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

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Potential air quality impacts of gas development

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

- Hazardous Air Pollutants/Air toxics, for example
  - Diesel particulate matter
  - Formaldehyde
  - Benzene, toluene, ethylbenzene, xylenes
- Criteria Pollutants
  - O_3 (VOC + NO_x + sunlight)
  - NO_2
  - $PM_{2.5}$
- Climate
  - CH_4
  - Black carbon

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

VOC and NO_x emissions contribute to O_3, fine particles

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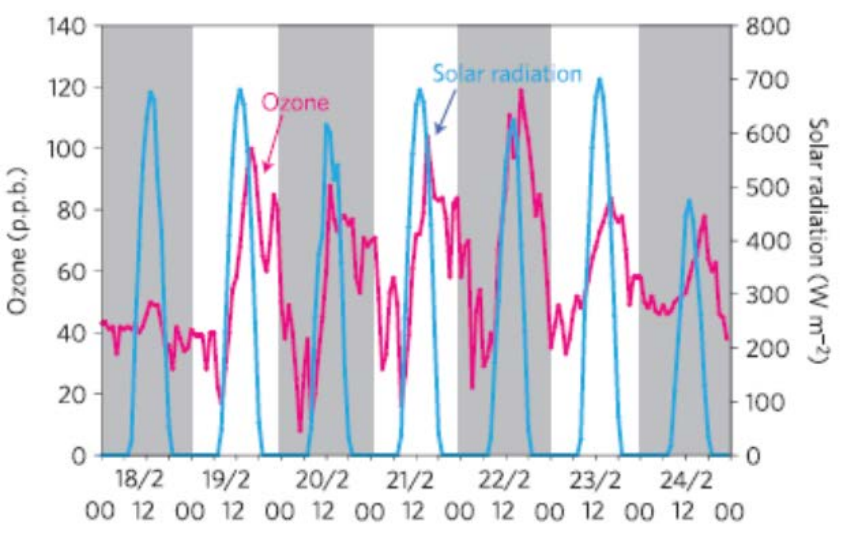
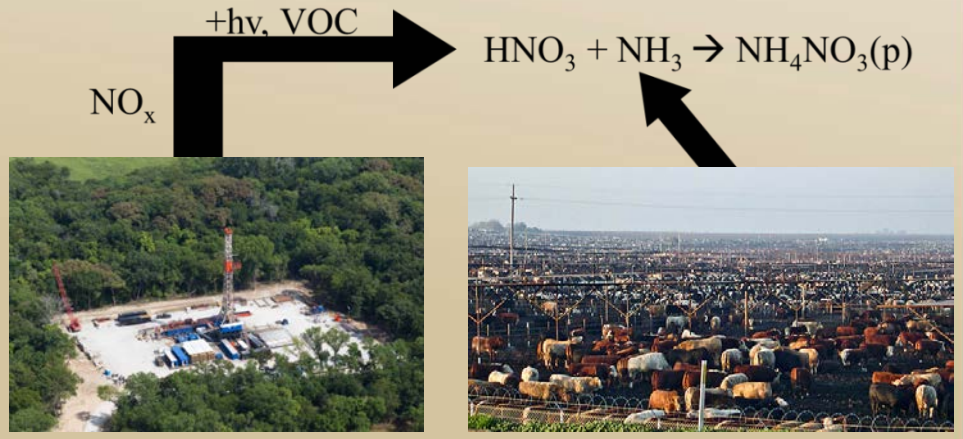


- Ground-level ozone (O_3) is formed by reactions of Volatile Organic Compounds (VOC) and Nitrogen Oxides (NO_x)

Schnell et al., 2009 – WY winter ozone

- NO_x is an important ingredient in fine particle and haze formation



Methane and climate

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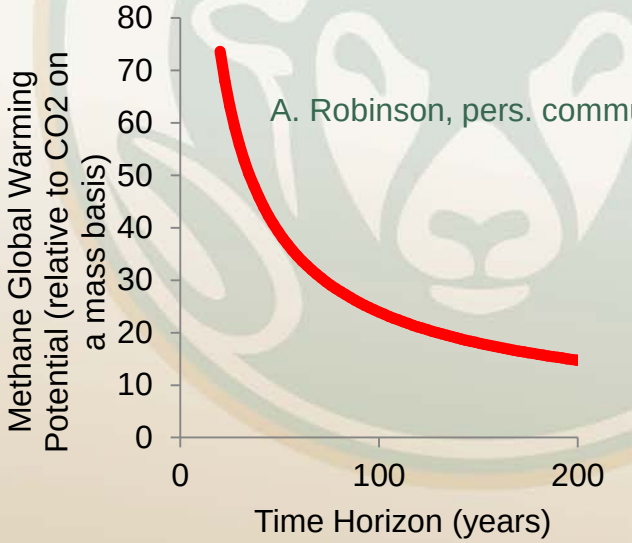
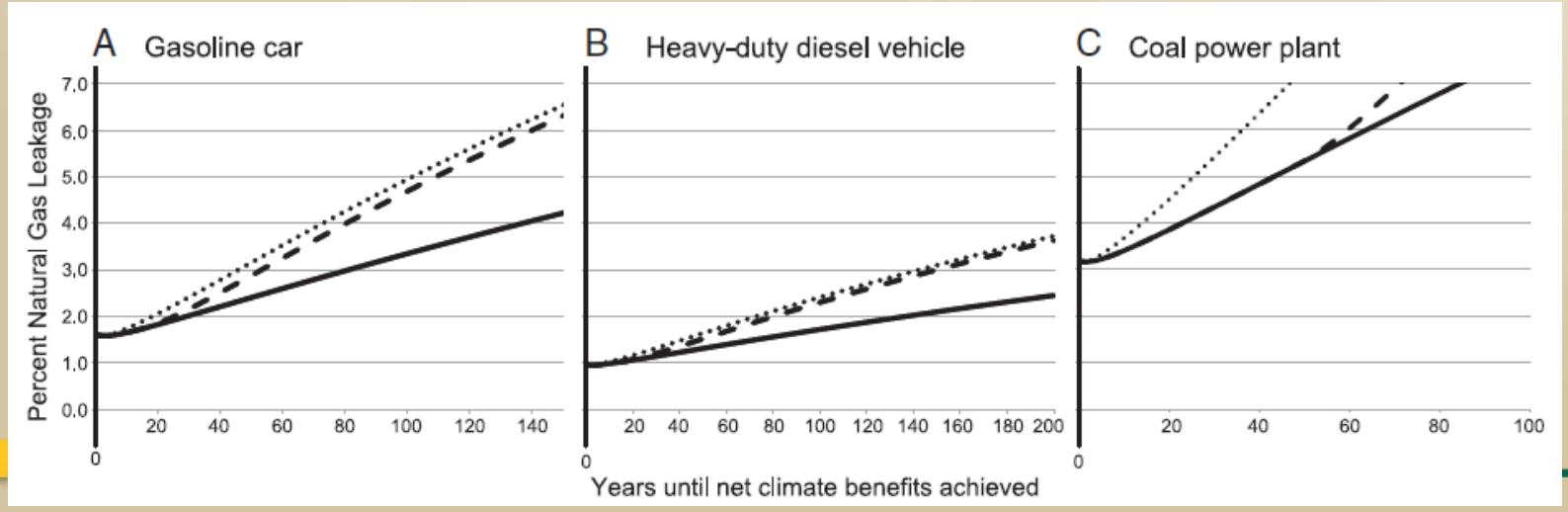
- Although natural gas use offers reduced carbon dioxide emissions, methane is a much more potent greenhouse gas

- Net climate benefit of fuel switching to natural gas depends on methane leakage and time horizon





Alvarez et al., PNAS, 2012

CSU air studies related to oil and gas development

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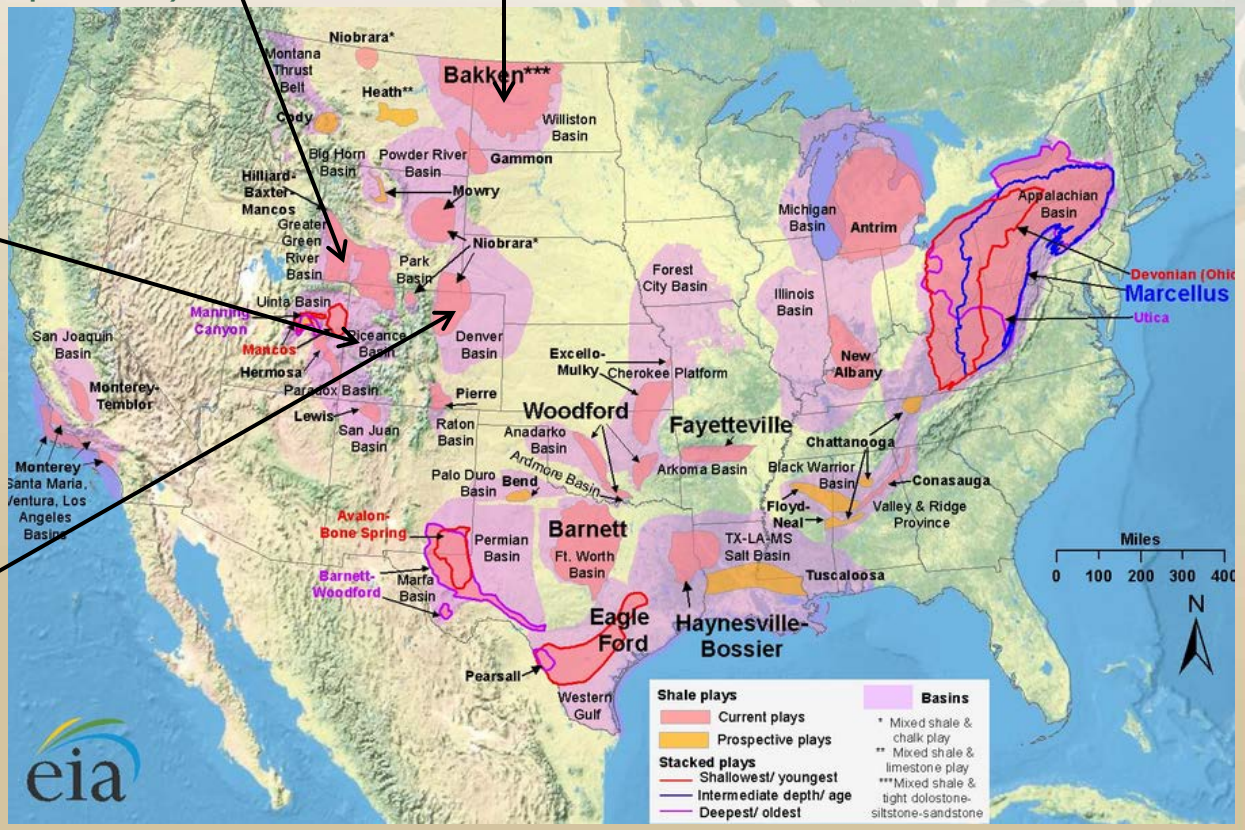
Boulder, WY
NH_3 and fine particle formation (2007-present)

Bakken Air Quality Study
Fine particles/haze, ozone, VOC
(winters 2012/13 and 2013/14)

Garfield County Emissions from new well development (11/2012 – present)

Front Range Emissions from new well development and production (7/2013 – present)



Garfield Study Overview

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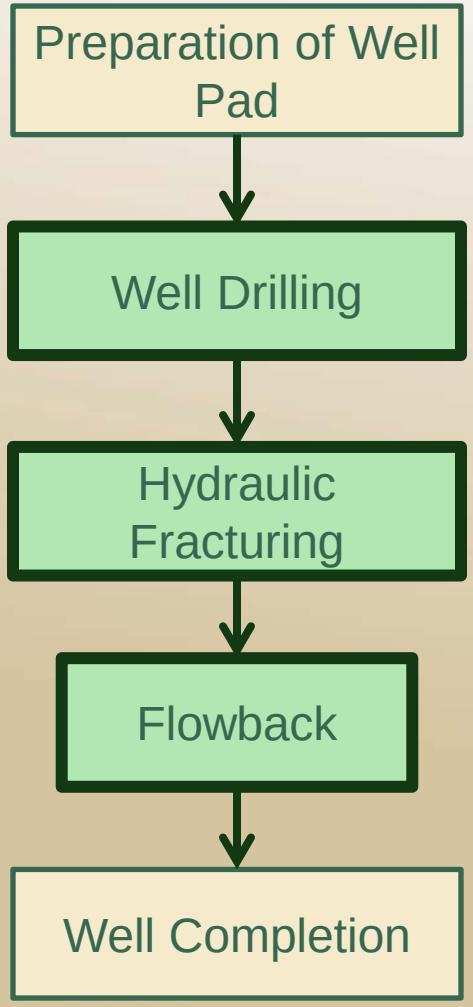

Objectives

- Quantify emissions of chemical compounds (air toxics, ozone precursors, NO_x, 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

Characteristics of this study

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- Focuses on new well development which has received little prior attention
- Includes air toxics and ozone precursors, not just methane
- Designed to quantify emissions rather than just measuring concentrations
- Emissions characterized separately for drilling, hydraulic fracturing, and flowback
- University/public/industry partnership provides
  - Objective, scientific approach
  - Full site access
  - Full information about on-site activity associated with measured emissions

Study partners

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- Study team
  - Colorado State University
    - Jeff Collett, PI
    - Jay Ham, co-PI
  - Air Resource Specialists, Inc.
- Technical Advisory Committee
  - Representatives from industry, CDPHE, USEPA, NCAR, BLM
- Operations Committee
- Sponsors
  - Garfield County
  - Encana, WPX Energy, Bill Barrett Corp., and Ursa Resources

Pre-Project Timeline

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- Sep 2011 – Initial meeting at CSU
- Oct 2011 – Meeting/field site tour in Garfield County
- Dec 2011 – Pre-proposal submitted
- May 8, 2012 – 1st Technical Advisory Committee (TAC) meeting
- May 2012 – Final proposal submitted
- Aug 2012 – Citizen Group Meeting and Garfield County presentation
- Late Oct 2012 – Contract signed; project begins

Budget Overview

- 3 year project (Nov. 2012-Oct. 2015)
- $1.76M budget
- Contributions from both industry and county
  - Contract with Garfield County signed late Oct 2012
  - $800K sought in industry support; $700K pledged to date
  - Four industry partners have provided, as gifts to CSU, between 33% and 100% of their pledges to date

Project Timeline

- Dec 2012 – Operations committee meeting
- Nov 2012 - spring 2013
  - Equipment acquisition
  - Installation
  - Testing
- Spring - summer 2013 – Meet with operators for
  - Training
  - Measurement plan review/approval
  - Initial site identification and initial field operations
- Spring - summer 2013
  - Model development
  - Testing and optimization of tracer release strategies

Emissions characterization

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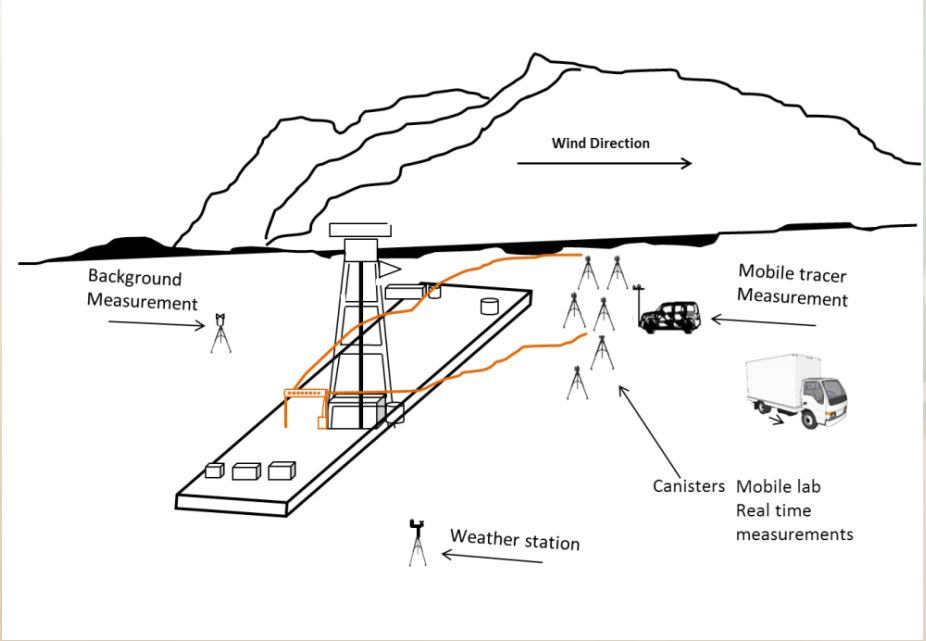
- Two independent approaches
  - Tracer method
  - Inverse dispersion modeling
- Combination of time-integrated and continuous measurements to observe temporal and spatial variability
- Mobile and fixed sampling platforms



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
- Carbonyls
- Acetylene

Meteorological Measurements

- Temp.
- RH
- Wind Direction
- Wind Speed

Meteorological Measurements

- Meteorological measurements help predict plume location and are used as modeling input
- Three tripod met stations with sonic anemometers
- One crank up tower to collect data at different heights

VOC Measurements (Offline)

- Volatile organic compounds (VOC)
  - Air toxics and ozone precursors
  - Silonite® coated canisters
  - Gas chromatography analysis with flame ionization and mass spectrometry detection

VOC Measurements (Online)

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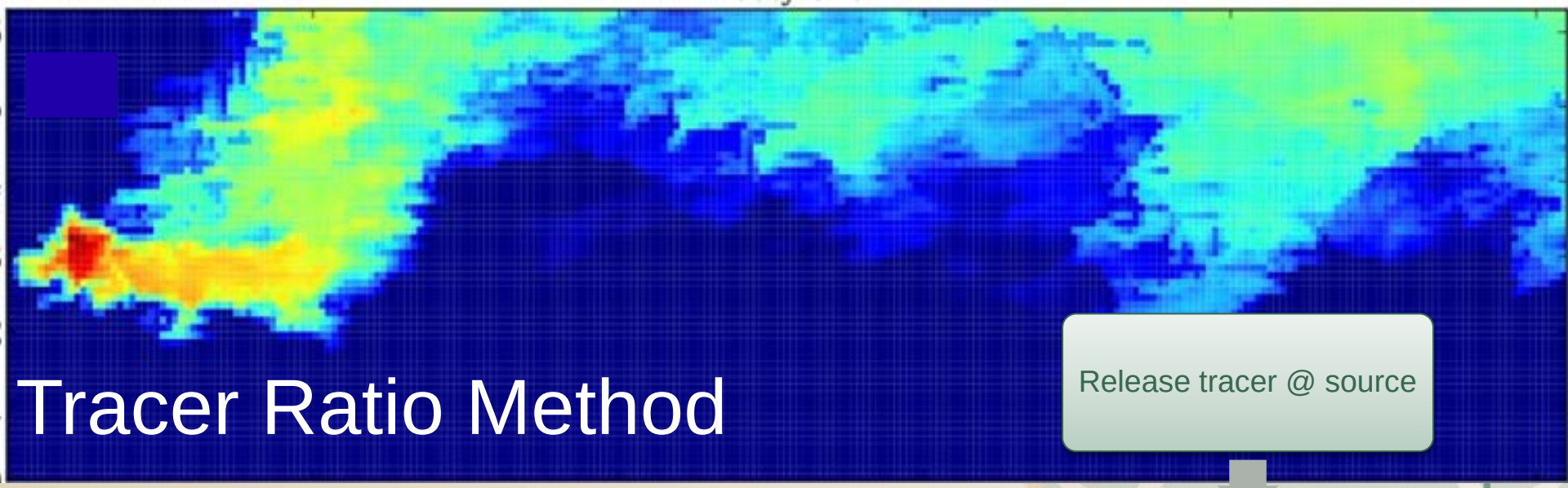
- CSU Mobile Lab
  - Real time measurements of VOCs using PTR-MS
  - Real time measurements of NO_X, CO, and O_3

- Hand-held ppb-RAE 3000
  - T-VOC measurements
  - Used to detect sources on well pad

Tracer Measurements

- Tracer (Acetylene) released at a known rate
  - co-locate with source
- Measurements
  - Real Time: Cavity Ring Down Spectroscopy Acetylene and Methane
  - Offline: Canister
- VOC/tracer ratio at each point provides an independent emission estimate



Tracer Ratio Method

- 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
  - Independent emissions estimate for use in dispersion modeling
  - Works in complex terrain

Release tracer @ source

Confirm plume trajectory with in situ measurement of tracer and CH_4

Position sample canister tripods and “arm”

Trigger sampling via wireless network when wind conditions optimal

Field Tests of Tracer Release and Measurement System

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Release of tracer gas (acetylene) and methane

Location: Christman Field, Fort Collins, CO

- Comparison of point vs manifold release systems
- Co-located and mis-located tracer release tests
- Various release rates

- These ongoing tests improve field tracer measurements, allow model testing, and will help assess measurement uncertainty

Sample Tracer Release Experiment

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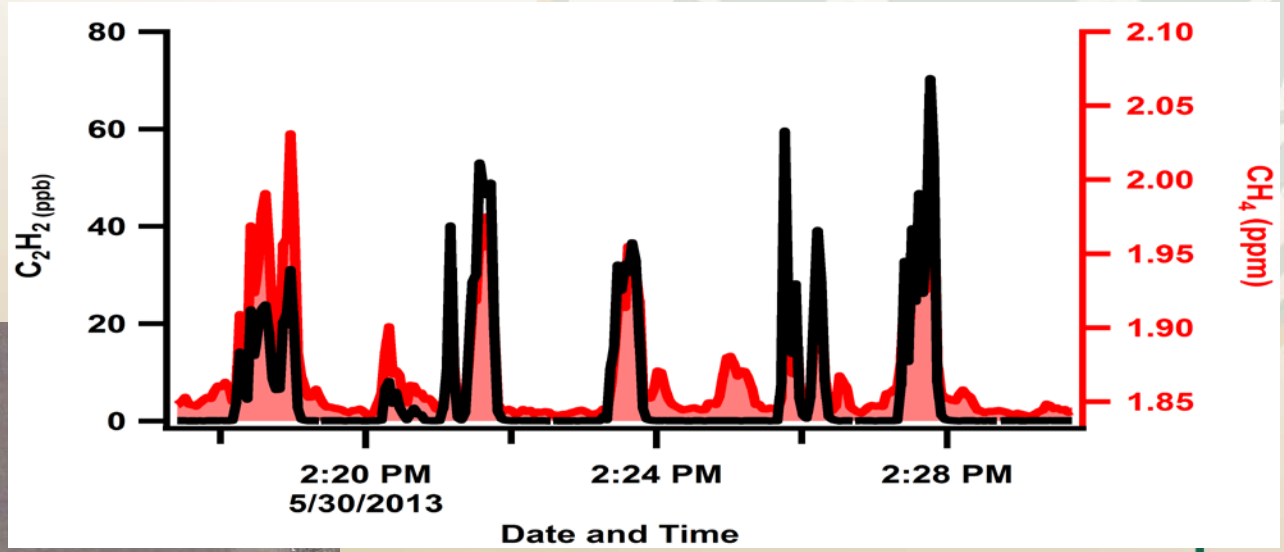
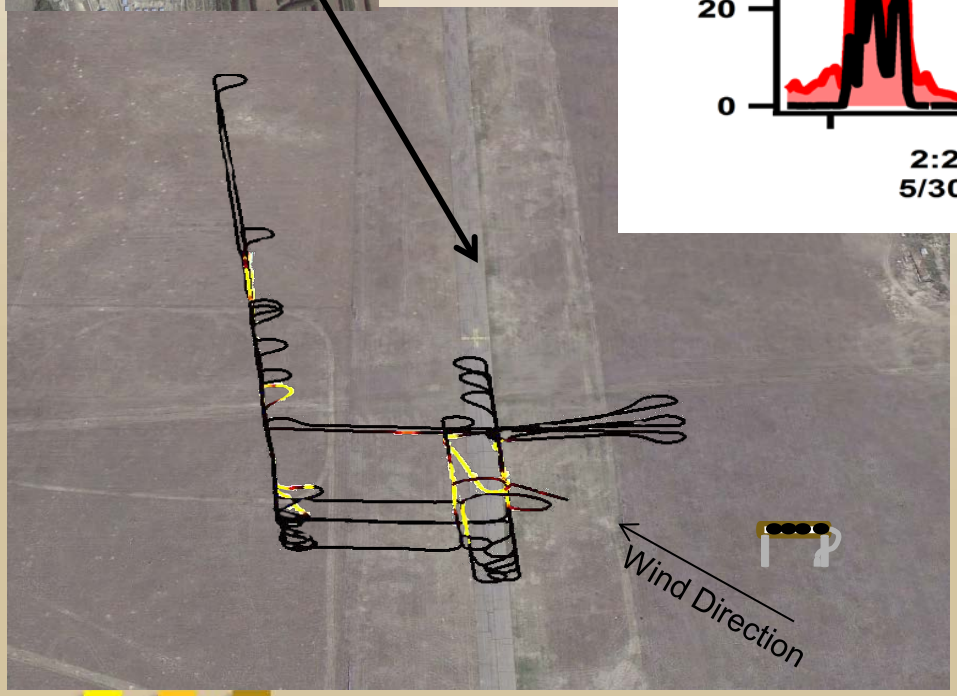


Released tracer and methane



View of plume tracker transects
Observed tracer plumes are shown in yellow

System for Atmospheric Modeling

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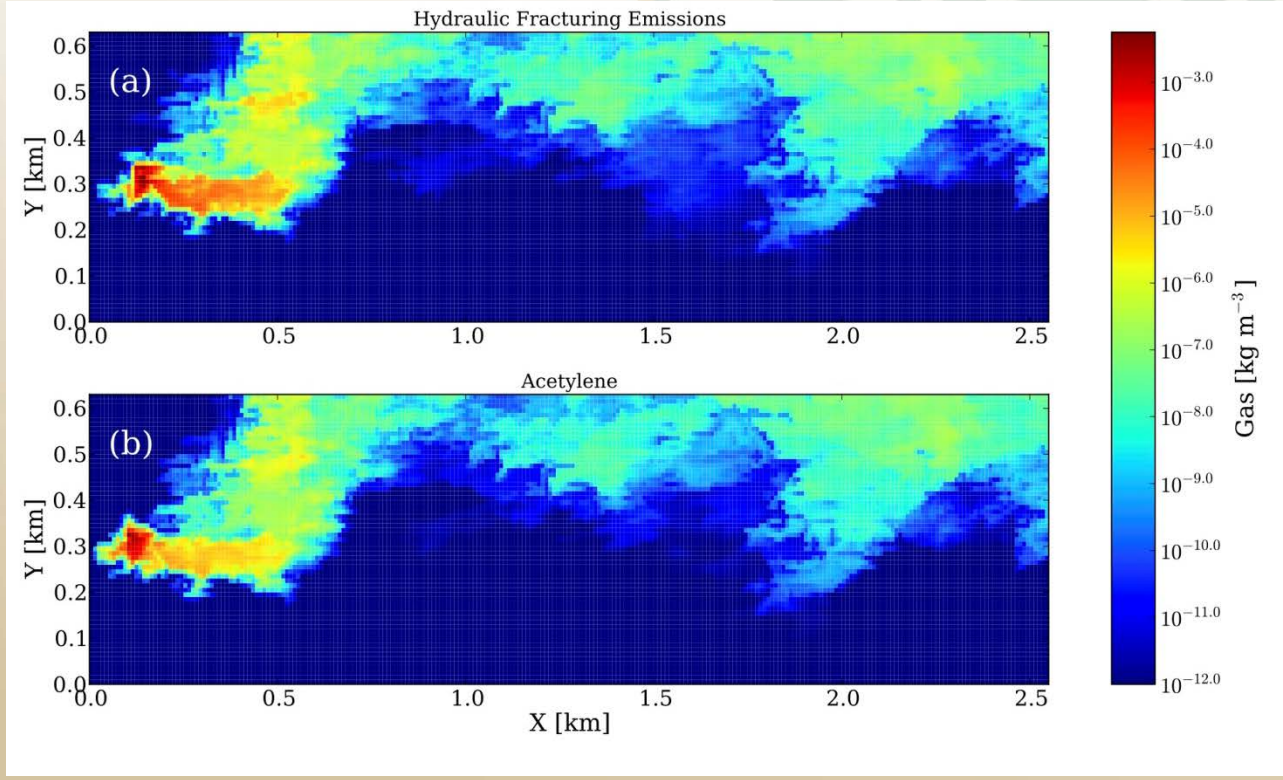
- 3D Large-Eddy Simulation (LES) fluid dynamics model
- Resolution: 10m x 10m x 5m
- 2 passive tracers
- No topography



Wind

This example shows modeled plumes for a 10x10 m acetylene release and a 30x30 m emission source release

2013 Field Measurements

- Spring 2013 – pilot scale field measurements
- July - December 2013 – 3 field experiments completed
- April - Sept 2013 – tracer release and plume tracking tests at CSU

- Met last week with study Technical Advisory Committee to review initial study results

Future Activities

- 2014/2015
  - Additional measurements
  - Data analysis
  - Modeling studies of emissions
  - Status reports to Garfield County and TAC
- Fall 2015 – Study complete
  - Peer-reviewed journal publication
  - Publish final study report and data
  - Public presentation of findings

Study products

- Emissions (mass/time) of air toxics, ozone precursors, and methane by activity
  - With operations context info
  - With uncertainties
- Ambient concentrations of speciated VOCs and methane
- Evaluation of dispersion model performance
- Peer-reviewed publications
- Peer-reviewed, high quality, public dataset
  - suitable for use in future health, air quality, and climate impact assessments