Emissions and near-field dispersion of air toxics from oil and gas drilling, completions, and production in Colorado

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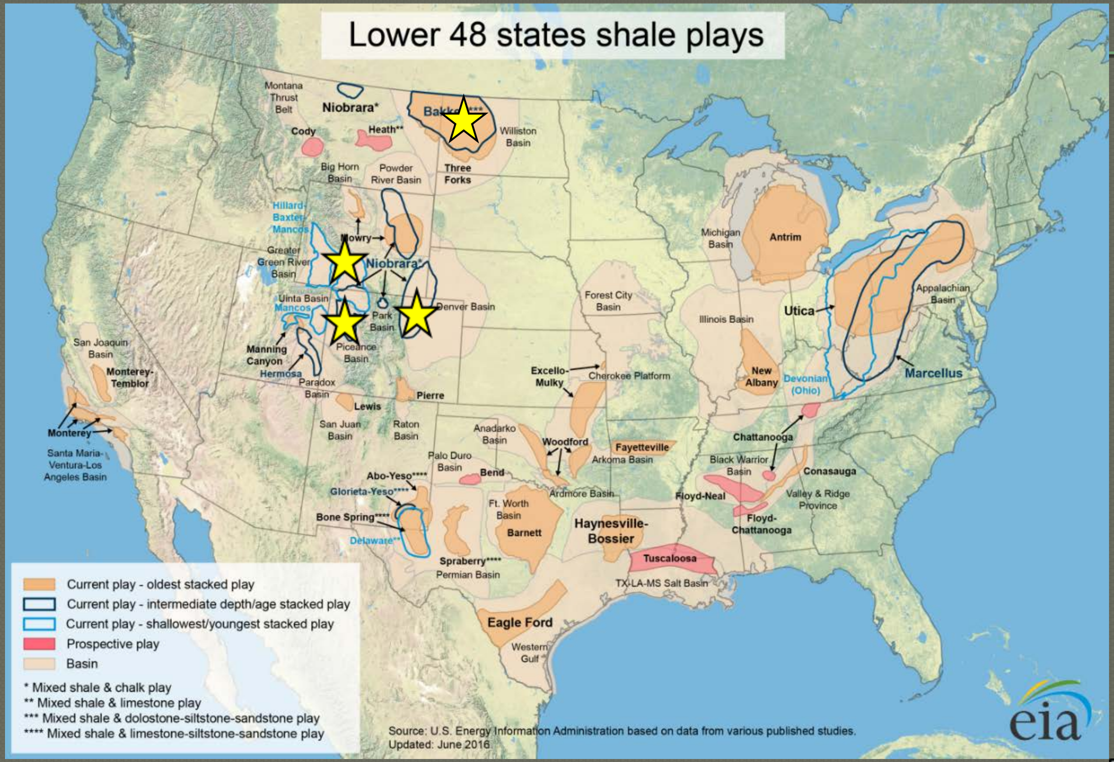
CSU Oil, Gas, and Air Quality Research – Western U.S.



- Characterization of air toxics, ozone precursors, and CH_4 emissions
  - Denver-Julesburg and Piceance Basins of Colorado

Photo: W. Malm

- Regional impacts on air quality, including PM formation and haze
  - Boulder, WY (Li et al., 2014)
  - Bakken, ND (Prenni et al., 2016, Evanoski-Cole et al., 2017)

CSU Garfield County and Front Range Studies

Garfield County

Well Drilling

Hydraulic Fracturing

Flowback

Production

Objectives

- Quantify emissions of chemical compounds (air toxics, ozone precursors, and methane) from oil and gas operations
- Characterize how these compounds are dispersed in the atmosphere downwind of the site
- Produce a public, high quality emissions dataset

Front Range

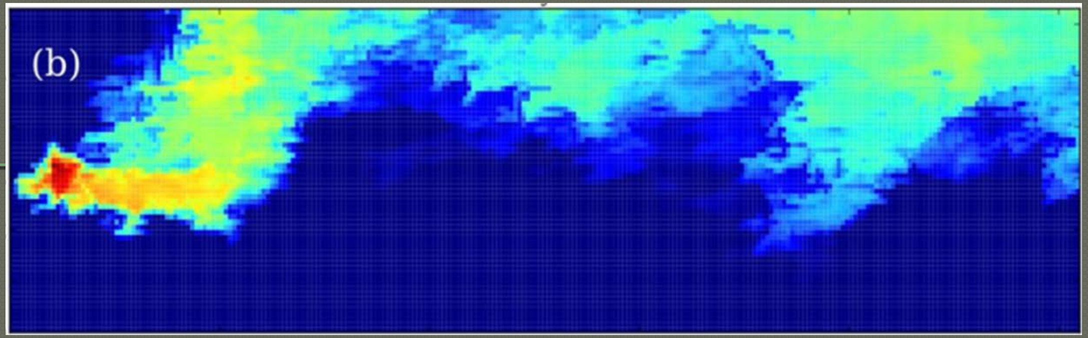
Well Drilling

Hydraulic Fracturing

Flowback

Production

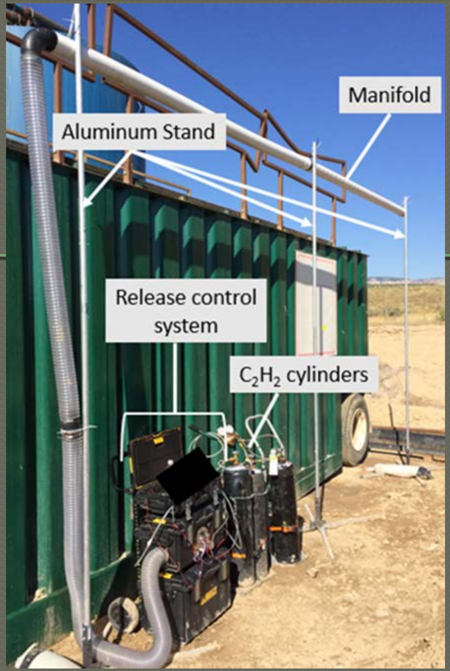
Why measure emissions?

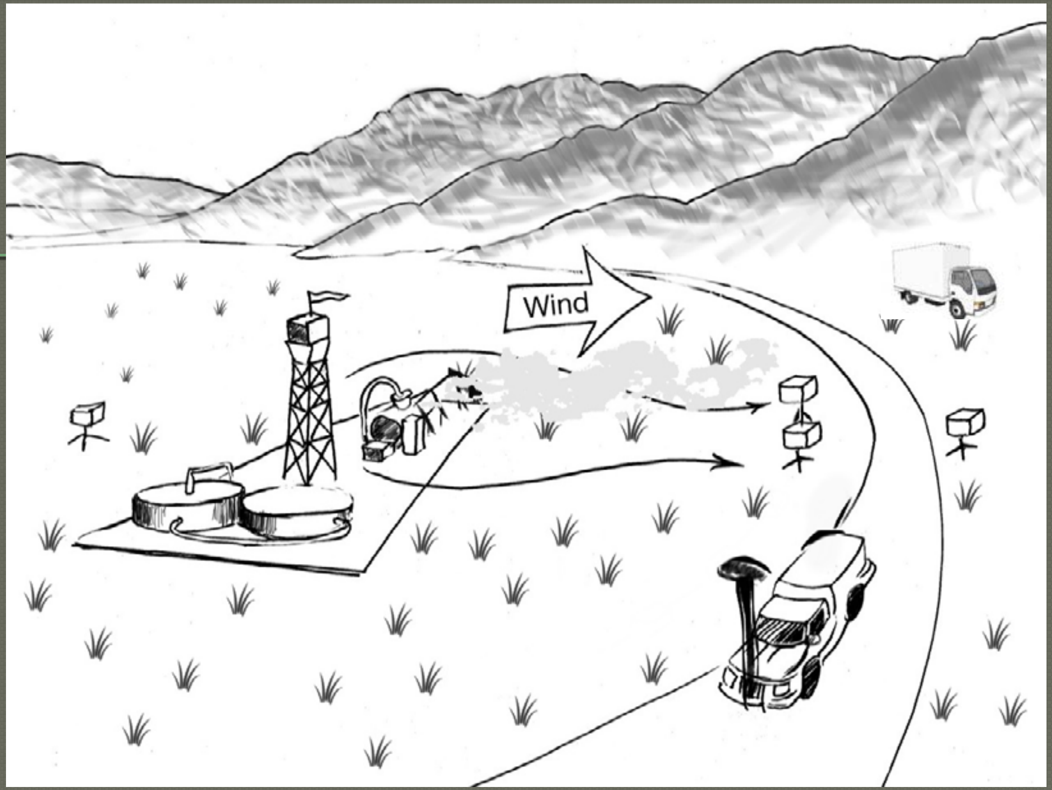


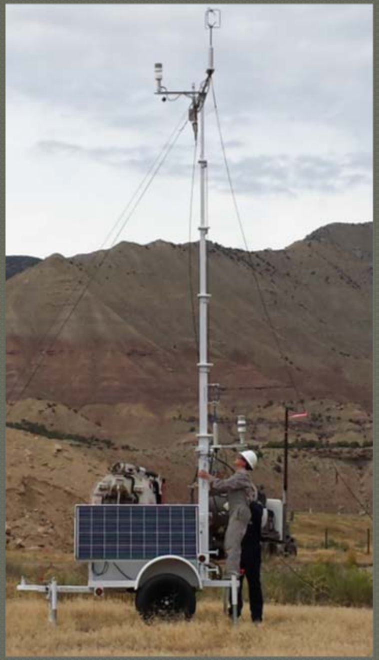
- Emissions are the amount of material emitted by an activity per unit time (e.g., grams per second)
- Air pollutant concentrations depend on
  - Emissions
  - Location
  - Weather conditions
- While concentrations are easier to measure, they provide information only for a single place and time
  - A dispersion model can be used to predict concentrations from known emissions for any place and time

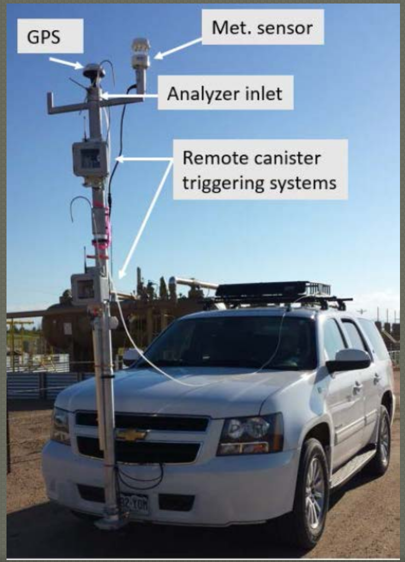
Measuring emissions

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



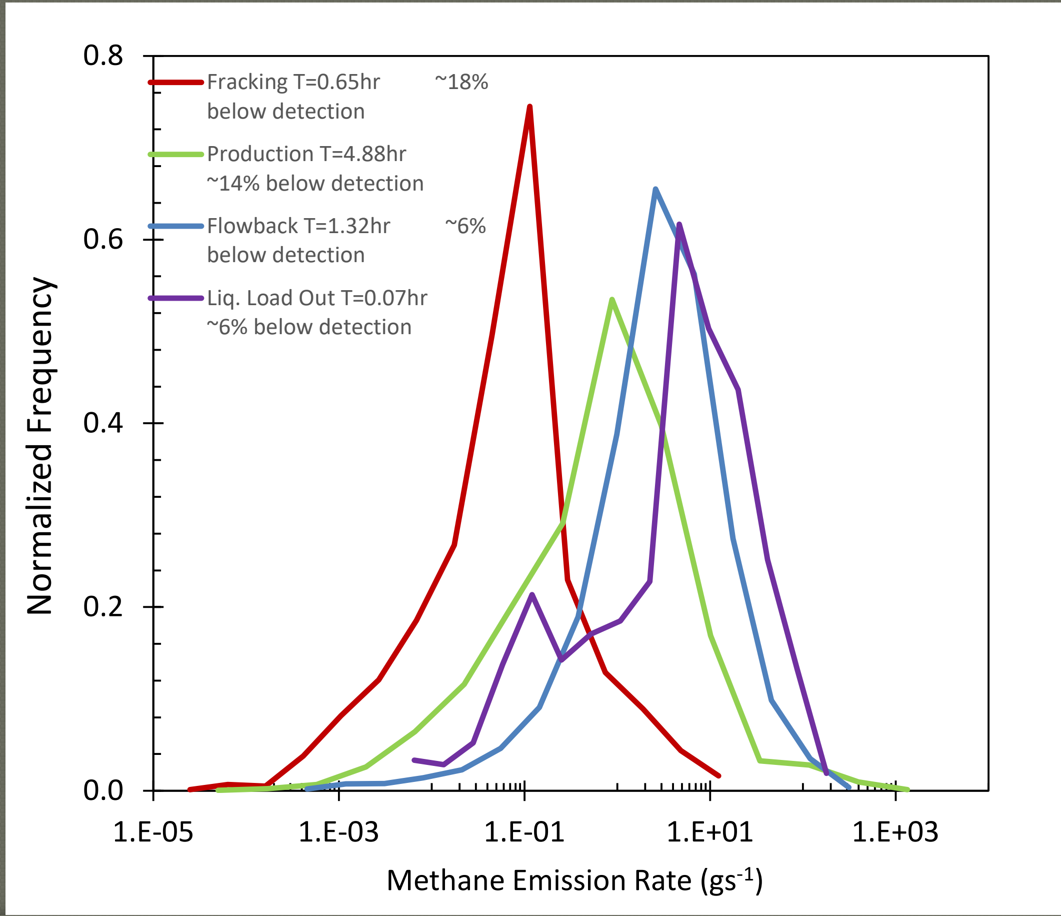






Methane emissions in Front Range study

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

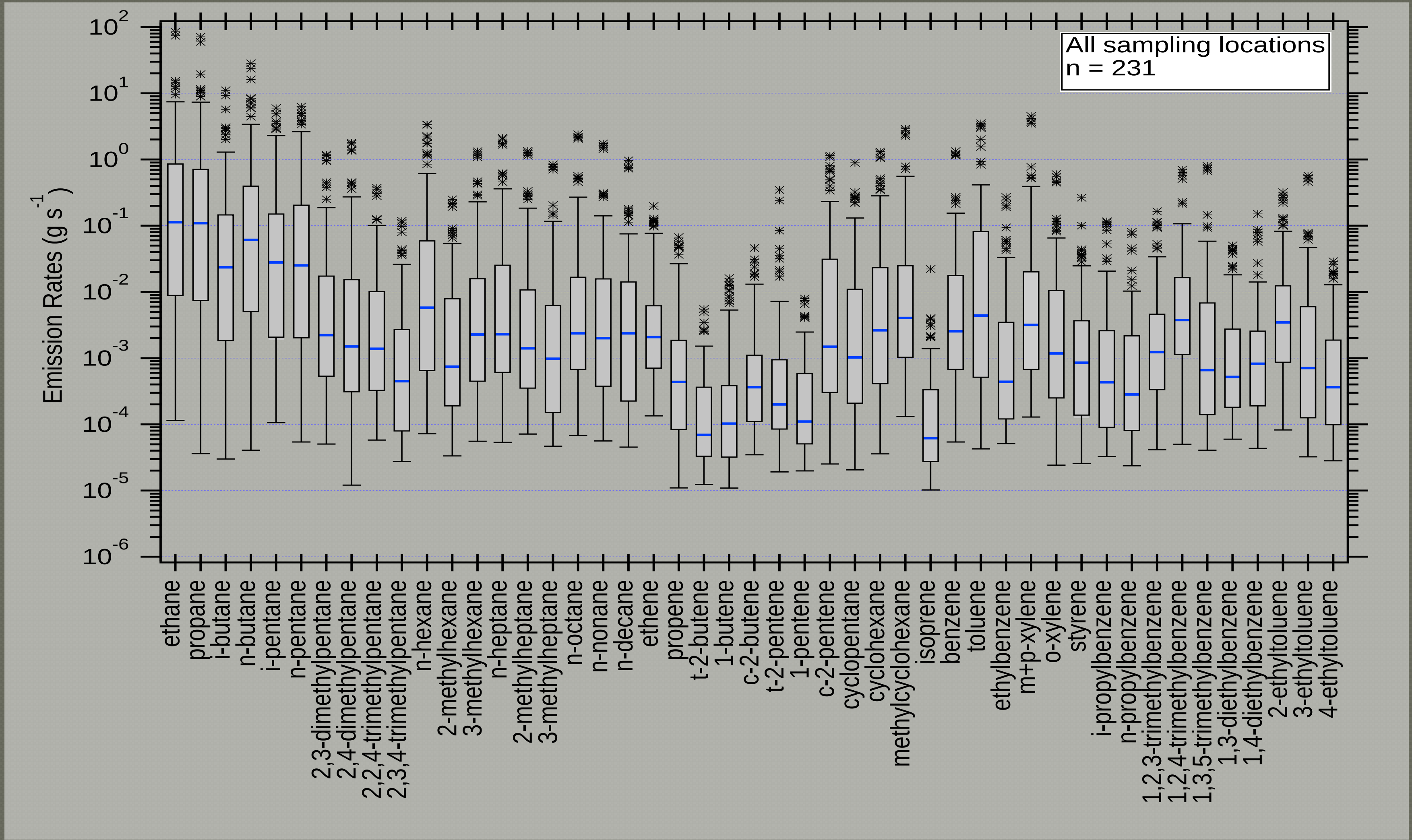
Activity	Median emission rate (g/s)	
	Garfield County	Front Range
Drilling	2.0	NA
Fracking	2.8	0.051
Flowback	40	2.8
Liquids Load Out	NA	4.8
Production	NA	0.60

Garfield County wells are gas producers

Front Range wells produce oil and gas

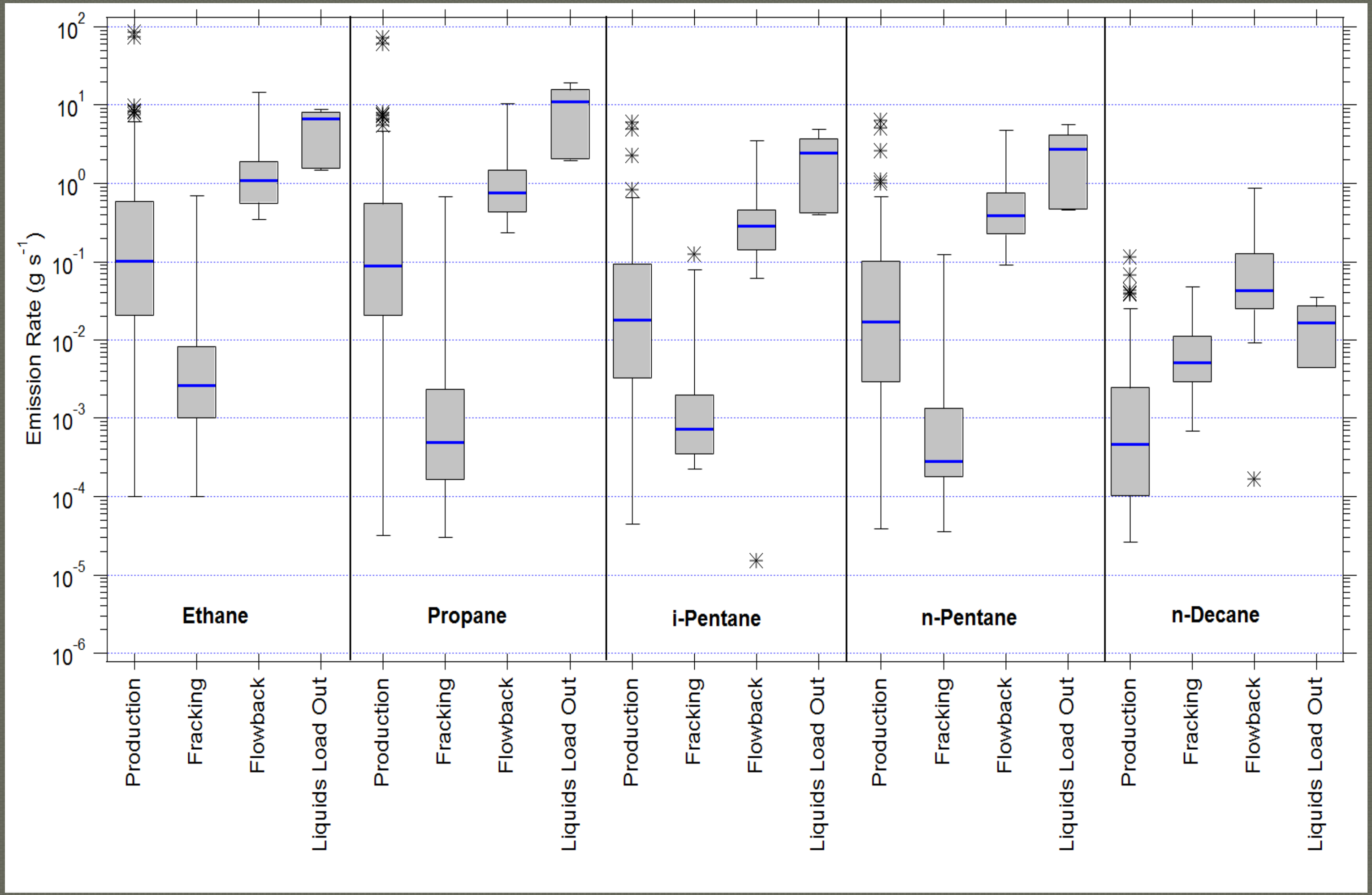
VOC emissions – Front Range study (all operations)

- VOC emissions vary widely
- Focus in this talk on alkanes and BTEX



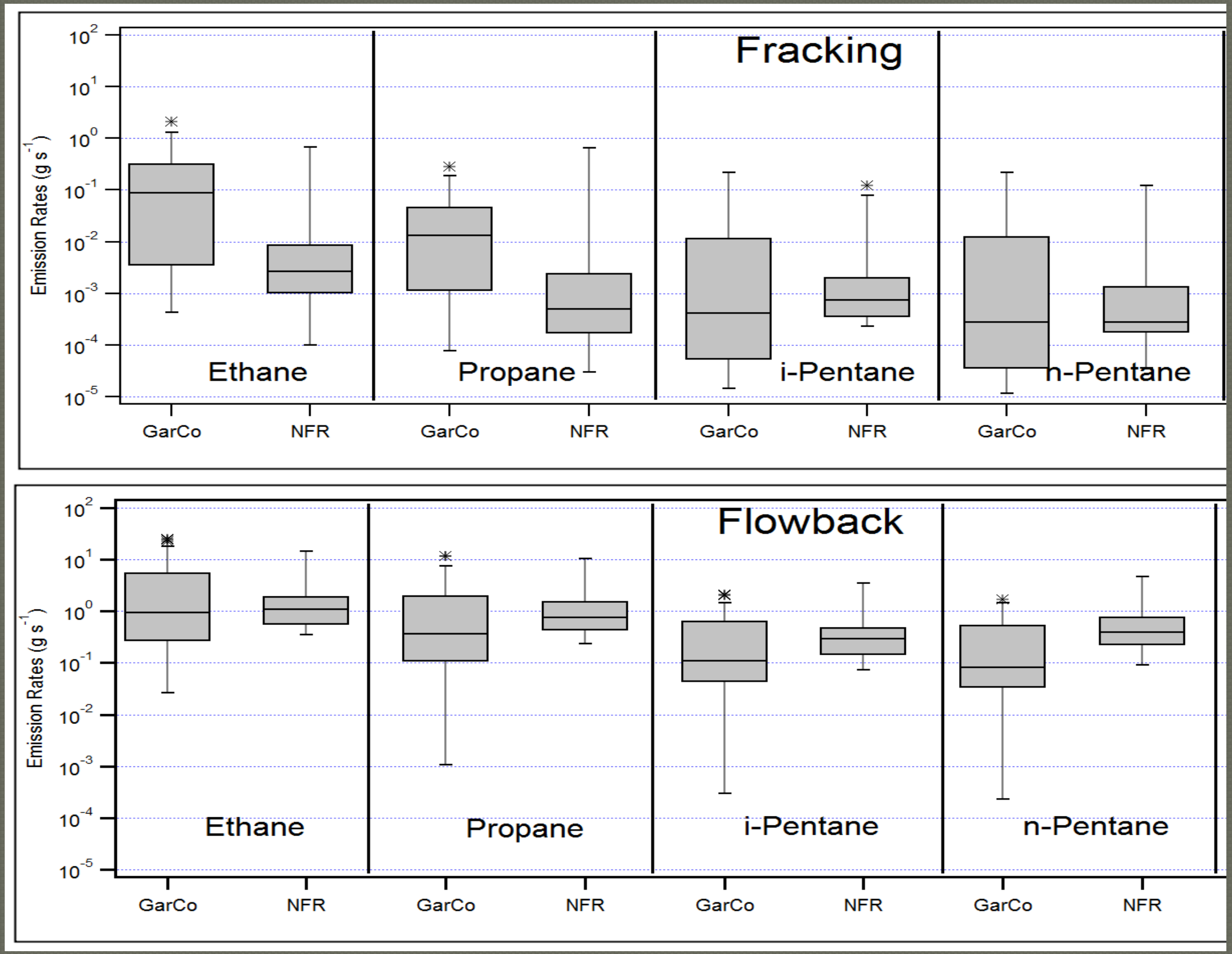
Alkane emissions by activity – Front Range

- Ethane & propane most abundant alkane emissions
- Flowback and liquids load out have highest alkane emissions
- Fracking lowest for light alkanes



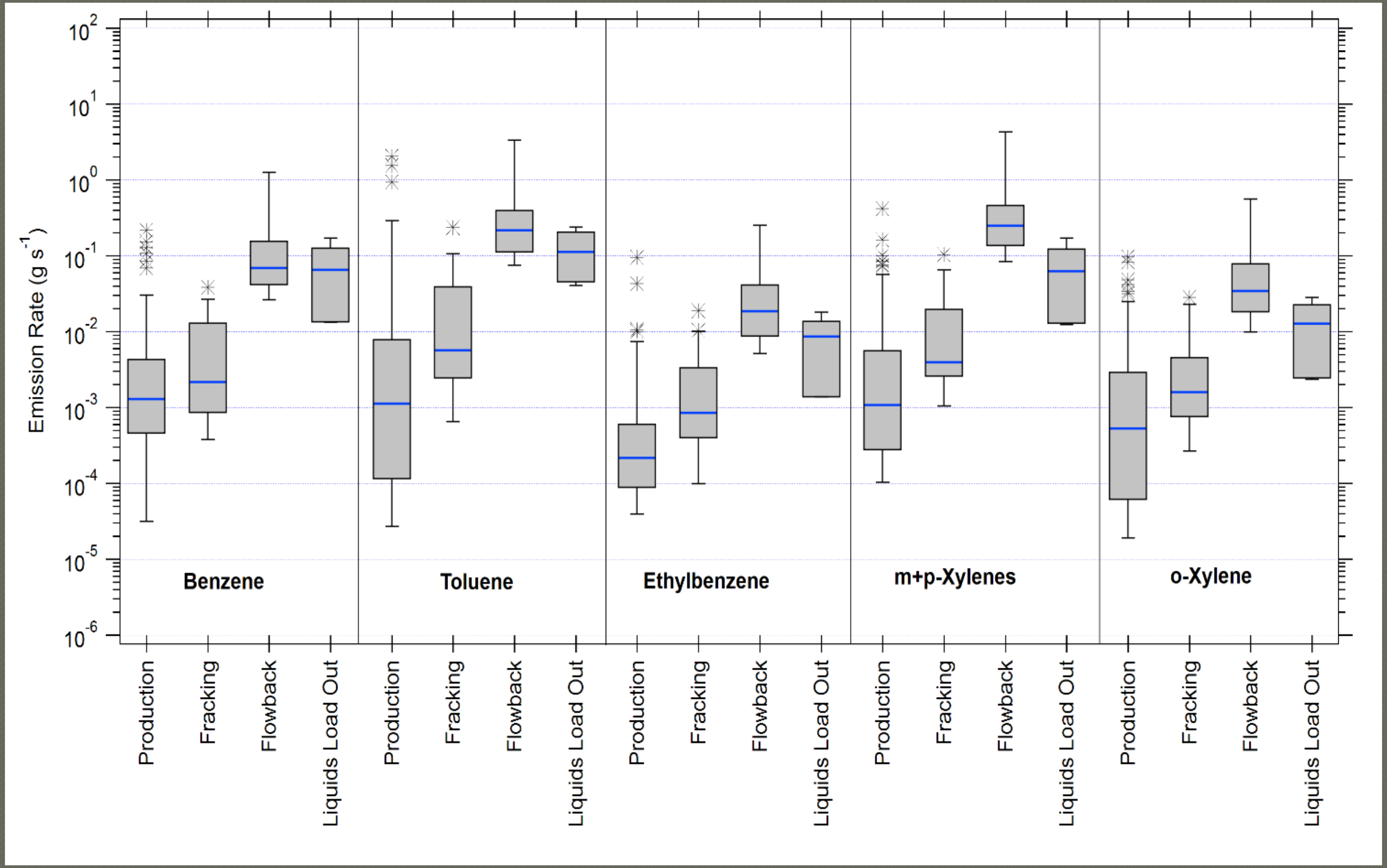
Alkane emissions comparison

- Fracking
  - Front Range ethane and propane emissions < Garfield County
  - Median pentane emissions similar
- Flowback
  - Median ethane emissions similar in two regions
  - Higher median propane and pentane emissions in Front Range



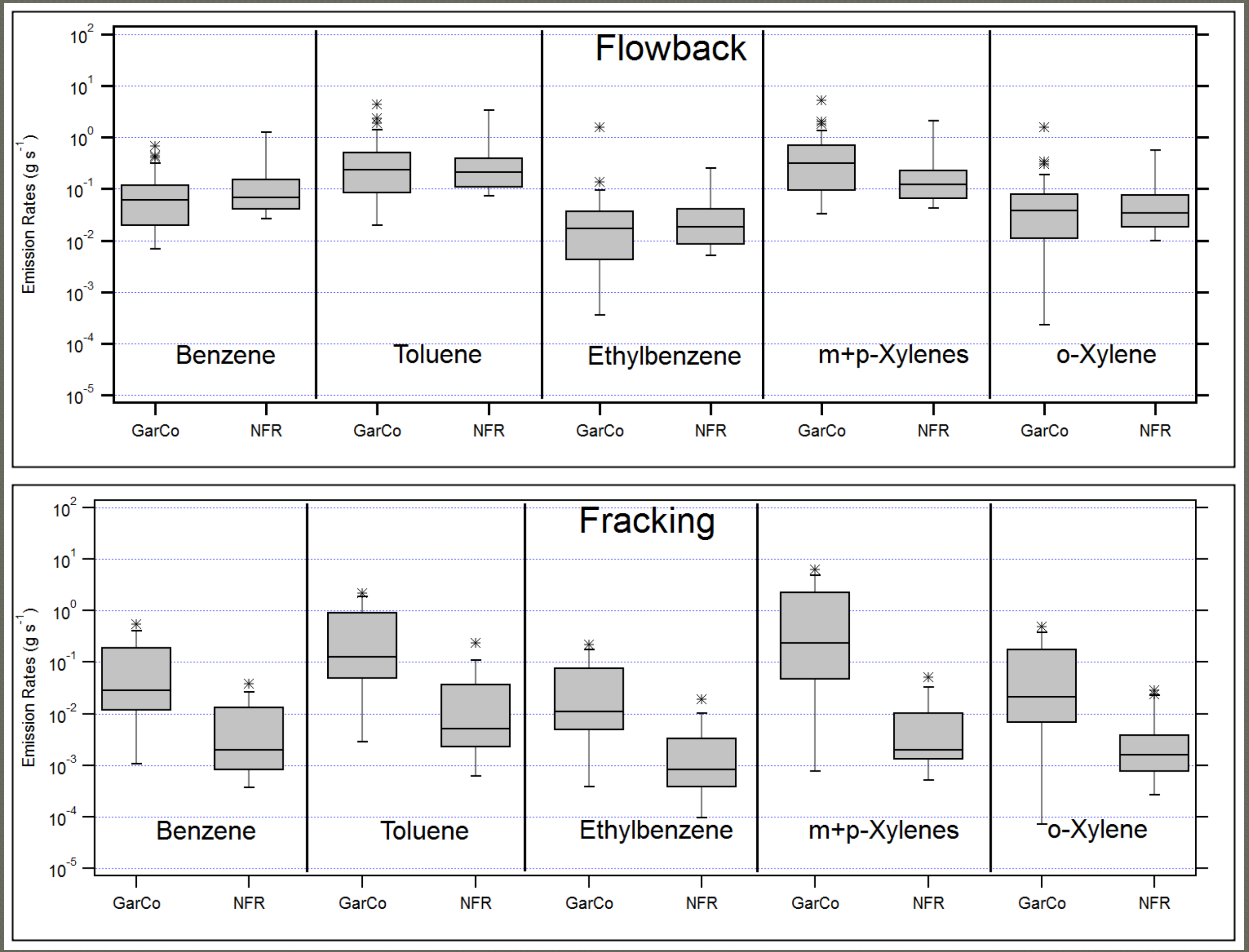
BTEX emissions by activity – Front Range

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



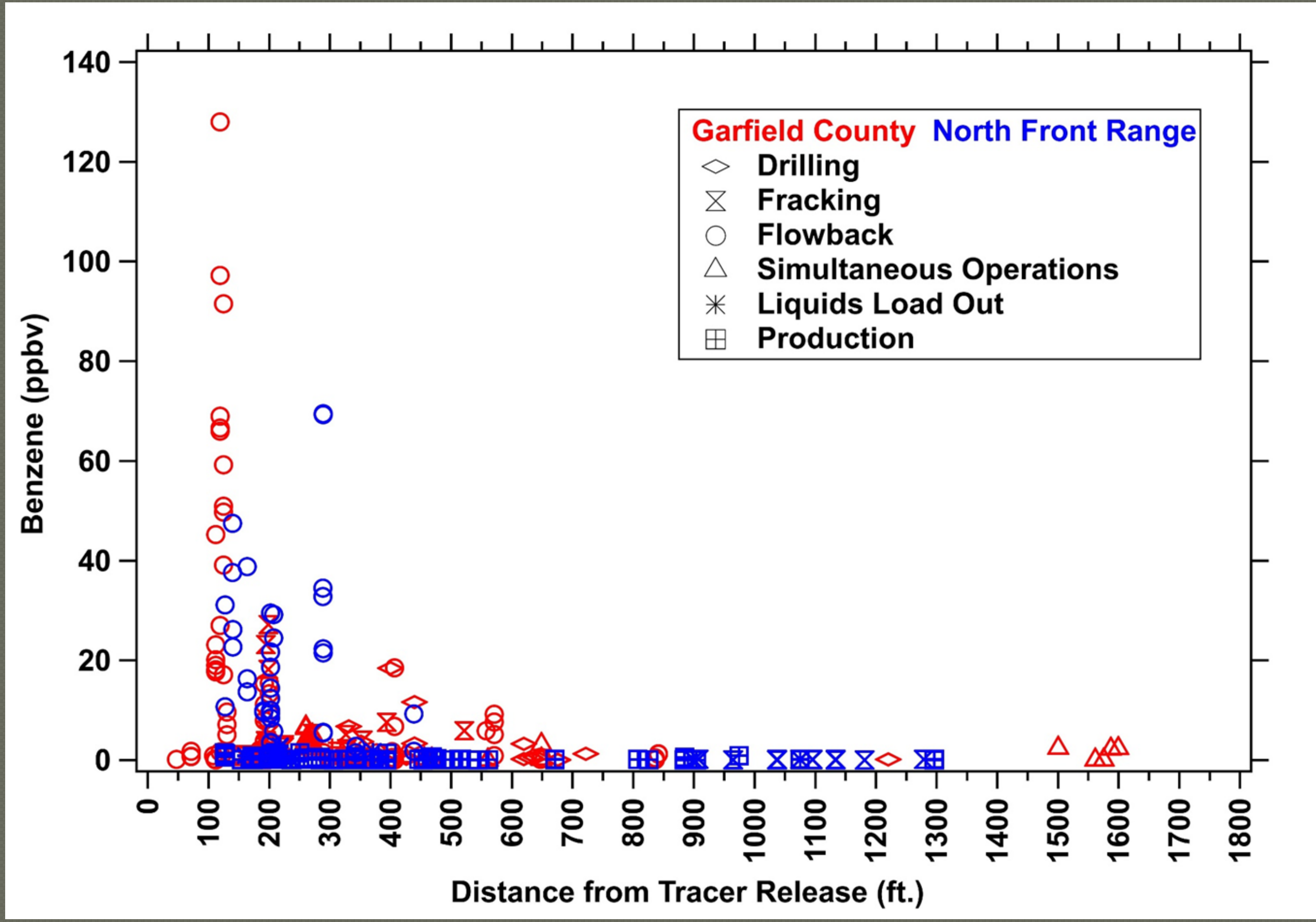
BTEX emissions comparison

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



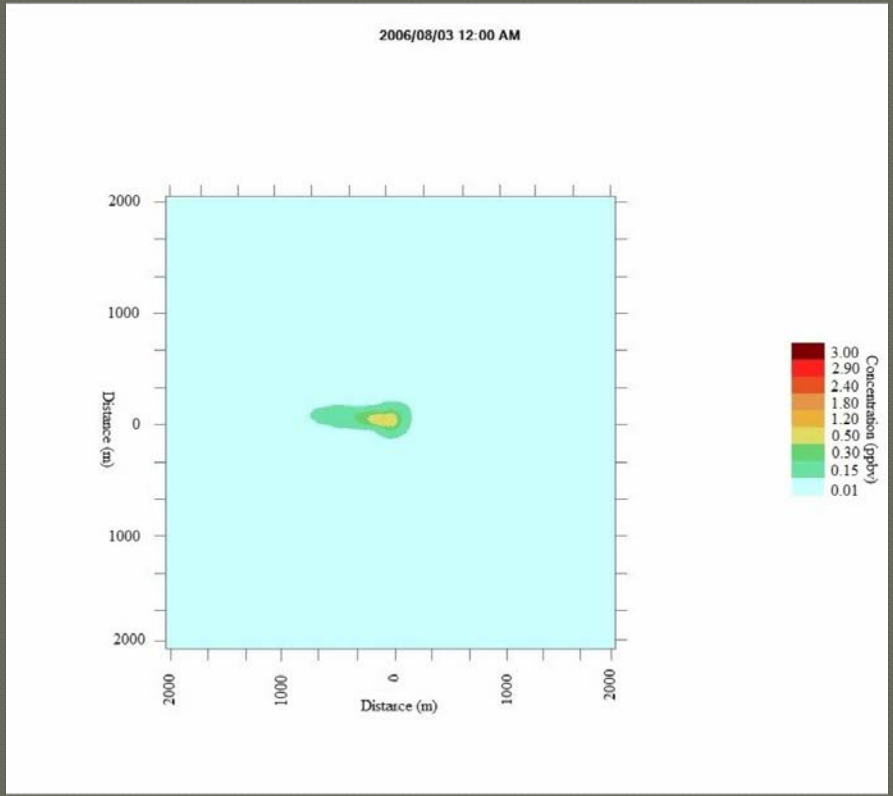
Observed benzene plume concentrations

- Highest benzene plume concentrations during flowback
- Concentrations < 20 ppbv beyond 400 feet
  - Emissions measurements targeted good dispersion periods
  - Higher concentrations can occur during poor dispersion



Dispersion model simulations

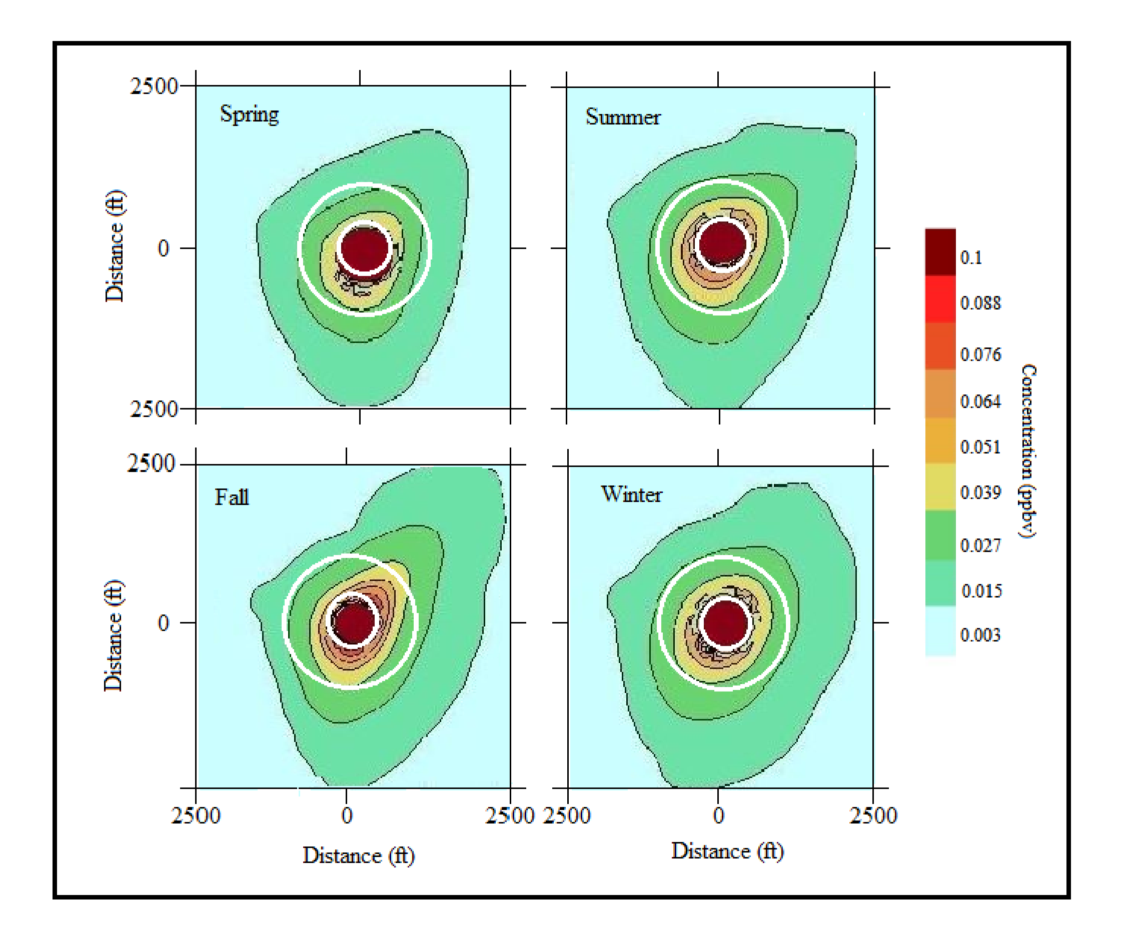
- EPA AERMOD dispersion model used to simulate concentration fields
- Model run hourly at example Front Range location
  - 2009 archived meteorology
  - Emission rate = median of observed benzene production facility emission rate (0.001 g/s)
- Example: hourly simulation
  - large hourly changes in plume location, shape, and concentrations



Average concentration increases – Front Range production

- Modeled benzene concentration maps for a Front Range site
  - constant 0.001 g/s benzene emissions

- Average benzene increase < 0.1 ppbv at distances > 500 feet



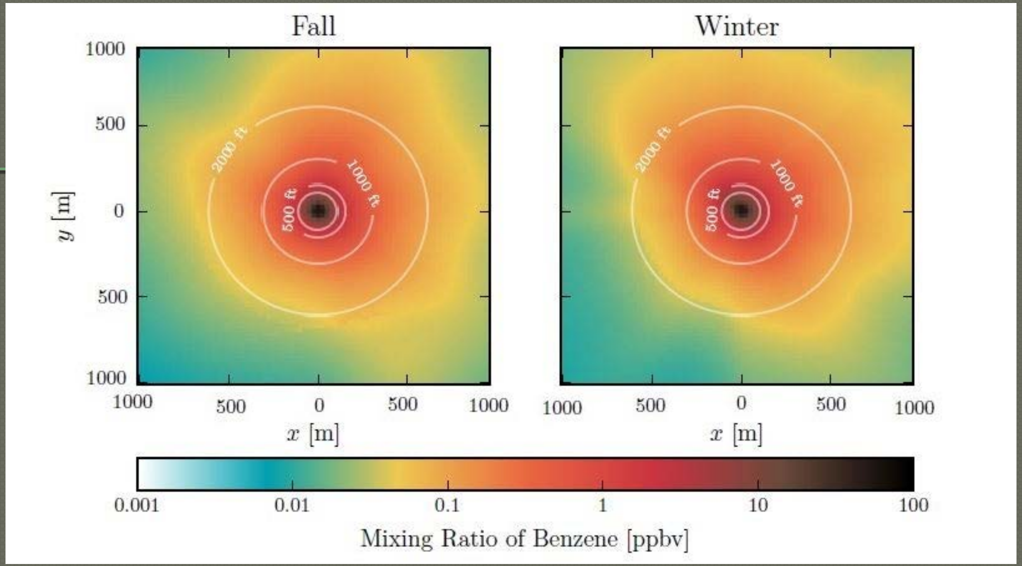
Comparison: current Fort Collins benzene concentrations ~ 0.1–0.4 ppbv

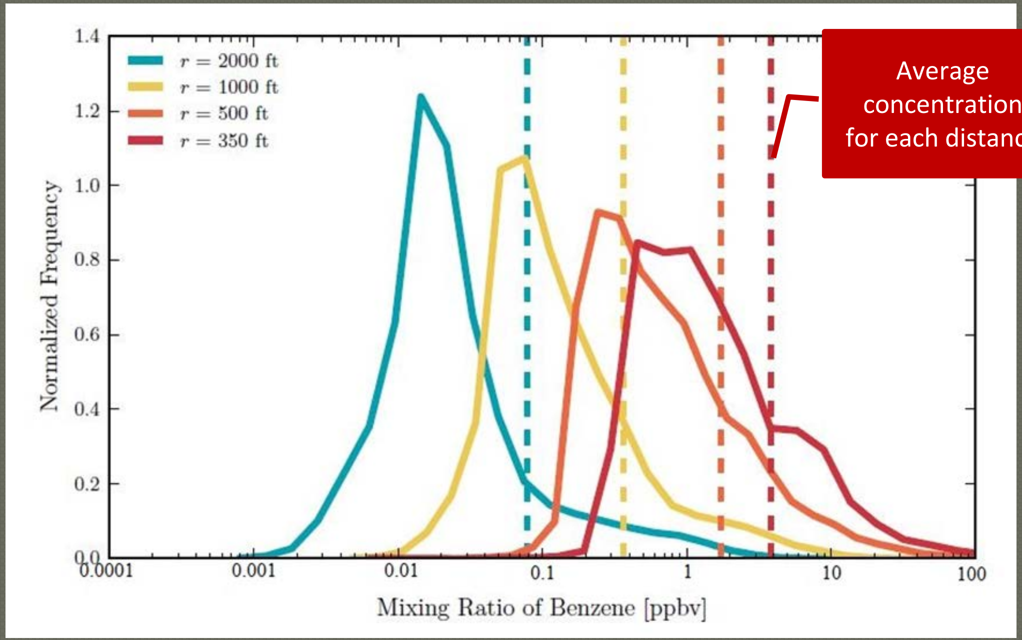
Benzene concentration increases – Garfield County high emission scenario

- Model run hourly at example location for all of 2014 using
  - Archived meteorological fields
  - 0.23 g/s benzene emissions (75th percentile of drilling, fracking, and flowback benzene emissions was 0.14 g/s)
- Avg concentration increase @ 500' ~ 1.8 ppbv   1000' ~ 0.36 ppbv

These should **not** be thought of as annual exposure distributions, since (1) a constant high emission rate was modeled and (2) drilling and completion activities last only several days per well

Spring and summer distributions are similar

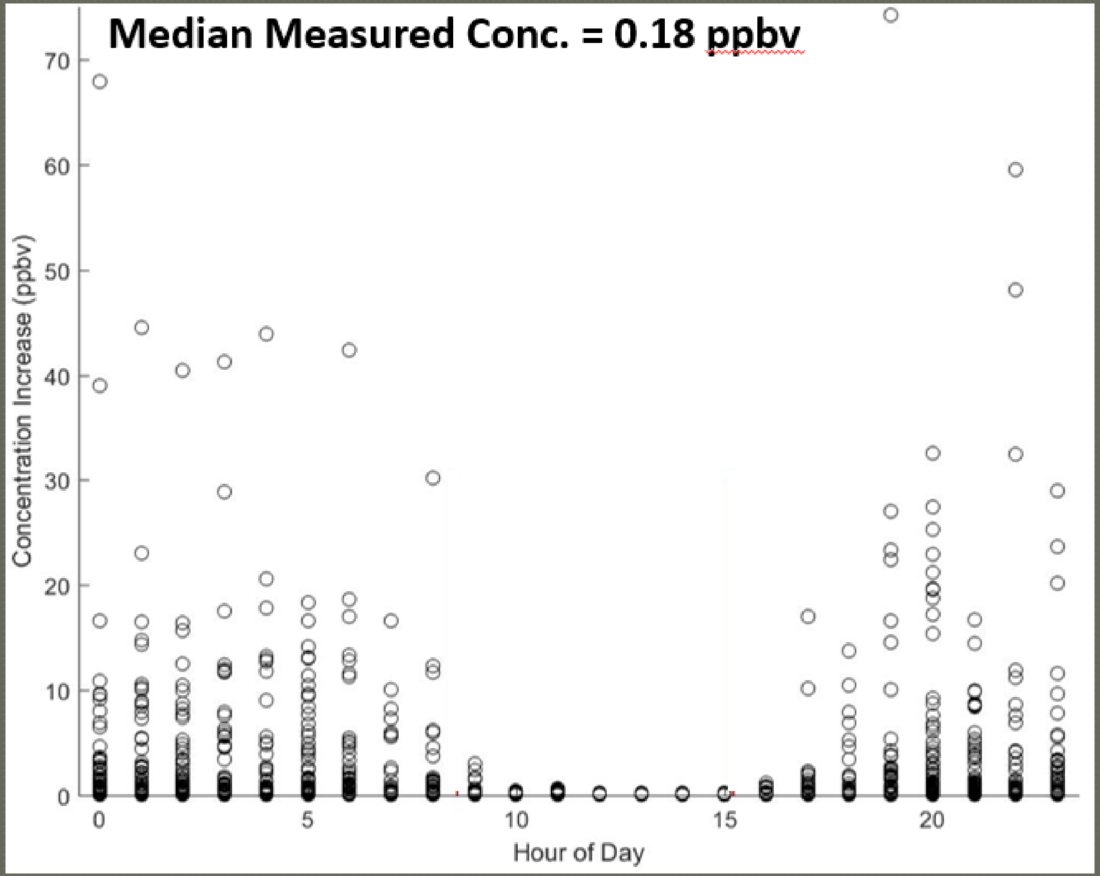




Average concentration for each distance

Hourly benzene concentration variability

- Variable meteorology yields wide range of modeled receptor concentrations
  - 1 yr simulation @ Front Range school location
  - Typical Front Range production emissions
- 73% of hours with no increase but significant benzene concentrations predicted in some hours
  - Strong day/night difference
  - Prevailing wind and stability effects

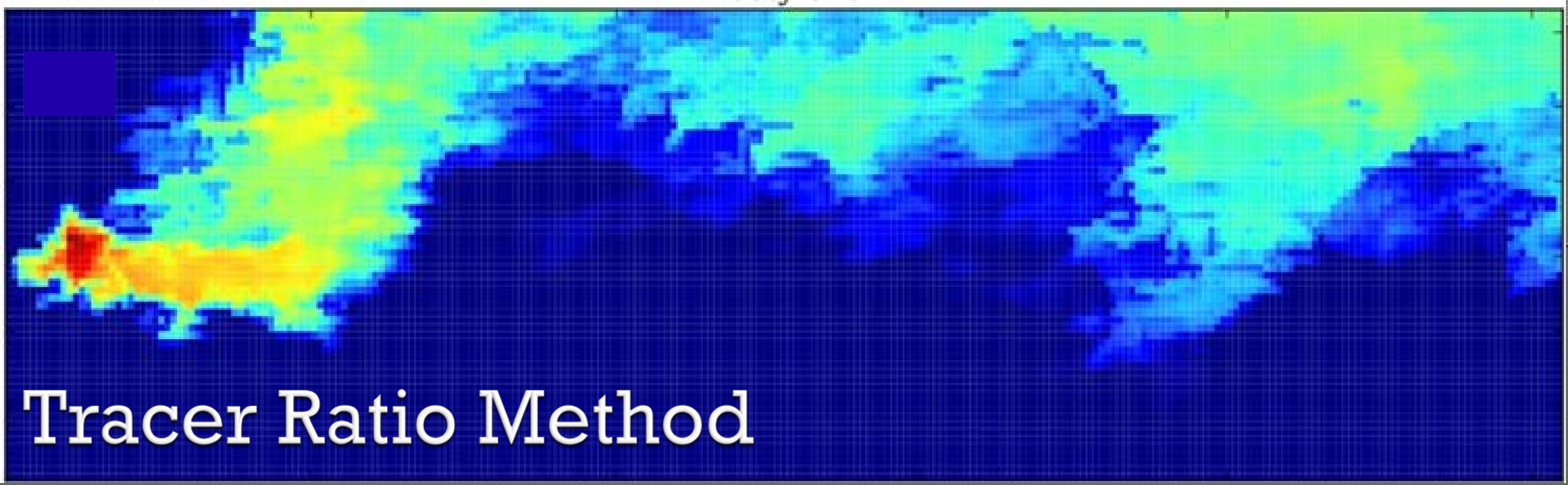


Concluding thoughts

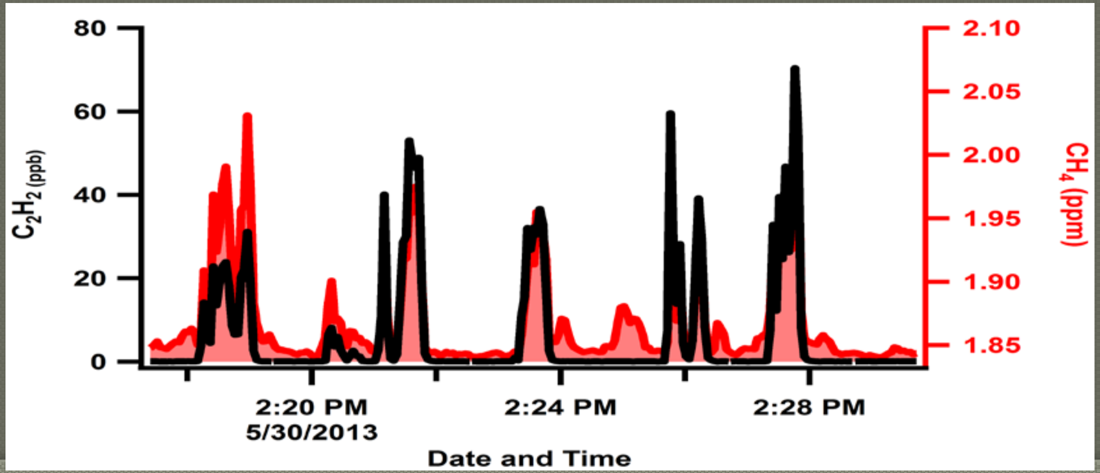
- We have examined O&G impacts on air quality at local to regional scales
  - $PM_{2.5}$ Ozone Methane Air toxics
- Measured emissions can drive dispersion models to predict conc. fields over many locations and meteorological conditions
- Long-term average conc. increase at Colorado setback distances typically modest compared to health-protective criteria levels
  - Consider risks of permitting community development closer than O&G setback distances
- Consider health effects of short-term exposure (e.g., hourly)
  - Highest emissions come from shorter-duration activities, especially flowback
  - Calm periods with poor dispersion and limited vertical mixing can produce higher exposure concentrations

Concluding thoughts (cont'd)

- Dispersion models reasonably accurate under good dispersion conditions
  - Need to better evaluate peak concentration predictions under stagnant conditions
- Need to continue to evaluate emissions as technology changes, e.g.
  - Larger pads
  - Improved vapor recovery during liquids unloading
  - Closed loop systems (what's at the other end of the pipe?)

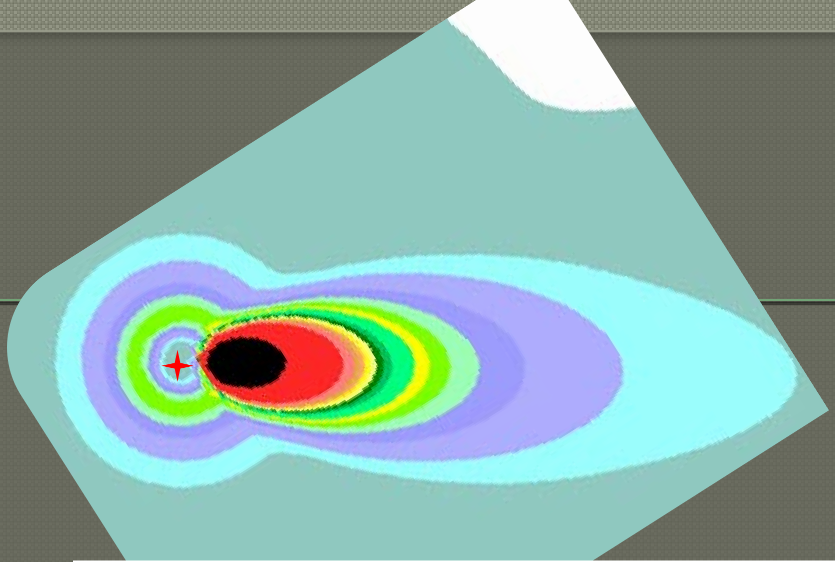


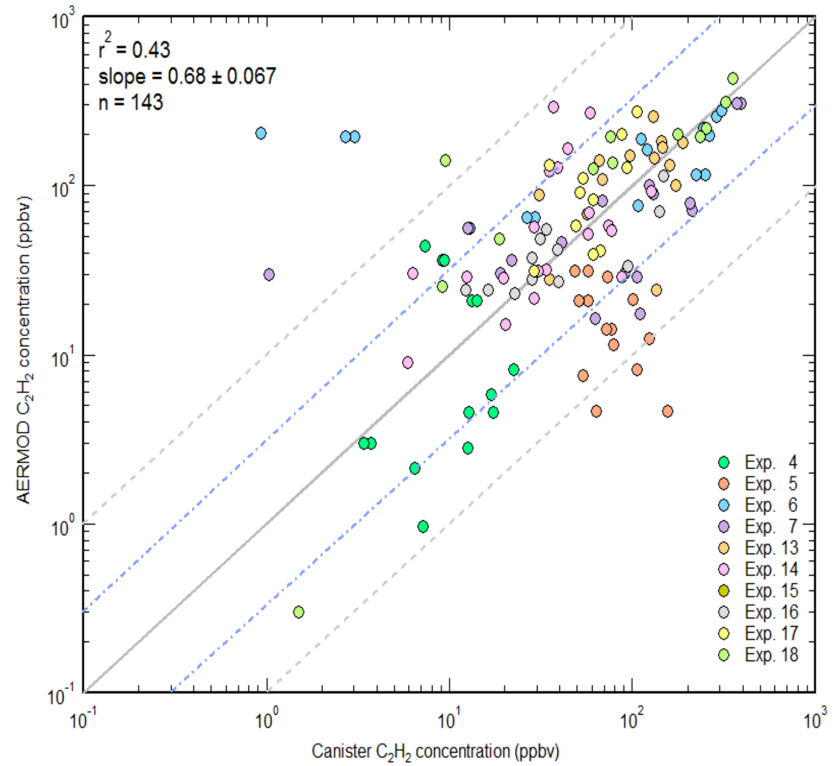
- Release acetylene tracer at known rate
- Tracer transported with source plume - identifies its location
- Dilution of tracer accounts for complex source plume dispersion
- Method validation showed accuracy of 23% and precision (rsd) of 17%



Dispersion model testing

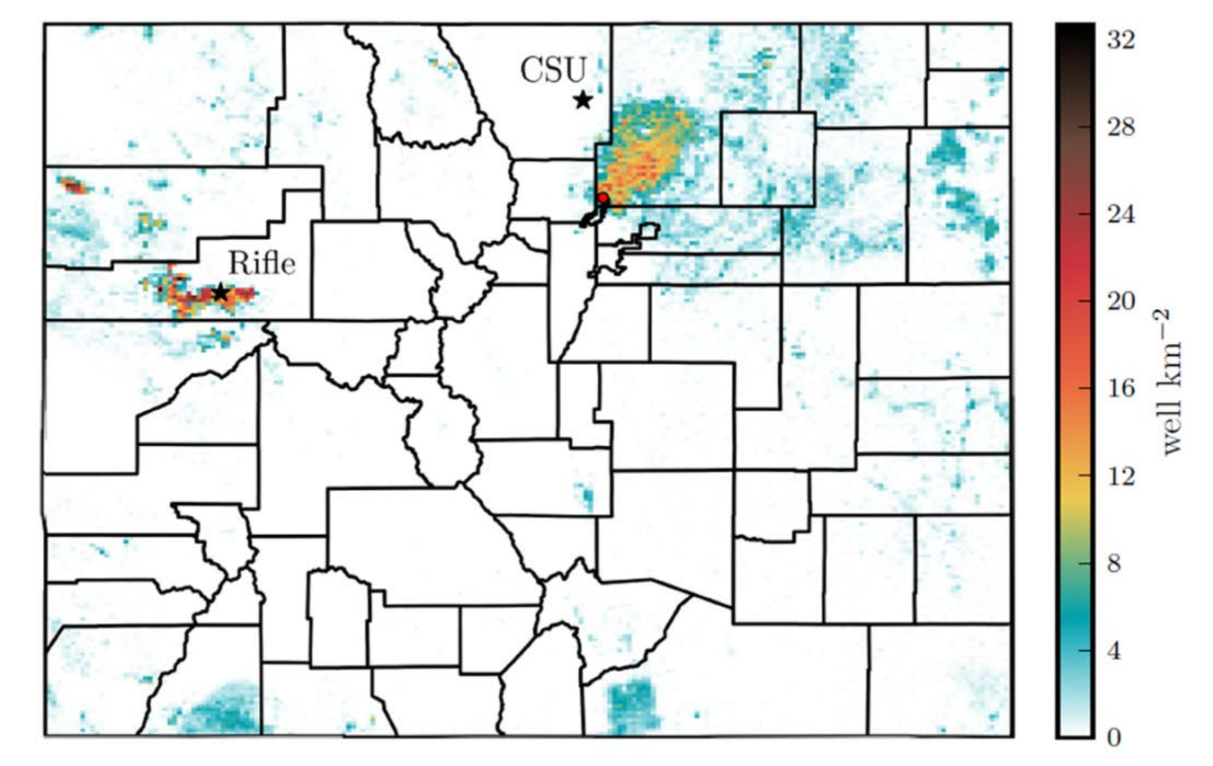
- EPA AERMOD dispersion model used to simulate concentration fields
- Model performance tested by comparing predicted and measured acetylene concentrations
  - Short-term simulations are challenging for a model like AERMOD
  - Low model bias with moderate scatter



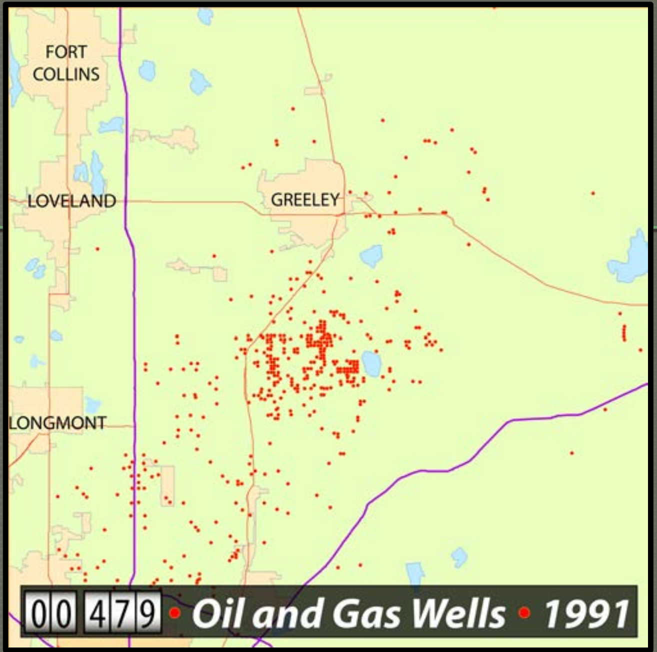


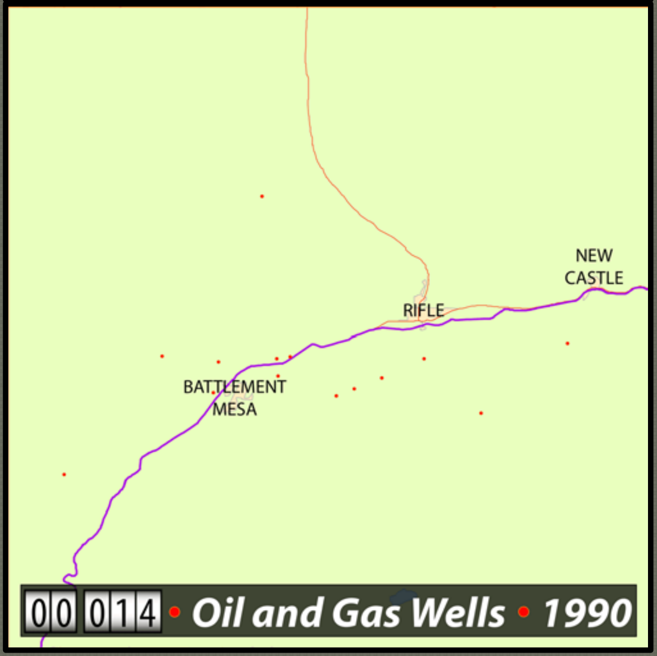
76% of simulated values within a factor of 3 of the observation

Colorado Oil and Gas



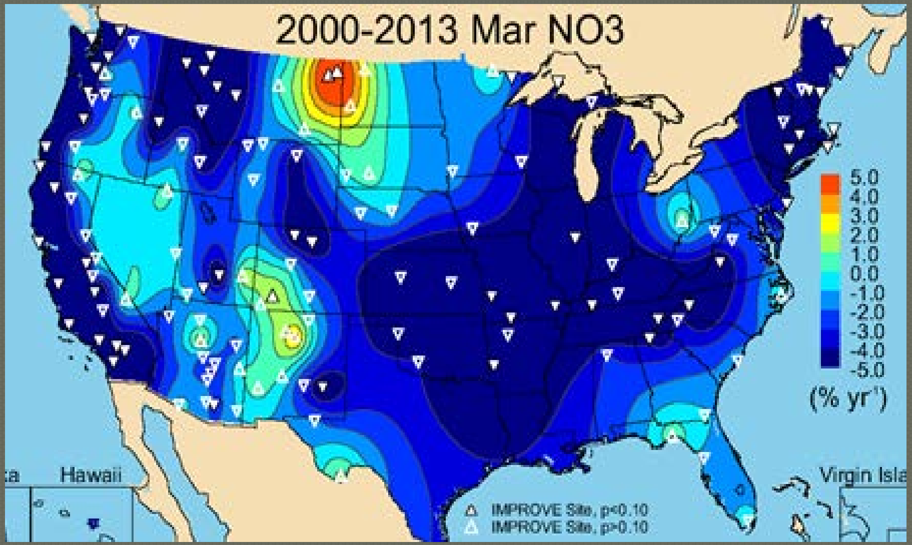
- Characterization of air toxics, ozone precursors, and CH_4 emissions
  - Garfield County
  - North Front Range





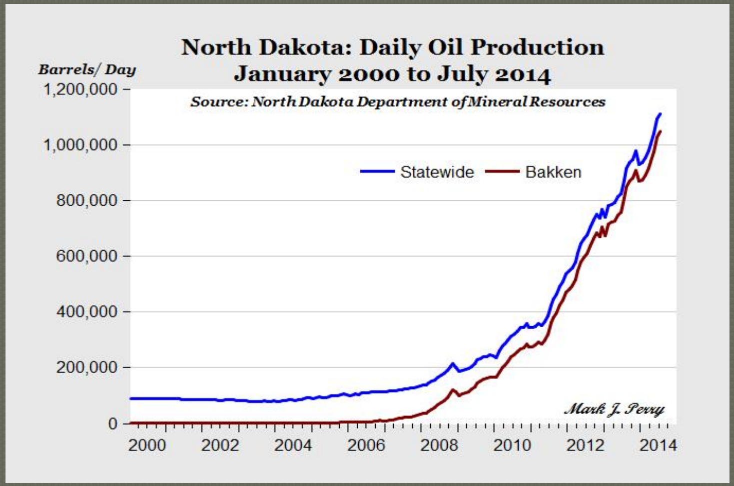
Maps produced by Center for Western Priorities

$PM_{2.5}$ nitrate concentration trends

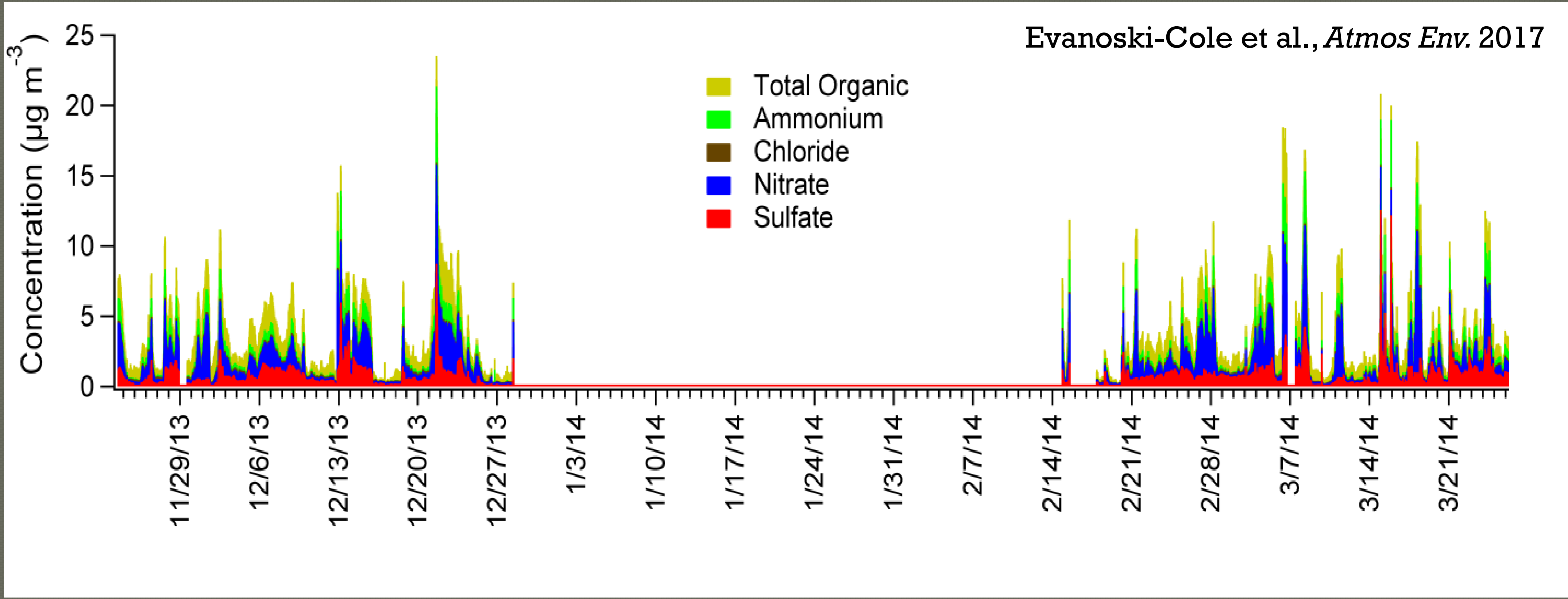


- NO_x emissions reductions greatly reduced $PM_{2.5}$ nitrate in much of U.S.
- Increasing winter nitrate in some regions

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



Bakken haze episodes



- Ammonium nitrate particles dominate winter haze
- Key ingredients are NO_x and ammonia