Assessing the Impacts of Emissions from Oil and Gas Extraction on Urban Ozone and Associated Health Risks

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Oil and gas production emits NO\textsubscript{x} and VOCs at least through engines powering drilling rigs & compressors, condensate storage tanks, and pneumatic devices.

(U.S. EPA, 2011 NEI)
Oil & Gas in the Rocky Mountain region

(Thompson et al., 2014)
Oil & Gas in the Rocky Mountain region

- Ambient VOC concentrations from flask canister observations
- March - May 2013
- Colorado Department of Public Health and Environment (Denver, Platteville) and Thompson et al. (Erie) measurements

(Thompson et al., 2014)
Importance of Ozone Precursors in Front Range

- History of challenge to achieve attainment, including current status of marginal nonattainment.
- Efforts to comply with National Ambient Air Quality Standards
- DISCOVER-AQ and FRAPPE missions to help understand challenges

Time Series of Monitored 4th Maximum 8-Hour Ozone Values

(CoColorado Dept. of Public Health & Environment)
Evaluation of Oil & Gas Contributions to MDA8 Ozone

Influence of Eagle Ford shale emissions on daily maximum 8-hr average (MDA8) ozone concentrations in eastern Texas explored through natural gas pricing for 33 day episode.

(Pacsi et al., 2015)
Attributing Ozone Effects to Emissions with CMAQ adjoint

\[ \frac{\partial \text{(cost function)}}{\partial \text{(emissions)}} \]

\[ \frac{\partial \text{(local MDA8)}}{\partial \text{(emissions)}} \]

\[ \text{(health risks associated with ozone exposure)} \]

\[ \partial \tilde{x} = (F')^T(x, \partial y) \]

Emissions influences are spatially resolved at the grid scale.

(Hakami et al., 2007)
Modeling Episode & Approach

May-September 2007

*Emissions*
EPA NEI 2008v2 with BEIS 3.14

*Chemistry*
Carbon Bond 05

*Meteorology*
WRF v3.1

*Resolution*
24 layers | 36x36 km²

*Model*
CMAQ adjoint

Example mean MDA8 O₃ from week long run in May 2007

*Cost Functions*
MDA8 | ozone-related health risks in urban areas adjacent to oil and gas development

(Capps et al., *in prep*)
Evaluating Emissions Influences on MDA8

Combined statistical areas encompassing four geographically-aggregated urban areas adjacent to oil and gas development to be evaluated.

MDA8 and exceedances of ozone NAAQS levels to be assessed.

- Marcellus & Utica shale plays in Appalachian Basin
- Eagle Ford, Haynesville, & Barnett shale plays
- Niobrara play in Denver Basin
- San Joaquin, Santa Maria, Ventura, and LA basins

U.S. Energy Information Administration
www.eia.gov/oil_gas/rpd/shale_gas.pdf
Estimate Risk due to Ozone Exposure

\[ \Delta M = M_0 P (1 - e^{-\beta \Delta C}) \]

where \( M_0 \) is the baseline mortality, \( P \) is the exposed population over 30 years old, \( \beta \) is 0.0427% per ppb \( O_3 \), and \( C \) is the 6-month mean of maximum hourly \( O_3 \).

\[ \Delta \text{Risk} = 1 - e^{-\beta \Delta C} \]

(BenMAP | Jerrett et al., 2009)
Enabling Emissions Scaling Factor and Absolute Emissions Sensitivities

- Added sensitivities with respect to absolute emissions and emissions scaling factors at each layer (with Matt Turner).

- Each array is propagated through the ACM2 continuous adjoint of vertical diffusion.

\[
\begin{align*}
\Delta \sum_{i=1}^{6 \text{ days}} \left[ \text{MDA8 Denver} \right] & \quad \Delta \sigma_{\text{emis, ethene}} \\
\partial \sum_{i=1}^{6 \text{ days}} \left[ \text{MDA8 Denver} \right] & = \partial \sigma_{\text{emis, ethene}}
\end{align*}
\]

- Adjoint-based influence of ethene on sum of June 1-7 average MDA8 for the Denver CSA within 25% of finite difference value (10% perturbation).
Denver MDA8 Sensitivities June 1-7

\[ \frac{\delta(\text{Denver MDA8})}{\delta(\sigma_{\text{emis}_{\text{i}}})} \] (ppm)

Ranking *sensitivities to surface VOC emissions* shows the relative importance of each species to MDA8 ozone formation.

*Spatially-refined sensitivities* allow investigation of efficient emissions control strategies.
Sensitivities to *absolute emissions* inform which emissions were responsible for formation of the ozone present.

Sensitivities with respect to *emissions scaling factors* convey the extent to which a change in emissions of a species (e.g., NO$_x$) in a location would impact Denver MDA8.
Comparison of Emissions Influences on Different Cities

\[
\frac{\delta(\text{Denver MDA8})}{\delta(\sigma_{\text{emis}_{\text{NO}_x}})} = 1.93 \text{ ppm}
\]

\[
\frac{\delta(\text{East TX MDA8})}{\delta(\sigma_{\text{emis}_{\text{NO}_x}})} = 0.95 \text{ (ppm)}
\]
Current Progress & Next Steps

- Adjoint forcing functions have been formulated to investigate ozone impacts of oil and gas development adjacent to U.S. urban areas for 2007.

- Sensitivities with respect to emissions scaling factors and absolute emissions have been implemented.

- With CMAQ adjoint, extend the analysis to the entire summer and to other urban areas as well as MDA8 NAAQS exceedances and ozone-based health risks.

- Continue to learn from field campaign results and extrapolate revisions to ozone implications.
Extra Slides
Sample results from other region
Projected Emissions Changes with Price

(McLeod et al., 2014)