (EFW), Haynesville (HAY), Marcellus+Utica (MAU), Niobrara+Denver-Julesburg (NIO)

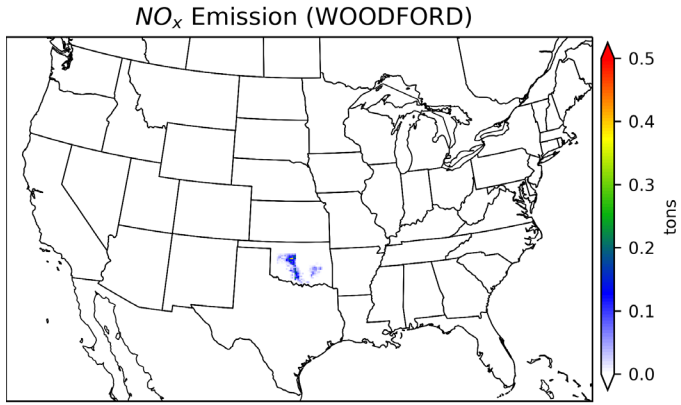
NOx emissions by play

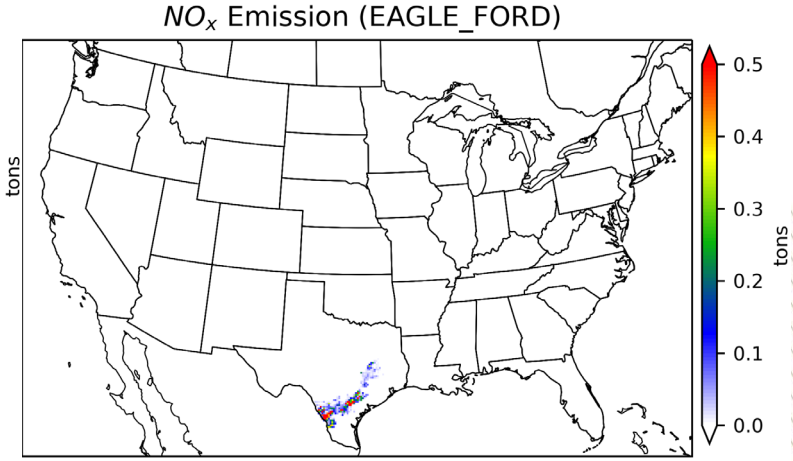


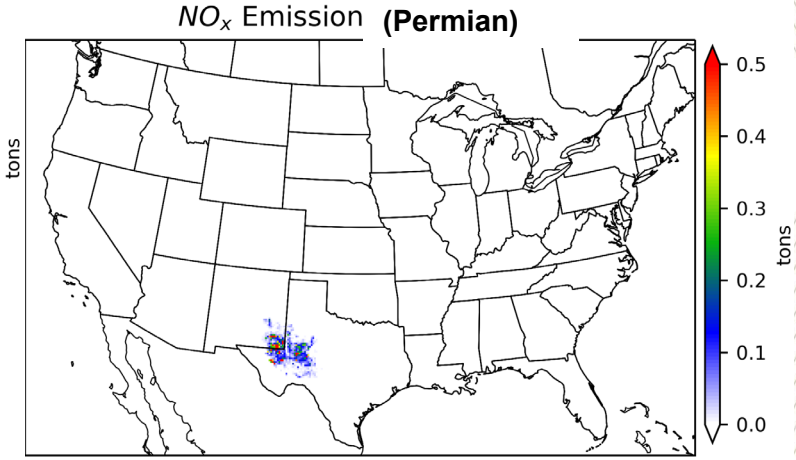












Also have VOCs, PM, SO2, air toxics,…

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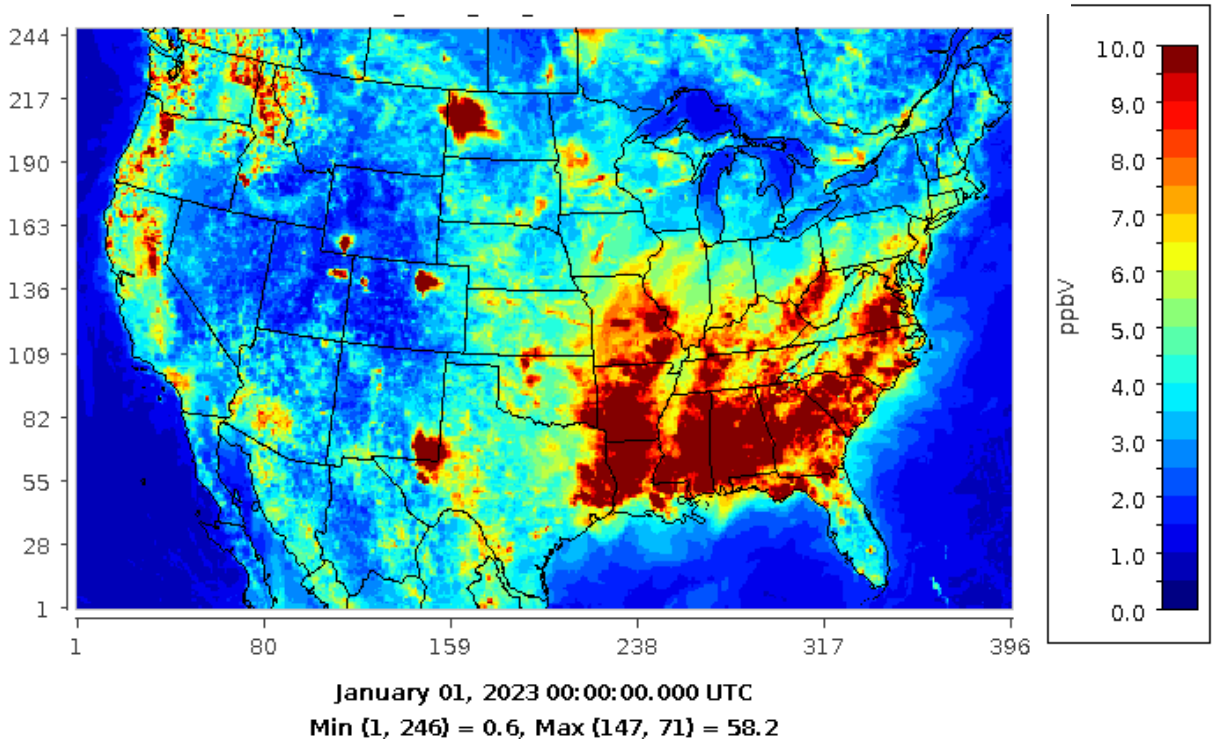
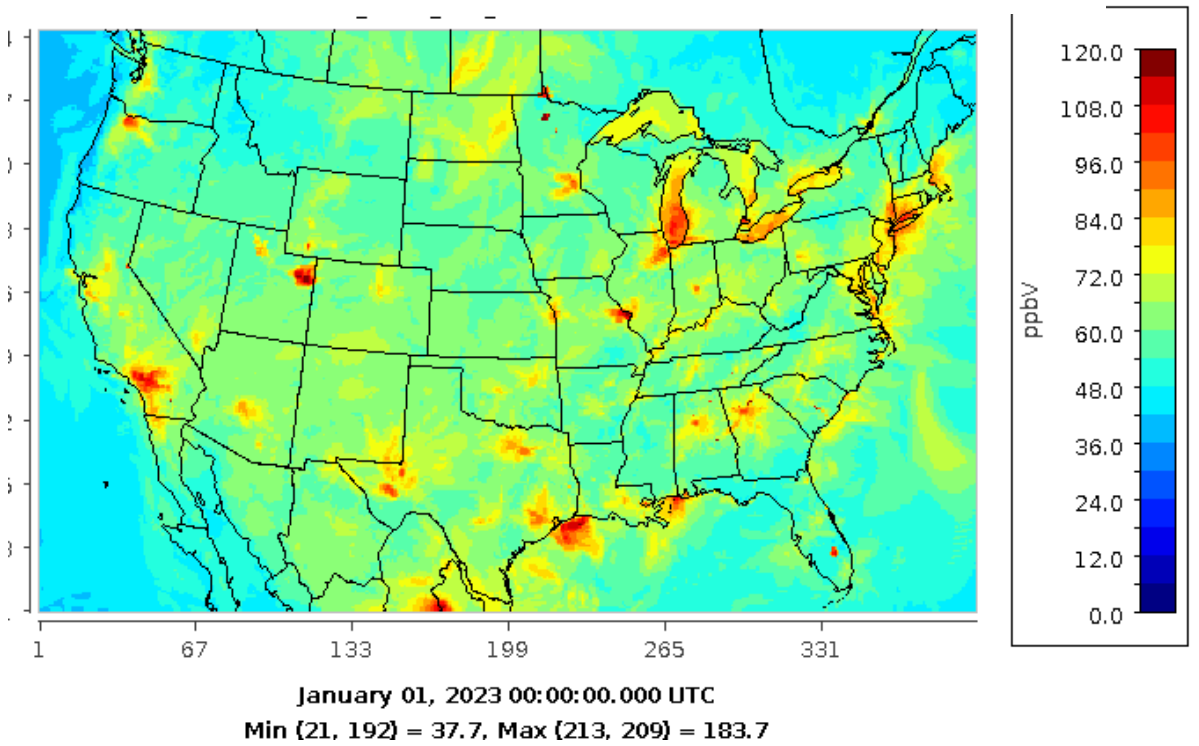
CMAQ Simulated Maximum Surface 1-hr Average Concentrations: January 2023-June 2024

Maximum Formaldehyde



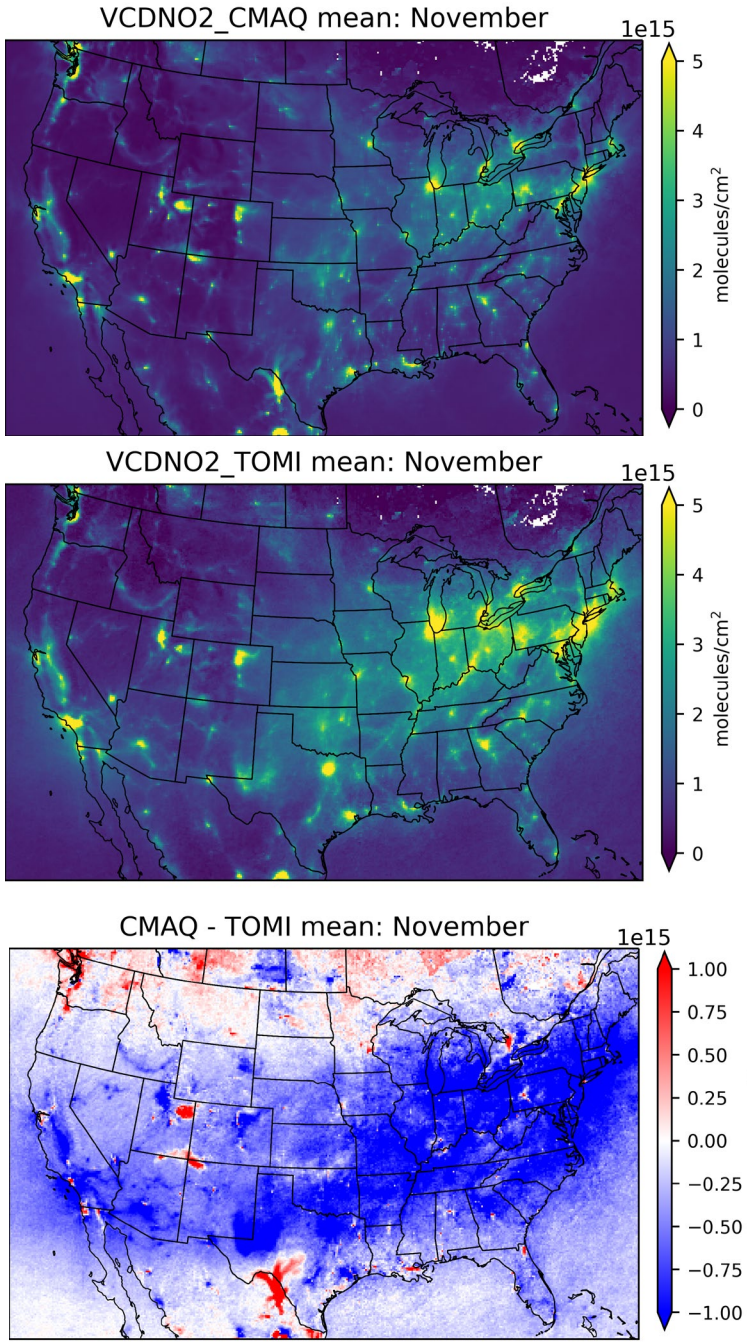
Maximum 8-hr ozone



Typical results: High ozone over cities, high formaldehyde over forests, but also…
Elevated ozone and formaldehyde over UOGD areas. Use ISAM to investigate.

CMAQ-TROPOMI (and TEMPO) Comparisons

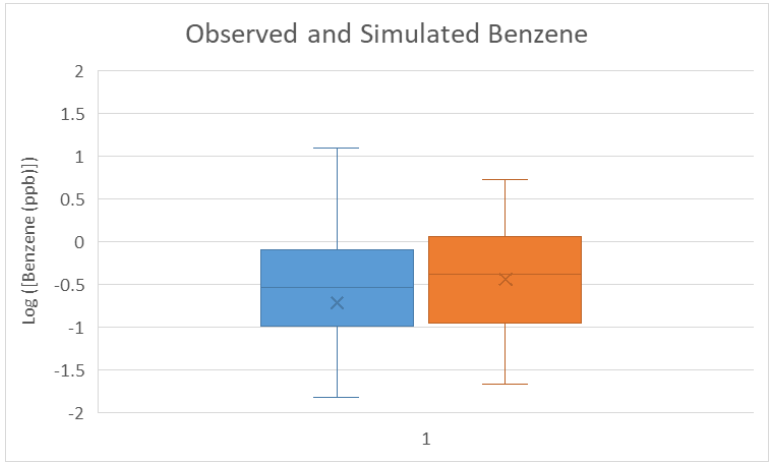
- Compare CMAQ vertical column densities (VCDs) with satellite-derived VCDs to identify areas where emissions estimates may be under or over estimated
  - NO_2, (HCHO…)
  - VCD: #molecules/cm^2 in a column from the surface upwards, i.e., amount of material per area, can be linked to emissions density
- 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)

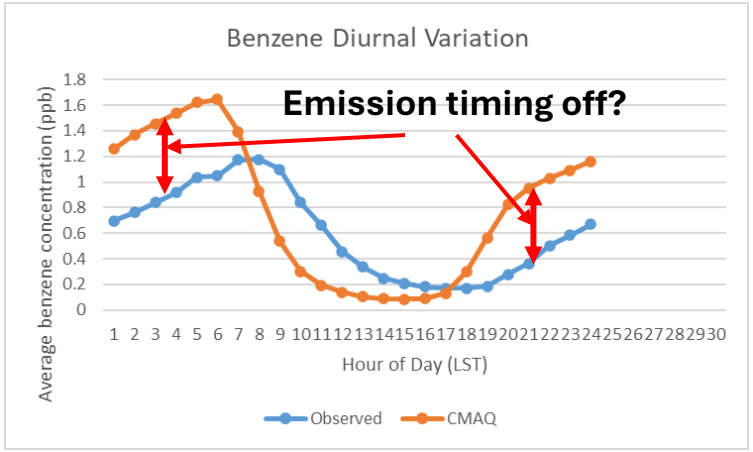


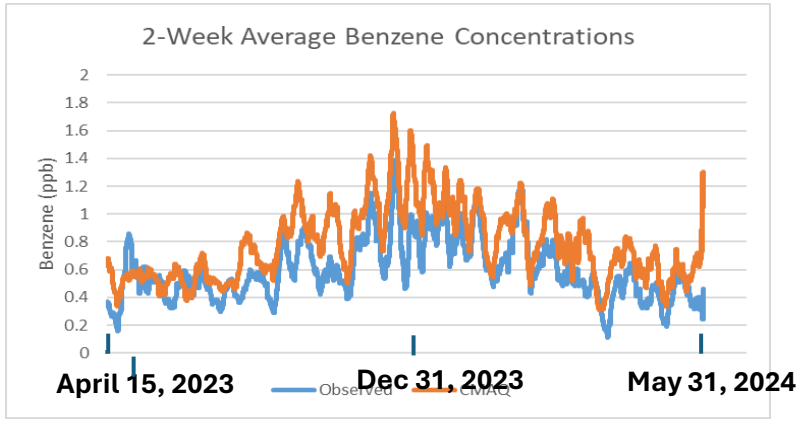
Comparing CMAQ results to TRACER Observations

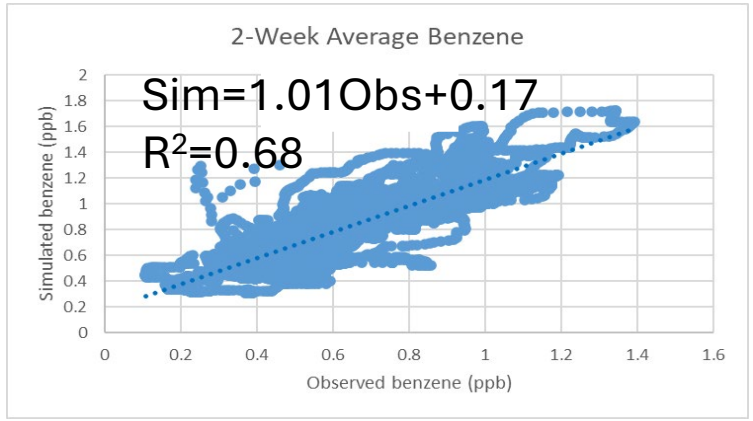
CMAQ Simulated vs. TRACER Loving NM Observations:
May 2023-May 2024

Benzene

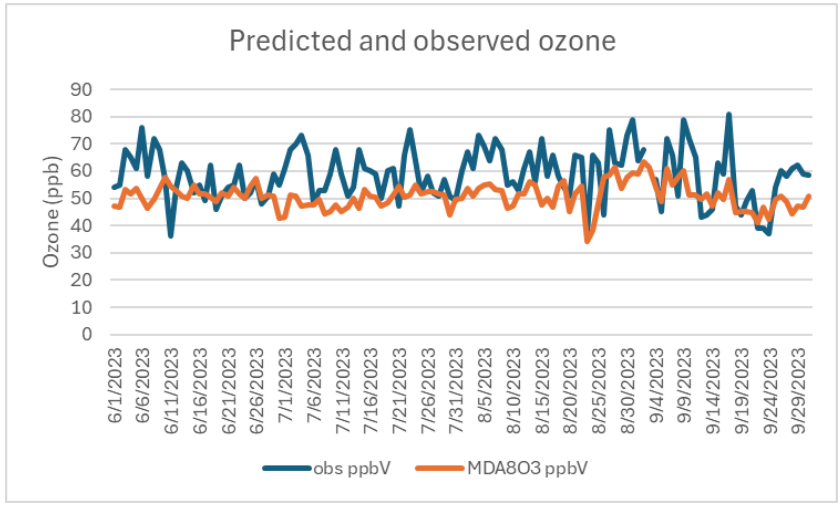








Ozone

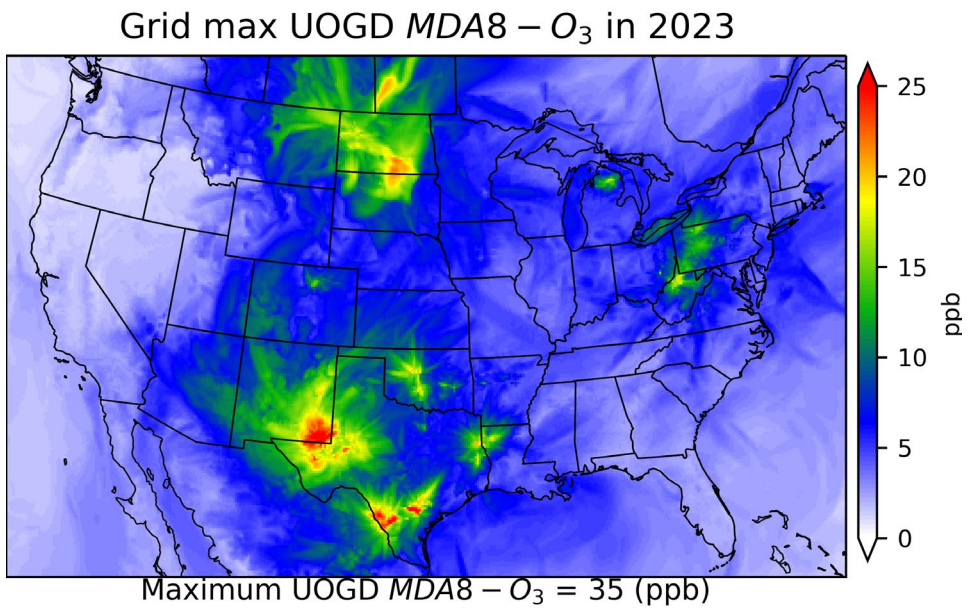


CMAQ results also successfully compared to observations in DJ-Basin area

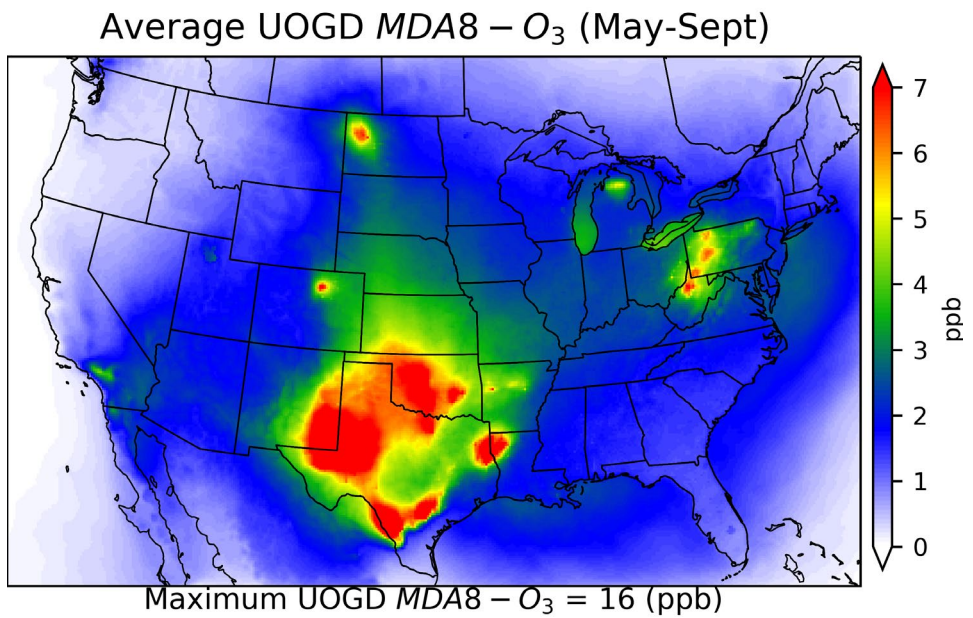
Oil and Gas specific impacts

- Used CMAQ-ISAM
  - Captures impact of non-linear chemistry
    - Important for HCHO, ozone
  - Resolution is “12 km”, so local emission impacts diffused
    - Don’t expect to see high spikes found in user TRACER with CALPUFF

UOGD Impacts on Ozone



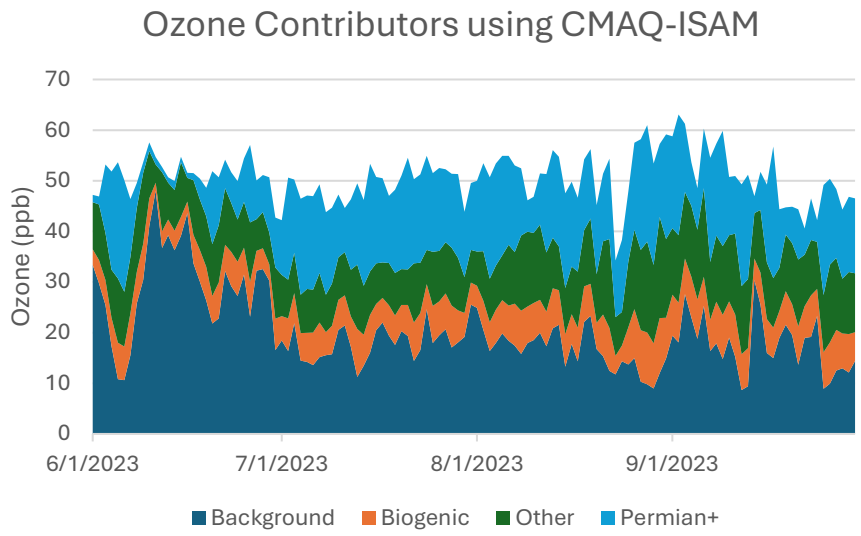
Maximum impact at any time



Average impact from May to September

Results comparable to TRACER team observations, though simulated peak ozone is…

- a bit lower than observed
- A bit less dynamic



Daily impact June 1-Sept. 31, 2023

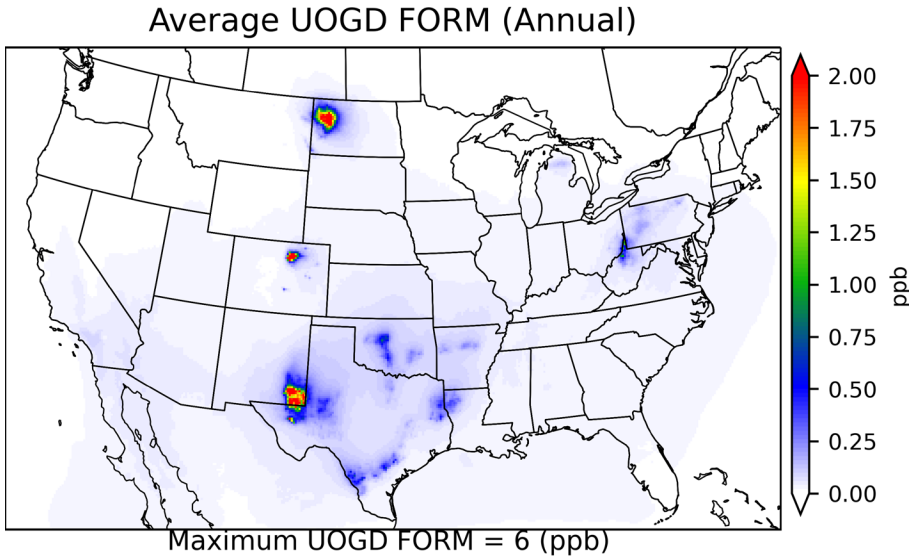
Permian +

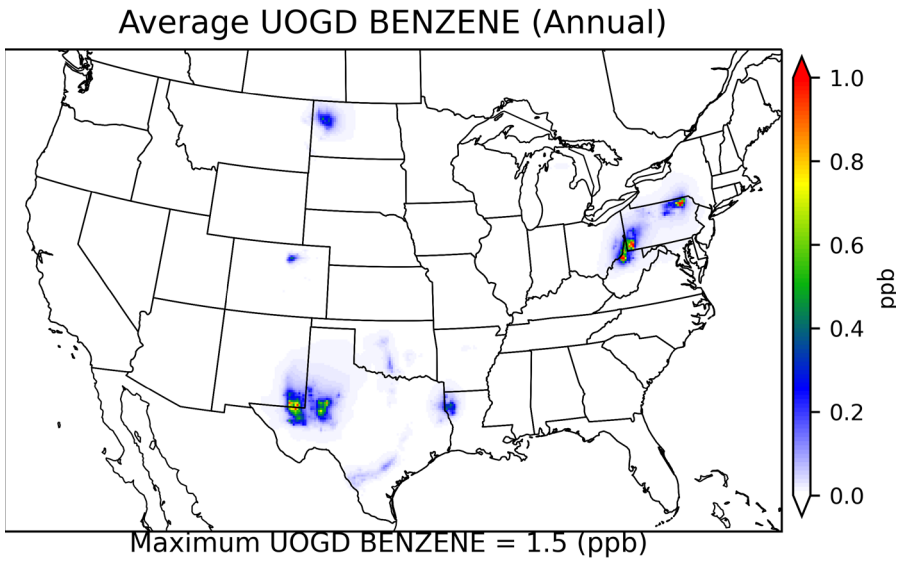
Biogenic

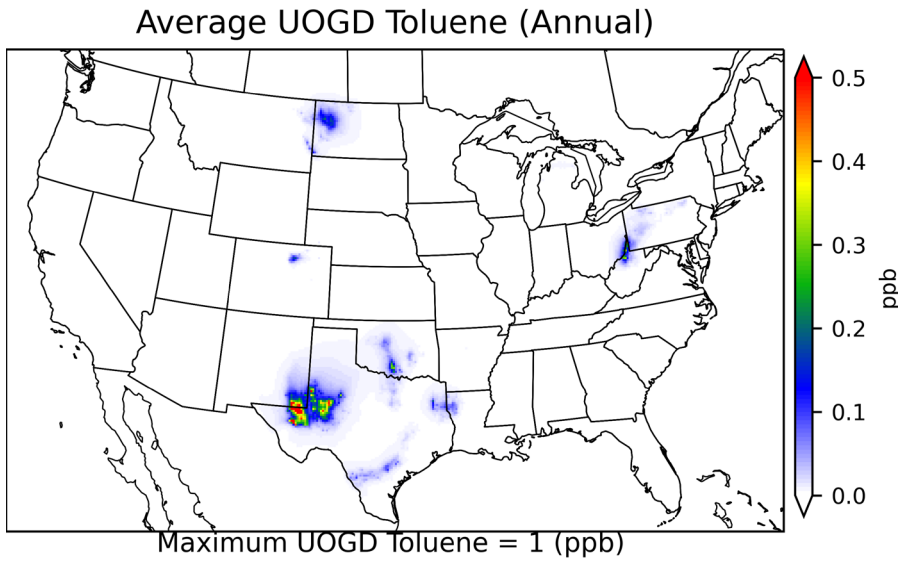
Other Anthropogenic

Background

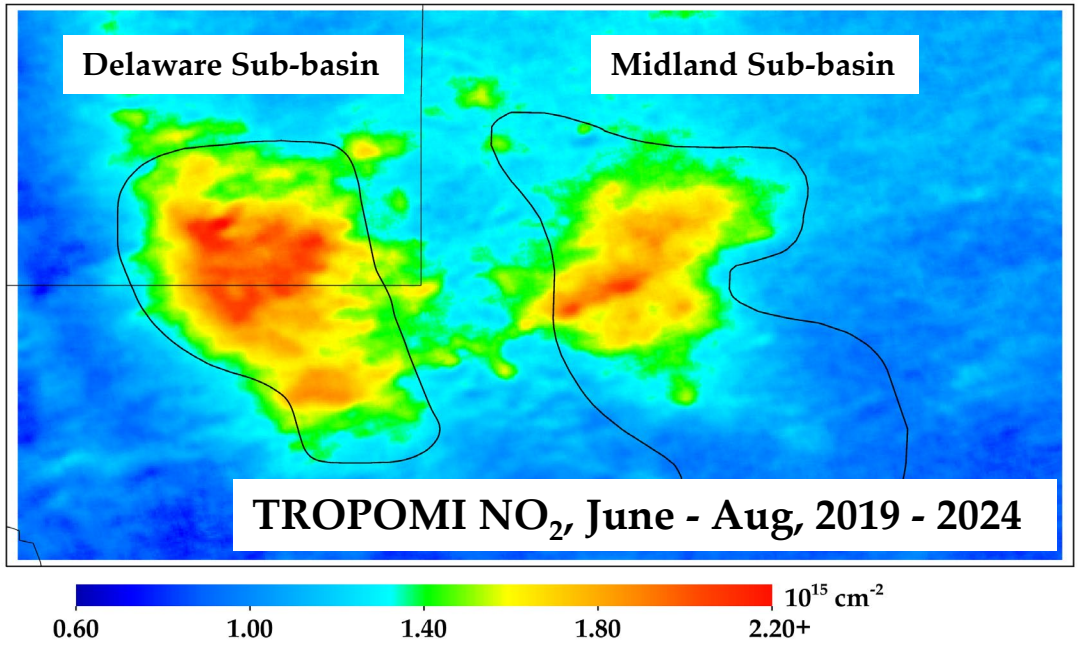
Other Pollutants: UOGD Impacts on formaldehyde, benzene and toluene

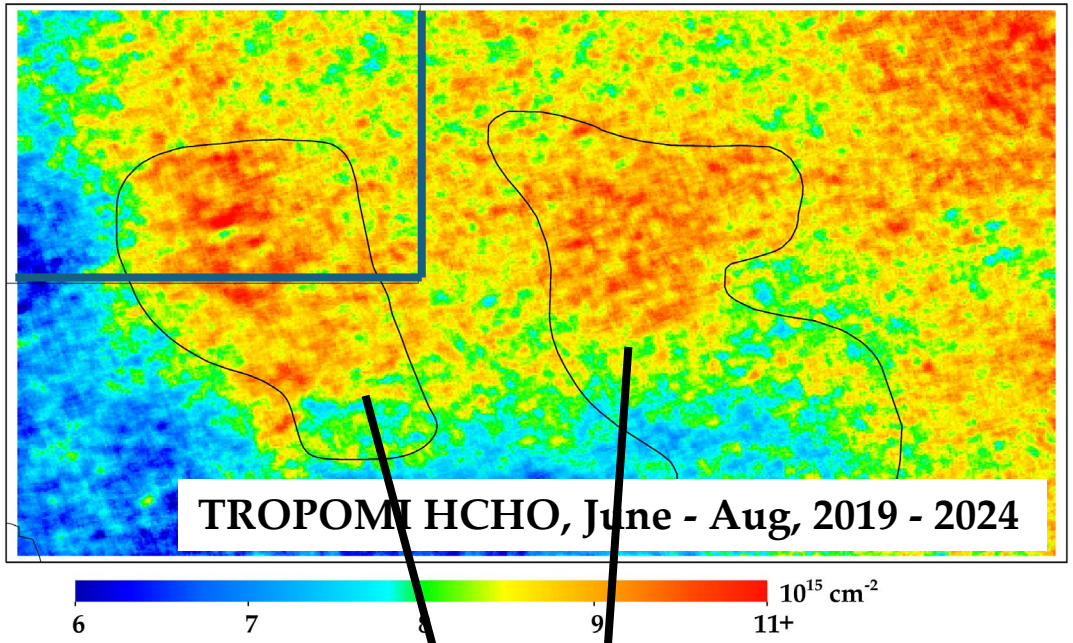


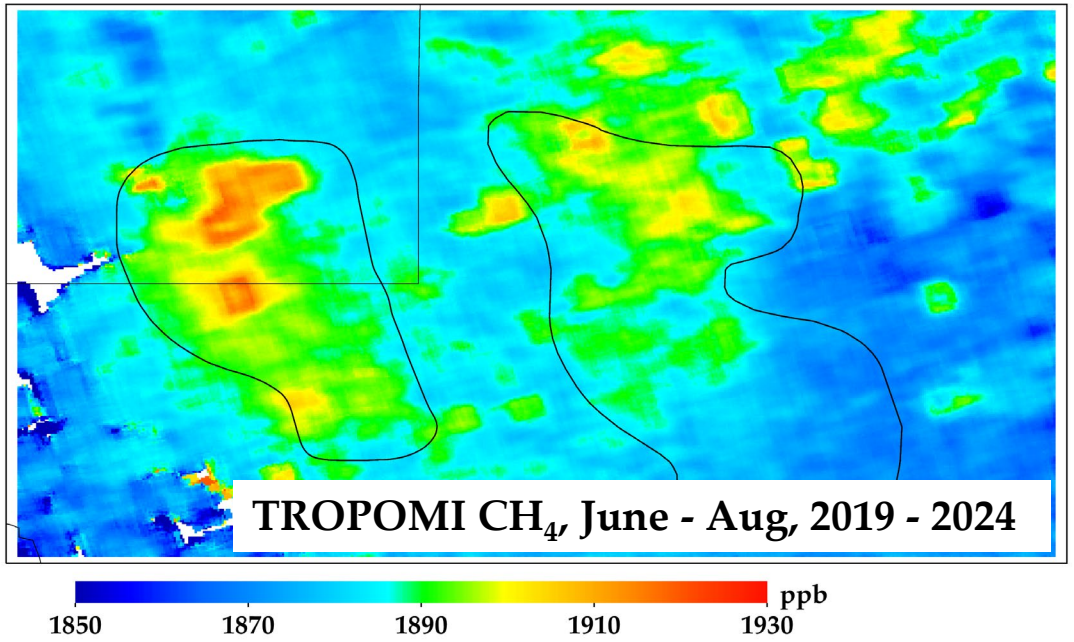


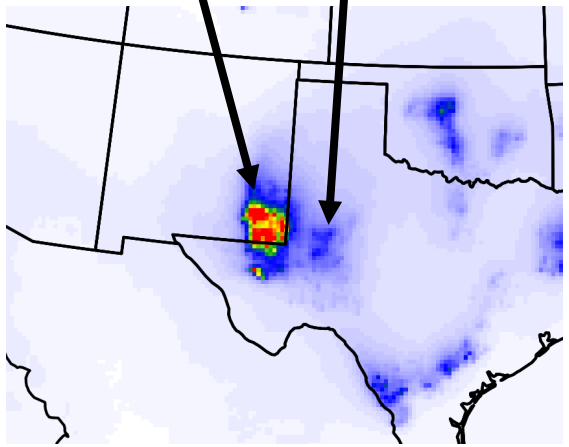


Permian basin as seen from TROPOMI: NO_2, HCHO & CH_4 VCDs







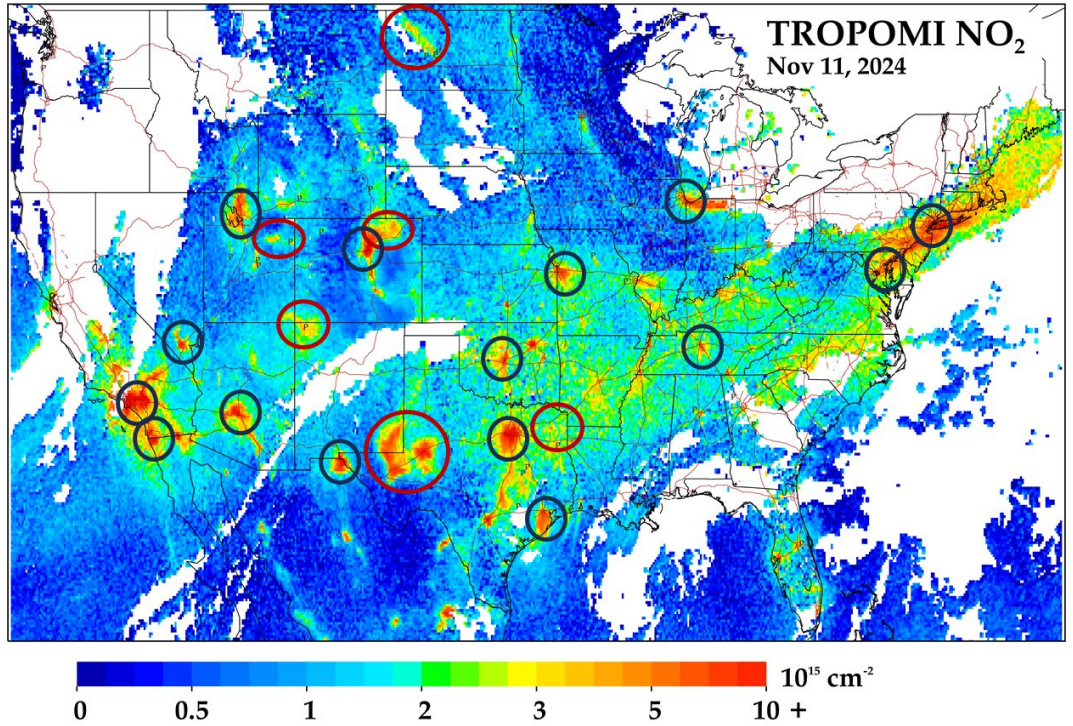


CMAQ HCHO from before

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 NO_2 VCDs for use in trend analyses

A typical day of TROPOMI NO2 VCD retrievals



Black: Urban, Red: OG

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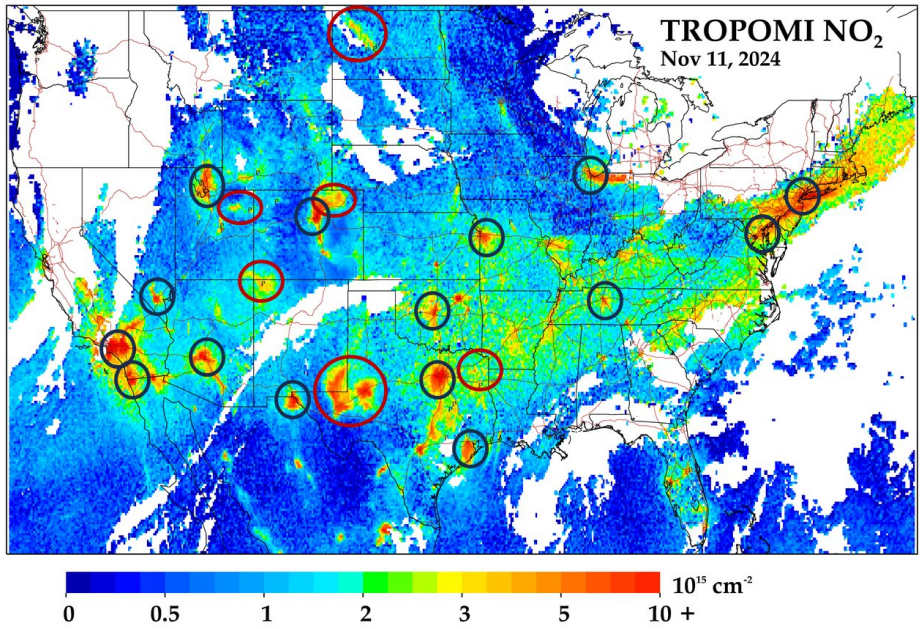
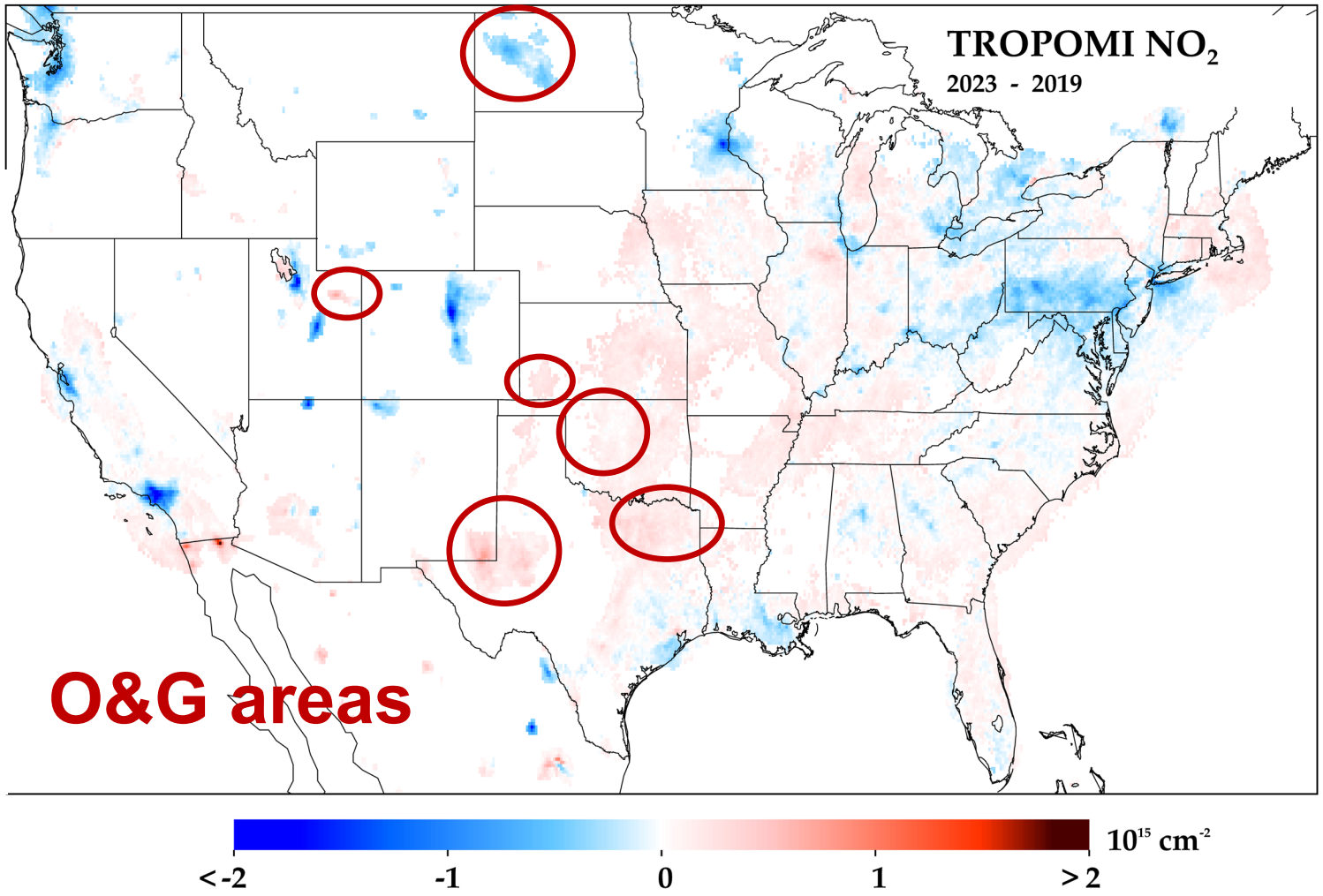
TROPOMI NO_2 Trends: 2023 vs. 2019

- 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 captured spatial and temporal trends and finds localized (at a “12 km” resolution) impacts on air toxics, while 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)

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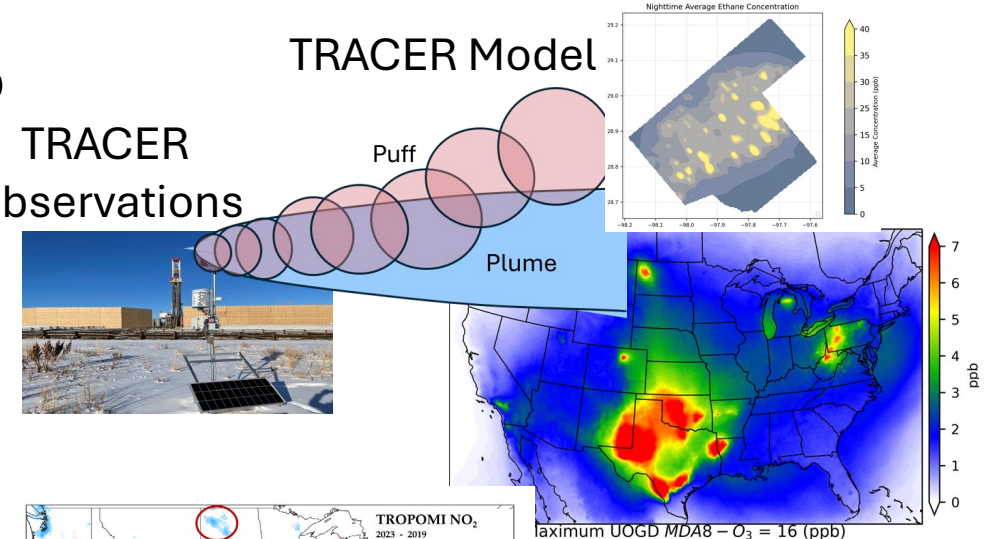
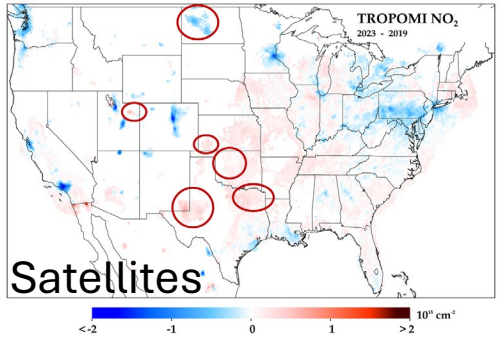
TRACER: Main take-home messages

- **TRACER** & Trend analysis research set out to advance our ability to better understand and **assess exposure** to UOGD operations
  - Model development
  - Ambient observations
    - Evaluate model
    - Understand emissions at a process level
- TRACER has developed a great set of **observations** to evaluate models for use at fine and more coarse resolutions
- Have a set of **models** for further use in exposure studies across scales (space & time)
  - Tie observations to specific sources and processes
  - Further development and testing warranted
    - Underway!
- **Satellite** observations are becoming more readily available and powerful
  - Evaluating models for exposure assessments
  - Capturing trends
  - Direct use in developing exposure estimates





CMAQ: Regional

HEI