Community Exposures Near Unconventional Oil and Gas Development

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colorado school of public health
UNIVERSITY OF COLORADO
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AirWaterGas
NSF Sustainability Research Network
NIH National Institute of Environmental Health Sciences
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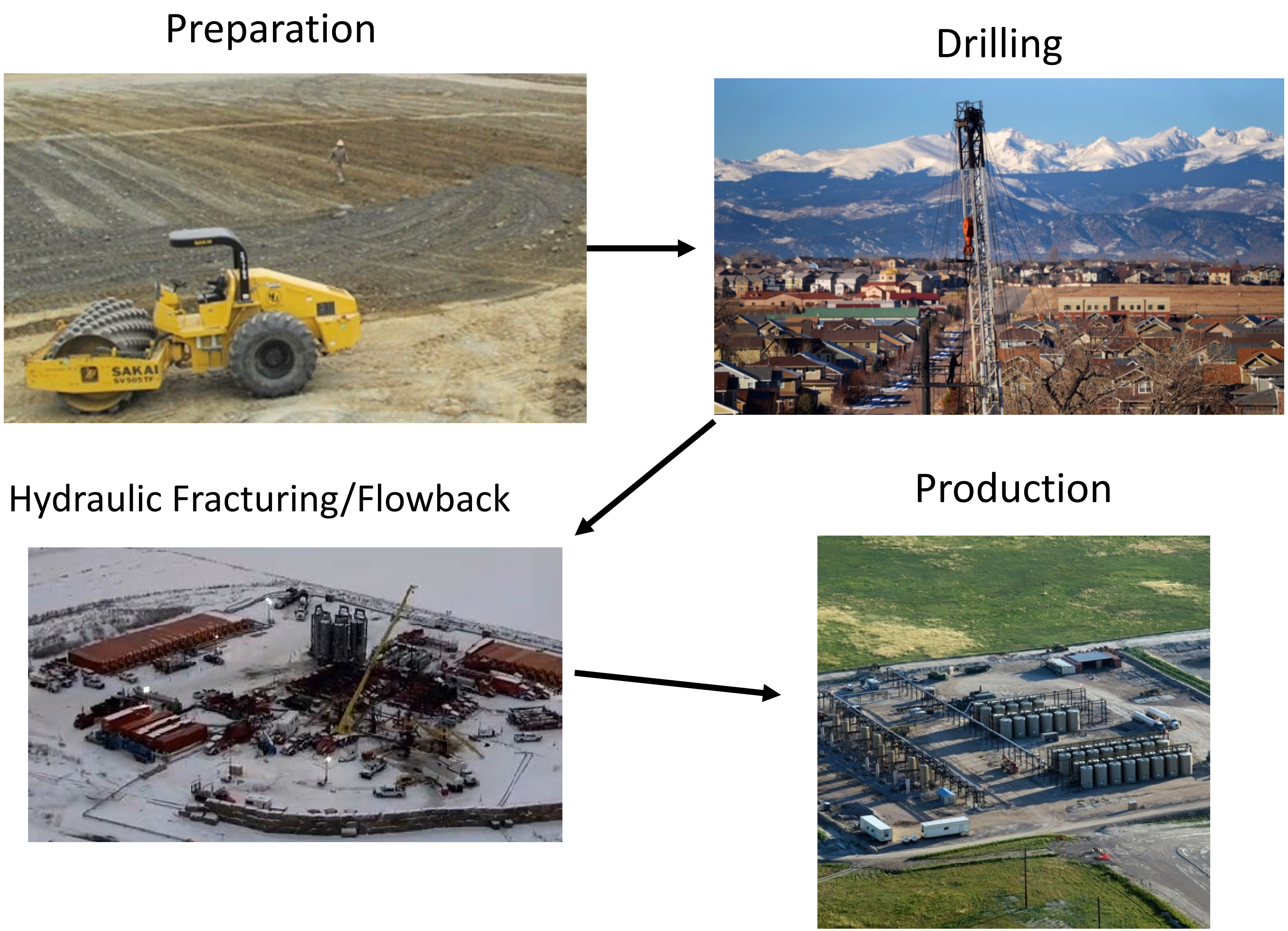
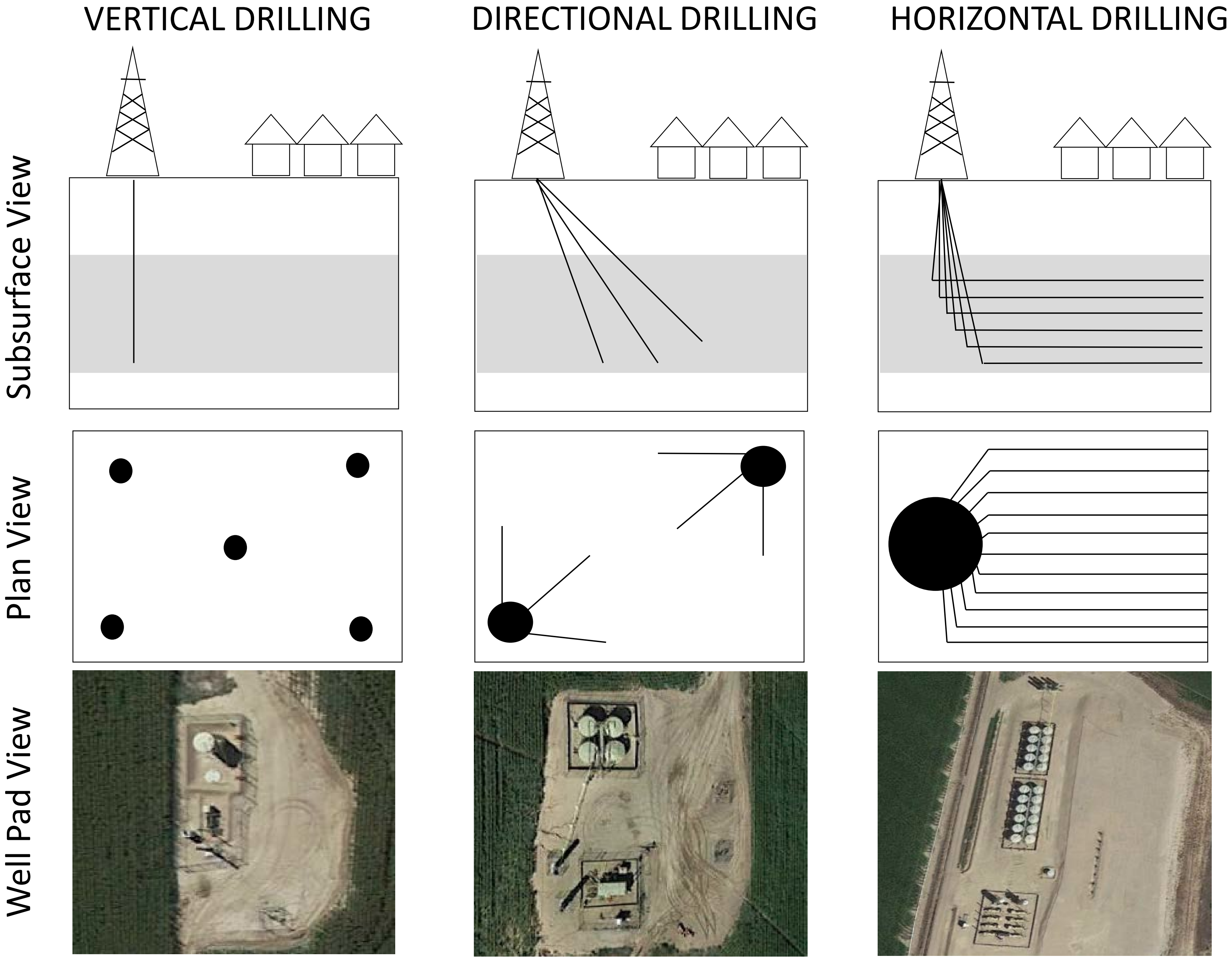
Central Questions and Roadmap

- What are the key exposures related to UOGD and do they vary by region?
- How is/should exposure measured or modeled?
  - Remote sensing? Area monitors? Residential or personal monitoring? Biomonitoring?
  - Model based on proximity, emissions, dispersion?
- Where have scientists gone beyond environmental monitoring and modeling and endeavored to quantify what people are exposed to?

NB: I have focused on the peer reviewed literature for the most part


Preparation
Drilling
Hydraulic Fracturing/Flowback
Production



Slide credit:
Dr. Adrienne Kropech,
CSM

Key Residential Exposure-Related Issues

Exposure Potential Varies by Phase of O&G Development

- Pad construction, Drilling (increasingly on multi-well pads), Fracturing/Flowback, Production

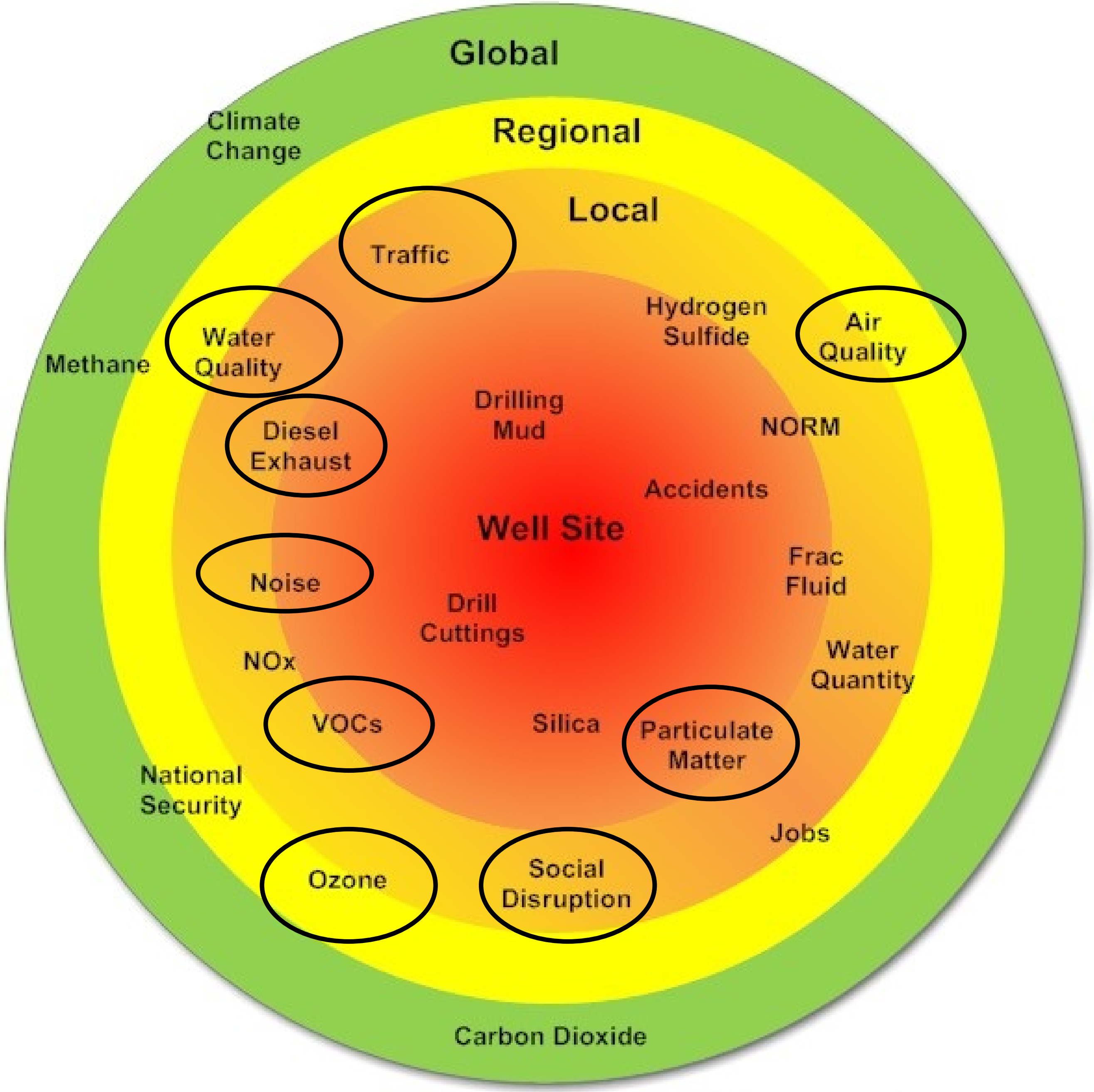
Proximity and Periodicity

- Well density near residences and increased use of multi-well pads
- Episodic and continuous exposures related to well development, production, and maintenance

Related Infrastructure and Activities

- Roads, compressor stations, pipelines
- Related accidents or incidents

Key Exposures:
Measurement and Modelling


Global
Regional
Local
Well Site
Climate Change
Methane
National Security
Carbon Dioxide
Traffic
Water Quality
Diesel Exhaust
Noise
NOx
VOCs
Ozone
Social Disruption
Jobs
Hydrogen Sulfide
Air Quality
NORM
Accidents
Frac Fluid
Water Quantity
Particulate Matter
Silica
Drilling Mud
Drill Cuttings

Key Exposures

- Air Pollution (Methane, NMHC/BTEX HAPs, PM, Black Carbon/PAHs, Ozone)
- Water Pollution (Methane, NMHC/BTEX, Metals, NORM)
- Noise, Light, Vibration
- Traffic
- Catastrophic Risk

Air Monitoring: VOCs

- Studies in CO, OK, PA, TX, UT, WV, and elsewhere have used central site monitors to estimate ambient exposure to the hazardous air pollutants (HAPS: typically NMHC with an emphasis on BTEX) for compliance monitoring, source attribution, and exposure estimation
  - Typically 24 hour averages, though some shorter duration measurements exist, e.g., 3 hr samples early in the morning in CO, 1 hr durations in UT and PA
  - Large numbers of samples and HAPs compounds measured and averaged over relatively large areas without accounting for the proximity of human receptors
- **Fewer studies have looked in close proximity to where people live or for shorter durations, e.g., hours or minutes**
  - Short duration measurements show considerable variability

Concentrations of Hazardous Air Pollutants Increase with the Density of UOGD

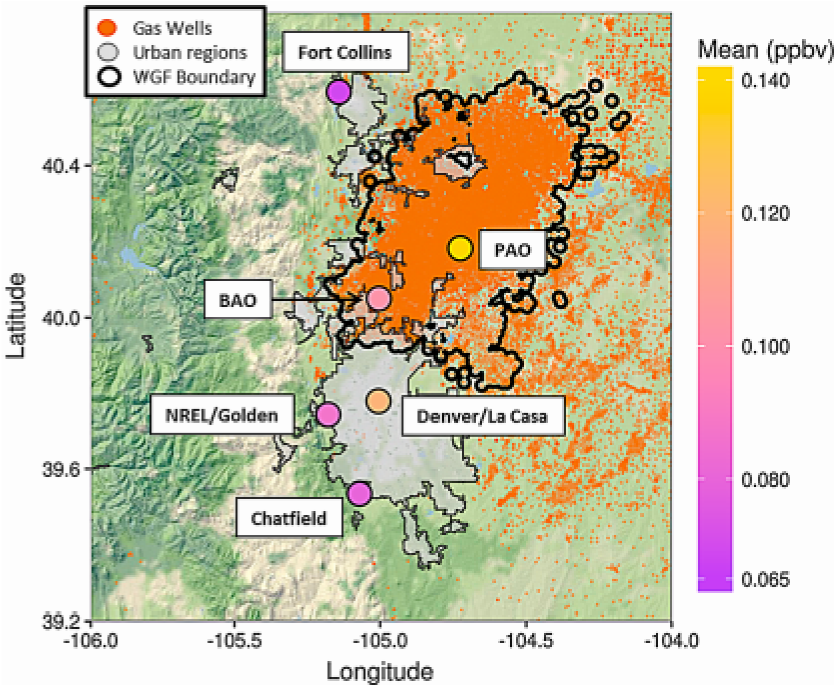


Figure 1. Map of the 2014 DISCOVER-AQ study area. The urban areas are shown in grey (data courtesy of the United State Census Bureau, http://www.census.gov/geo/maps-data/data/tiger.html). The boundary of the WGF is shown in black along with the gas wells (brown points) (data courtesy of the Colorado Oil and Gas Conservation Commission, http://cogcc state.co.us/). The DISCOVER-AQ ground sites are plotted and colored using the mean benzene volume mixing ratio measured during the aircraft spirals over each site. Benzene statistics were calculated using data from the bottom 1 km ag for each site.

Halliday et. al. 2016

Impact of Marcellus Shale Natural Gas Development in Southwest Pennsylvania on Volatile Organic Compound Emissions and Regional Air Quality

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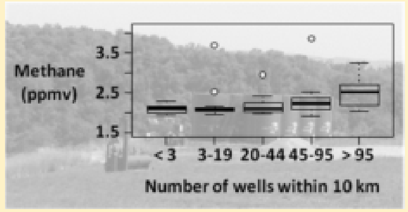
Supporting Information

ABSTRACT: The Marcellus Shale is the largest natural gas deposit in the U.S. and rapid development of this resource has raised concerns about regional air pollution. A field campaign was conducted in the southwestern Pennsylvania region of the Marcellus Shale to investigate the impact of unconventional natural gas (UNG) production operations on regional air quality. Whole air samples were collected throughout an 8050 km^2 grid surrounding Pittsburgh and analyzed for methane, carbon dioxide, and C_1-C_{10} volatile organic compounds (VOCs). Elevated mixing ratios of methane and C_2-C_8 alkanes were observed in areas with the highest density of UNG wells. Source apportionment was used to identify characteristic emission ratios for UNG sources, and results indicated that UNG emissions were responsible for the majority of mixing ratios of C_2-C_8 alkanes, but accounted for a small proportion of alkene and aromatic compounds. The VOC emissions from UNG operations accounted for 17 ± 19% of the regional kinetic hydroxyl radical reactivity of nonbiogenic VOCs suggesting that natural gas emissions may affect compliance with federal ozone standards. A first approximation of methane emissions from the study area of 10.0 ± 5.2 kg s^{-1} provides a baseline for determining the efficacy of regulatory emission control efforts.



Swarthout et al, 2015

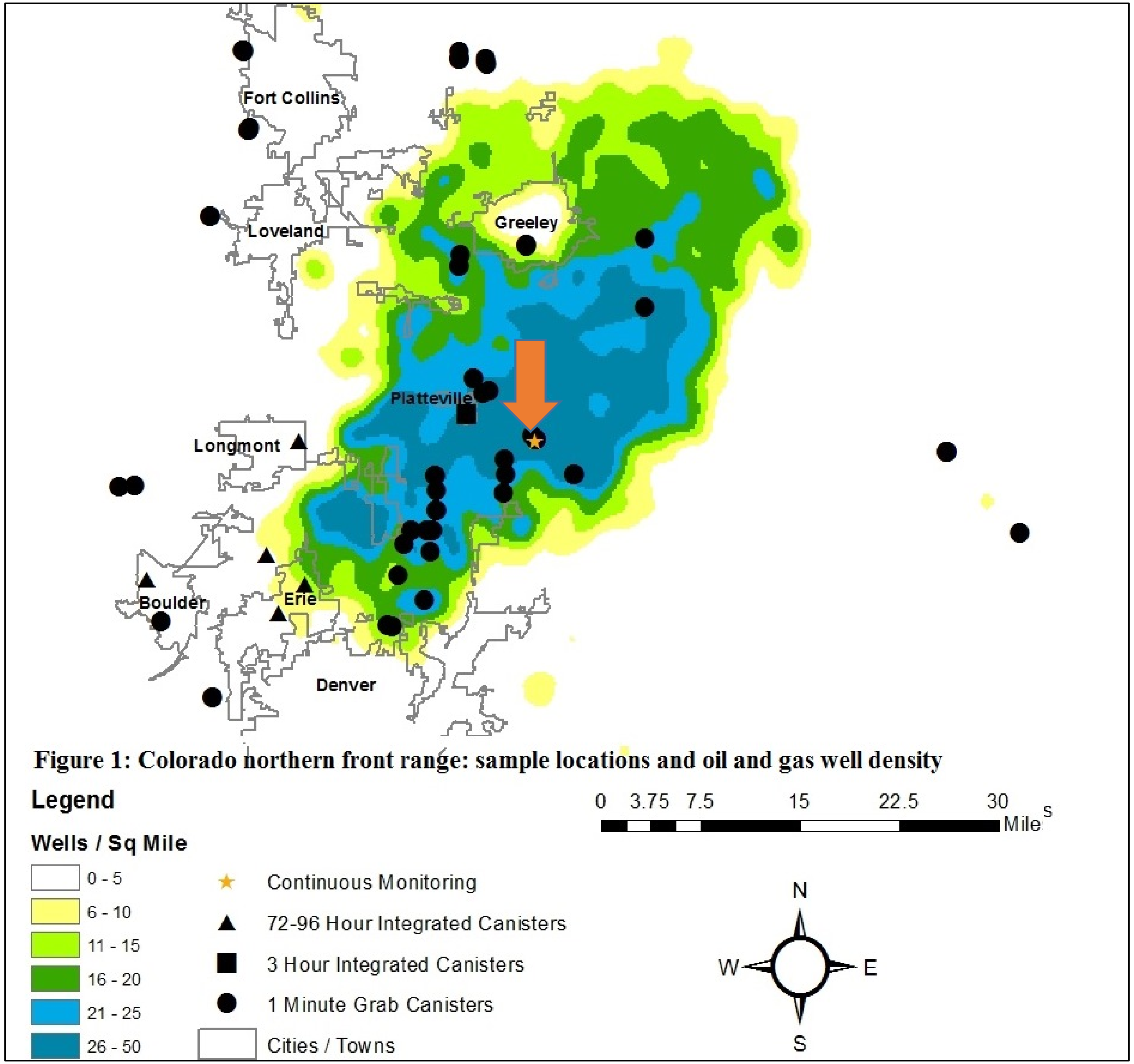
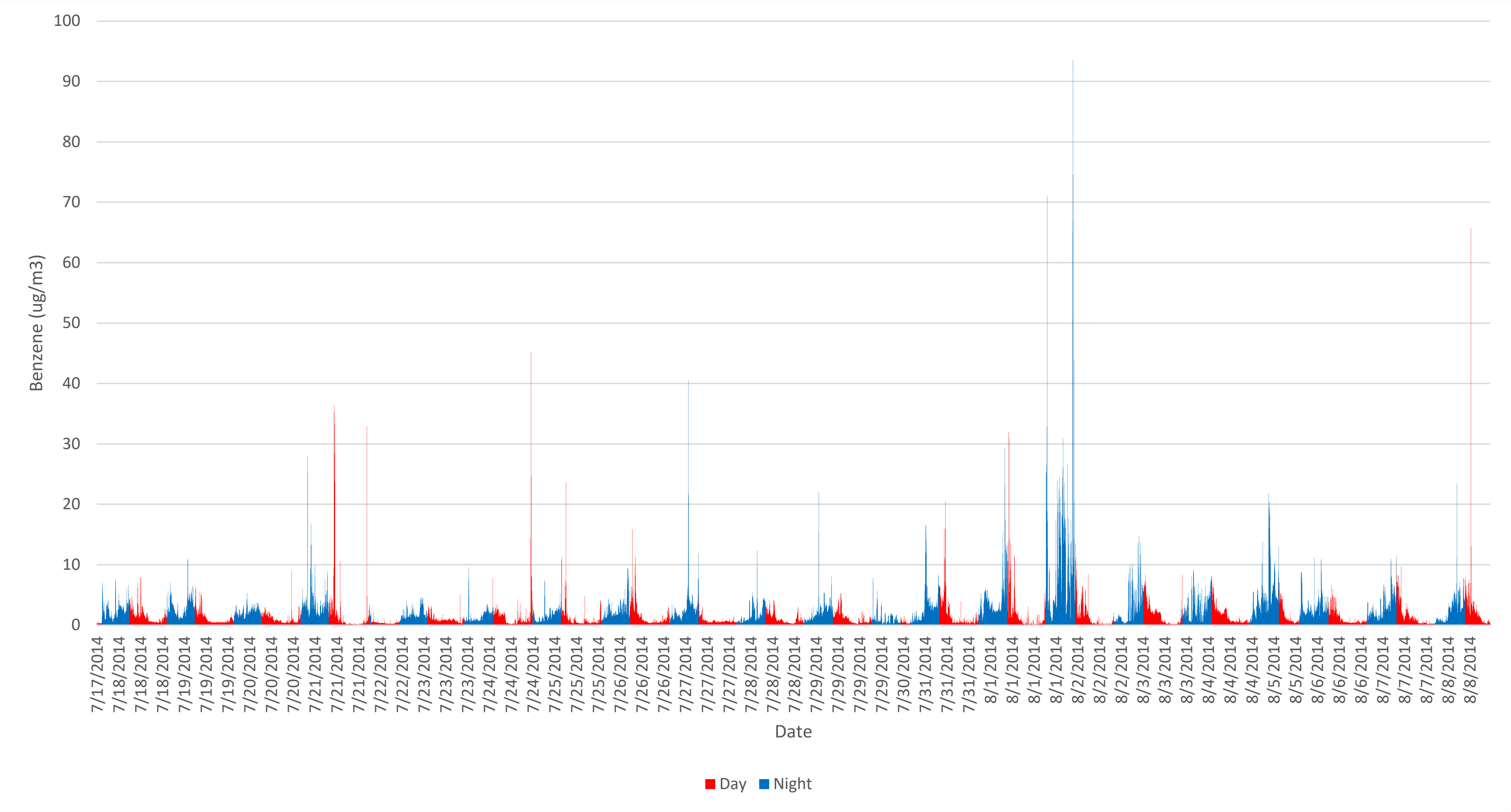


Figure 1: Colorado northern front range: sample locations and oil and gas well density

1 Minute Time Series Benzene PTR-MS Measurements Platteville, CO, 7/17/14-8/8/14.

Data from: Halliday et al 2016



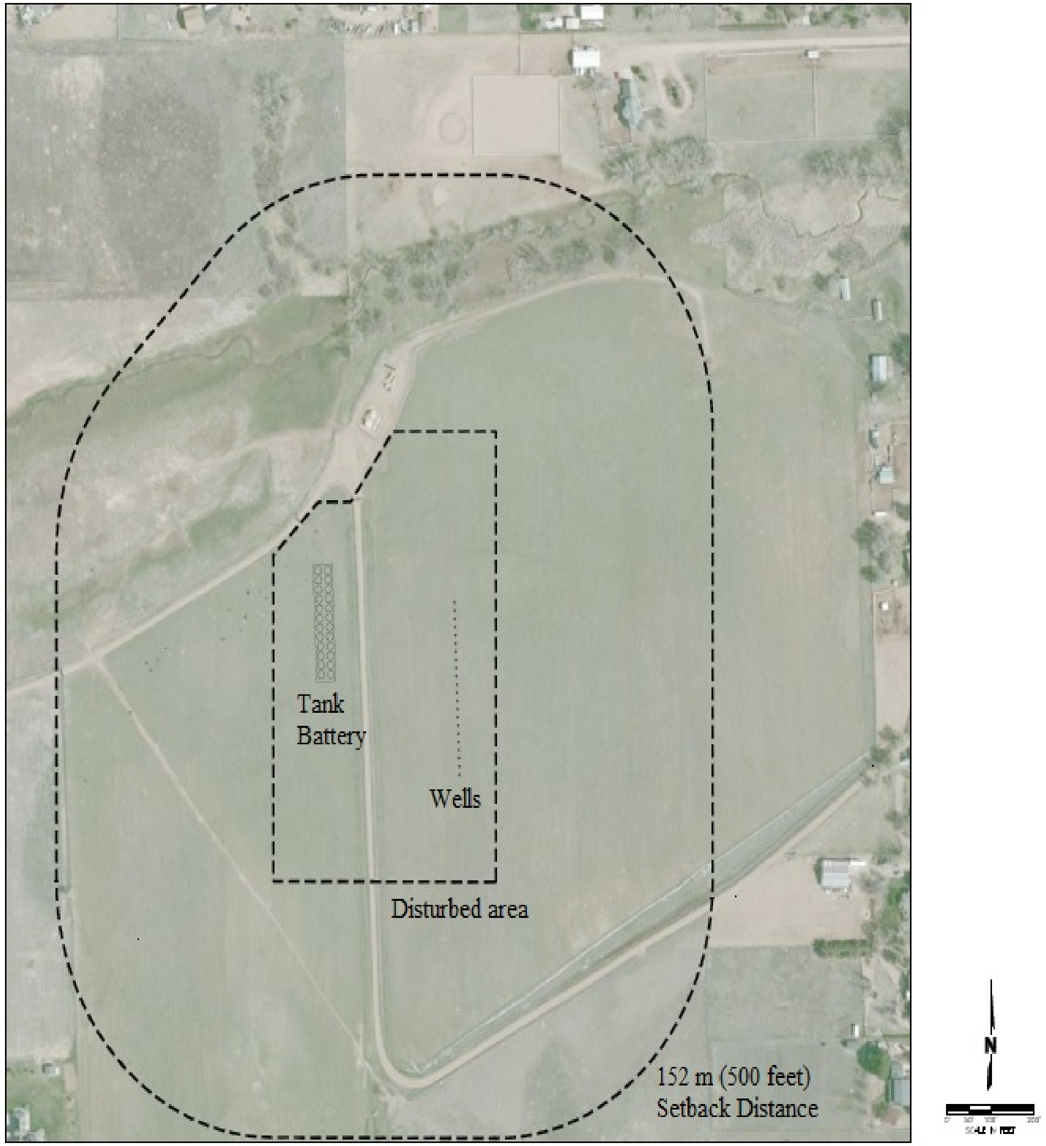
Night/Day Ratios

Compounds	95 UCL of Mean (ProUCL) (ug/m³)	**Night/Day Ratio (Medians)**
Acetaldehyde	2.2	**1.1**
Acetone	8.9	**1.0**
Benzene	1.8	**3.0** ⇦
H_2S	0.6	**2.1**
Toluene	2.8	**3.9** ⇦

Key point: Night-day differences are significant, particularly for the aromatics, less so for other compounds

Noise

- A- and C- (low frequency) weighted noise measured in relatively few studies, but results similar across basins
  - An important co-exposure related to traffic and pad activities (Hays, McCauley, & Shonkoff, 2017)
  - Sound walls have limited efficacy, particularly for low frequency noise and within common setbacks (Radke et al 2017)
  - Multi-well pads and related infrastructure, such as compressor stations, are substantial sources of noise in the range of concern near homes (Blair et al 2018; Boyle et al 2017)
- Operators have compliance data they collect in some states though it is typically not accessible to communities or researchers



"Noise levels exceeding 50 dBA or 60 dBC may cause annoyance and be detrimental to health"

Noise at a Multi-well Pad (Blair et al 2018):

- Measurements at ~1050 to 1800 ft from pad center over 3 months during site prep and drilling
- Maximum one-minute equivalent continuous sound levels over a one-month period were 60.2 dBA and 80.0 dBC.
- Overall, 41.1% of daytime and 23.6% of nighttime dBA one-minute equivalent continuous noise measurements were found to exceed 50 dBA,
- 97.5% of daytime and 98.3% of nighttime measurements were found to exceed 60 dBC.

Modelling Exposure in Health Studies

- Most exposure estimates in health studies have used proximity as proxy for exposure
  - Studies to date are for the most part cross-sectional, i.e. one point in time for exposures and/or health effects
  - Exposure metrics use inverse distance weighting or related approaches and/or limited measurements; temporal specificity needed
- Emerging approaches: Incorporating production and/or emissions data (e.g., Kohler et al 2018, Allshouse et al 2017)
- Several dispersion and multiple source apportionment studies; limited use in health effects studies
- No studies using remote sensing or sensor-based approaches (yet)

Quantifying Exposure

Personal Exposure and Biomonitoring

- Personal Exposure
  - No data in the peer reviewed literature
- Blood VOCs measurement
  - Little peer reviewed data
  - Background levels and multiple sources of common chemicals are a limitation
- Blood and Urinary Biomarkers of Exposure and Effect
  - Example using BTEX (next slide)
  - Other examples: Diesel and/or PM biomarkers of exposure/effect used in traffic-related air pollution studies

Example: BTEX Biomarkers of Exposure and Effect

Biomarkers of Exposure

Parent Compounds

Benzene
Toluene
Ethylbenzene
o-Xylene
m&p-Xylene

Metabolites:
Benzene: N-Acetyl-S-(phenyl)-L-cysteine (SPMA), t,t-muconic acid (t,t-MA)[1], *Ethylbenzene*: PGA, *Xylenes*: 2MHA, 3&4MHA

Biomarkers of Effect

Short Term DNA damage: 8-hydroxydeoxyguanosine (8-OHdG)[2,]
Lipid Peroxidation: malondialdehyde (MDA)[3]

[1]Caron-Beaudoin É, Valter N, Chevrier J, Ayotte P, Frohlich K, Verner M-A. Gestational exposure to volatile organic compounds (VOCs) in Northeastern British Columbia, Canada: A pilot study. *Environment international.* 2018;110:131-138)
[2]Andreoli R, Spatari G, Pigini D, et al. Urinary biomarkers of exposure and of oxidative damage in children exposed to low airborne concentrations of benzene. *Environmental Research.* 2015;142:264-272; Franken C, Koppen G, Lambrechts N, et al. Environmental exposure to human carcinogens in teenagers and the association with DNA damage. *Environmental Research.* 2017;152:165-174; Li J, Lu S, Liu G, et al. Co-exposure to polycyclic aromatic hydrocarbons, benzene and toluene and their dose–effects on oxidative stress damage in kindergarten-aged children in Guangzhou, China. *Science of The Total Environment.* 2015;524–525:74-80; Kim S, Vermeulen R, Waidyanatha S, et al. Modeling Human Metabolism of Benzene Following Occupational and Environmental Exposures. *Cancer Epidemiology Biomarkers & Prevention.* 2006;15(11):2246-2252).
[3]Choi Y-H, Kim JH, Lee B-E, Hong Y-C. Urinary benzene metabolite and insulin resistance in elderly adults. *Science of The Total Environment.* 2014;482–483:260-268).

Measurement Approaches

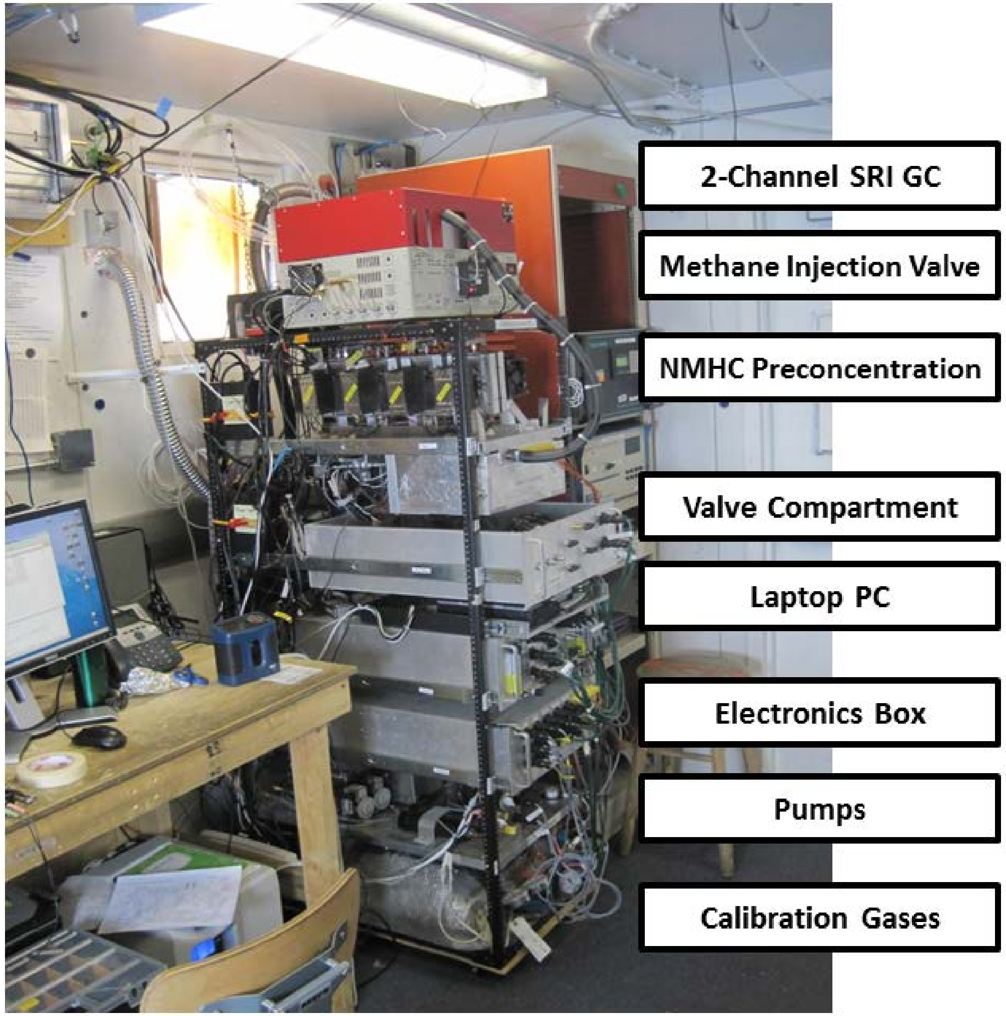


Photo credits: D. Helmig

The 2 Million Dollar Challenge

- Cost is a major issue for HAPS, less so for PM, BC, Ozone, Noise
- Where: Central site, residential, personal, and biomonitoring
  - Short-term residential and personal VOCs are a challenge
- What: BTEX/NMHC, BC, PM, Ozone, noise appropriate biomarkers
  - Ancillary information related to allostatic load if feasible
- Study Design:
  - Explore long- and focus on short-term exposures
  - Nested longitudinal study across years/seasons and locations

Circling Back: Central Questions

- What are the key exposures related to UOGD and do they vary by region?
  - Response: HAPs do not appear to vary substantiallyi by region; ozone and other pollutants may
- How is/should exposure measured or modeled?
  - Remote sensing? Area monitors? Residential or personal monitoring? Biomonitoring?
  - Model based on proximity, emissions, dispersion?
  - Response: See the $2 million dollar challenge
- Where have scientists gone beyond environmental monitoring and modeling and endeavored to quantify what people are exposed to?
  - Response: Limited to date

Final Thoughts

What do we know?

- Secondary data source exposure estimates have strengths and limitations in this context
- Timing exposure estimates to phase of development is important, as are multi-well pads
- Techniques from related fields may help with exposure estimation (Remote sensing, TRAP studies, etc.)

What don't we know?

- Limited shorter duration measurements of BTEX, Black Carbon, PM, and other air pollutants of interest used (e.g., glutaraldehyde) or emitted in large volumes near where people live
- Limited information on pollutants sourced to diesel engines
- Limited information on how exposures vary by region (or operator)

What would we like to learn?

- Tie exposures to the range of activities and environmental factors present during UOGD: this is needed to develop smart(er) setback policies
- Understand the effects of exposure to chemical mixtures and noise/traffic/accidents on health

Acknowledgments

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- Collaborators at other institutions too numerous to list
- Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the NSF, NIEHS, or funders of any of the studies cited.

Questions?