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What is Known about Ozone

- Ozone is formed through complex, non-linear reactions between Nitrogen Oxides (NOx) and Volatile Organic Compounds (VOCs) in the presence of sunlight
- Ozone precursors can react and form ozone locally, and they can also travel and react far from where they were emitted making ozone a local, regional and increasingly a global issue
- VOCs emitted from Oil and Gas (O&G) Operations can lead to the formation of ozone

NOAA's HYSPLIT Model creates "Back-Trajectories" showing the path and speed of air flow



Source: Air Pollution Control Division, State of Colorado.

Use HYSPLIT wind speed and direction data to show likelihood that air traveled through a certain point before reaching Rocky Mountain National Park in 2009



Source: Gebhart et al., 2014. Submitted.

Spring 2006 Residence Time Map



Summer 2006 Residence Time Map



Current Colorado O&G Well Locations (Red dots) and Shale Basins (Green Areas)



Source: COGCC GIS O&G Well Locations Updated Daily. Available at: <u>http://cogcc.state.co.us/Home/gismain.cfm</u> Basin Boundaries from EIA: <u>http://www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/maps/maps.htm#shaleplay</u>

Summer 2006 Residence Time Map



Two Examples of Ozone (> 75 ppb) in Rural areas occurring as a direct result of O&G activity

- Uinta Basin, Utah
- Upper Green River Basin, Wyoming Declared non-attainment in 2012.
- What Scientists know:
 - Requires Snow Cover
 - Very Stagnant Air and Shallow Boundary Layer
 - Emissions of ozone precursors from O&G activities
 - These are NOT unique characteristics!
- Scientists suggest that winter-time ozone could be occurring in other non-monitored regions of the US as a result of O&G activities¹.

Colorado O&G Well Map with AQ Monitor Locations (Yellow Boxes)



Modeled Impacts of O&G VOC emissions in the Non-Attainment Area

- Results include thirteen days in a June/July 2006 modeling episode with modeled ozone concentration greater than 70 ppb at Greeley monitor (Weld Tower)
- Greeley monitor model result statistics:
 - Average ozone concentration 72 ppb (of 13 "high" days)
 - Average contribution from in-state sources 17 ppb
 - Average contribution from O&G VOC emissions 1 ppb (5% of controllable emissions on average)
 - Contribution from O&G VOC emissions > 2 ppb on four days
 - On three days, ozone would be below 70 ppb if O&G VOC emissions were eliminated

2008 Modeling results show widespread ozone decreases (right column) as a result of a 20% reduction in VOC emissions from O&G in the Denver/Julesburg Basin





Two Methods To Estimate Emissions: "Bottom Up" and "Top Down"

Equipment Count x Production Factor

x Emissions Factor

Ambient Measurements

- + Meteorological Data
- + Inverse Modeling
- + Unique Tracers or Ratios

Emissions Estimate

Emissions Estimate

- In Colorado, these two sources of emissions estimates do not match and scientists are working hard to understand why.
- Top down estimates suggest that bottom up inventories under-estimate VOC emissions from O&G by 50 – 200%^{1,2}.

^{1.} Gilman, J.B. et al., 2013. Source Signature of Volatile Organic Compounds from Oil and Natural Gas Operations in Northeastern Colorado. Environ. Sci. Technol. 47, 1297–1305. 2. Swarthout, R.F. et al., 2013. Volatile organic compound distributions during the NACHTT campaign at the Boulder Atmospheric Observatory: Influence of urban and natural gas sources. Journal of Geophysical Research: Atmospheres 118, 10,614–10,637.