Characterizing Air Emissions from Natural Gas Drilling and Well Completion Operations in Garfield County, CO

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Final study presentation
prepared for the
Garfield County Commissioners
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Oil and gas development

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Improvements in horizontal drilling and hydraulic fracturing techniques have greatly expanded U.S. oil and gas production

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

Colorado oil and gas

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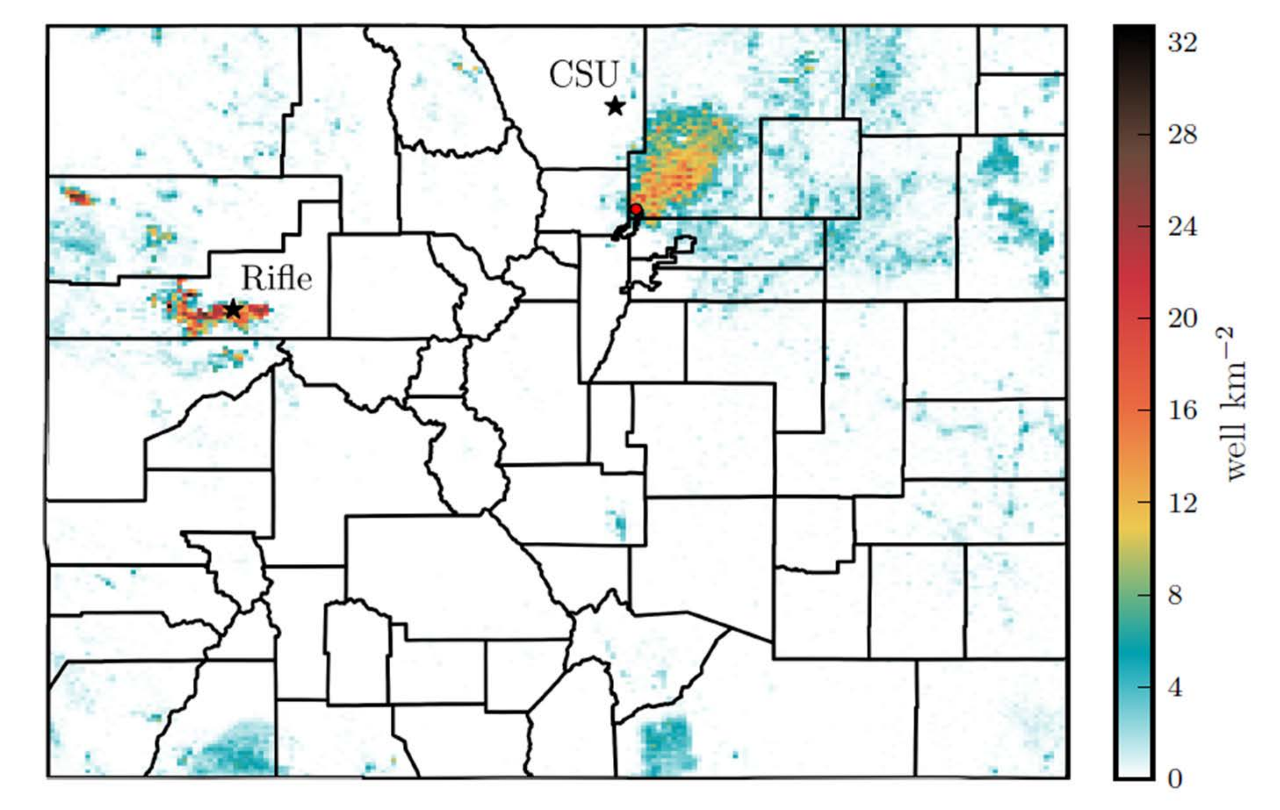
Much of the Colorado development has occurred in Weld (Denver-Julesburg Basin) and Garfield (Piceance Basin) counties.



Source: Landan MacDonald, M.S. thesis, Colorado State University, 2015

Potential air quality impacts

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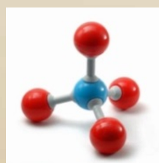
- While natural gas offers a cleaner-burning alternative to combustion of other fossil fuels, air pollutant emissions are associated with its production and distribution
- Climate
  - CH_4



- Ozone
  - (VOC + NO_x + ) → O_3
- Air toxics
  - VOCs such as BTEX (benzene, toluene, ethylbenzene, xylenes)

VOCs are volatile organic compounds

Garfield County study

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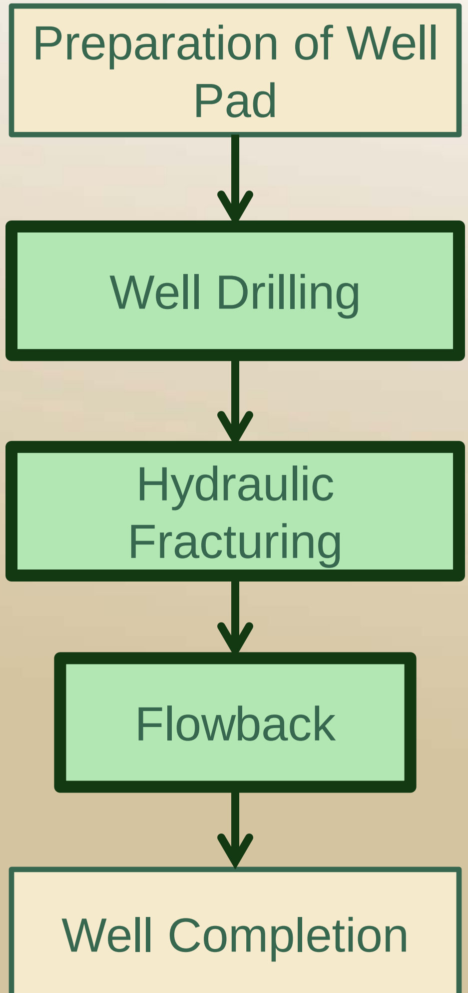

Objectives

- Quantify emissions of chemical compounds (air toxics, ozone precursors, and methane) during new well development
- Characterize how these compounds are dispersed in the atmosphere downwind of the site
- Produce a peer-reviewed, public dataset of high quality emissions data

Source of Figures: http://lingo.cast.uark.edu/LINGOPUBLIC/natgas/wellprep/index.htm

Study partners

Colorado State University

- Study team
  - Colorado State University
    - Jeff Collett, PI
    - Jay Ham, co-PI
    - Arsineh Hecobian, Project Manager
  - Air Resource Specialists, Inc.
- Technical Advisory Committee
  - Representatives from industry, CDPHE, USEPA, NCAR, BLM
- Operations Committee
- Sponsors
  - Garfield County
  - Industry

Encana Corporation	WPX Energy
Bill Barrett Corporation	Ursa Resources Group
Caerus Oil and Gas	Laramie Energy

CSU research team

Prof. Jeff Collett (PI)

Prof. Jay Ham (co-PI)

Prof. Jeff Pierce (co-I)

Dr. Arsineh Hecobian (Project Manager)

Dr. Andrea Clements (Postdoc)

Ms. Kira Shonkwiler (Research Associate)

Dr. Yong Zhou (Research Scientist)

Dr. Yury Desyaterik (Research Scientist)

Mr. Landan MacDonald (MS student)

Mr. Brad Wells (MS student)

Ms. Noel Hilliard (MS student)

Study timeline

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- CSU approached about possible study in Sept. 2011
  - Technical Advisory Committee constituted spring 2012
- Proposal submitted May 2012
  - Aug. 2012 Citizen Group meeting and presentation to County
- 3 year project plan (Nov. 2012-Dec. 2015)
  - Extended through spring 2016 due to decreased drilling and completions activity
  - $1.8M original budget
    - $1M Intergovernmental Agreement with Garfield County
    - $700K provided (as gift support) by industry partners

Hallmarks of the study

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- University/public/industry partnership
  - Objective, scientific approach
  - Full site access and activity information
- Novel focus on new well development
  - Drilling, hydraulic fracturing, and flowback
- Novel focus on air toxics, ozone precursors, and methane
- Designed to quantify emissions rather than just measuring concentrations
  - Provides information needed for use in subsequent health and air quality impact assessments

Why measure emissions?

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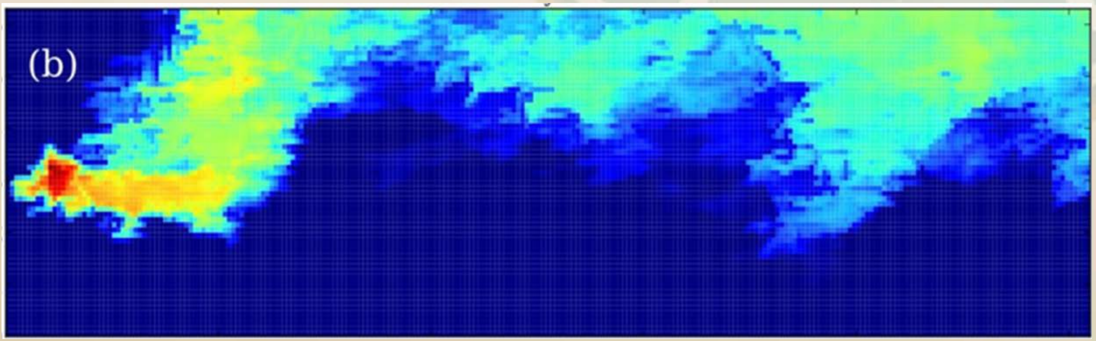
- Emissions are the amount of material emitted by an activity per unit time (e.g., grams per second)
- Air pollutant concentrations depend on
  - Emissions
  - Location
  - Weather conditions



- While concentrations are much easier to measure, they provide information only for a single place and time
  - A concentration measured today gives little predictive value for concentrations in the future or at another location

Why measure emissions?

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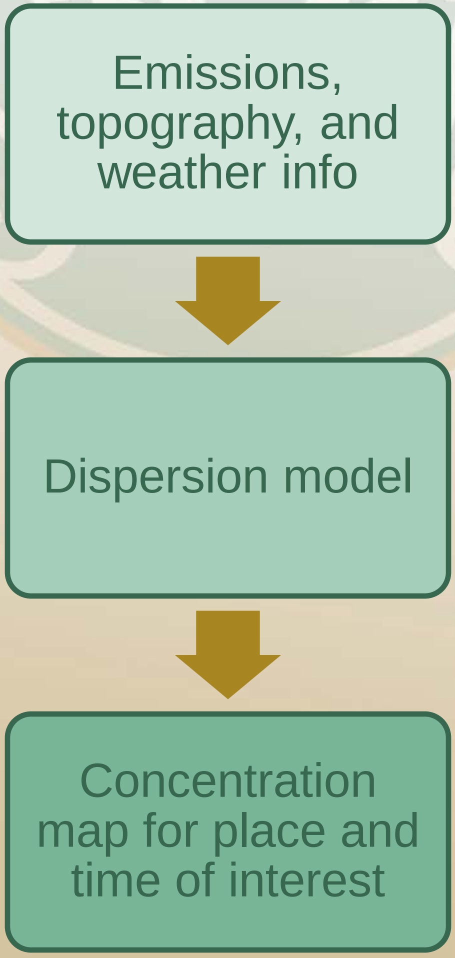
- Accurately determining emissions is the key to predicting impacts at any place and time
- Atmospheric dispersion models can be used to simulate 3D maps of concentration from input of
  - Emissions
  - Topography
  - Weather conditions
- One can then predict
  - Air pollution exposure and associated health risks
  - Impacts on regional air quality, including ozone formation
  - Climate impacts from methane emissions



Overall study approach

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- Method selection and validation
- Identify upcoming drilling, fracking, and flowback activities
- Select activities for sampling
  Conduct field measurements to quantify air pollutant emissions
- Analyze data and summarize emissions by activity
- Use field observations to test dispersion model performance
- Prepare final dataset for public release and use in upcoming CDPHE health risk assessment

Emissions characterization

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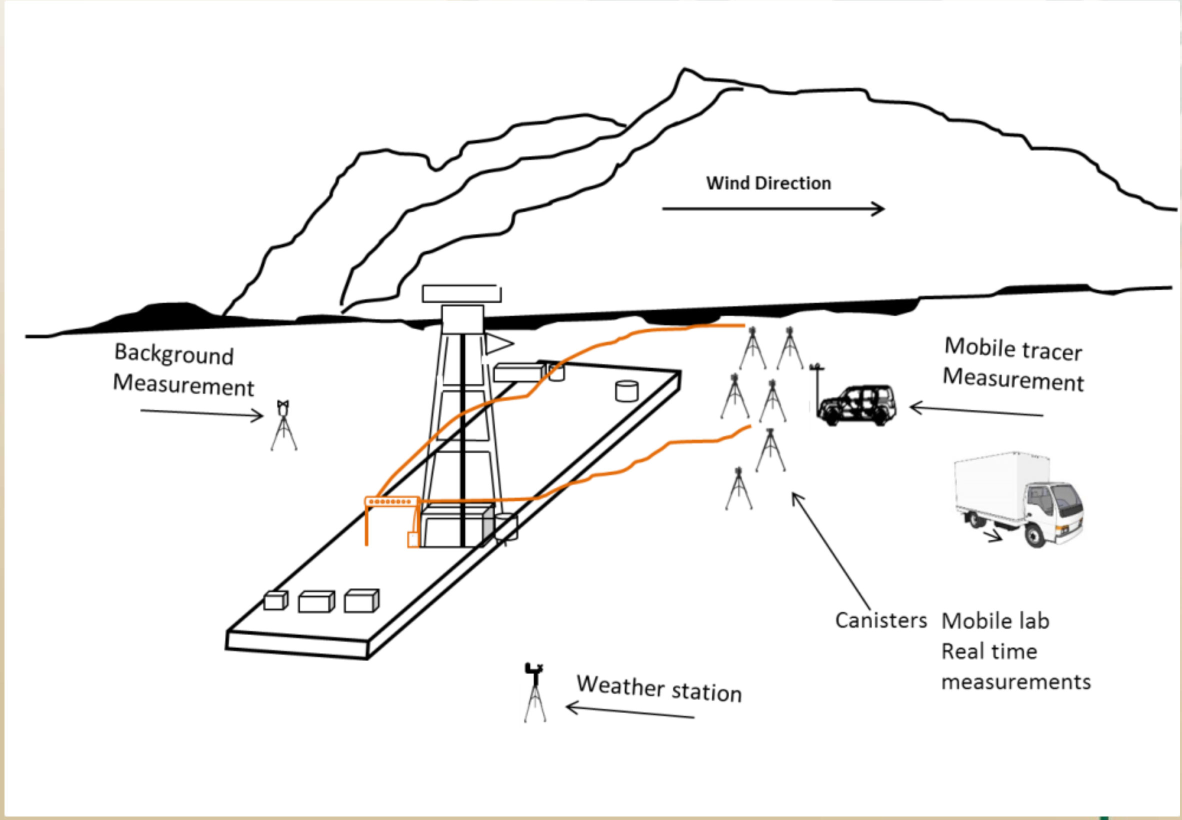
- Locate and sample plume of emissions coming from on-pad activities
- Use combination of time-integrated and continuous measurements to observe temporal and spatial variability
- Mobile and fixed sampling platforms



Study measurements

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Mobile 4WD Plume Tracker

- Acetylene (tracer)
- CH_4
- Met
- GPS

CSU Mobile Lab

- VOCs
- NO_X
- CO
- WD & WS data

Integrated Measurements

- VOCs
- Acetylene

Meteorological Measurements

- Temp.
- RH
- Wind Direction
- Wind Speed

Meteorological measurements

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- Meteorological measurements help predict plume location and are used as dispersion model input
- Tripod met stations with sonic anemometers
- Crank up tower to collect data at 3 and 10 m

Mobile methane and plume tracer measurements

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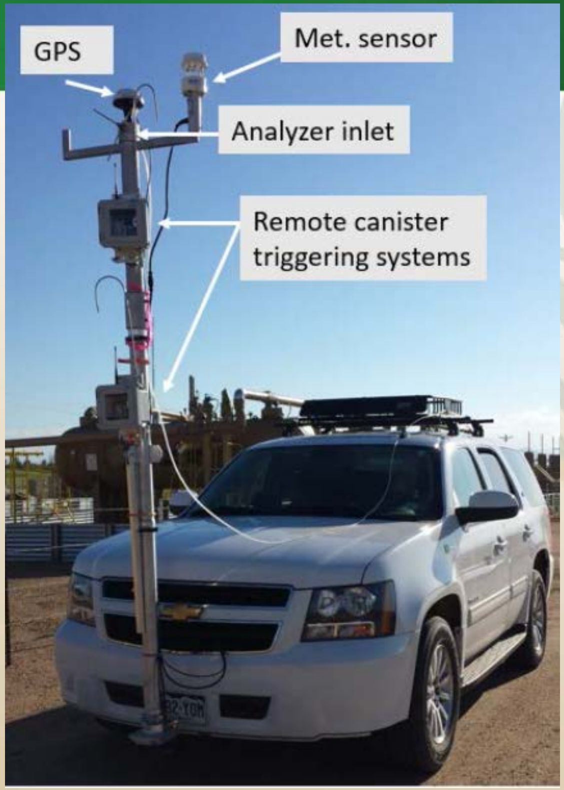
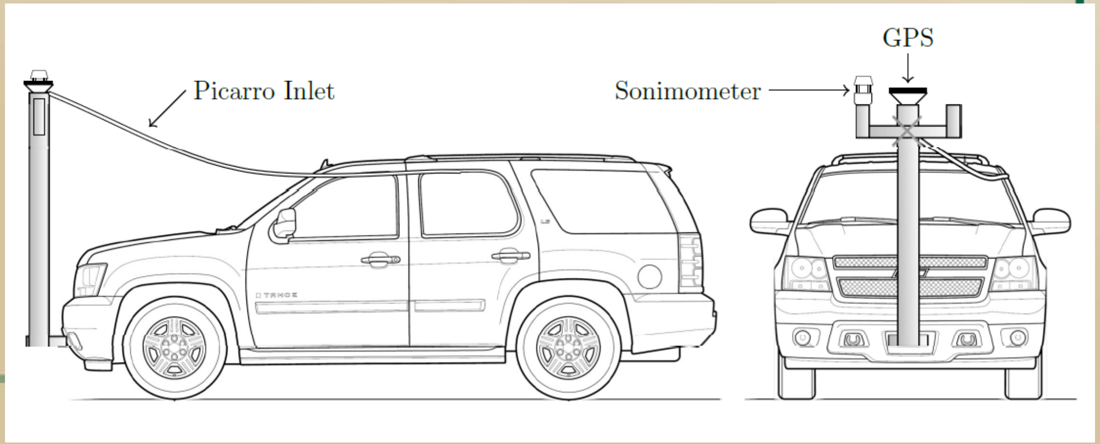
- Hybrid SUV equipped with instruments to continuously measure
  - Position
  - Winds
  - Methane
  - Plume tracer (acetylene)
- Locate and sample plume





VOC sample collection

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- Volatile organic compounds (VOC)
  - Air toxics, ozone precursors, and acetylene tracer
  - Collected using Silonite® coated canisters

VOC measurements (offline)

Colorado State University

- Volatile organic compounds (VOC)
  - Air toxics, ozone precursors, and acetylene
  - Gas chromatography analysis
  - 48 compounds typically quantified

VOC measurements (online)

Colorado State University

- CSU Mobile Lab
  - Real time measurements of VOCs using PTR-MS
  - Real time measurements of NO_X, CO, and O_3
- Hand-held ppb-RAE 3000
  - Total VOC measurements
  - Used to confirm major source locations on well pad

Typical field configuration

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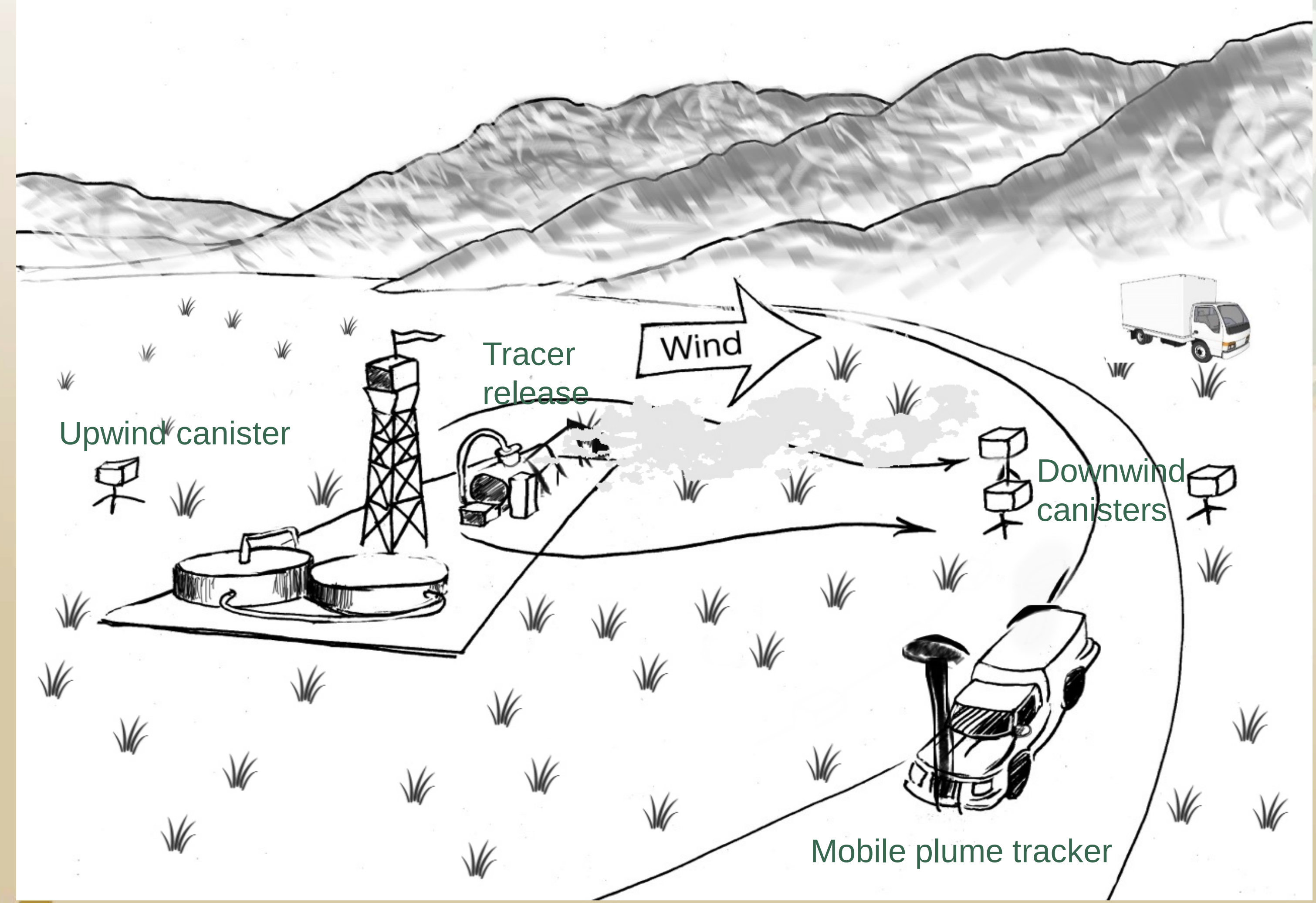
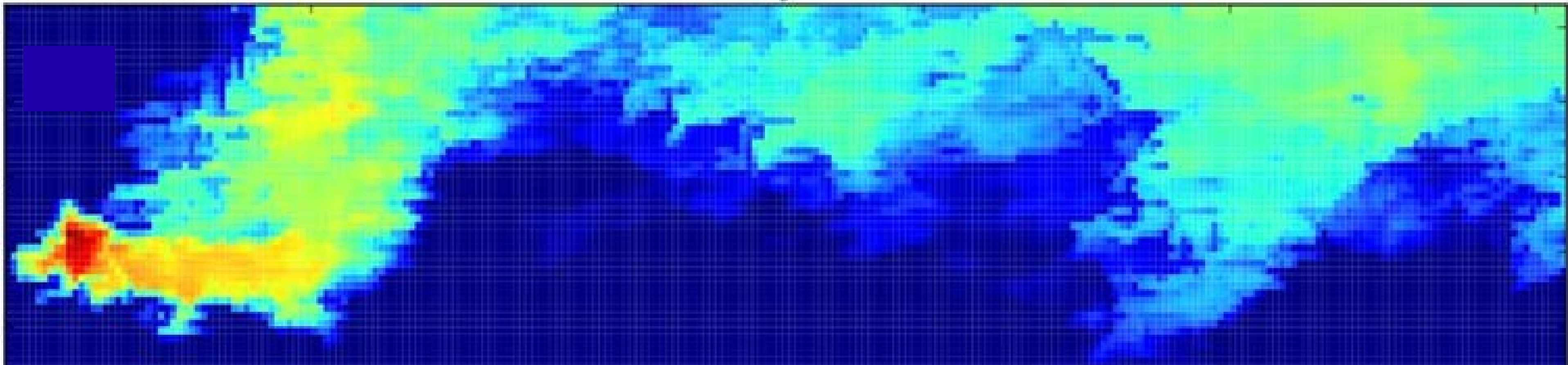
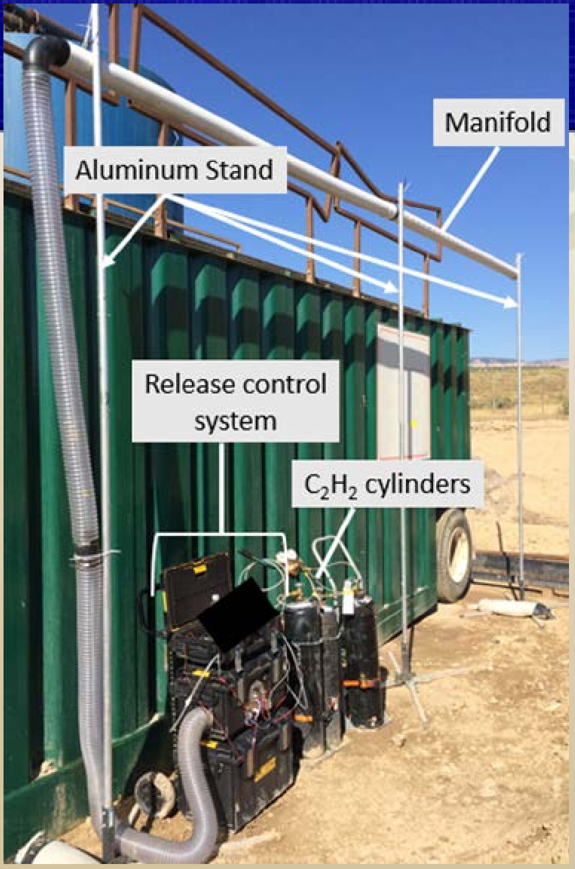
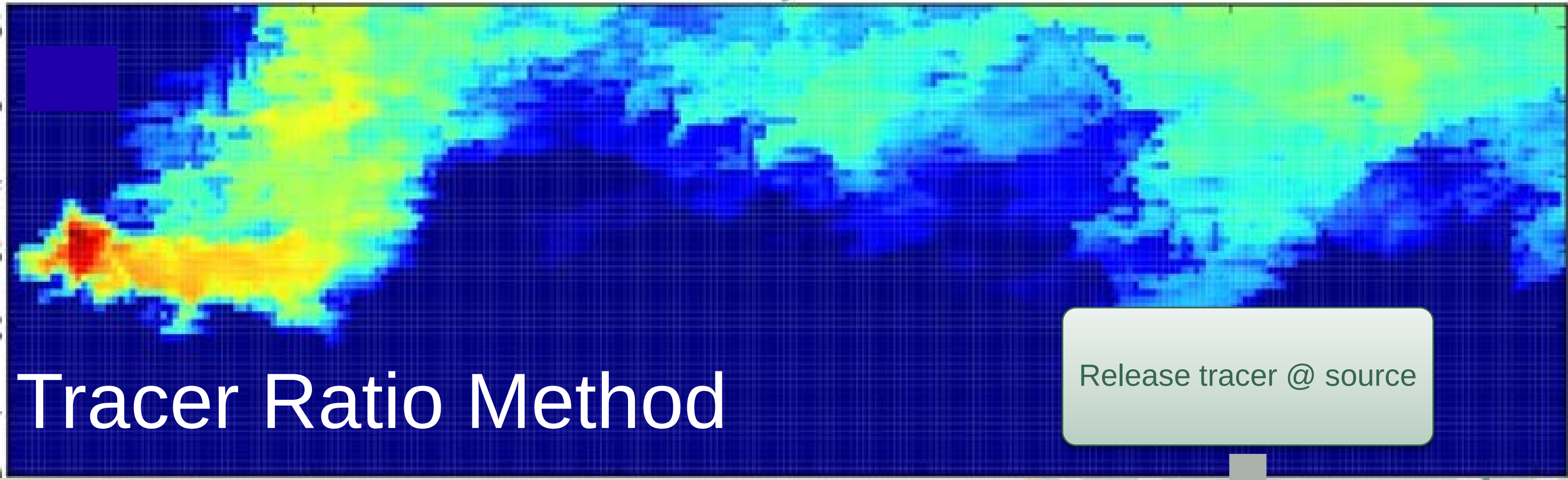




Tracer Ratio Method

- Approach
  - Release tracer at known rate
  - Tracer is carried downwind with source plume and identifies its location
  - Dilution of tracer accounts for complex source plume dispersion
  - The emission rate ratio of a target VOC and the tracer is equal to the background-corrected ratios of their concentrations





Tracer Ratio Method

- Key Assumptions
  - Release point for tracer is same as for VOCs
  - Same processes transport tracer and VOCs
  - No chemical transformation
- Key Advantages
  - Don’t need to capture entire plume
  - Works in complex terrain

Release tracer @ source

Confirm plume trajectory with in situ measurement of tracer and CH_4

Position VOC canister samplers and “arm”

Trigger sampling remotely when wind conditions optimal

Field validation of tracer ratio method

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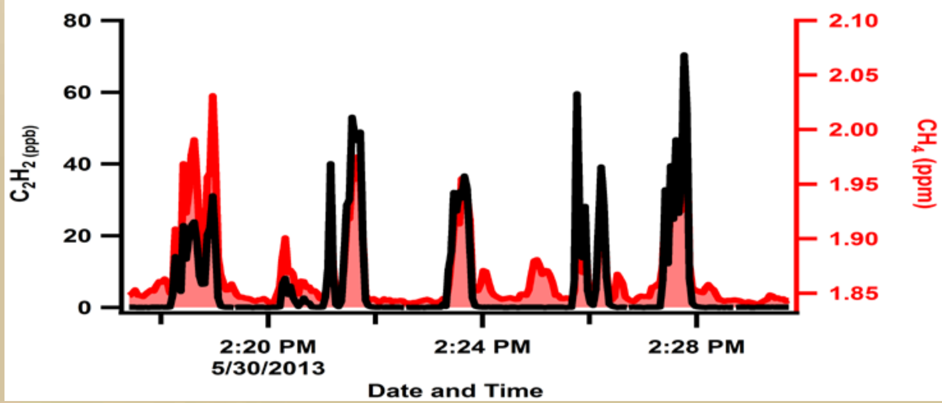
Co-located release of tracer gas (acetylene) and methane

Christman Field, Fort Collins, CO

- Emit acetylene and methane at known rates
- Observe downwind concentrations of acetylene and methane
- Determined accuracy (23%) and precision (17%) of tracer ratio method



Field study summary

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Operation type	Number of emission experiments
Drilling	5
Hydraulic fracturing	5
Flowback	6
Remote fracking	1
Fracking/flowback	2
Drilling/fracking/flowback	1
Fracking/workover/flowback	1

Measurements were completed during 2013-15

Measured emissions include all activities occurring on the pad

Methane emissions

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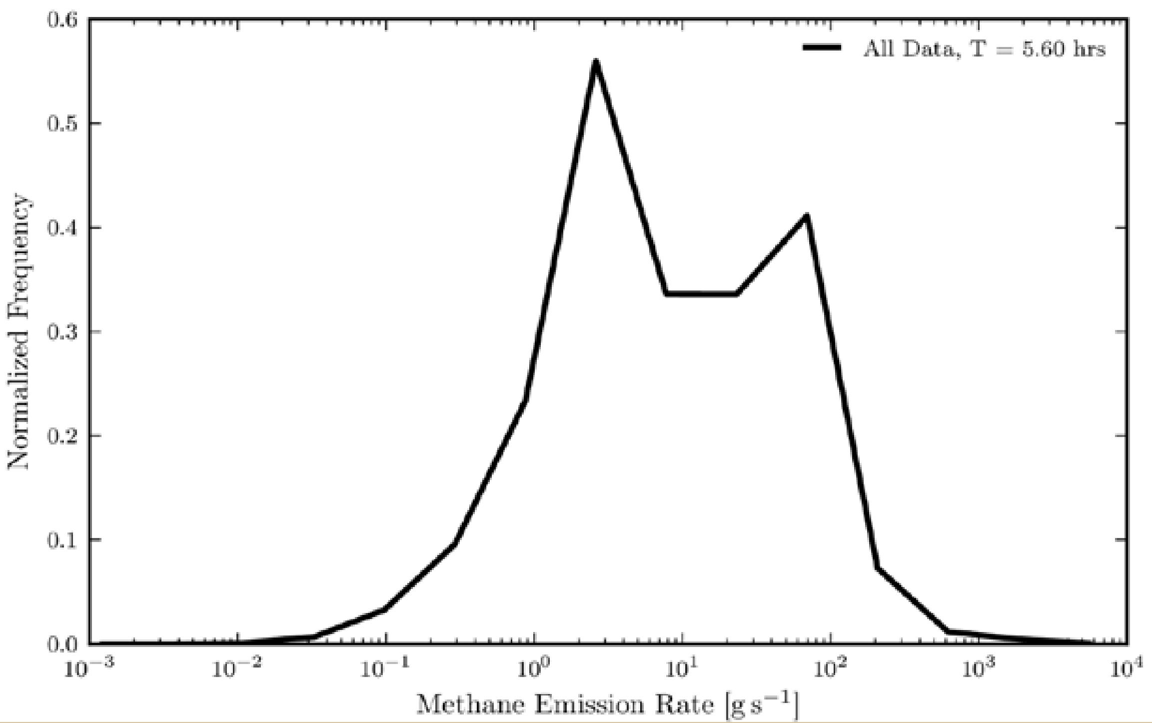
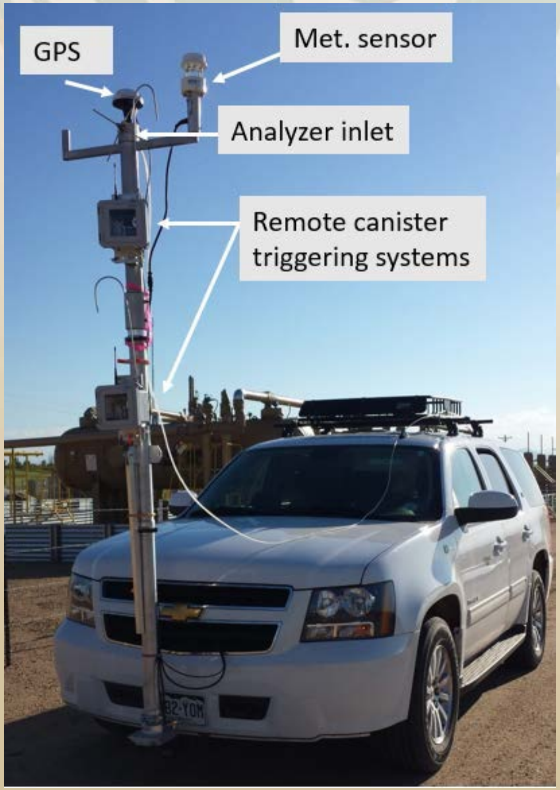
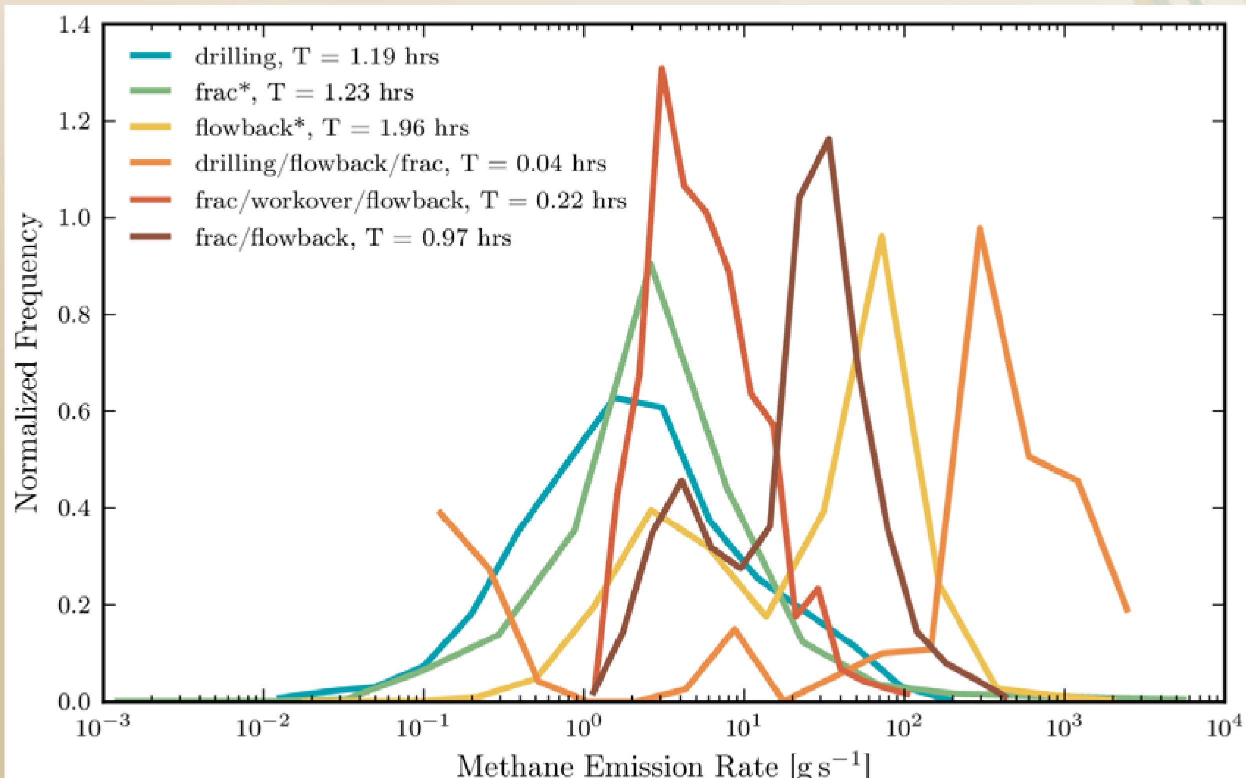
- Methane and acetylene tracer concentrations measured 3 times per second





Methane emissions

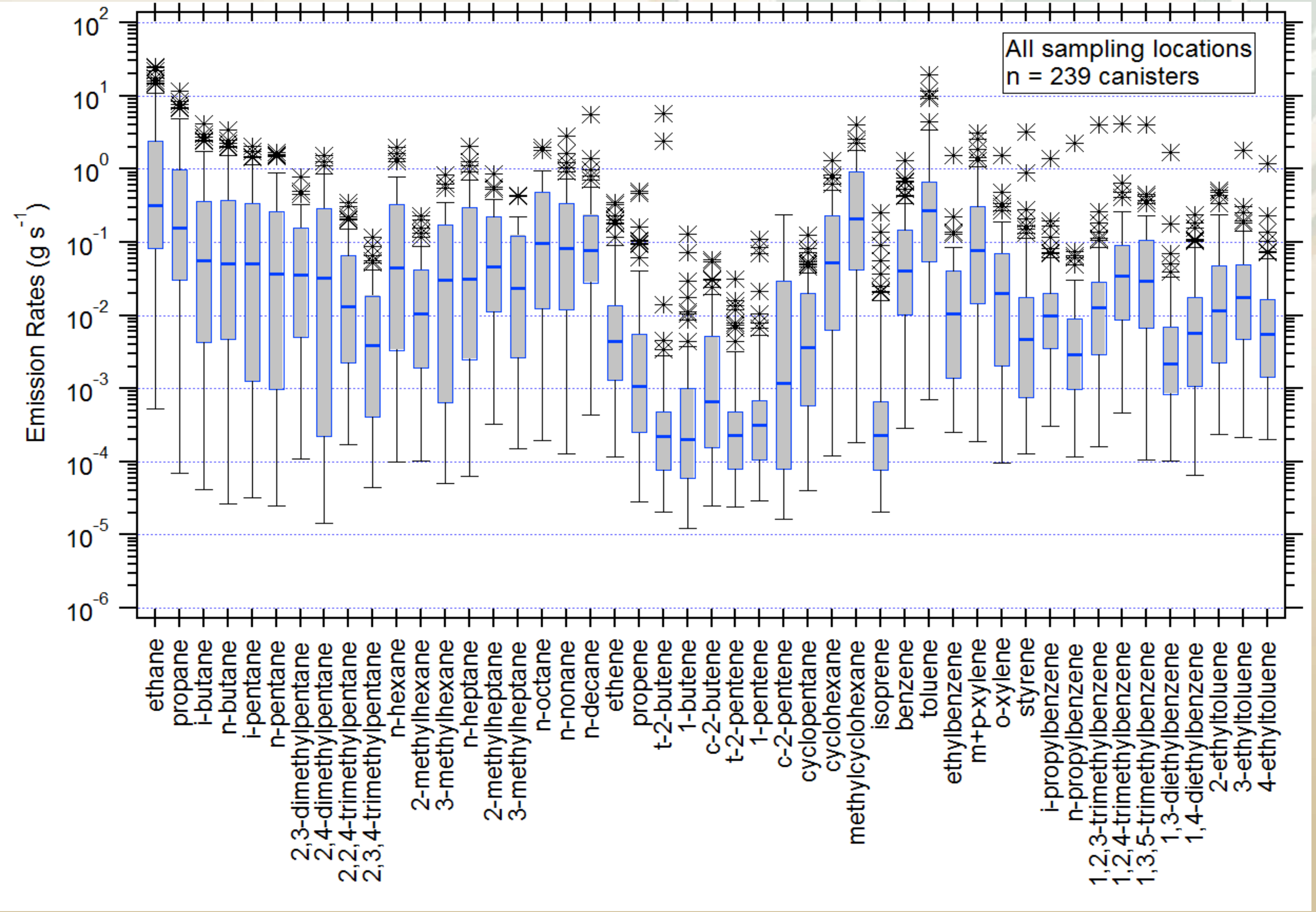
- Methane emissions during flowback typically much larger than fracking and drilling emissions



Activity	Median emission rate (g/s)
Drilling	2.0
Fracking	2.8
Flowback	40

VOC emissions

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



Some VOCs of interest

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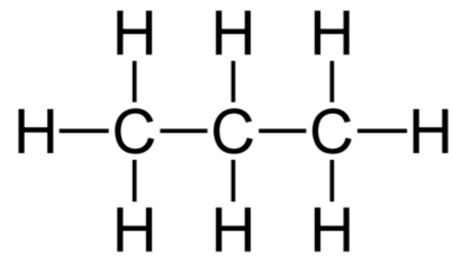
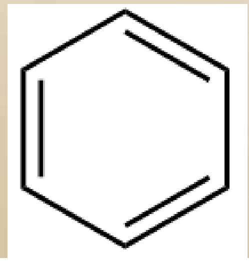
- Alkanes – ethane, propane, butane, pentane, etc….
  - Smaller alkanes are important constituents of natural gas
  - Not a major direct health concern
  - React slowly, but can be important contributors to ozone production when abundant
- BTEX – benzene, toluene, ethylbenzene, xylenes
  - Air toxics → possible health concern
  - Can be emitted from oil and gas deposits and from combustion processes

C_3H_8
Propane





Benzene C_6H_6

VOC emissions summary

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- Methane emissions are most abundant followed by light alkanes (ethane and propane) and toluene

	Drilling Median (g s^{-1})	Fracking Median (g s^{-1})	Flowback Median (g s^{-1})
Methane	2.0	2.8	40
Ethane	0.13	0.088	0.93
Propane	0.12	0.013	0.37
i-Pentane	0.0070	0.00041	0.11
n-Pentane	0.0026	0.00027	0.081
Benzene	0.0037	0.029	0.062
Toluene	0.088	0.12	0.24
Ethylbenzene	0.00086	0.011	0.017
m+p-Xylene	0.0026	0.12	0.16

Alkane emissions by activity

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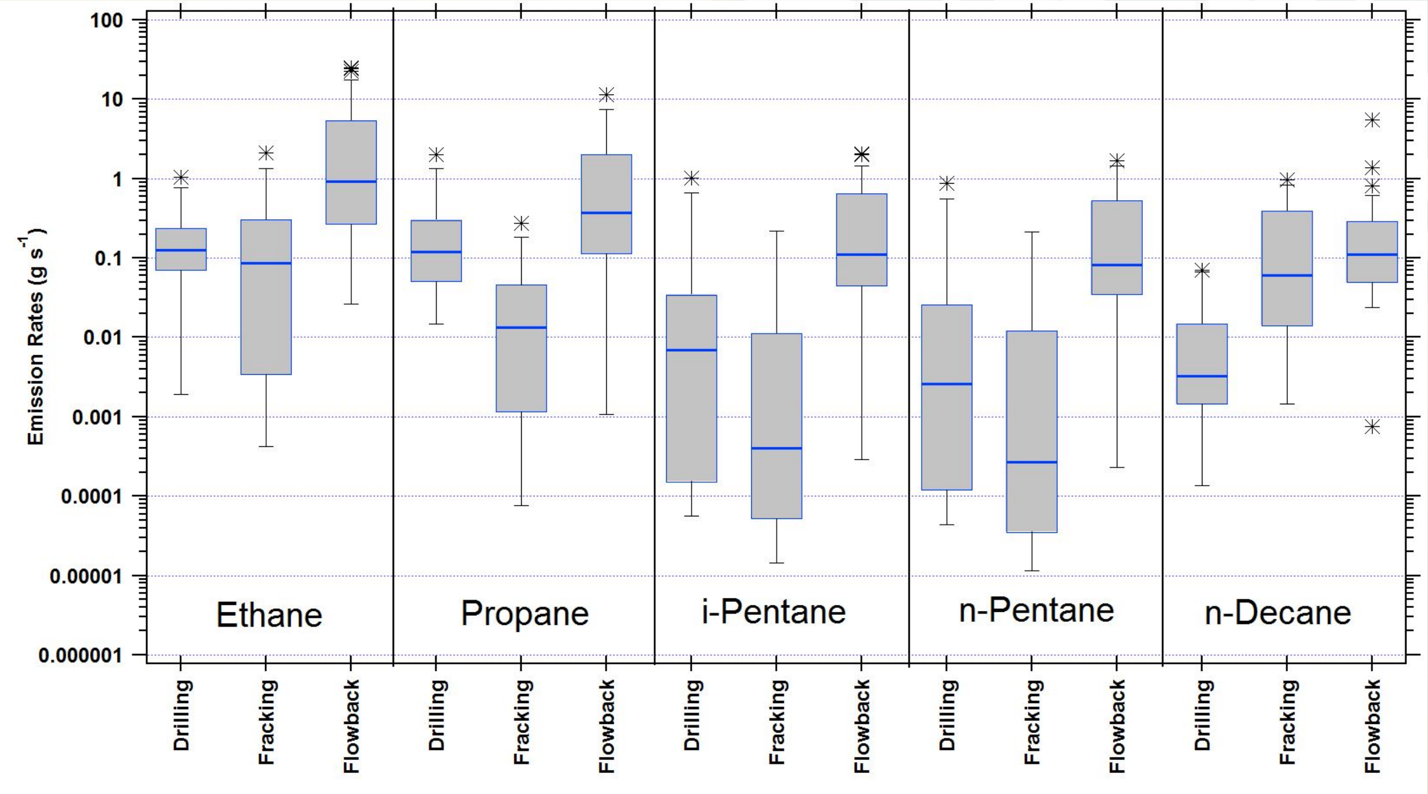
- Ethane and propane are most abundant emission components
- Flowback has highest median alkane emissions
  - similar to methane finding



BTEX emissions by activity

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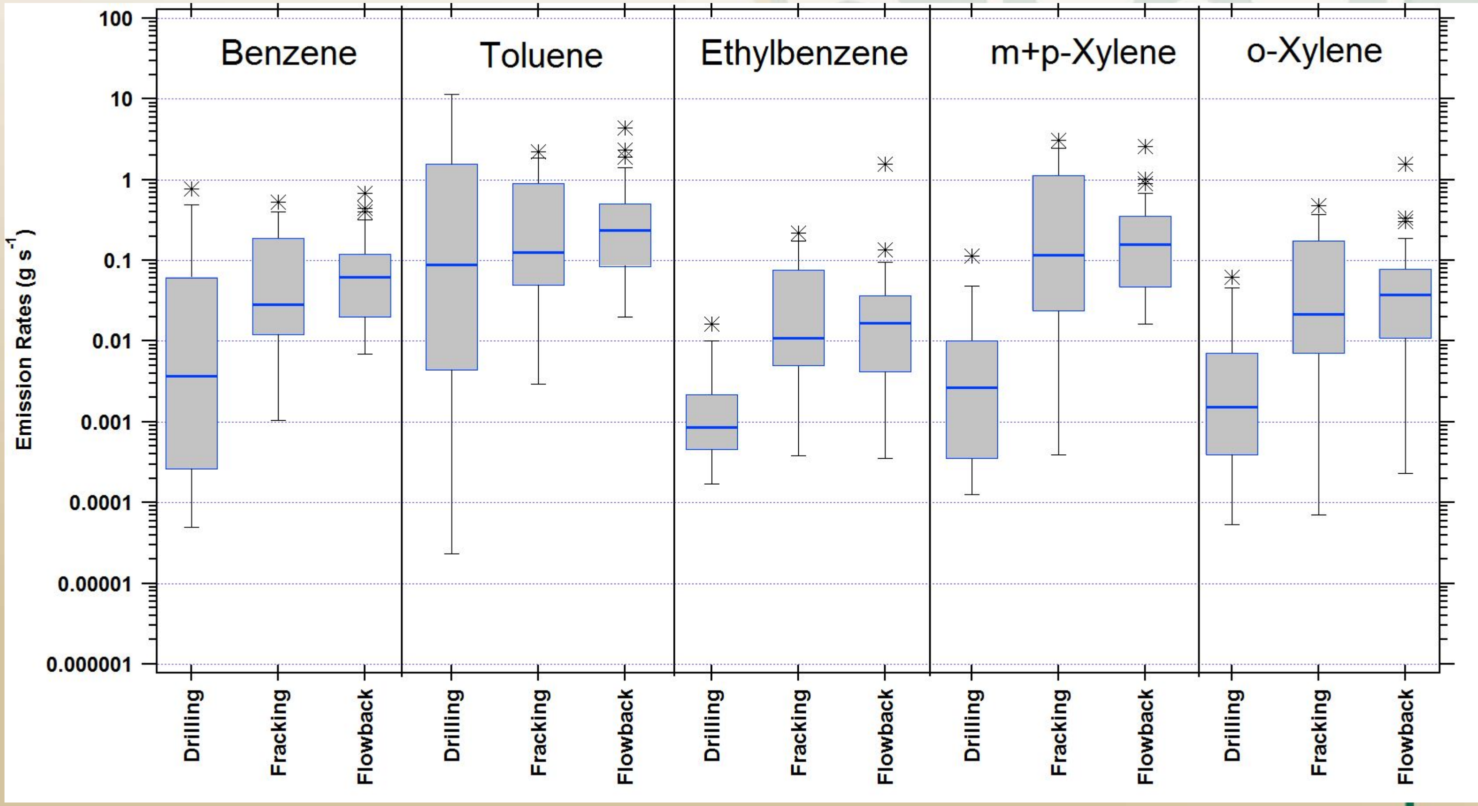
- Toluene is the most abundant emission component
- Flowback has highest median BTEX emissions
  - similar to methane and alkane findings



Dispersion model testing

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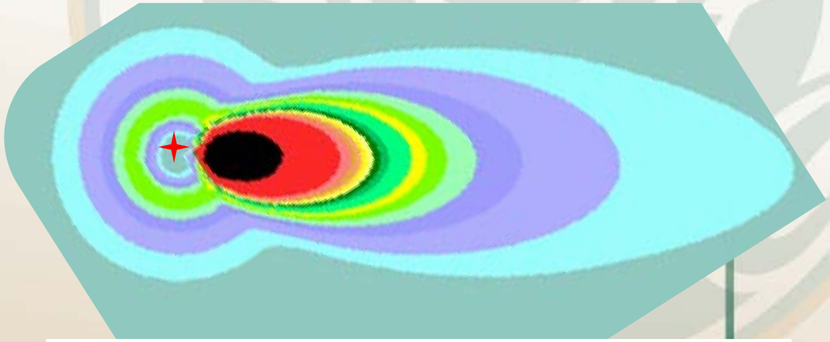
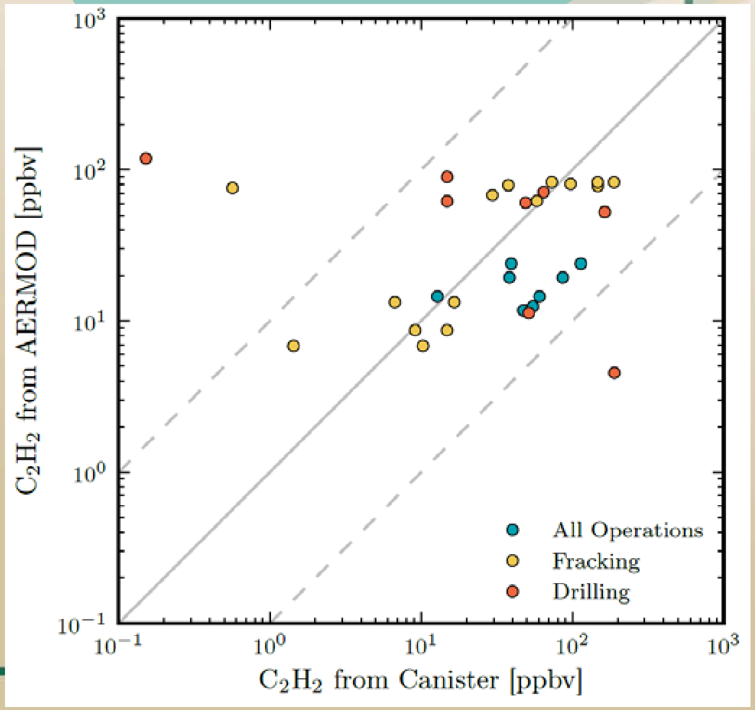
- EPA AERMOD dispersion model used to simulate concentration fields
- Model performance tested by comparing predicted and measured acetylene concentrations
  - Short-term simulations are challenging for a model like AERMOD
  - Model bias was low but scatter was moderate





Dispersion model simulations

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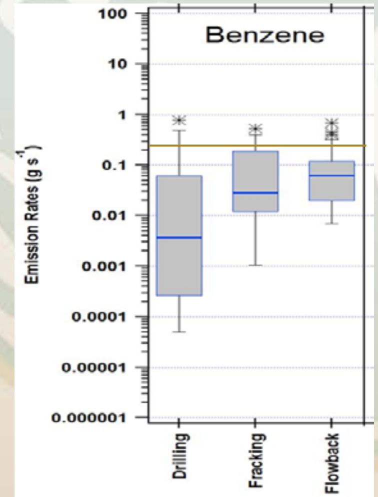
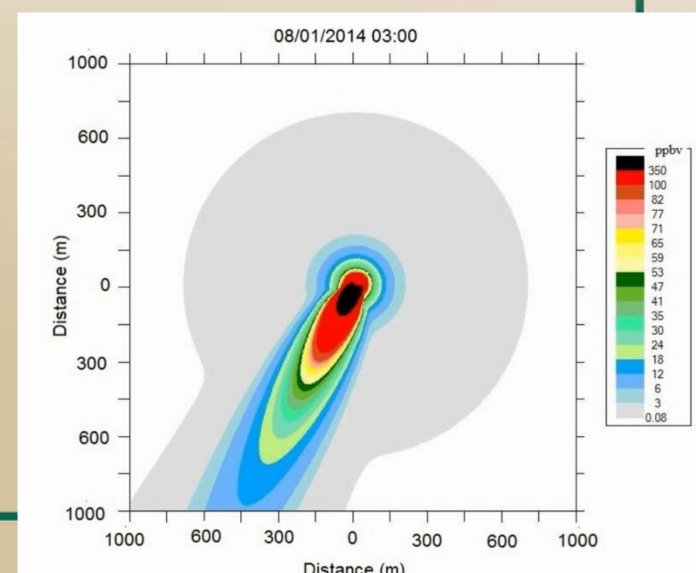
- EPA AERMOD dispersion model used to simulate concentration fields
- Model run hourly at example locations for all of 2014 using
  - Archived meteorological fields
  - 0.23 g/s benzene emissions (75th percentile of study benzene emissions was 0.14 g/s)
- Example here shows one day of hourly simulations for one location
  - Note large changes in emissions plume location, shape, and concentrations





Benzene hourly 0.23 g_s 20140801.wmv

Dispersion model simulations

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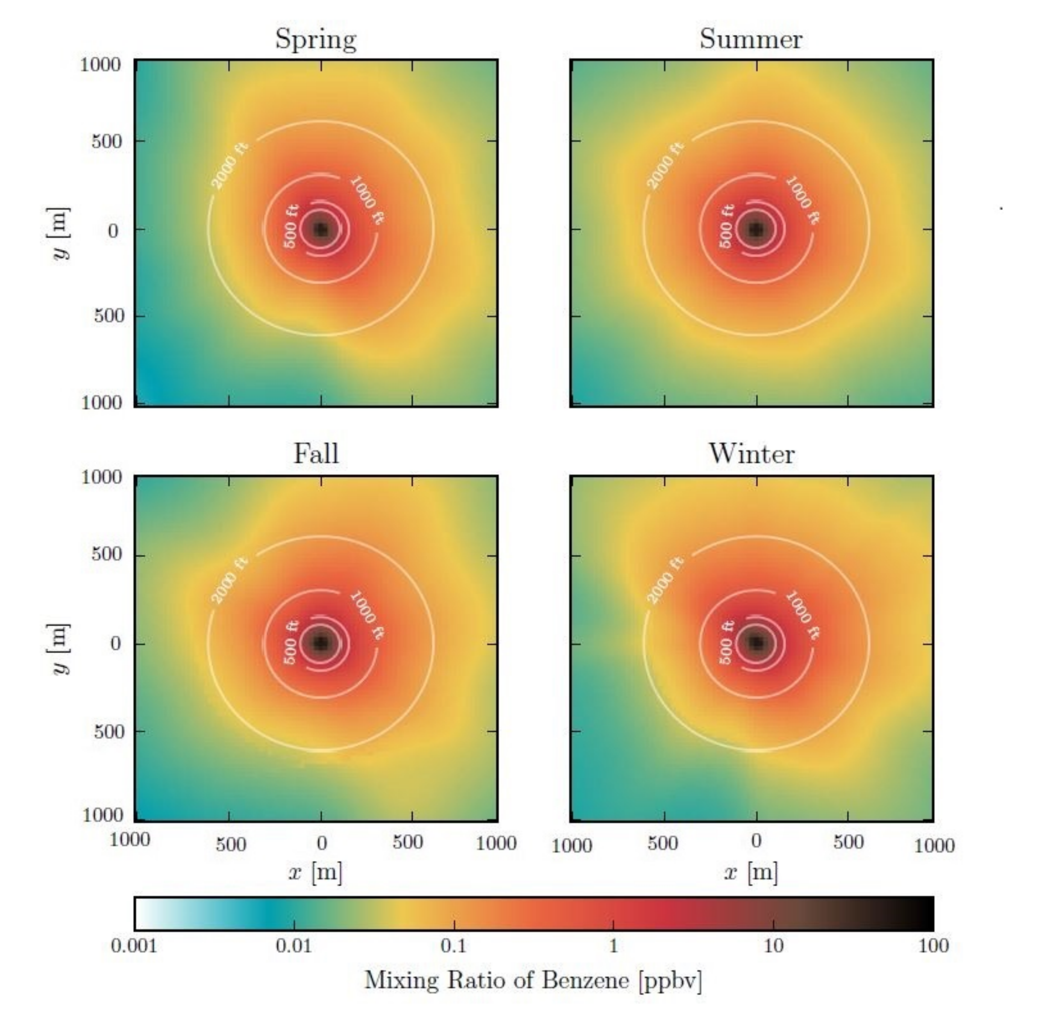
- A health risk assessment would likely run a longer scenario, varying weather conditions and emissions
- Here we show seasonal average benzene concentration maps for a simulation for all of 2014 with constant (high) 0.23 g/s benzene emissions



Dispersion model simulations

Colorado State University

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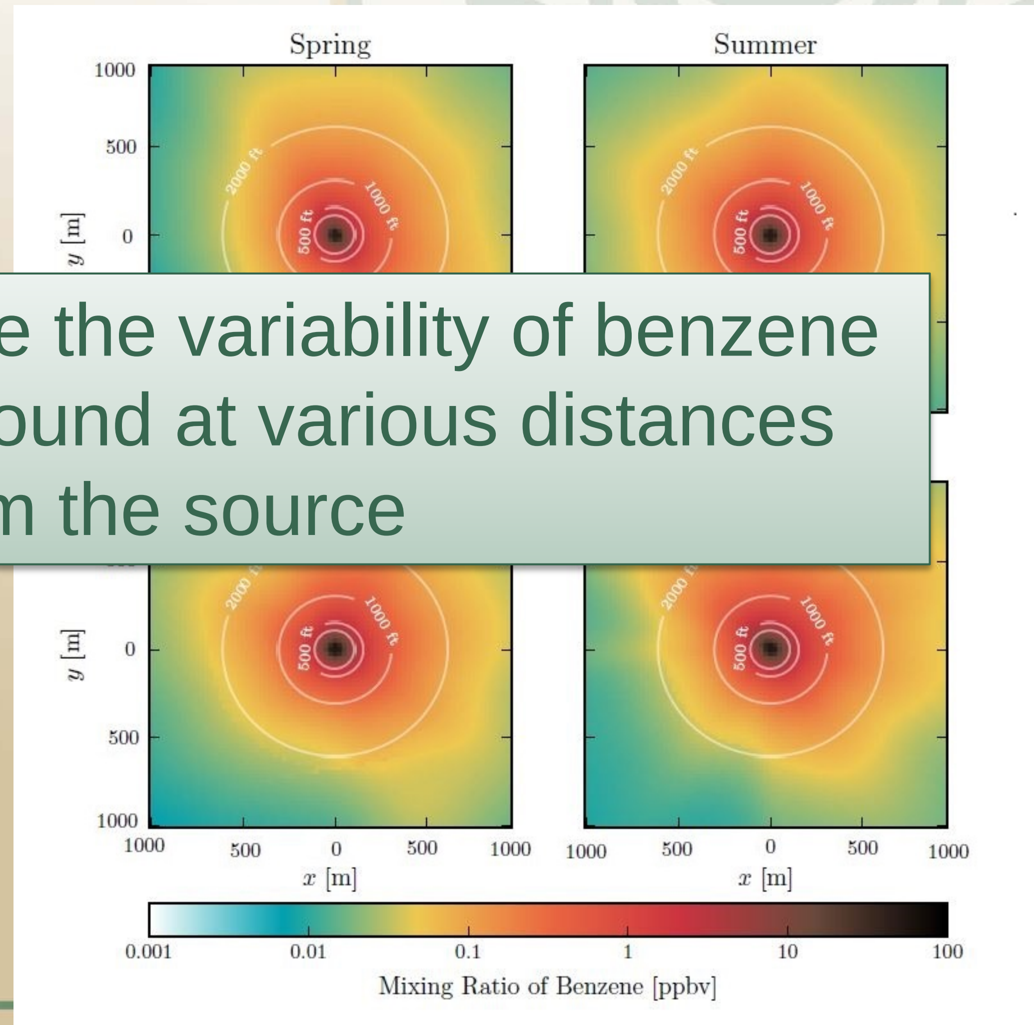

Let's now examine the variability of benzene concentrations found at various distances from the source

Concentration probabilities

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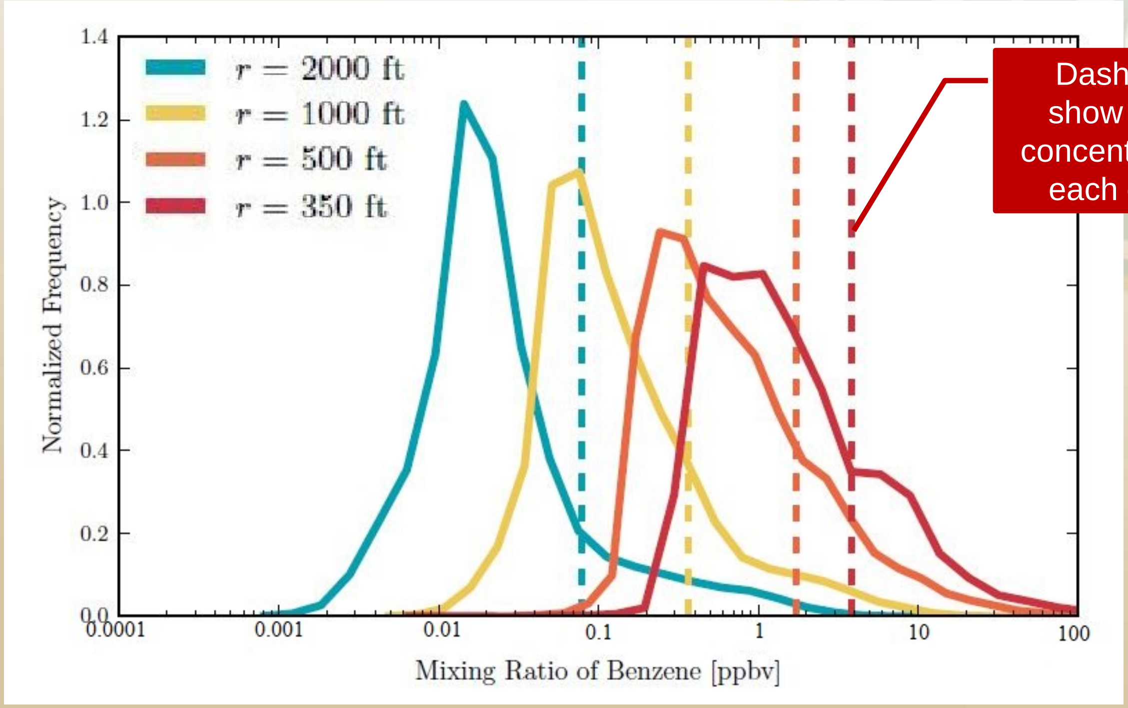
Distributions of simulated concentrations with distance for constant (high) 0.23 g/s benzene emissions and 2014 meteorology



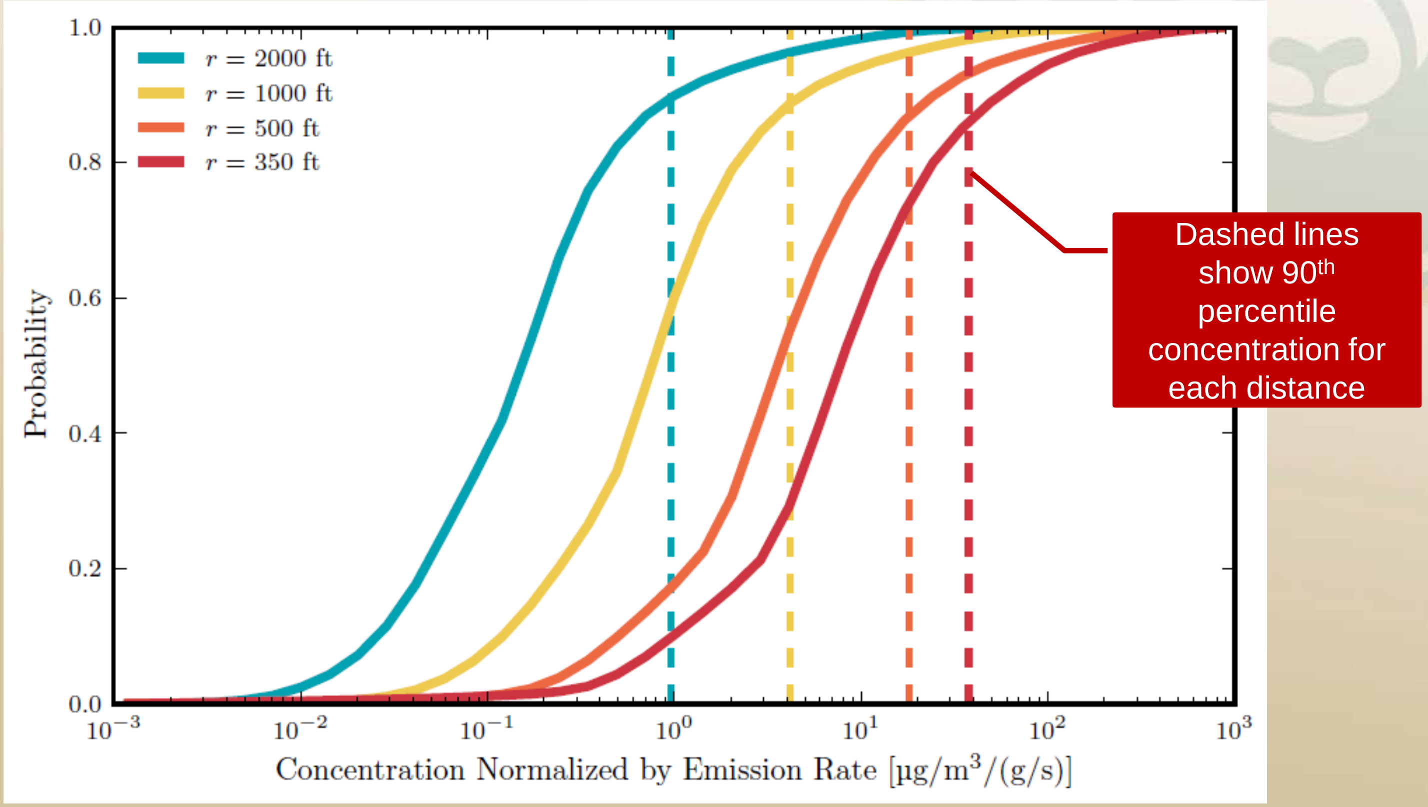
Dashed lines show average concentrations for each distance

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

Concentration probabilities

Colorado State University

These cumulative distributions, reflecting a year of dispersion simulations at several Garfield County locations, show the likelihood a concentration will fall below a given value (expressed per unit emission rate)



Example: at 350 feet distance for a study median benzene emission rate of 0.04 g/s, concentrations from a single well activity are expected to be <1.6 µg/m^3 (0.5 ppbv) 90% of the time

Next steps

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- Project final report will be made available on county website
- Full study dataset will be posted online approximately July 1 at CSU (http://hdl.handle.net/10217/172972)
- CSU preparing peer-reviewed journal articles on methane and VOC emissions
- CDPHE launching health risk assessment soon using CSU Garfield County and Front Range emissions study findings

Summary

Colorado State University

- Garfield County chartered a unique and much needed study of air pollutant emissions from natural gas development
  - Novel focus on emissions during **drilling and completions**
  - Novel focus on **air toxics, ozone precursor, and methane** emissions
  - Full **wellpad access** provided through active industry participation
- **Robust set of activity-specific emissions** are key to future assessment of health and air quality impacts of natural gas development
  - **CDPHE health study** will launch soon for Colorado
  - Study findings are eagerly awaited and will have **national impact**