CSU studies of air quality impacts of oil and gas development from local to regional scales

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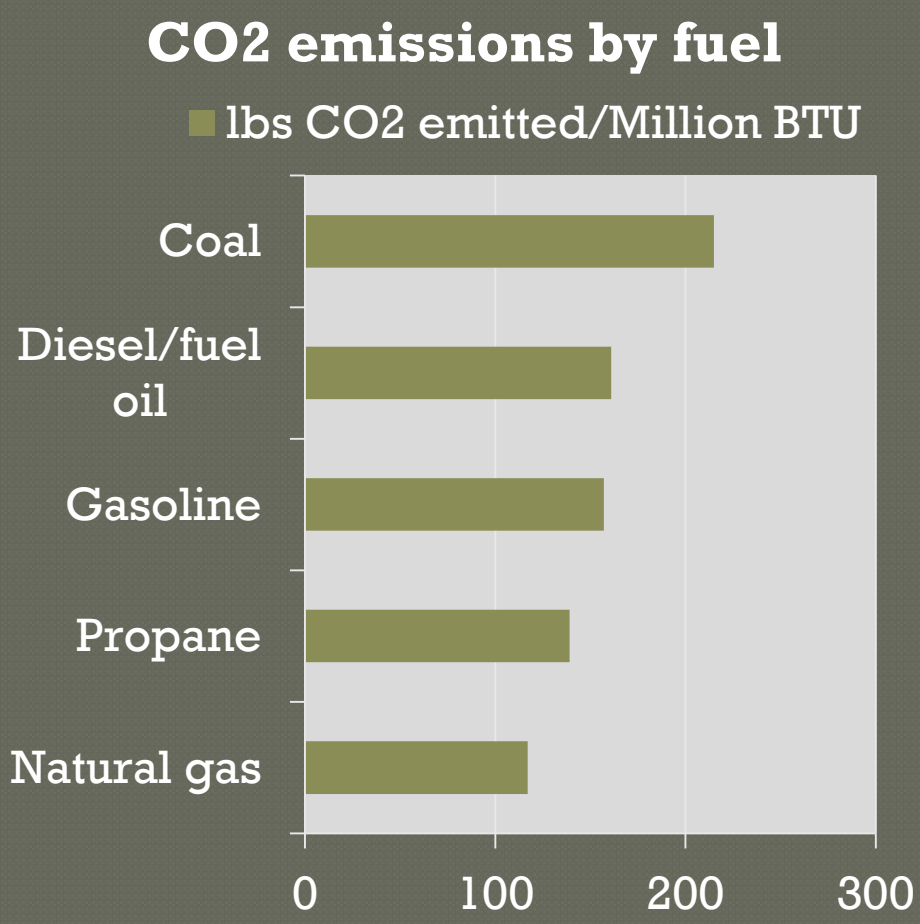
Potential air quality benefits of natural gas

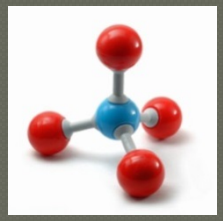
- Natural gas offers a cleaner burning alternative to coal, with lower emissions of
  - SO_2
  - NO_x
  - Particulate Matter (PM)
- The higher energy intensity of natural gas also reduces CO_2 emissions

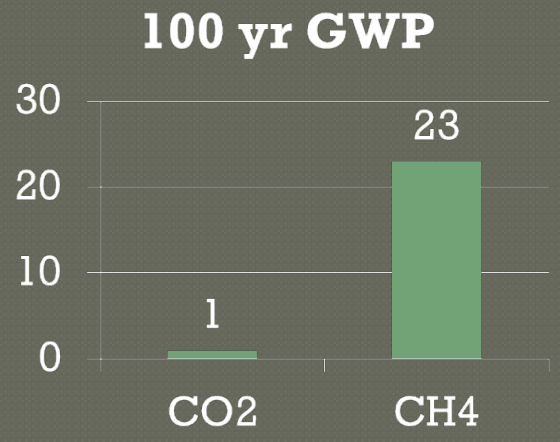


Source: U.S. Energy Information Administration (EIA)

Potential air quality impacts

- Climate
  - Methane (CH_4)
  - Black carbon





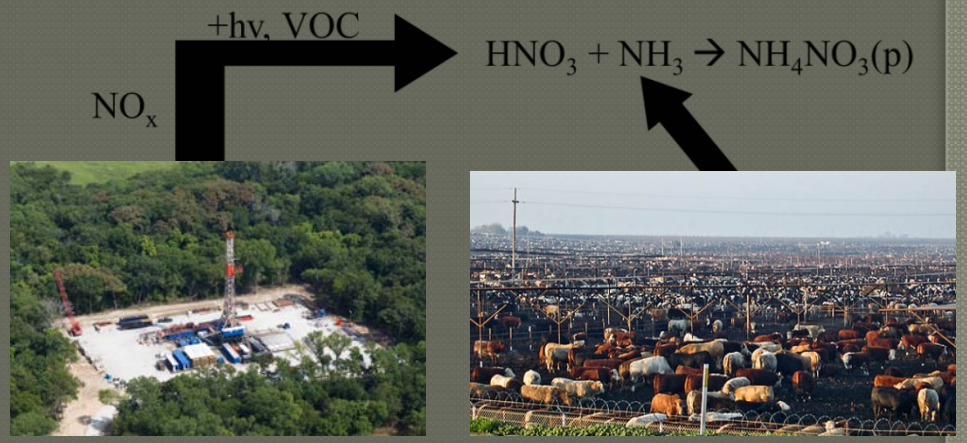
- Criteria Pollutants
  - O_3 (VOC + NO_x + sunlight)
  - $PM_{2.5}$ (particles < 2.5 microns)

VOCs (volatile organic compounds) and NO_x (nitrogen oxides) are both emitted by O&G operations

- Air toxics
  - VOCs such as BTEX (benzene, toluene, ethylbenzene, xylenes)

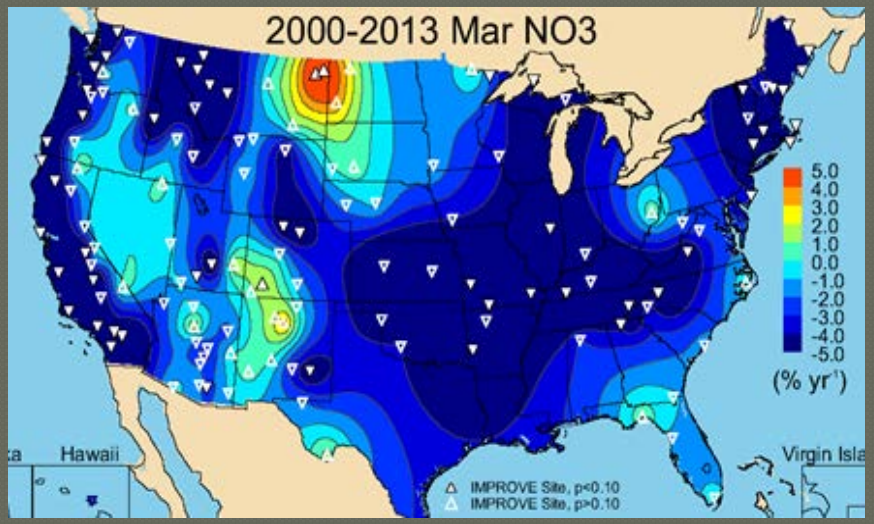
Fine particle formation and haze

- Nitric acid production
  - $NO + O_3 \rightarrow NO_2 + O_2$
  - $NO_2 + OH \rightarrow HNO_3$
- Ammonium nitrate production
  - $NH_{3(g)} + HNO_{3(g)} <=> NH_4NO_{3(p)}$
  - Particles favored at low T, high RH
- Ammonium nitrate particles
  - Submicron
  - Remain several days in the atmosphere
  - Important cause of haze



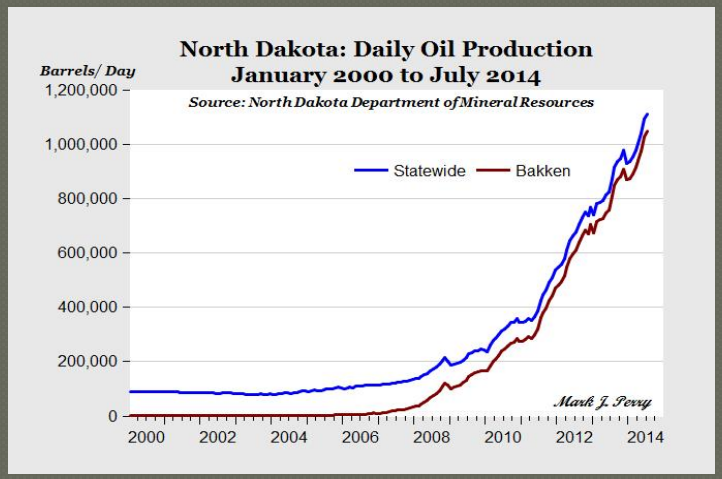
W. Malm

$PM_{2.5}$ nitrate concentration trends

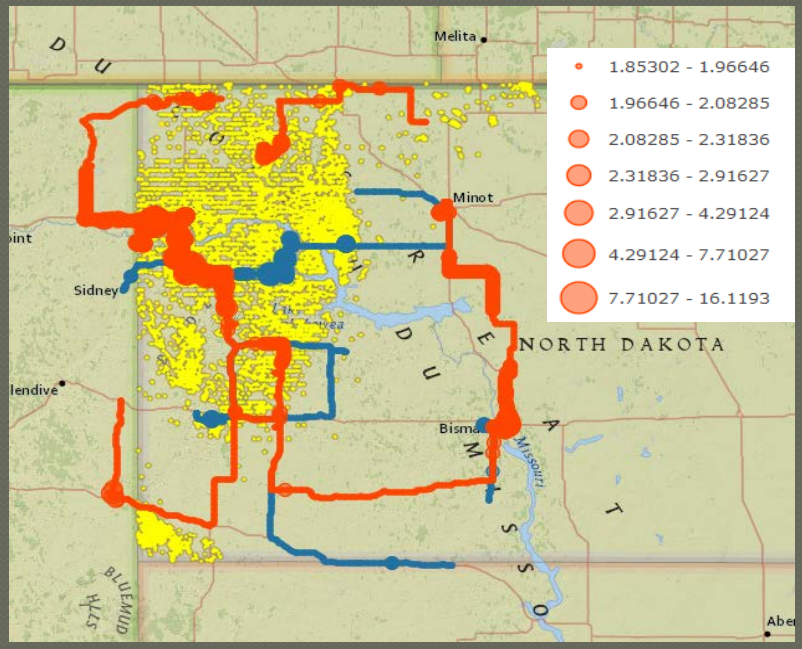


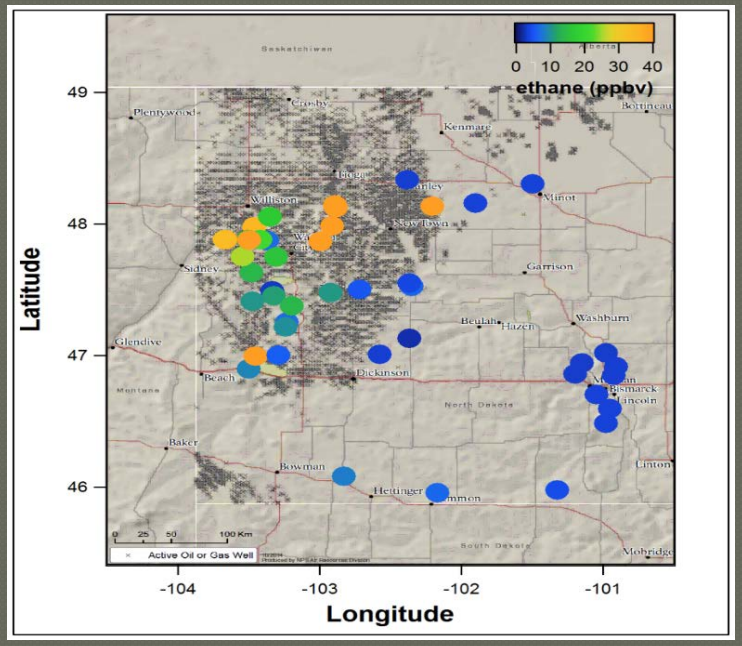
- NO_x emissions reductions greatly reduced $PM_{2.5}$ nitrate in much of U.S.
- Increasing winter nitrate in some regions

- Increases in U.S. oil and gas production may be relevant



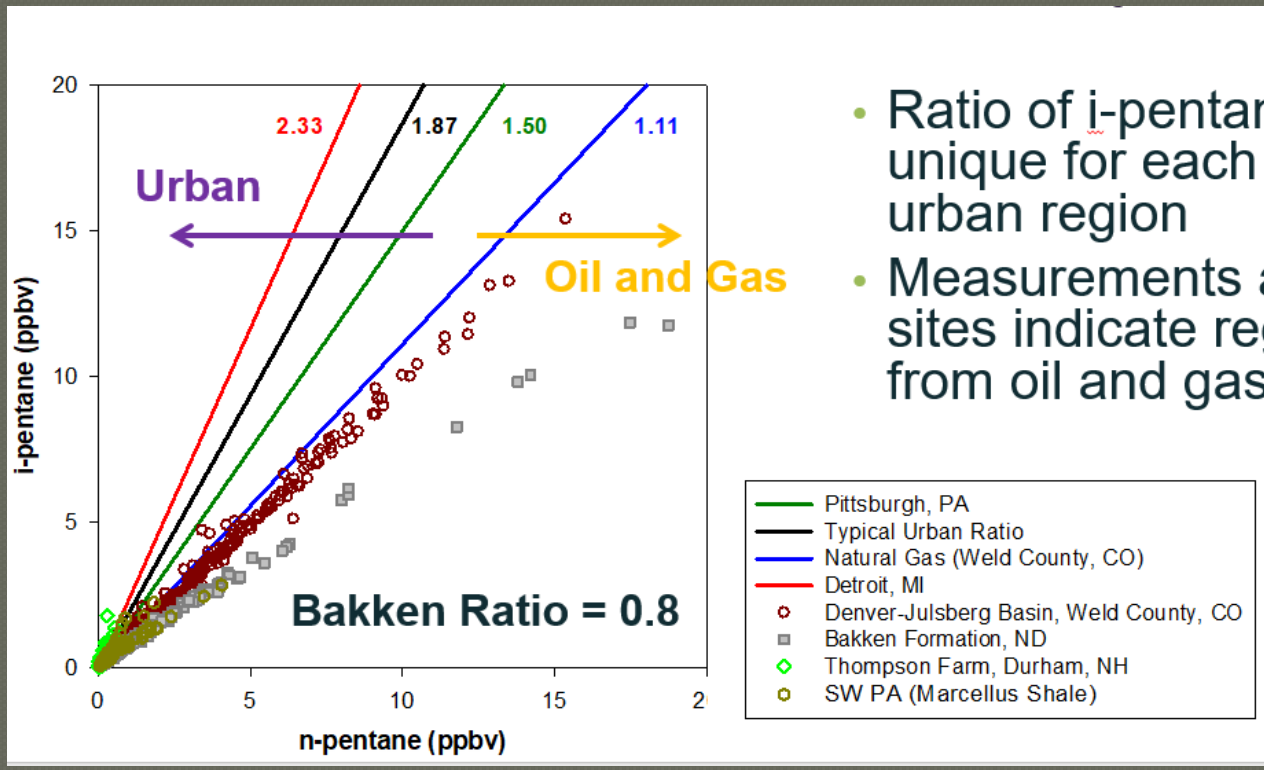
Spatial patterns of methane and ethane





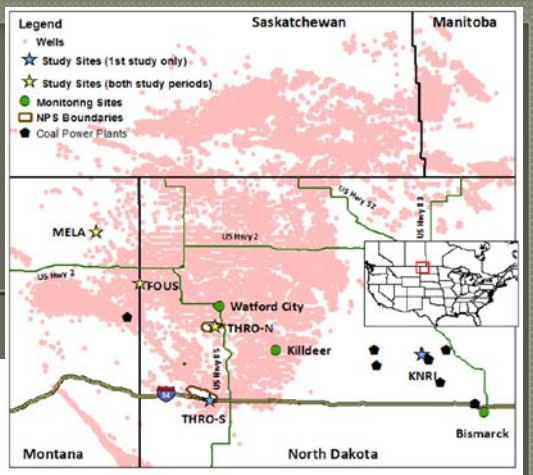
Methane elevated in oil and gas production and some other regions; ethane tied more directly to oil and gas

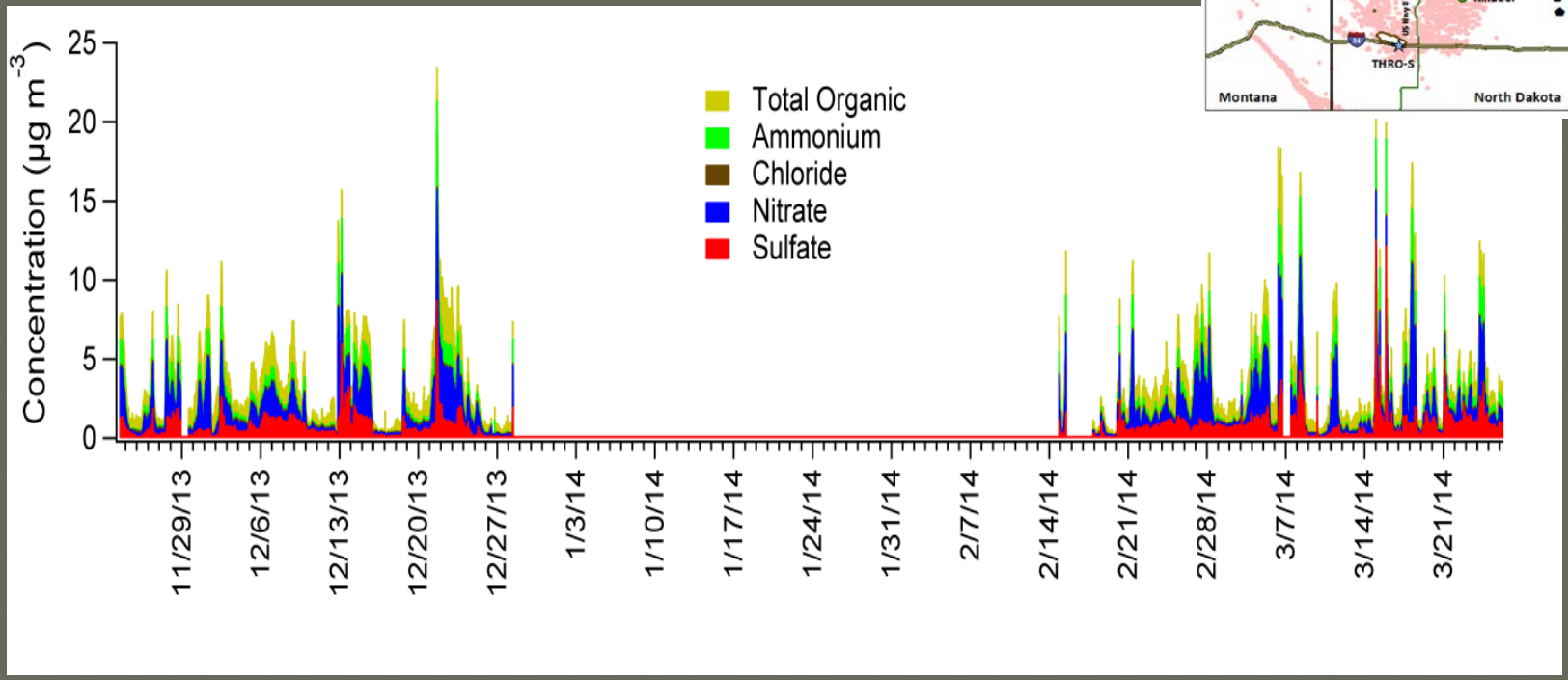
VOC signatures of oil and gas



- Ratio of i-pentane to n-pentane is unique for each oil and gas or urban region
- Measurements at all Bakken sites indicate regional influence from oil and gas activity

Bakken haze episodes



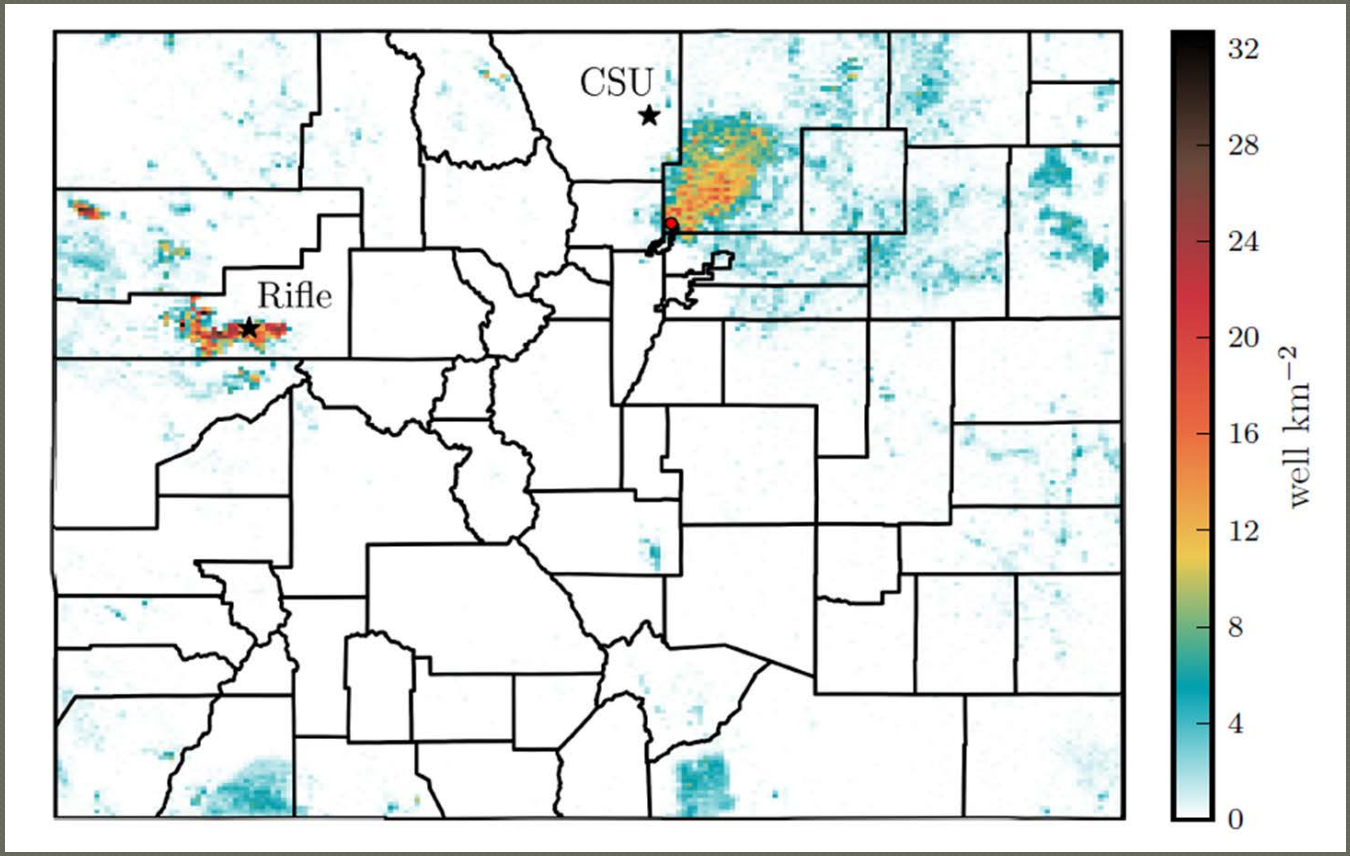


- Ammonium nitrate particles dominate winter haze
- Form over several hours during stagnation periods
- Key ingredients are NO_x and ammonia

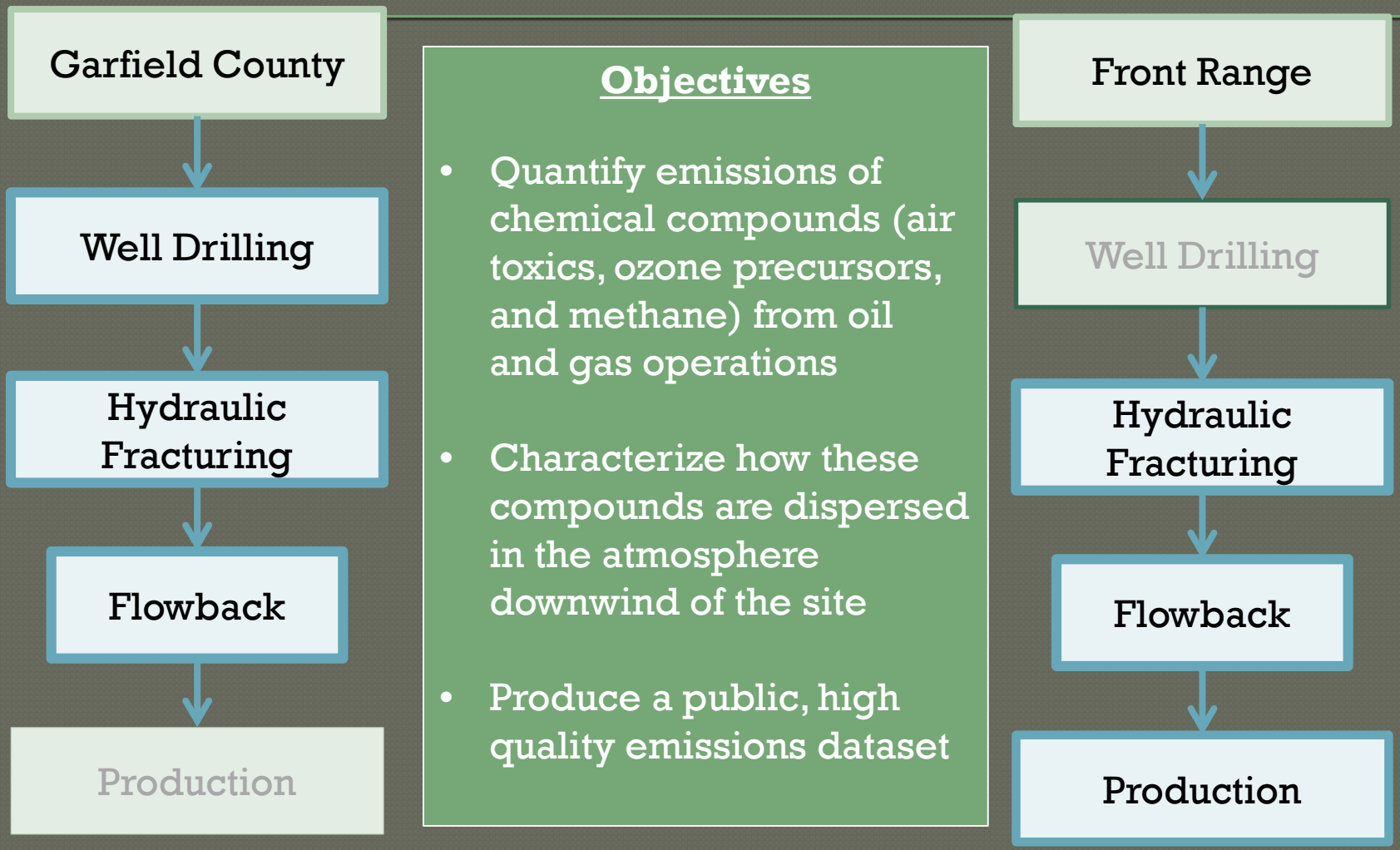
Evanoski-Cole et al., *Atmos Env.* 2017

Colorado oil and gas

Colorado development has occurred mainly in Weld (Denver-Julesburg Basin) and Garfield (Piceance Basin) counties.

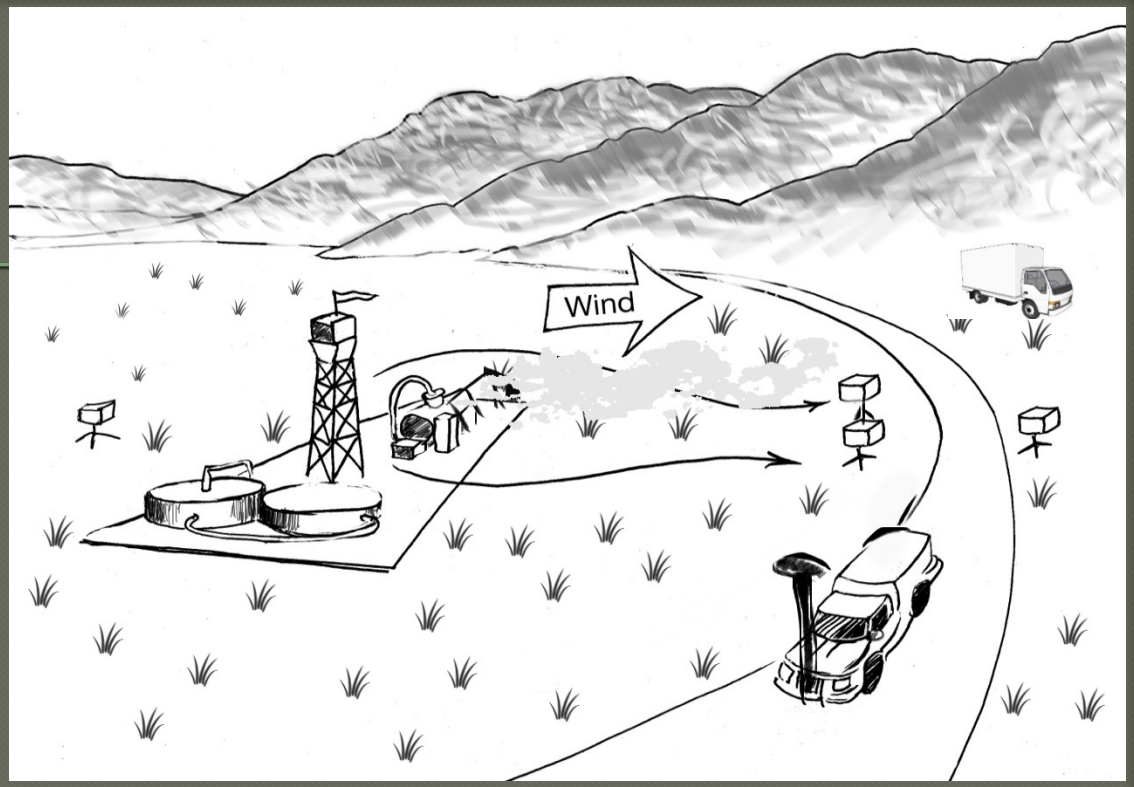


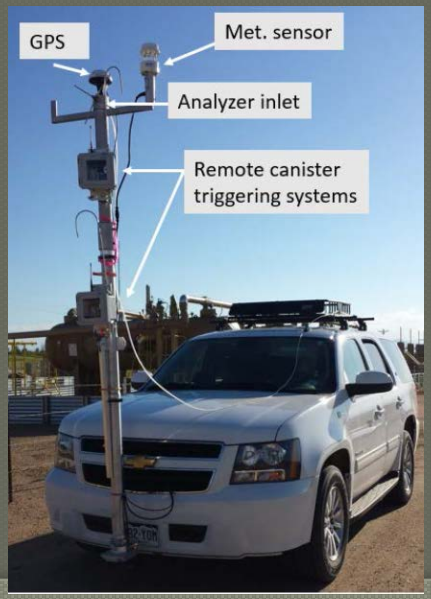
CSU Garfield County and Front Range Studies



Measuring emissions

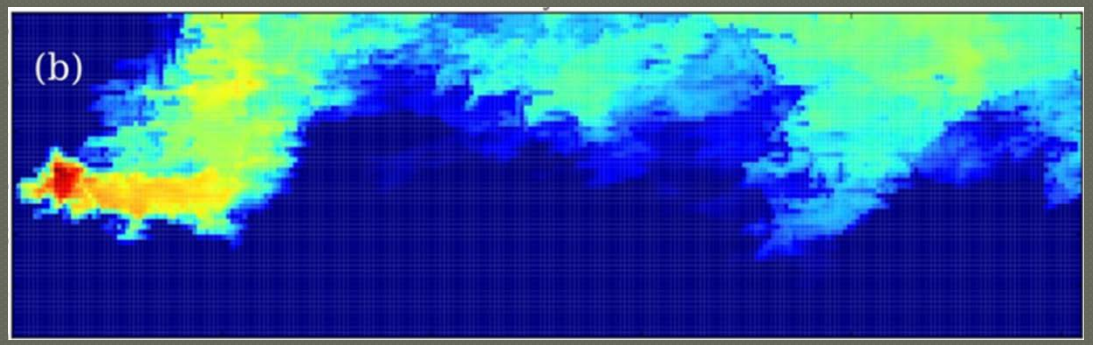
- Several monitoring platforms to locate and sample emissions plume
- Tracer ratio method used to characterize methane and VOC emissions





Why measure emissions?

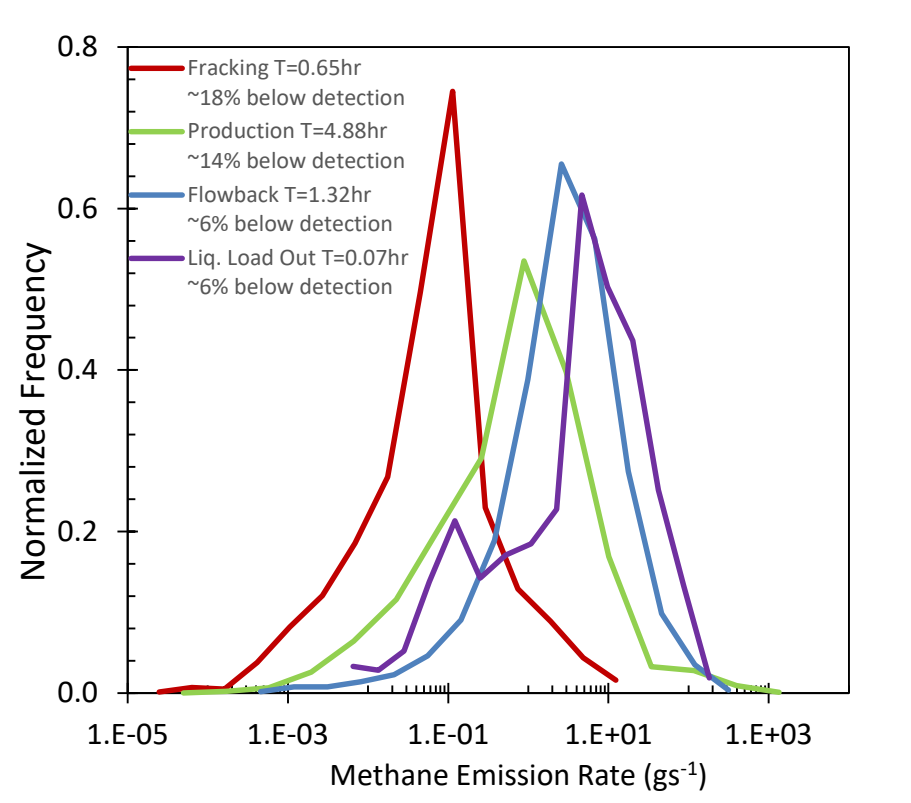
- Emissions are the amount of material emitted by an activity per unit time (e.g., grams per second)
- Air pollutant concentrations depend on
  - Emissions
  - Location
  - Weather conditions



- While concentrations are easier to measure, they provide information only for a single place and time
  - A meteorological model can be used to predict concentrations from known emissions for any place and time

Methane emissions in Front Range study

Methane emissions: flowback & liquids load out > production > fracking



Operation Type	Mean ($g\ s^{-1}$)	Median ($g\ s^{-1}$)
Fracking	0.29	0.051
Flowback	7.6	2.8
Production	5.7	0.60
Liquids load out	13.0	4.8

Methane emissions comparison

- Flowback and liquids load out >> drilling, fracking, and production
- During well completion: Front Range < Garfield County

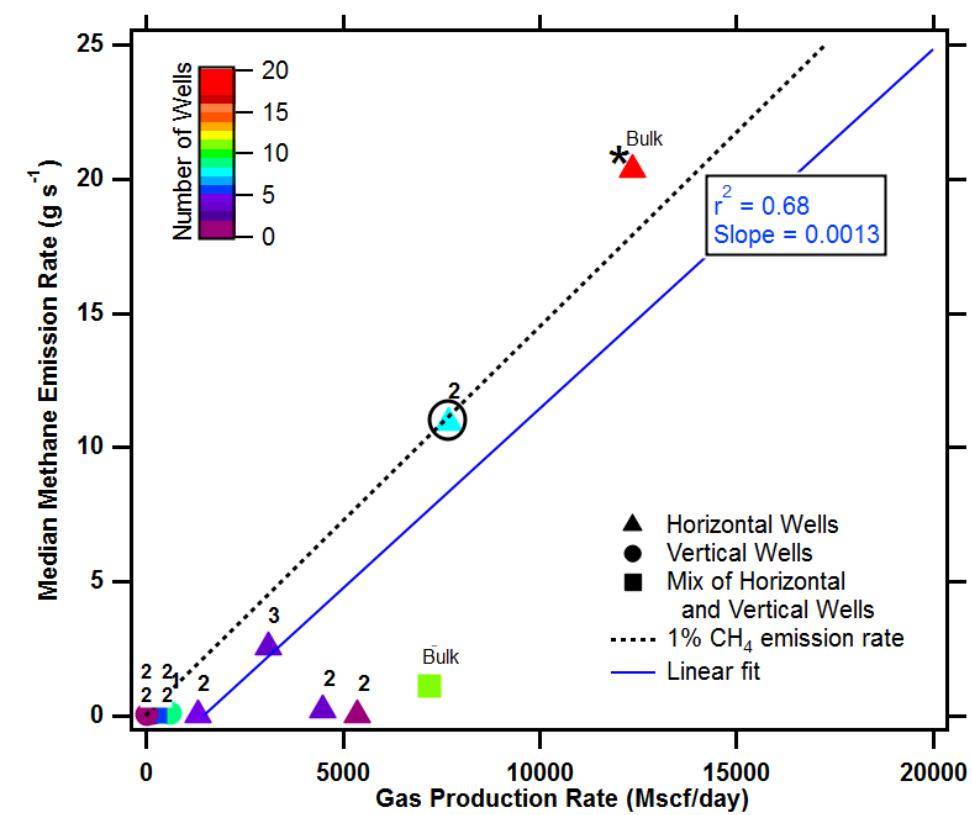
Activity	Median emission rate (g/s)	
	Garfield County	Front Range
Drilling	2.0	NA
Fracking	2.8	0.051
Flowback	40	2.8
Liquids Load Out	NA	4.8
Production	NA	0.60

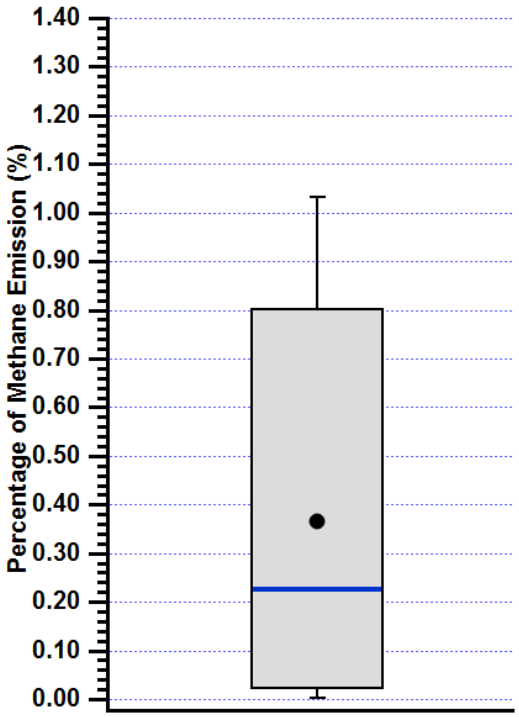
Garfield County wells are gas producers

Front Range wells produce oil and gas

Front Range production site methane emissions

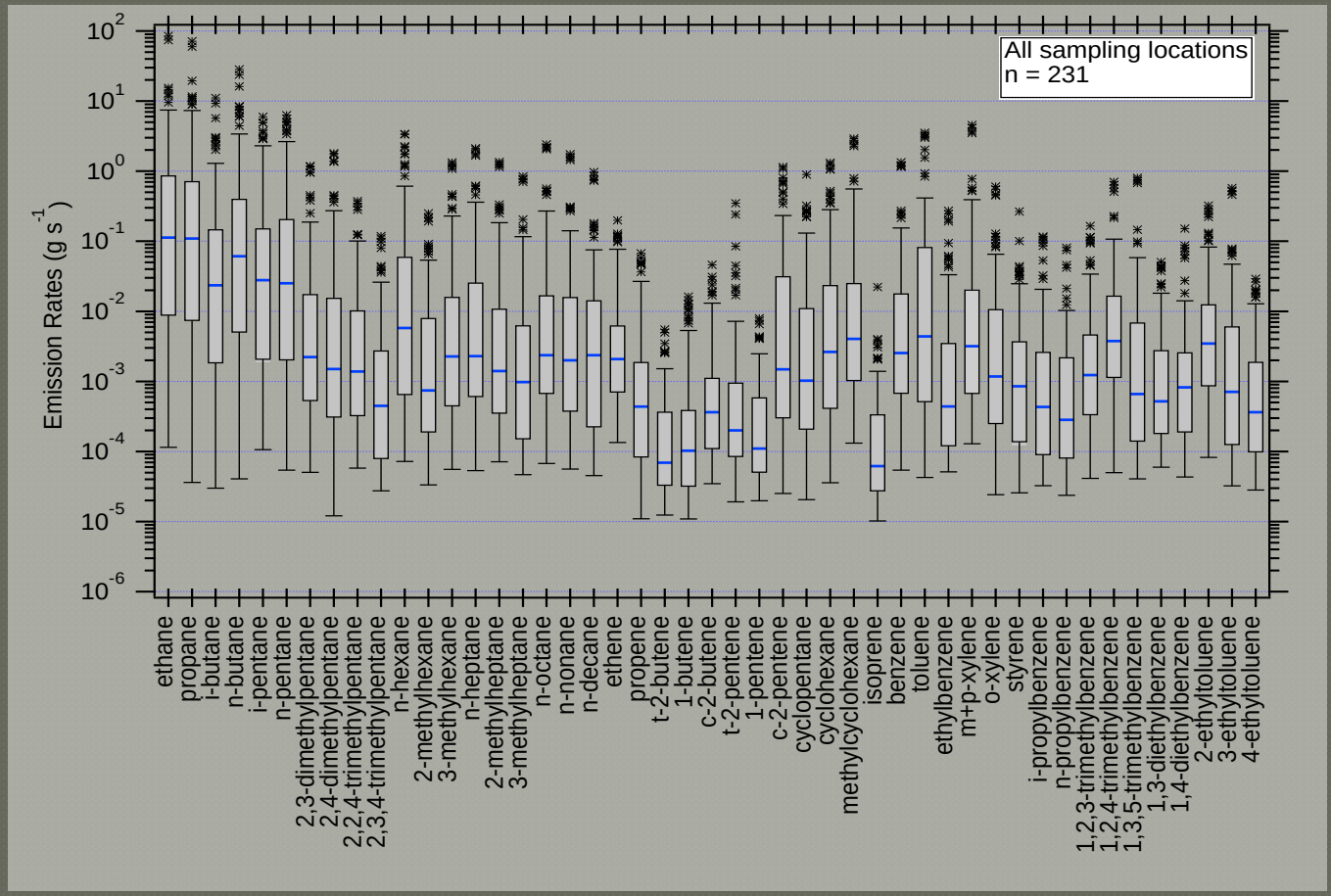
- Nearly all methane emission rates observed from production sites were below 1% of methane produced, with a mean < 0.4%





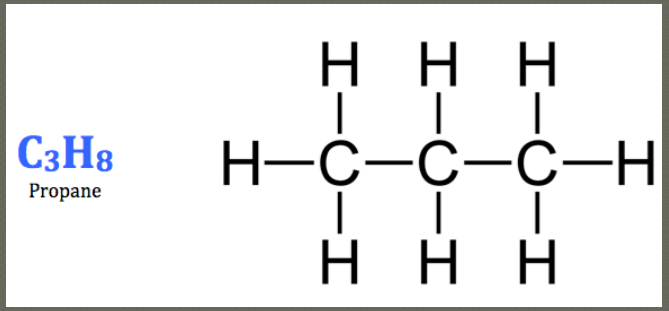
VOC emissions – Front Range study (all operations)

- VOC emissions vary widely by compound and for a given compound

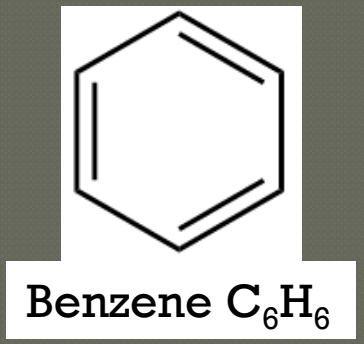


Some VOCs of interest

- Alkanes – ethane, propane, butane, pentane, …
  - Important constituents of natural gas
  - Small alkanes not a major direct health concern
  - React slowly, but can be important contributors to ozone production when abundant

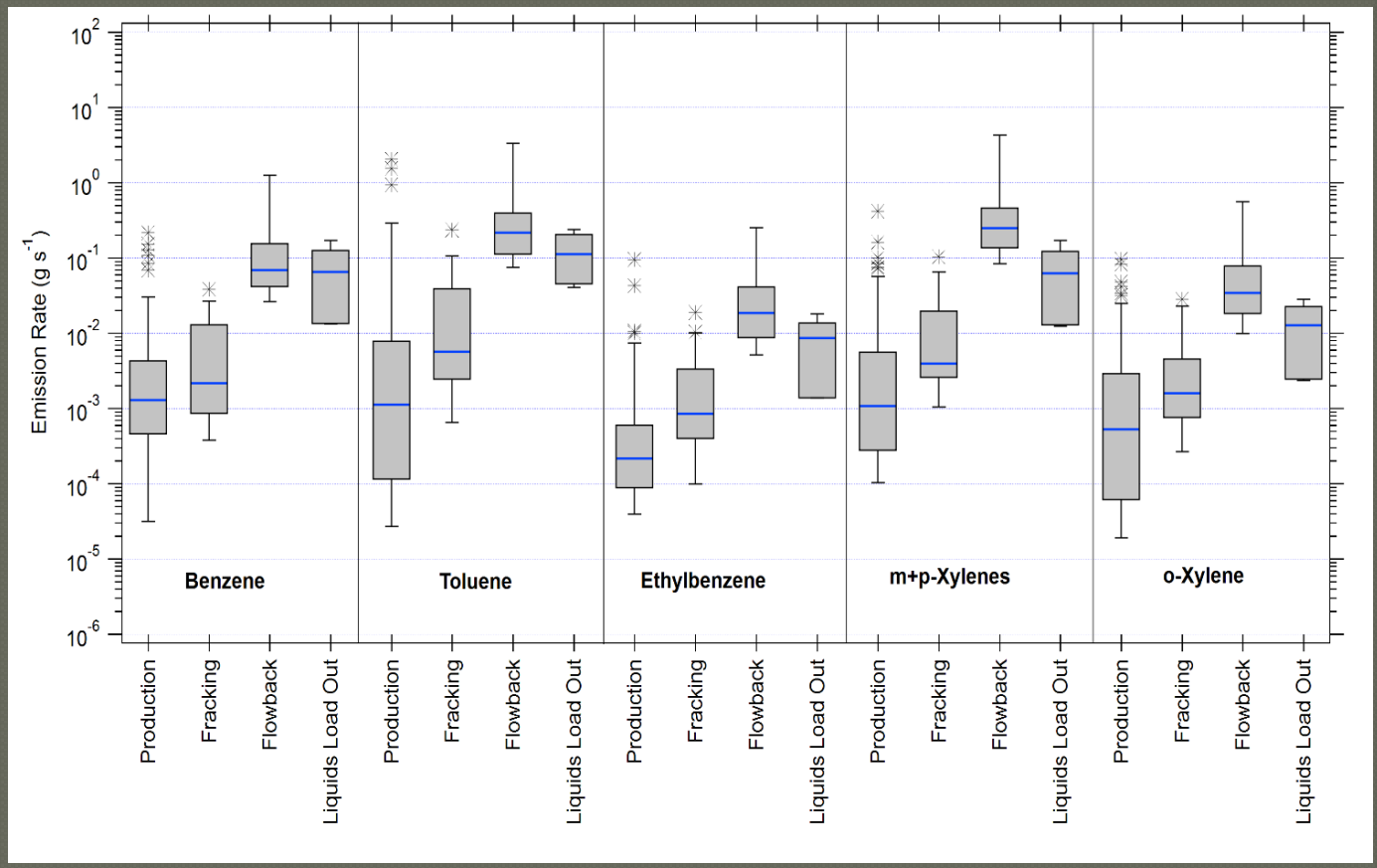


- BTEX – benzene, toluene, ethylbenzene, xylenes
  - Air toxics → possible health concern
  - Can be emitted from oil and gas deposits and from combustion processes



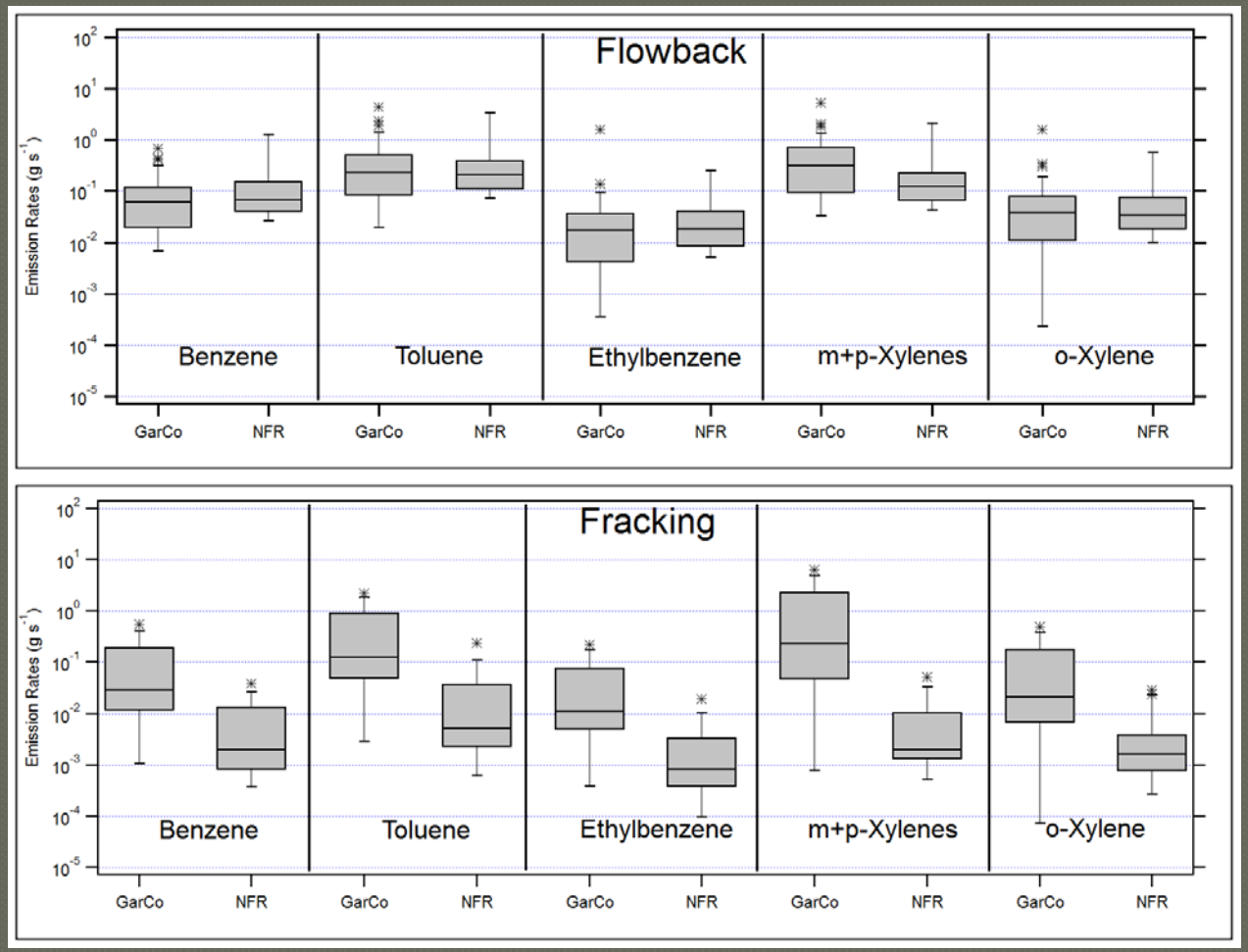
BTEX emissions by activity – Front Range

- Liquids load out and flowback have highest BTEX emissions
- Production has lowest BTEX emissions



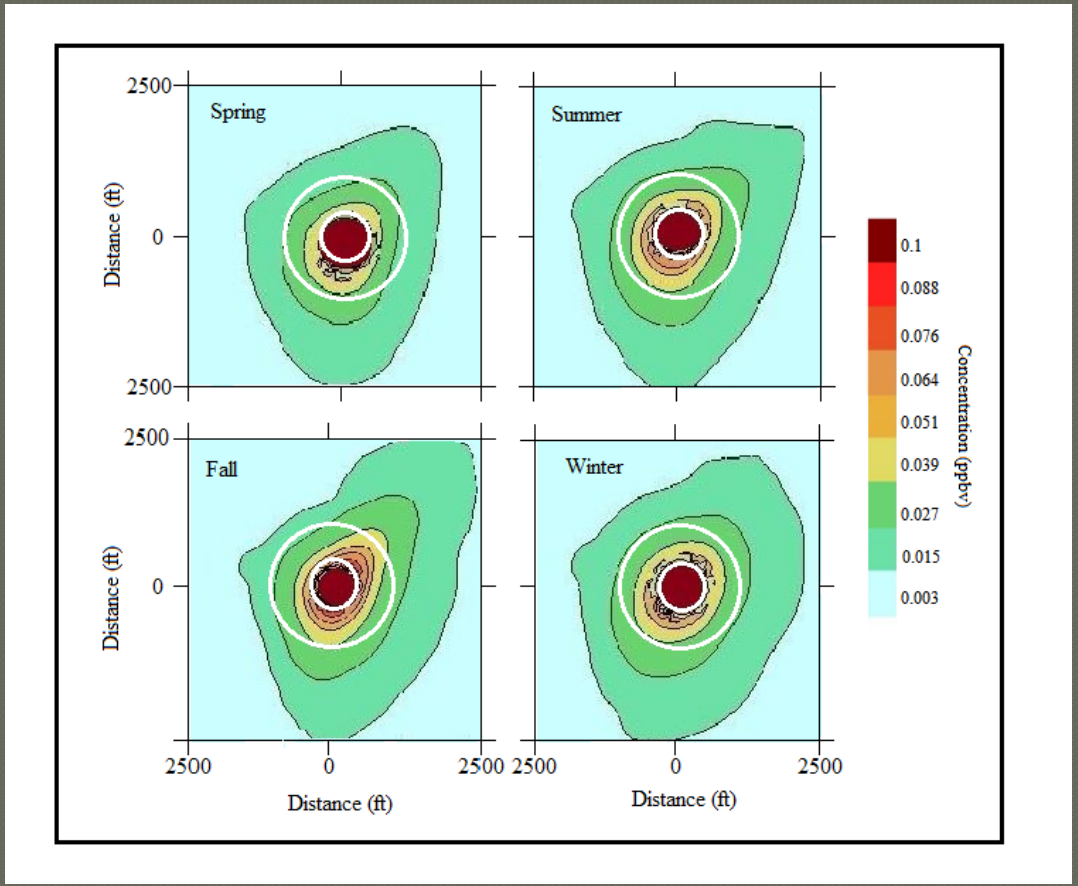
BTEX emissions comparison

- Flowback
  - Front Range and Garfield County BTEX emissions similar
- Fracking
  - Front Range BTEX emissions < Garfield County



Translating emissions to concentrations

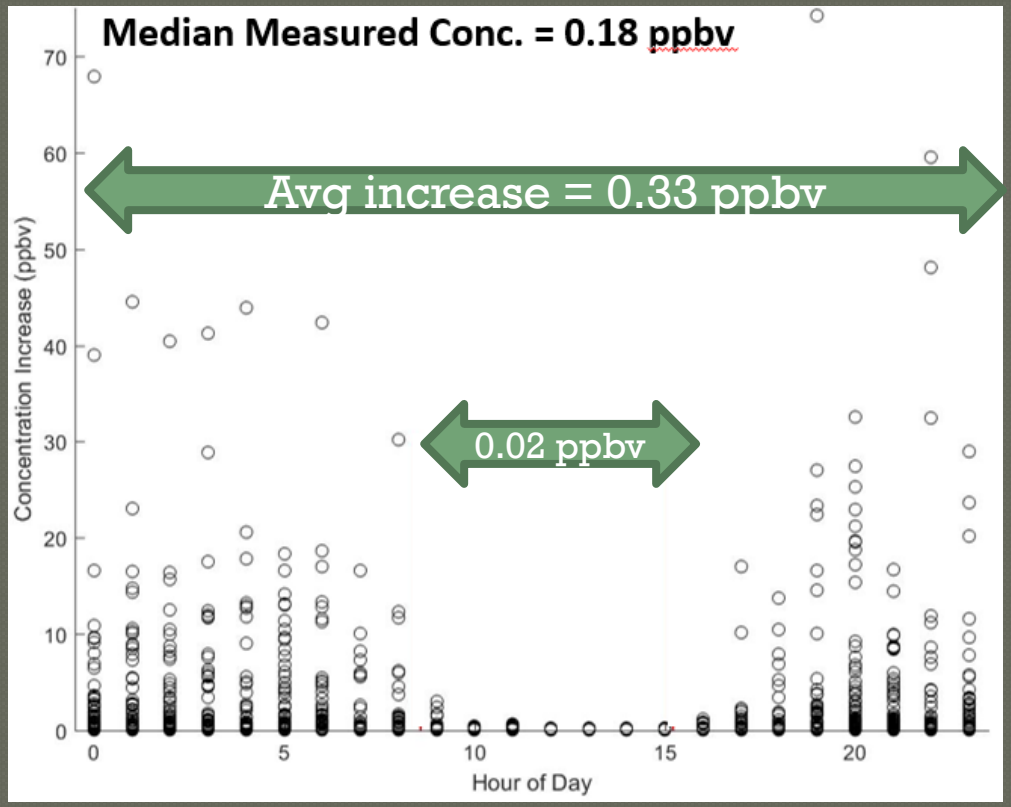
- Modeled benzene concentration maps for a Front Range site
  - constant 0.001 g/s benzene emissions
- CDPHE-sponsored study now completing a more sophisticated health risk assessment using CSU Garfield and Front Range emissions



Comparison: current Fort Collins benzene concentrations ~ 0.1–0.4 ppbv

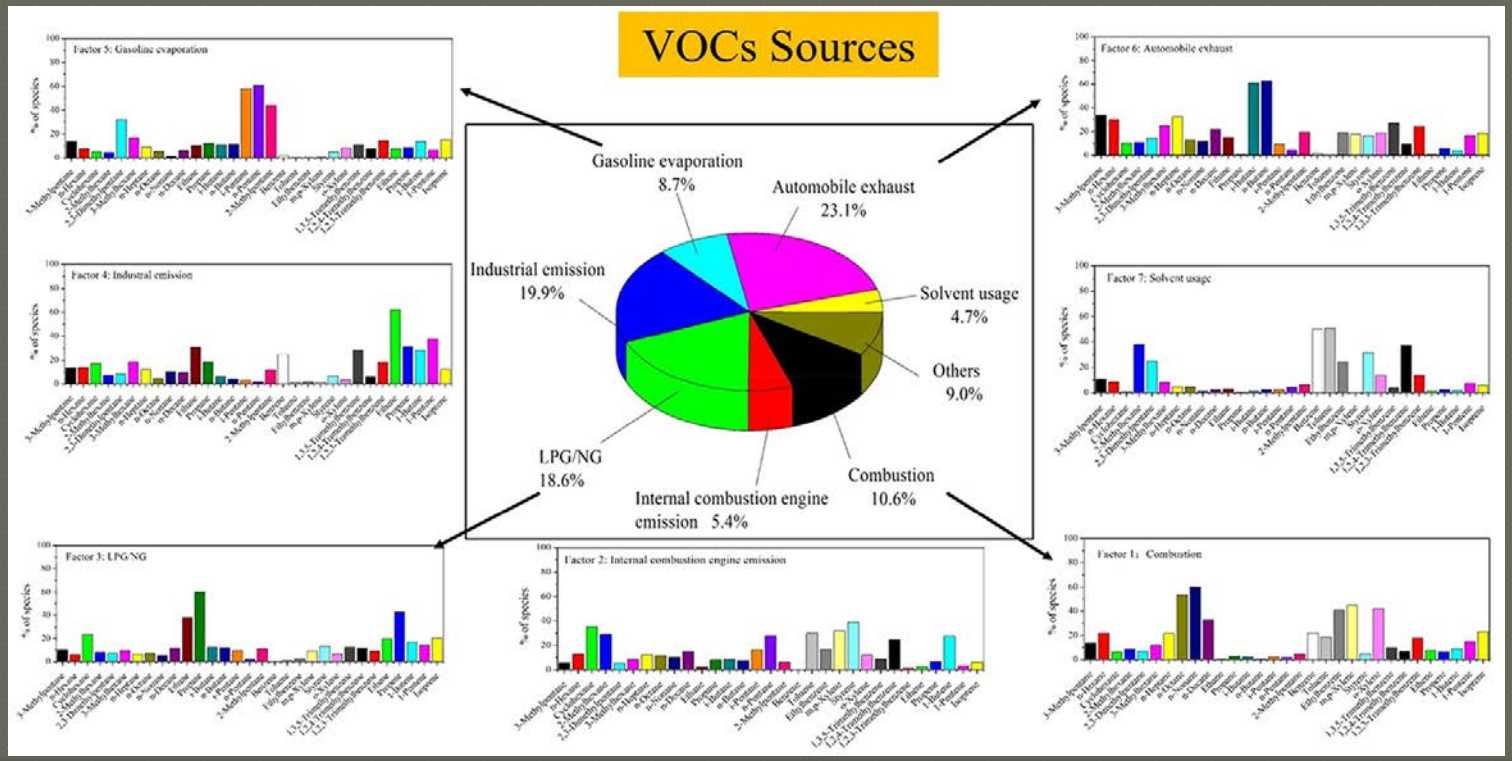
Hourly Benzene Concentration Variability

- Variable meteorology produces wide range of concentrations at a given point
  - 1 yr simulation, Front Range location 2000' from hypothetical pad, emissions typical of Front Range production site
- Average concentration increase is small
  - Individual hours occasionally significantly elevated at night



Source contributions to ambient air pollution

- 2018/19 CSU project with Garfield County
- Determine source contributions to ambient VOCs
  - Analyze variability in ambient VOC data to identify source profiles
  - Measure source profiles and fit them to ambient VOC data



Liu et al. (2016) *Env. Poll.*

Concluding thoughts

- CSU has examined O&G impacts on air quality at local to regional scales
  - $PM_{2.5}$ and haze
  - Ozone
  - Methane
  - Air toxics
- At neighborhood scales, hourly air toxics exposure evaluation highest priority
  - Average conc. increase often modest compared to risk thresholds
  - Highest emissions come from limited-duration activities
  - Watch for forthcoming CDPHE O&G health risk assessment
- Ozone & $PM_{2.5}$ increases potential concern on a regional scale
  - A few hours required to form these pollutants from direct emissions
- Climate forcing (methane) is a global-scale issue