

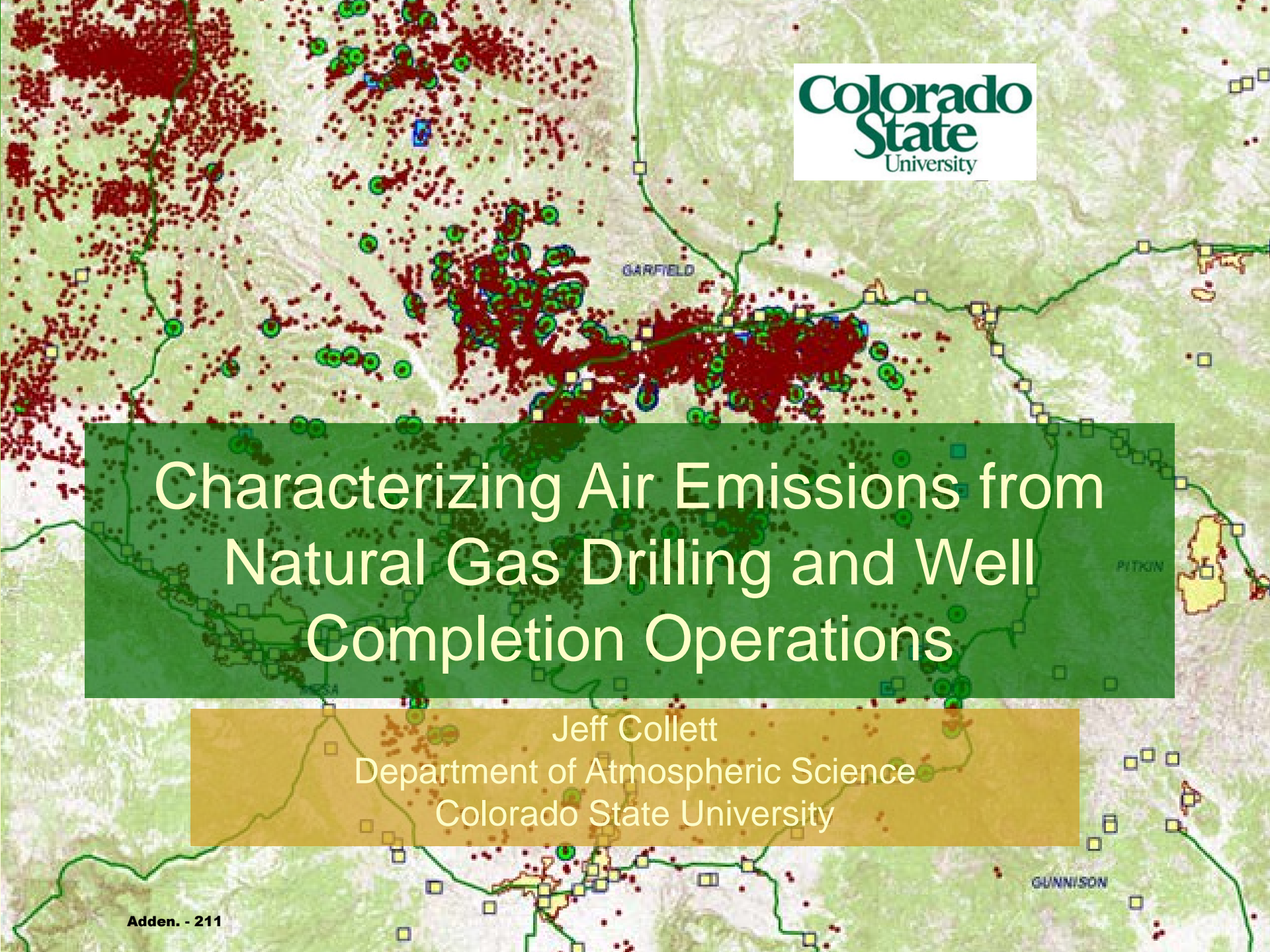
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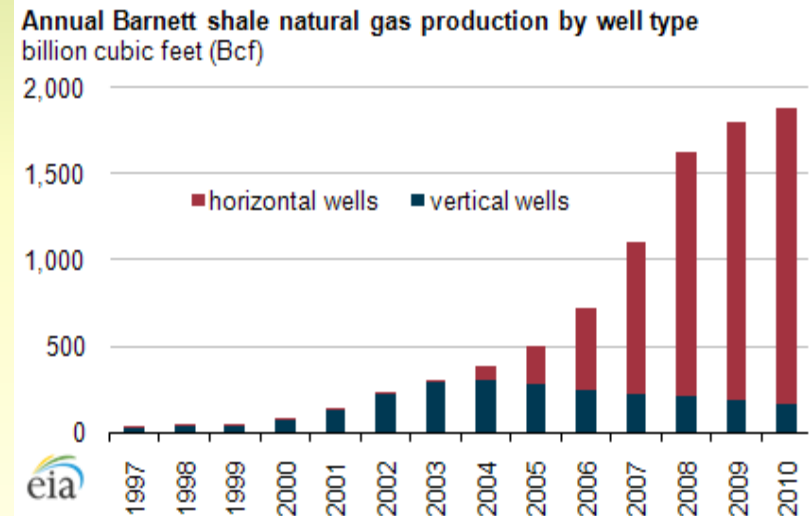
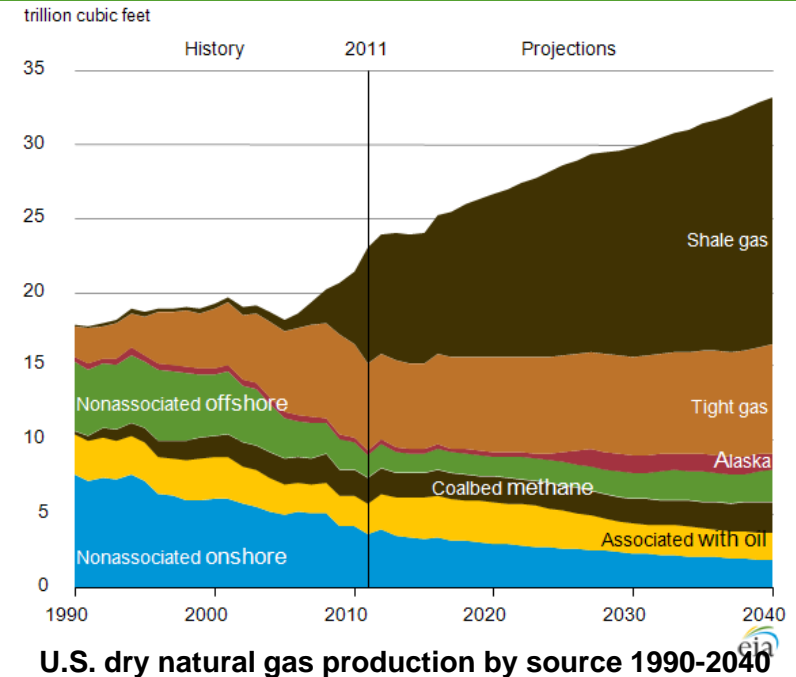
# Characterizing Air Emissions from Natural Gas Drilling and Well Completion Operations

Jeff Collett  
Department of Atmospheric Science  
Colorado State University



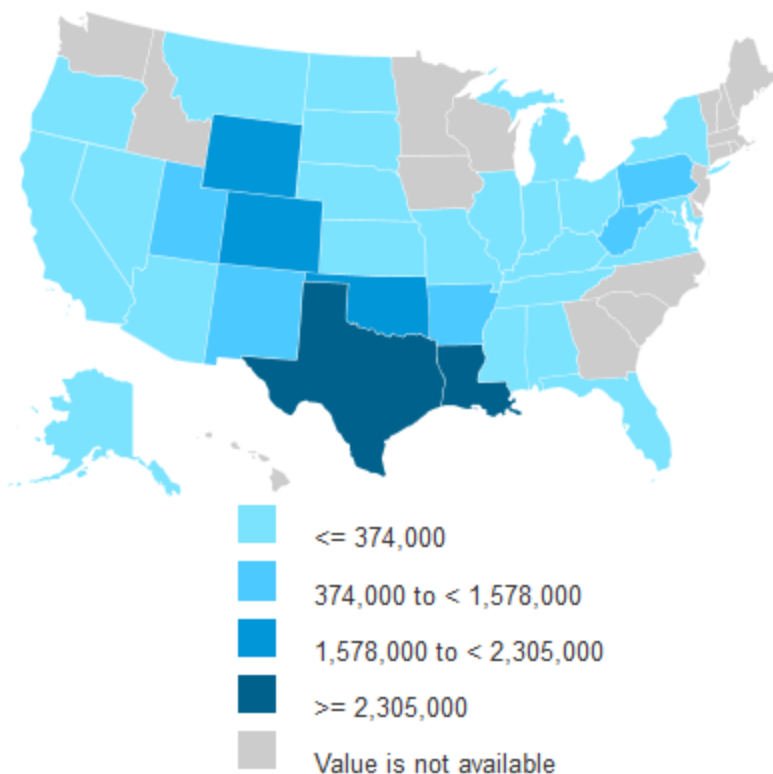
# Unconventional Gas Extraction

## Lower 48 States shale plays

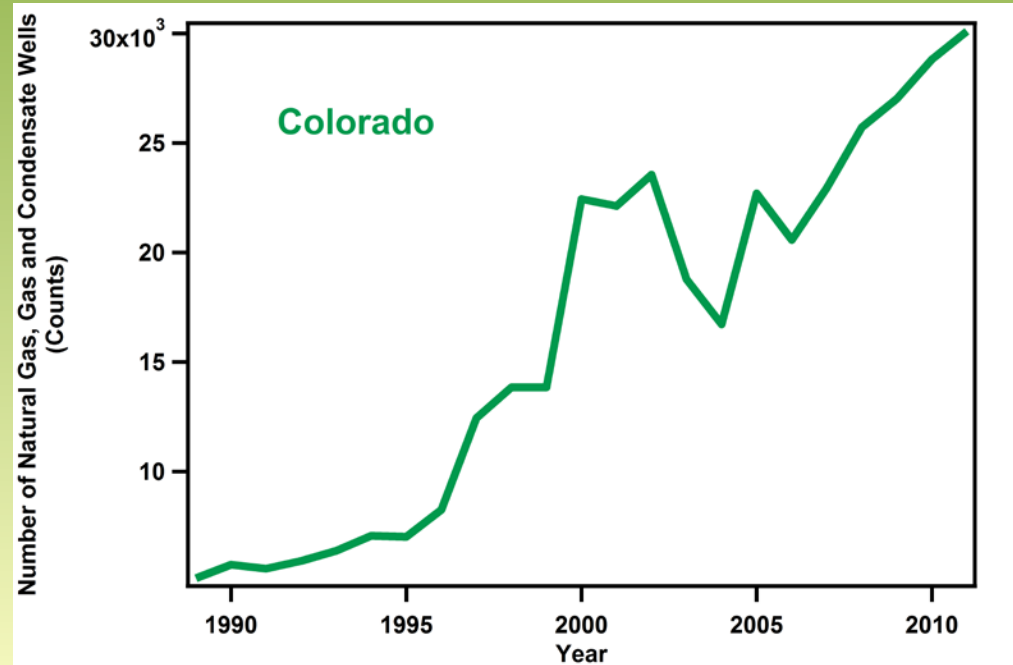


# Natural Gas Wells and Production in U.S.

Rankings: Natural Gas Marketed  
Production, 2011  
(million cu. ft.)



**Adden. - 213**

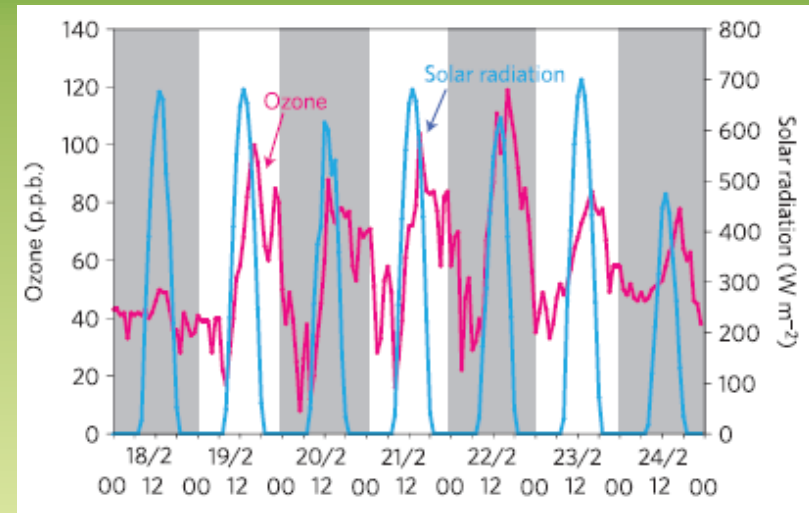


Number of Natural Gas Producing Wells in  
Colorado

# Potential Air Quality Concerns

Schnell et al., 2009

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

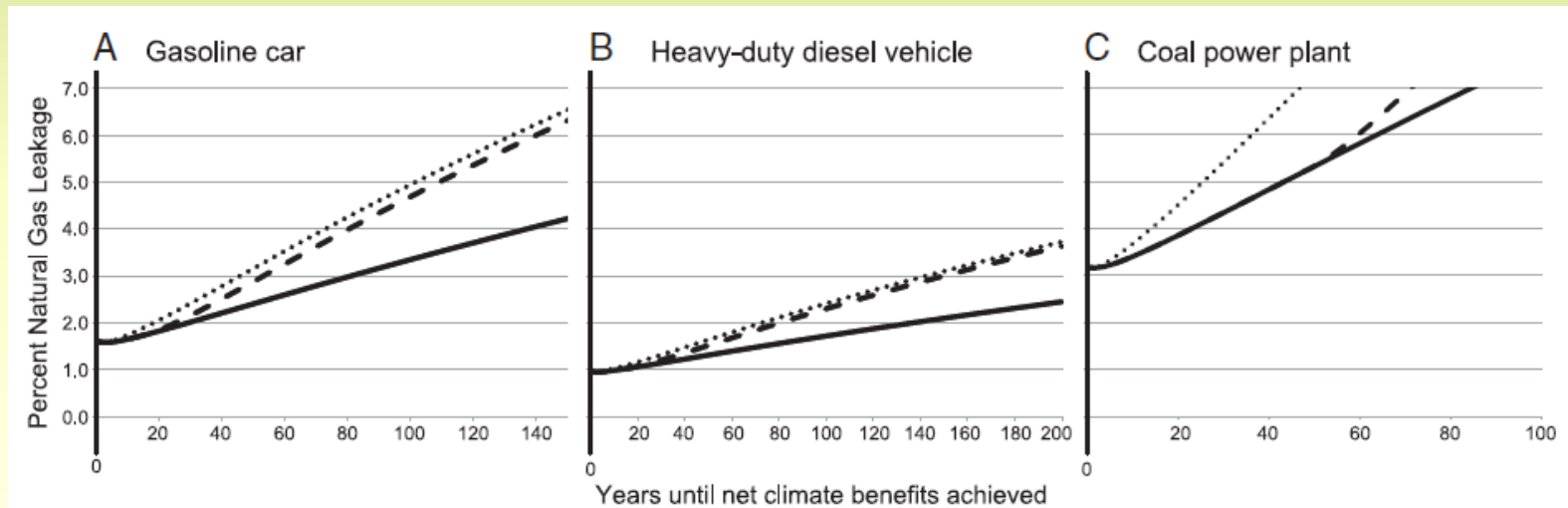
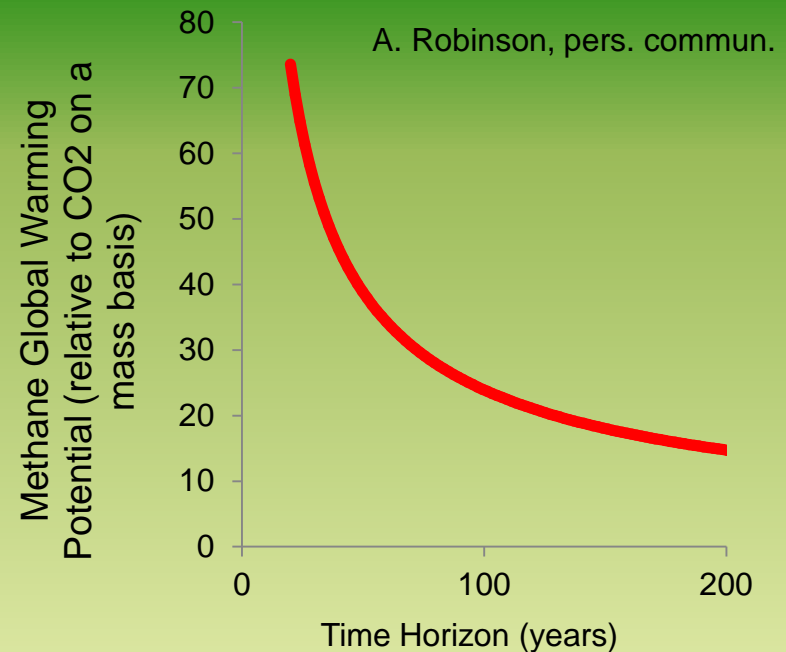


Denver brown cloud (Denver Post)



# Methane and climate

- 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 leakage rate and time horizon

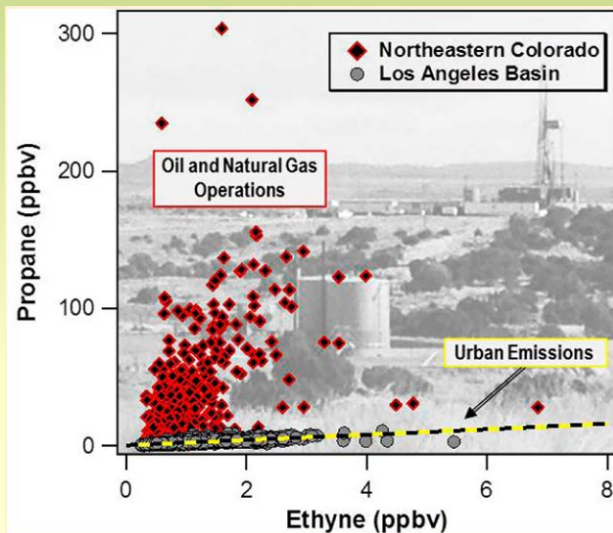


# Previous VOC Measurements in Colorado

- Characterization of VOCs in the Colorado Front Range

Pétron et al., *J. Geophys. Res.*, Vol. 117, D04304, 2012

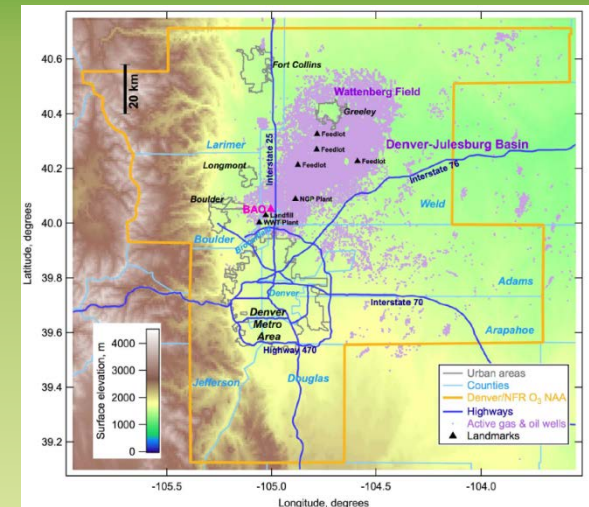
- Regional overview of processes impacting ambient alkane and benzene levels in Northeastern Colorado.
- Observation of enhanced atmospheric alkane ratio with signature from oil and gas operations.



- Signature of VOCs from Oil and Gas Operations

Gilman et al., *Env. Sci. & Tech. Res.*, 47, 1297-1305, 2013

- Observed signature of oil and natural gas activities.
- Observed VOCs associated with oil and gas activities at all sites



- A gap exists in direct measurement of emissions of specific activities, especially for new well development

# CSU Emissions Study Goals

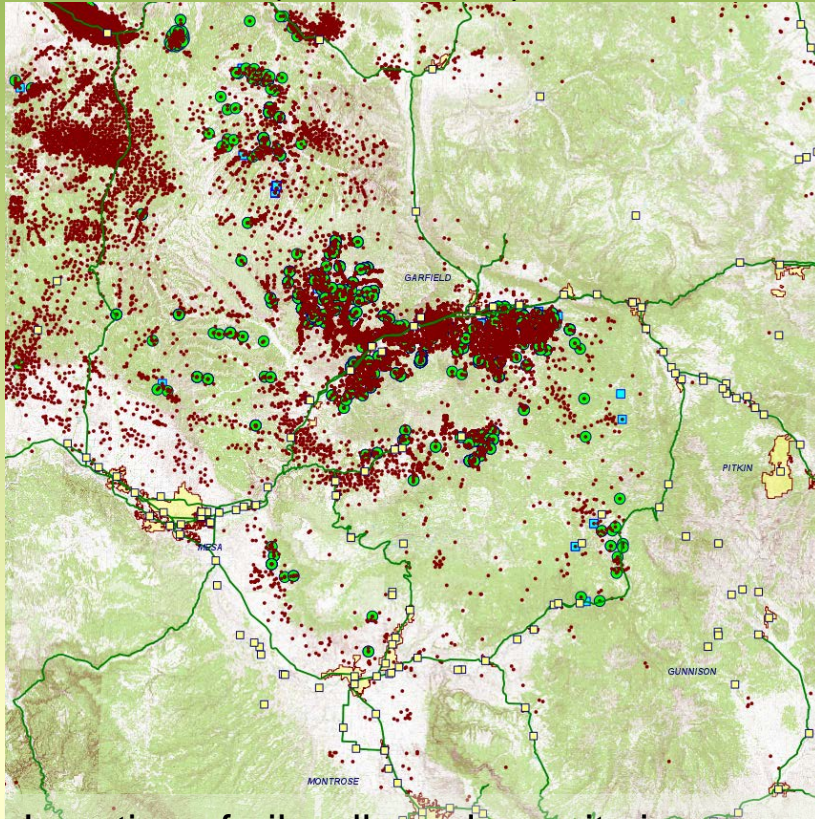
- Characterize emissions and downwind dispersion of air toxics, ozone precursors, and methane
- Consider oil and gas sources in western Colorado and Front Range
- Work with industry to gain full site access and activity information
- Focus on new wells (Garfield County). Focus on new wells and other activities where emissions are least well understood (Front Range).



# Two studies...

## Garfield County Study

(2012-2015)

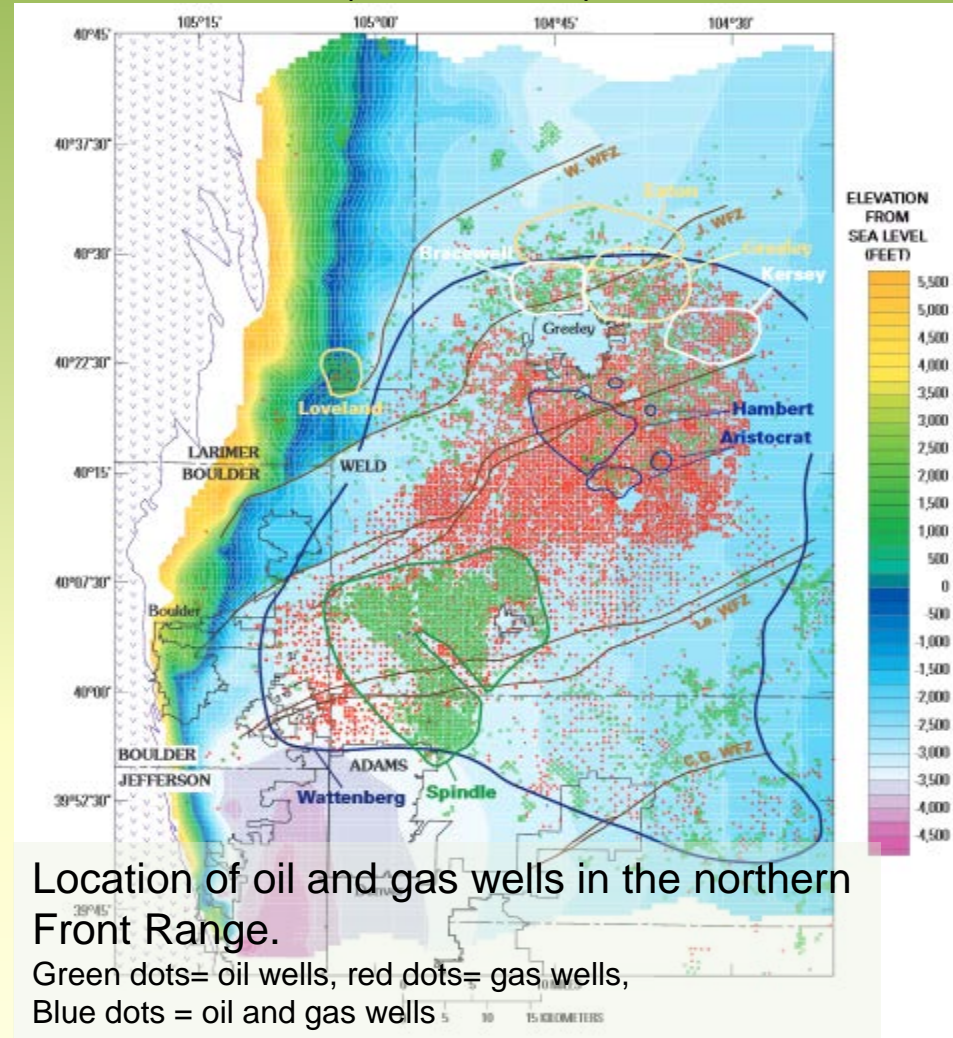


Location of oil wells and permits in Garfield County, CO and the surrounding area.

Red dots= oil wells, green circles= issued permits, blue squares= pending permits

## Front Range Study

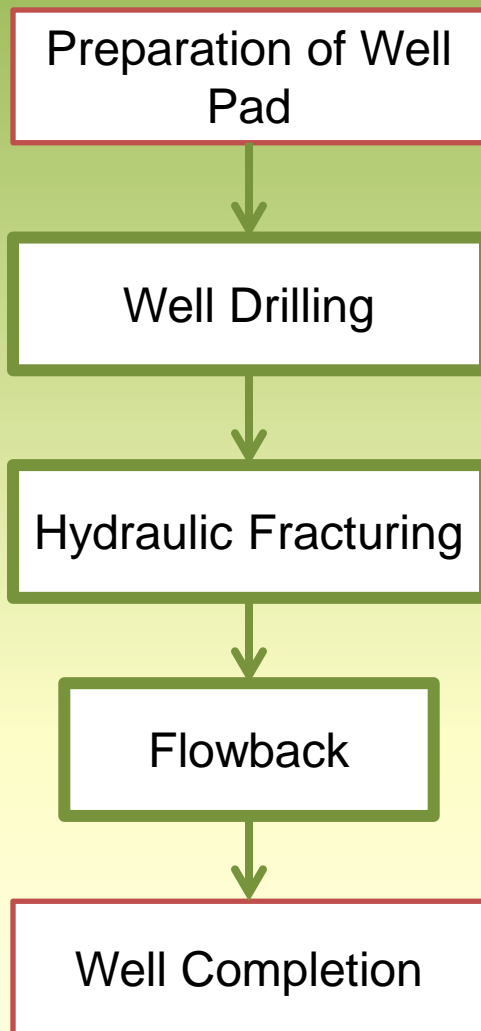
(2013-2016)



Location of oil and gas wells in the northern Front Range.

Green dots= oil wells, red dots= gas wells, Blue dots = oil and gas wells

# Garfield Study Overview



## Objectives

- Quantify emissions of chemical compounds (especially VOCs) 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

# Study partners

- 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





# Technical Objectives



- Quantify air emissions during specific activities
  - Mass of each compound released vs. time (e.g., g/s)
  - Detailed operator information about on-site activity
  - Focus on air toxics, ozone precursors, and CH<sub>4</sub>
- Measure and model the spatial extent of the dispersing plume
  - Concentration vs. distance from source
  - Up to a few km

# Approach



- Multiple, 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



## Mobile 4WD Plume Tracker

- $C_2H_2$
- $CH_4$
- GPS



## CSU Mobile Lab

- VOCs
- $NO_x$
- CO
- WD & WS data



## Integrated Measurements

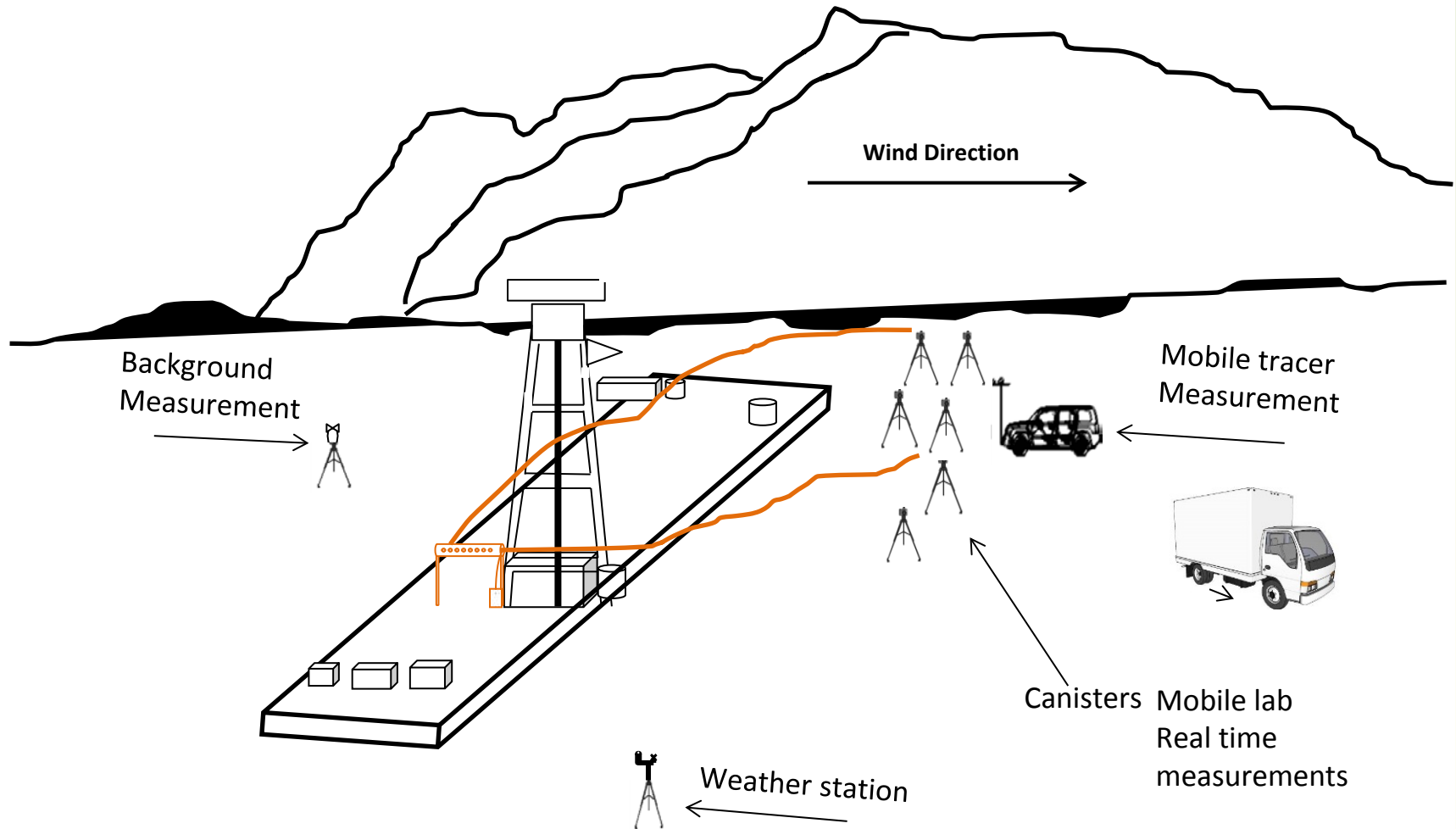
- VOCs
- Carbonyls
- $C_2H_2$



## Meteorological Measurements

- Temp.
- RH
- Wind Direction
- Wind Speed

# Field deployment strategy



# 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)

- VOCs (TO-15 and O<sub>3</sub> precursors)
  - Silonite<sup>®</sup> coated canisters
  - GC-MS/FID
  - Several canisters per case study
  - Collection time of 3-30 min.



- Carbonyls (TO-11a)
  - Cartridges
  - ~ 3-5 cartridges /case study
  - Collection time of a few hours





# VOC Measurements (Online)

- CSU Mobile Lab
  - Real time measurements of VOCs using PTRMS
  - Real time measurements of  $\text{NO}_x$ , CO, and  $\text{O}_3$
- Hand-held ppb-RAE 3000
  - T-VOC measurements
  - Used to detect sources on well pad



# Tracer Measurements

- Tracer (Acetylene) released at a known rate
- Measurements
  - Real Time:
    - Cavity Ring Down Spectroscopy
  - Offline:
    - Canister



# Tracer Ratio Method

- Conservative tracer is released at a known rate ( $Q_T$ ) near the source
  - Acetylene ( $C_2H_2$ )
- Dual analyzer measures concentrations of tracer ( $C_T$ ) and compounds of interest ( $C_{i,j,k}$ ) downwind of source
- Emission rates ( $Q_{i,j,k}$ ) are calculated from  $Q_T$  and the ratio of concentration between  $C_2H_2$  and the compound of interest (e.g.,  $C_i/C_T$ ).





# Tracer Ratio Method

- Theoretical Assumptions

- Assumes the release point for tracer is the same as that for the VOCs
- Assumes turbulent processes transporting tracer and VOCs are the same
- Assumes no chemical transformation between release point and sample point

- Measurement Challenges

- Must accurately measure mass flow of the tracer and the VOC/tracer concentration ratios

- Key Advantages

- Don't need to capture entire plume
- Provides independent estimate of emissions for use in dispersion modeling
- Tracer released (acetylene) naturally occurring concentration less than 1 ppbv
- Acetylene decomposes slowly in atmosphere with a half life of ~13 days



Model dispersion using  
real-time on-site met.  
and smoke release



Release tracer @ source



Confirm plume trajectory  
with in situ measurement  
of tracer and CH<sub>4</sub>



Position sample canister  
tripods and "arm"



Trigger sampling via  
wireless network when  
wind conditions optimal



# Verification of Tracer Ratio Method

## Release of tracer (acetylene) and methane

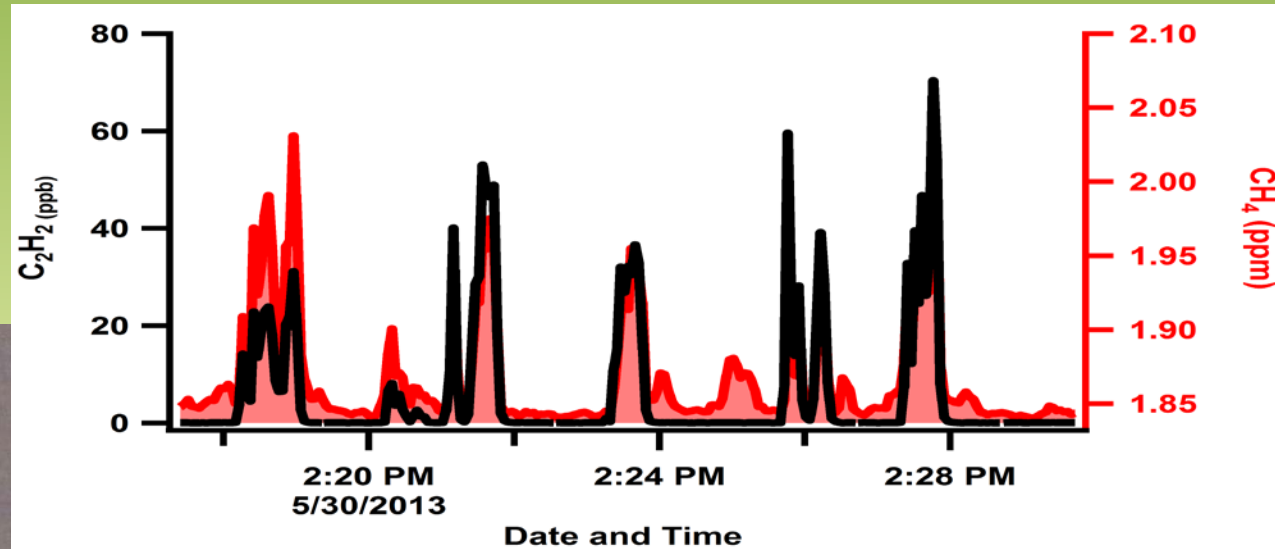
*Location: Christman Field, Fort Collins, CO*

- Comparison of point vs. manifold release systems
- Co-located and mis-located tracer release tests
- Various release rates
- Diverse meteorological conditions
- These tests improve field tracer measurements, allow model testing, and help assess measurement uncertainty



# Tracer Release System Validation

Christman Field



Released tracer and methane

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



# Modeling the Plumes

- System for Atmospheric Modeling (SAM)
  - 3D Thermodynamic, fluid-dynamic model
  - Resolution: 20m x 20m x variable
  - 2 tracers
  - Unidirectional wind

