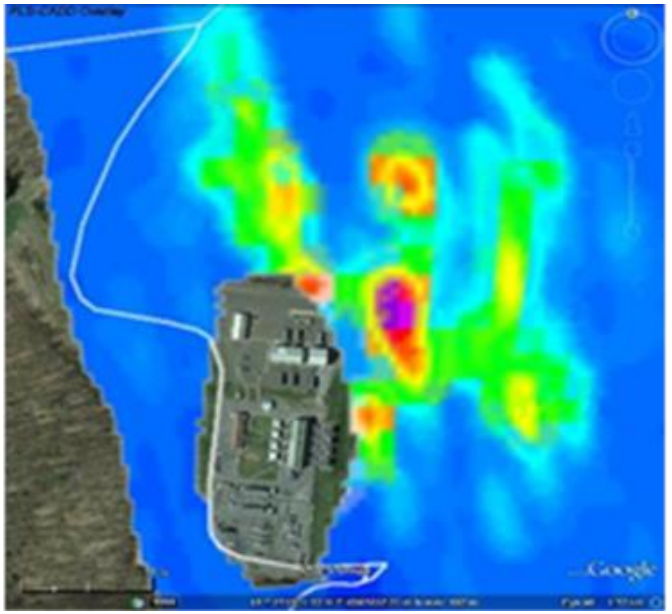
Driving Innovation ♦ Delivering Results

Mastering the Subsurface Through Technology, Innovation and Collaboration: Carbon Storage and Oil and Natural Gas Technologies Review Meeting



Understanding Impacts to Air Quality from Unconventional Natural Gas Development

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National Energy Technology Laboratory

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NETL's Assessment of Shale Gas Development's Air Quality Impacts

Problem:

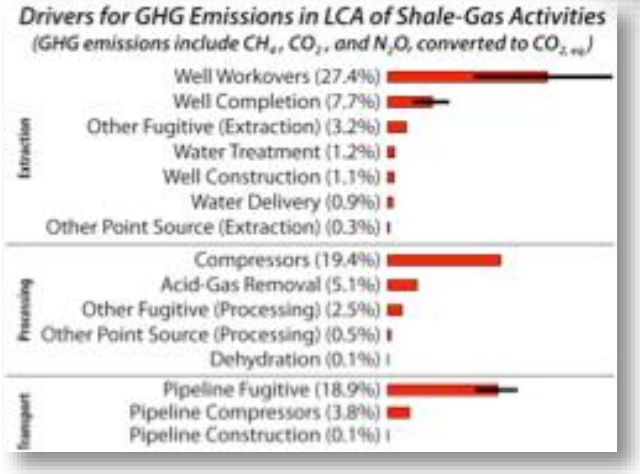
- Uncertain/inaccurate values for emission factors associated with large contributors to life-cycle emissions

Objectives:

- To collect field data of representative ambient and point source air emissions

Emissions of methane, volatile organic compounds, particulate matter, reactive nitrogen, carbon dioxide

NETL's Mobile Air Monitoring Laboratory



NETL's Use of Multiple Measurement Approaches:

Ambient	Point-Source
Values integrated over an area	Values for a specific location and/or operation
Plume interception dependent on local meteorology	Determination of background concentrations not necessary
Continuous measurements capture variations in operator/equipment activity	Provides a "snapshot" or short-term measurement

Program Benefit

Provide objective data to help quantify the environmental and safety risks of oil and gas development

- **The Methane Emissions Quantification Program aims to improve the accuracy of methane emission information currently used to identify and prioritize methane reductions within the natural gas infrastructure and the accuracy of the methane emissions reported for the natural gas infrastructure in the Environmental Protection Agency (EPA) Greenhouse Gas (GHG) Inventory.**
  - Optimizing detection and measurement techniques
  - Quantifying emissions
  - Determining the significance of emission sources when considered in an inventory context
- **Onshore Unconventional Resources Program – Air Quality task aims to improve the assessment of impacts to air quality from oil and gas exploration and production activities**
  - Use NETL's stationary ambient air monitoring laboratory, vehicle-based methane plume surveying equipment, and infrared cameras to conduct targeted on-site measurements
  - Use collected data in numerical models to understand emission rates and local and regional air quality impacts

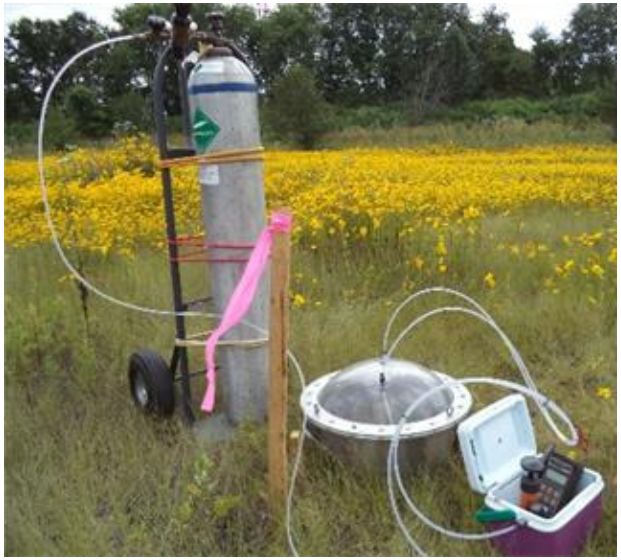
NETL Facilities/Capabilities

NETL's Mobile Air Monitoring Laboratory

VOCs, NO_x, ozone, CH_4 + $\delta^{13}C_{CH4}$, CO_2 + $\delta^{13}C_{CO2}$, PM_{10}, $PM_{2.5}$, Meteorological Data

Unattended, remote operation via satellite link

- Source Emissions Measurements: HiFlow Sampler, Dynamic Flux Chamber
- Tracer Release for Indirect Methane Emissions Measurements



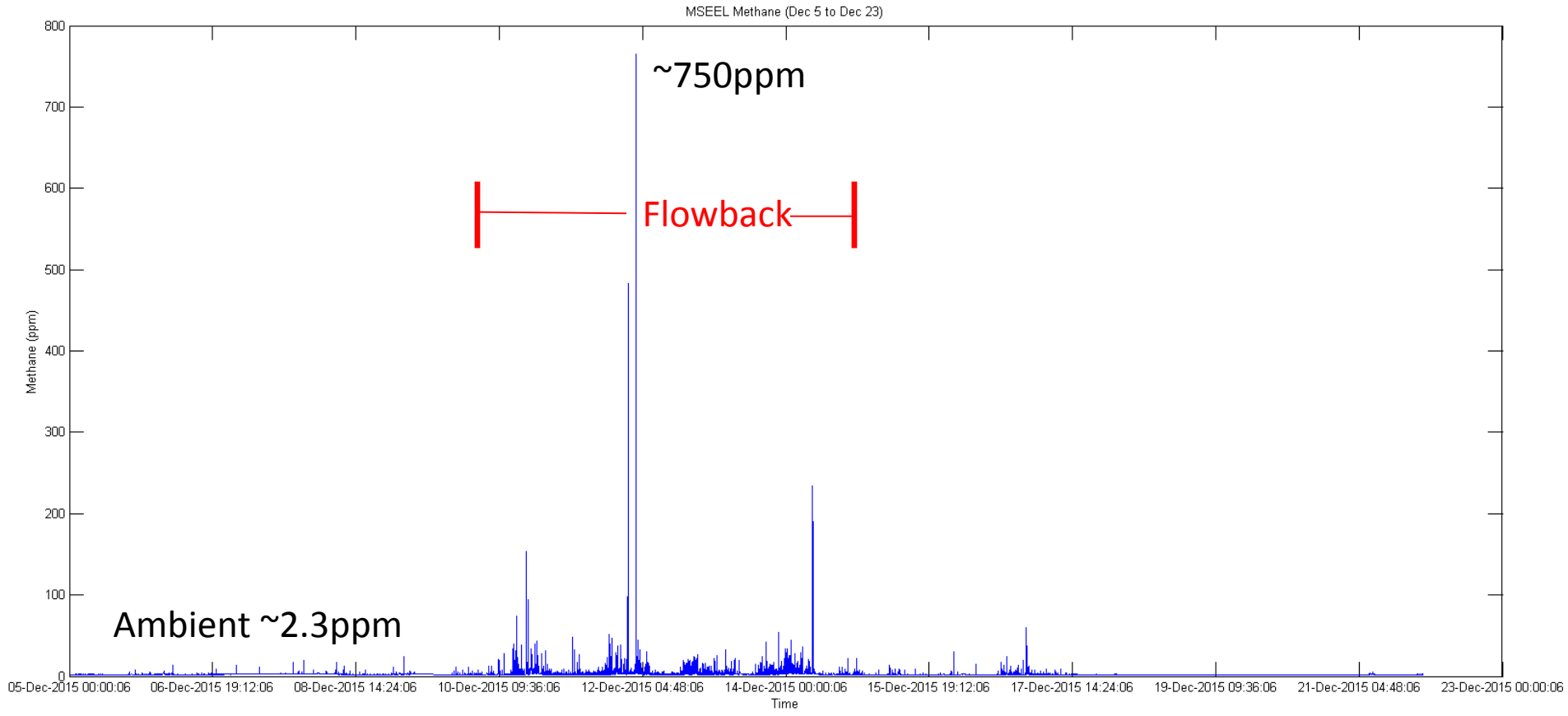
NETL's Mobile Air Monitoring Laboratory

- **Pollutants Measured:**
  - VOCs (Perkin Elmer Ozone Precursor Analyzer, GC-FID)
  - Ozone, NO_x (Teledyne-API Gas Analyzers)
  - Methane and Carbon Isotopes in Methane (Picarro CRDS)
  - CO_2 and Carbon Isotopes in CO_2 (Picarro CRDS)
  - PM_{10} and $PM_{2.5}$ (Thermo Fisher TEOM 1405DF)
  - Organic and Elemental Carbon in Aerosols (Sunset Labs NDIR)
- **Meteorological Station (Davis Vantage Pro2 Plus, R.M. Young Ultrasonic Anemometer)**
  - Wind Speed and Direction
  - Temperature
  - Relative Humidity
  - Barometric Pressure
  - Rainfall
  - Solar Intensity

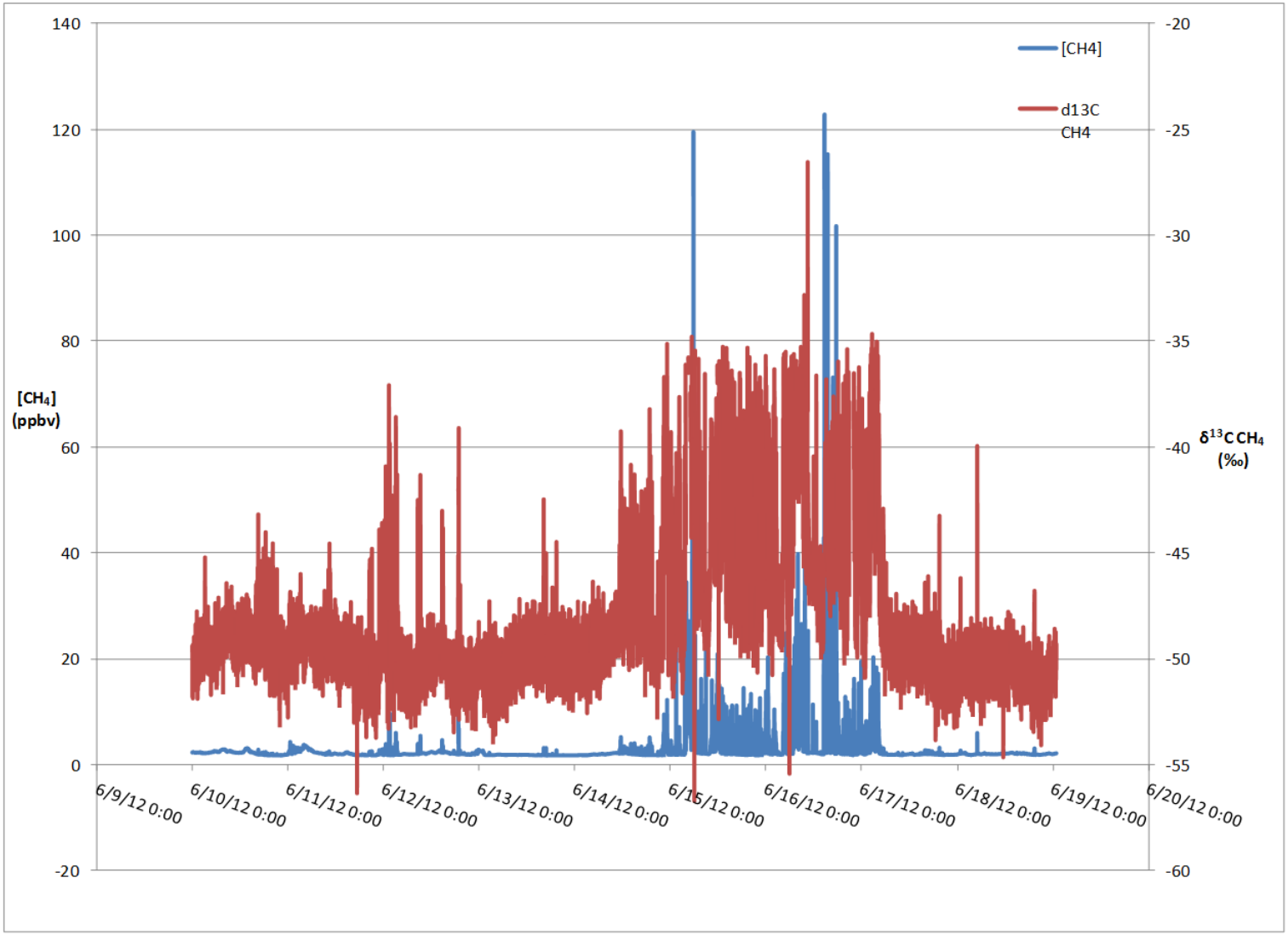
NETL's Ambient Air Monitoring Program

- **Marcellus Shale Energy Environmental Laboratory (MSEEL), Morgantown, WV (9/14 – 2/15)**
  - Two wells
  - Laboratory located on NNE corner of well pad
  - Vertical and horizontal drilling, hydraulic fracturing, flowback, production
- **Greene County Well Pads (2) (3/6/12 – 6/19/12 and 6/11/13 – 7/10/13)**
  - Six wells (two frac events) at one pad; Four wells at second pad
  - Laboratory located directly on well pad (northwest corner, southwest corner)
  - Baseline (pre-fracking), hydraulic fracturing, flowback, production
- **MCC Partners Site in Washington County (7/15/11 – 3/5/12, 7/11/13 - 4/28/14)**
  - Laboratory located 600 m northeast from well pad center
  - Baseline, horizontal drilling, hydraulic fracturing, flowback, production

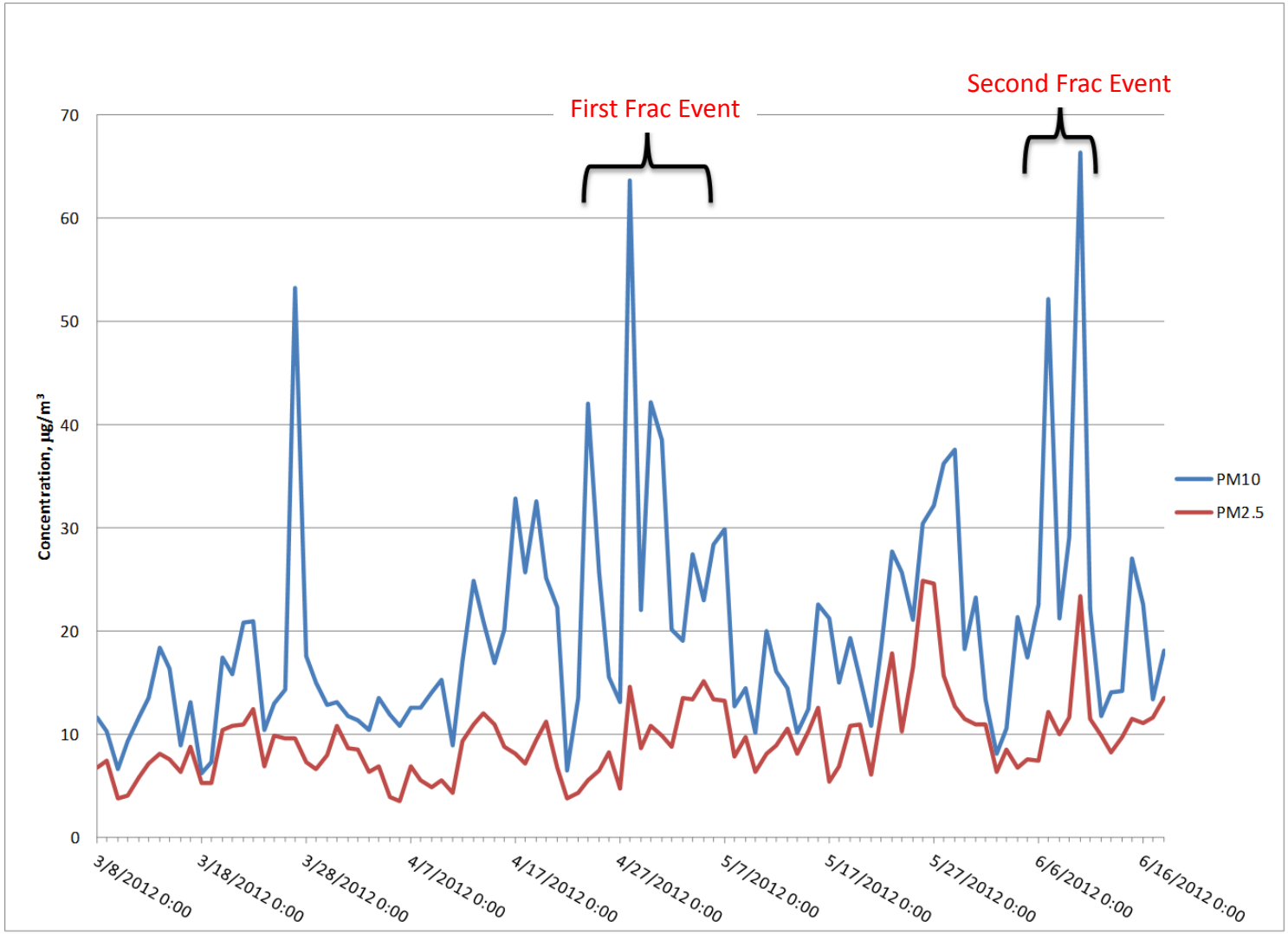
Methane Concentration at MSEEL



Isotopic Methane – Natural Gas Tracer (Greene County Well Pad)



24-Hour Average Particulate Matter (PM) Concentration at Greene County Well Pad



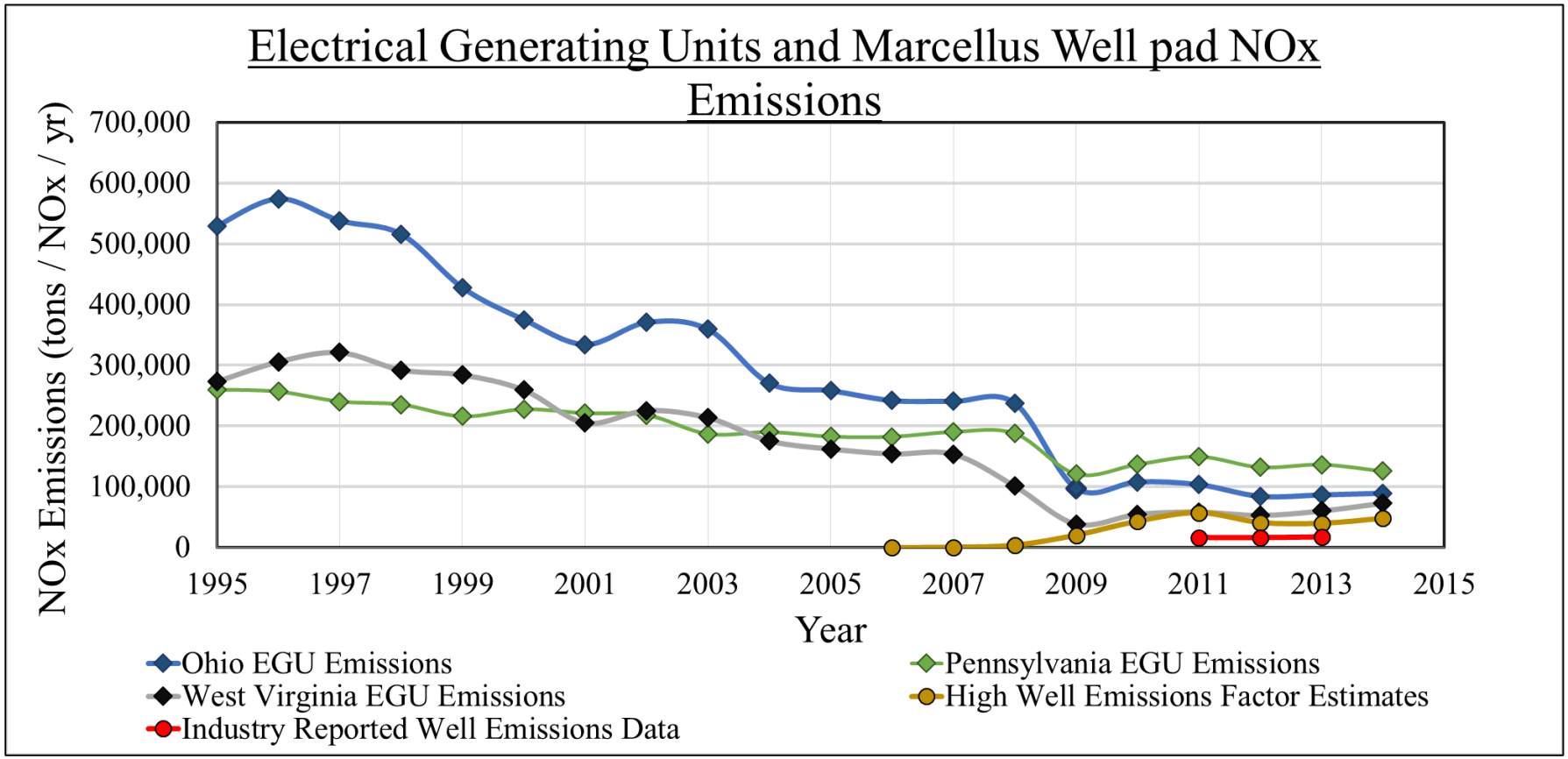
Volatile Organic Compound Concentrations at a Greene County, PA Well Pad

Compound*	Background (ppb)	First Frac Event (ppb)	Second Frac Event (ppb)
Hexane	0.3	0.6	0.4
Benzene	0.3	0.4	0.2
Toluene	0.7	1.3	2.3
Ethane	24.1	34.6	34.0
Propane	11.2	42.1	110.8
Isobutane	2.9	3.1	3.0
n-Butane	4.6	4.8	4.1
Isopentane	2.2	3.4	3.2
n-Pentane	1.8	2.2	1.8

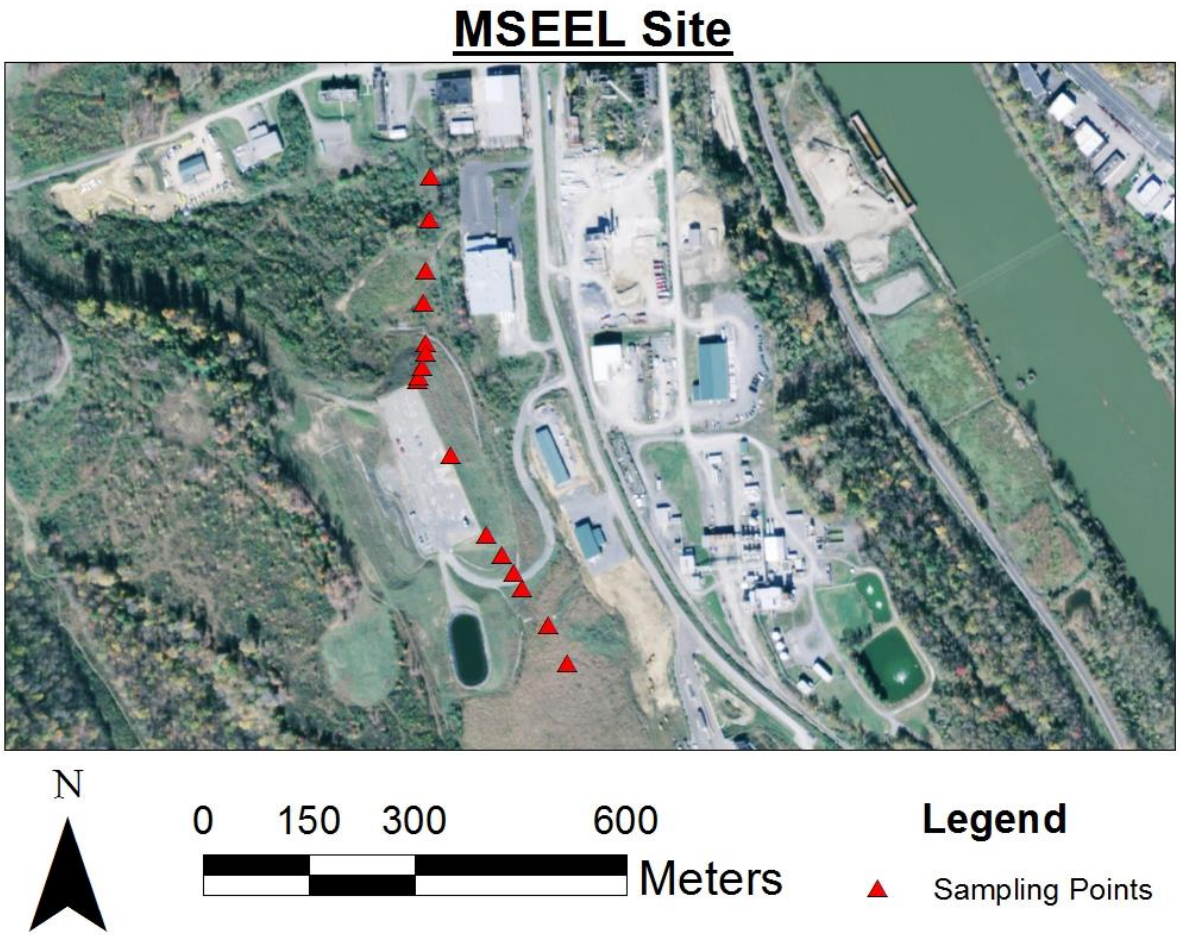
**Compounds detected in at least 25% of the samples. Preliminary data, do not cite*

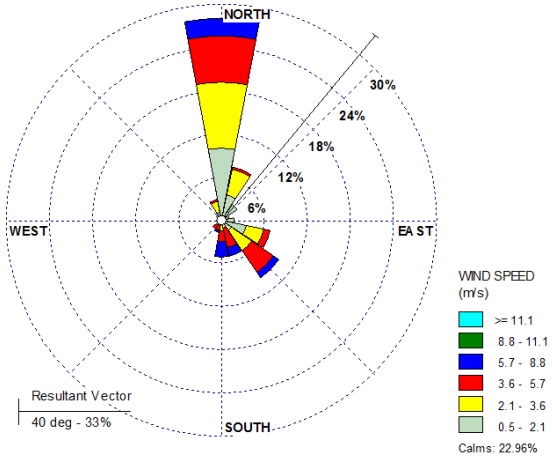
Fate and Transport of N-Containing Compounds

Measurement of ambient air concentrations and deposition fluctuations of NO_2 and HNO_3 along upwind and downwind transects adjacent to a Marcellus Shale unconventional well pad



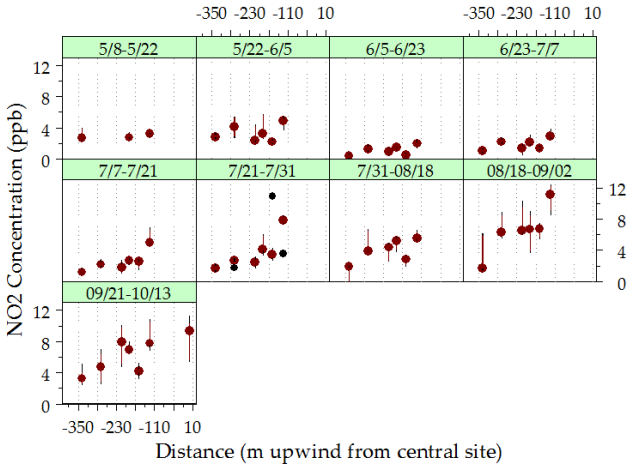
Reactive Nitrogen Emissions, Deposition: Marcellus Shale Energy Environmental Laboratory

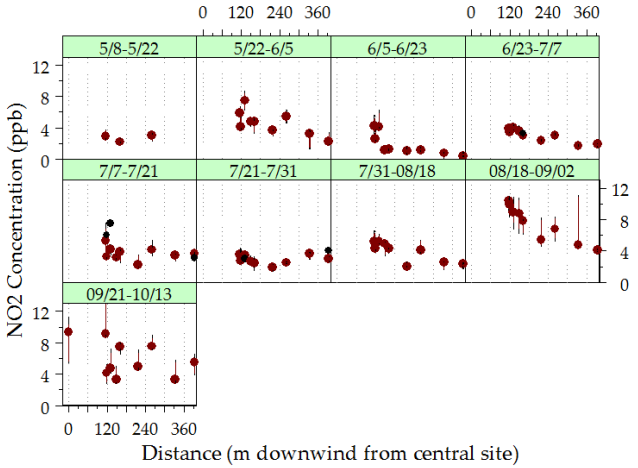




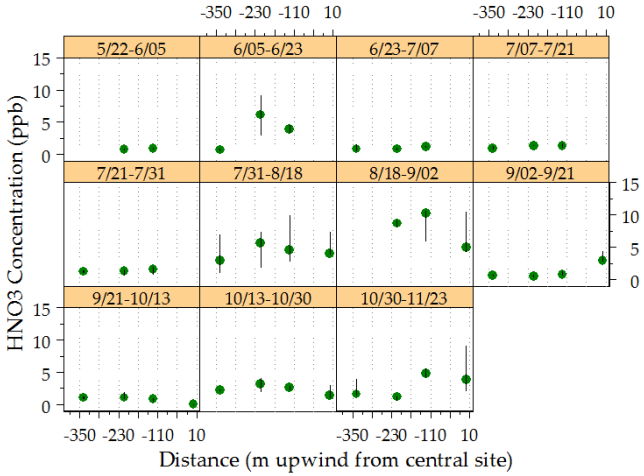
Biweekly passive filter samples analyzed from May-Nov. 2015, background through fracking

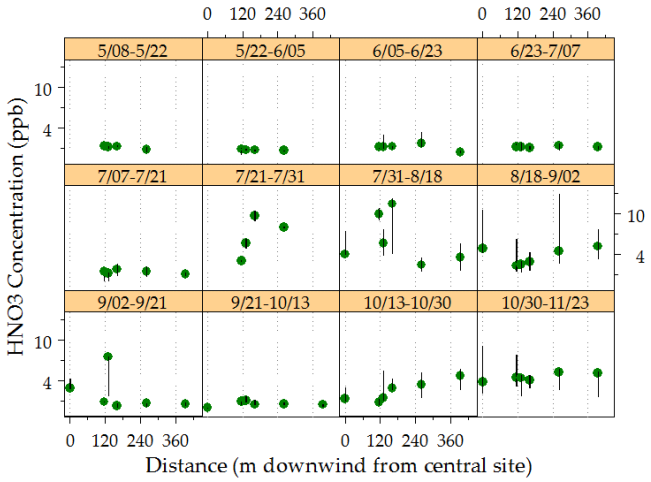
Reactive Nitrogen Emissions, Deposition: Key Accomplishments





During periods of heightened activity, NO_2 concentration initially peaks near the well pad and decreases with distance upwind and downwind, returning to background levels ~300 m from the central site



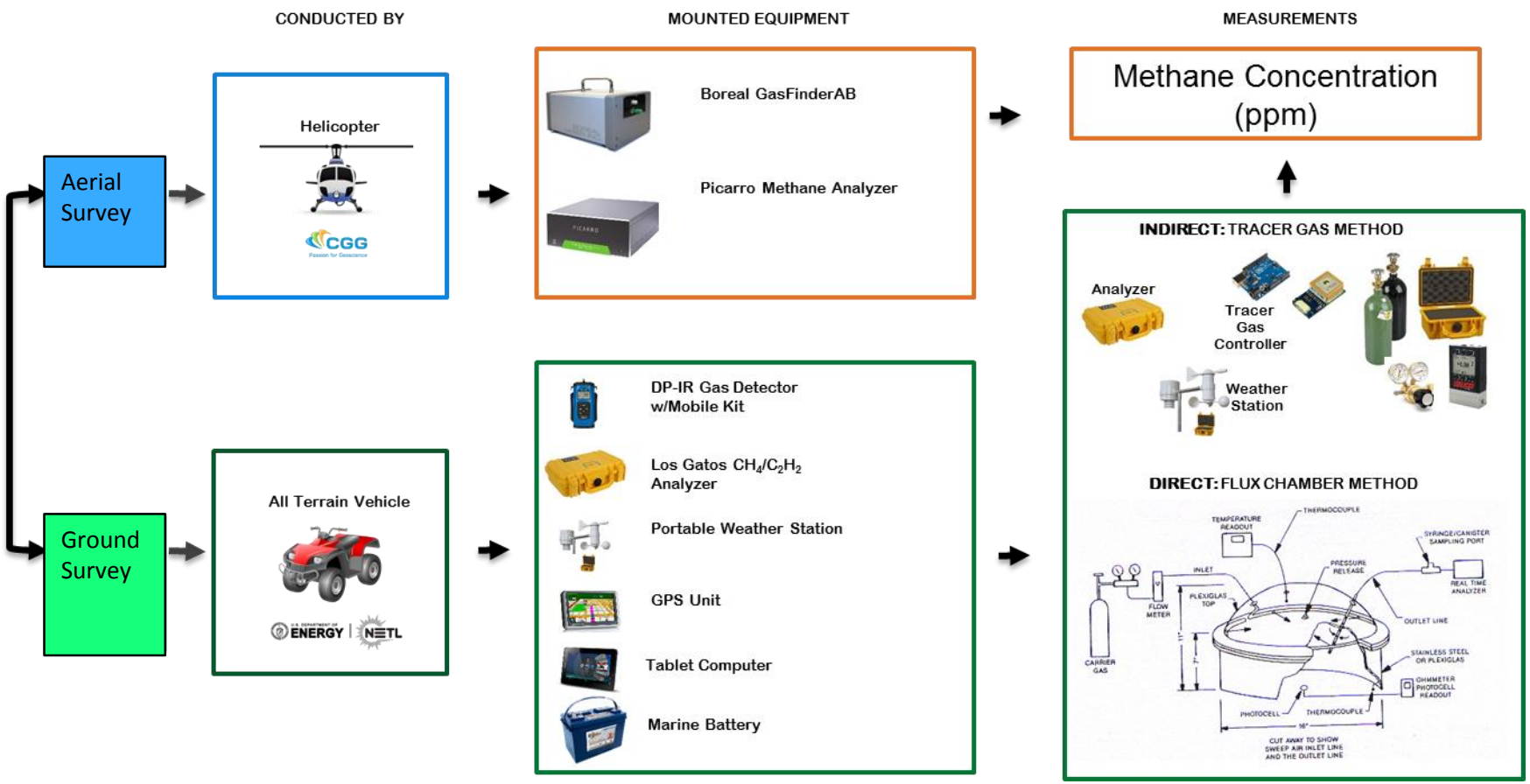


HNO_3 concentration peaks ~150 m away from the well pad during periods of heightened activity

Evidence of oxidation of NO_2 by O_3. The time-weighted ambient concentration of NO2 does not surpass the NAAQS

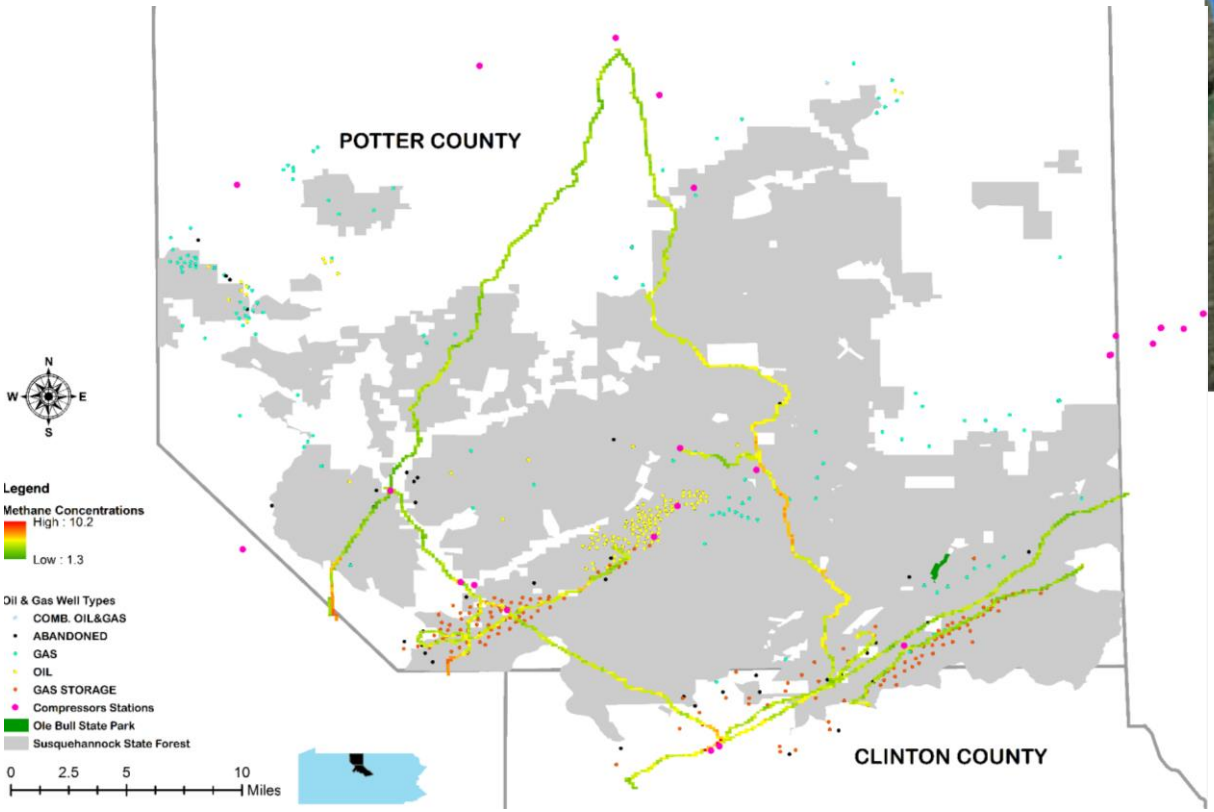
Natural Gas Pipeline Leak Rate Estimation

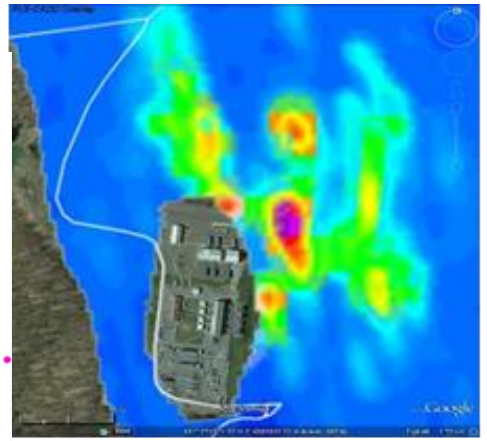
- **Pipeline Study Design**



Mundia-Howe et al., 2015

Natural Gas Pipeline Leak Rate Estimation



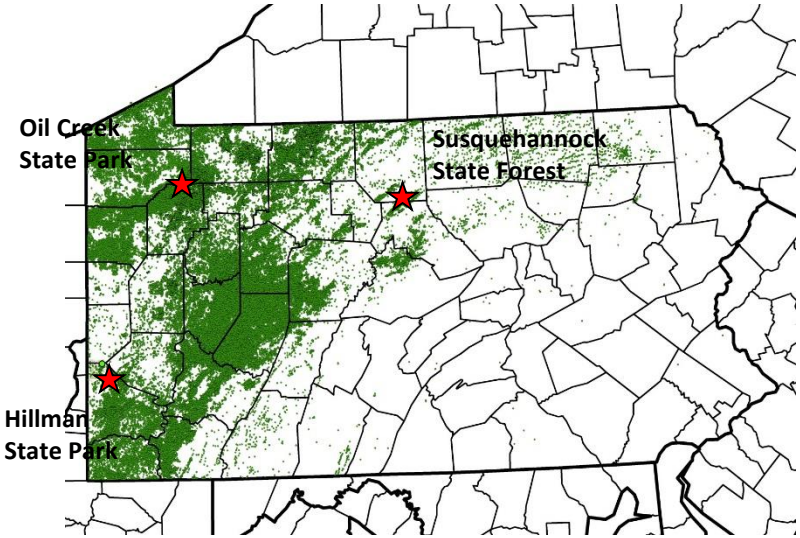


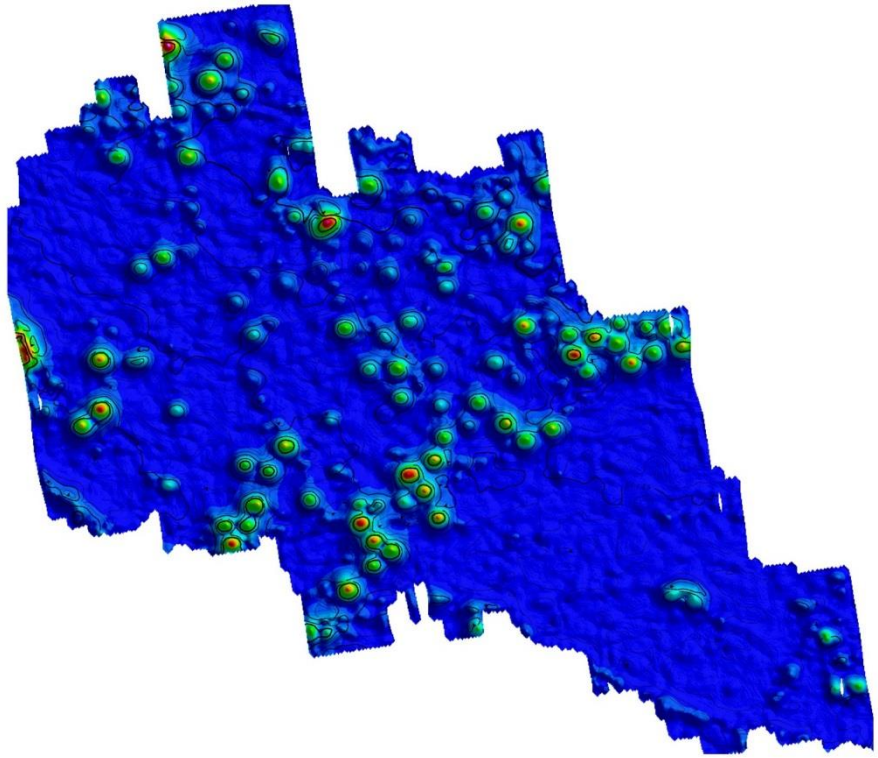
Aerial Detection of Methane from a compressor station

2016: Gathering pipelines, UAVs

Legacy Well Methane Emissions

Emission rate from abandoned wells unknown; could contribute to "top-down" vs. "bottom-up" discrepancy



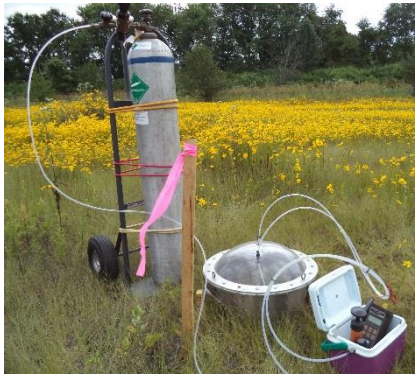
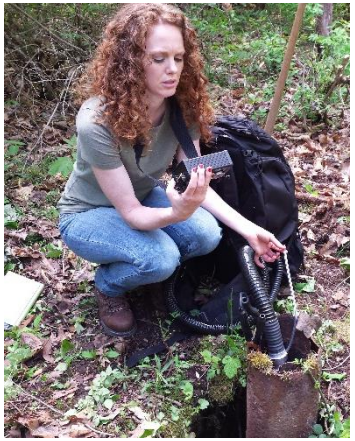


Aeromagnetic Survey of Hillman State Park, PA

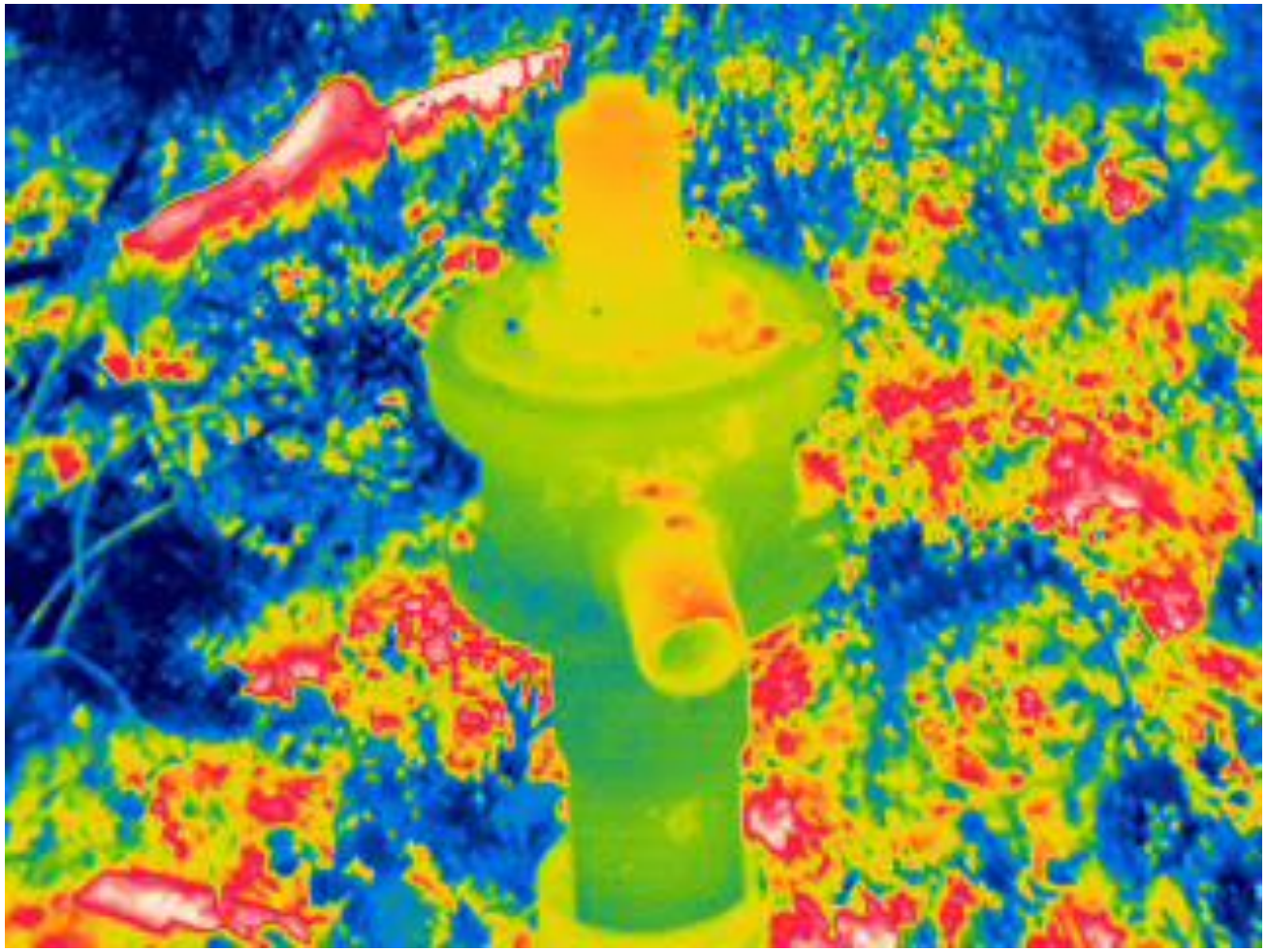
Legacy Well Methane Emissions

- **Abandoned wells present a risk to current development**
  - Conduit for gases and fluids to migrate to surface, unknown locations
- **Methods development**
  - HiFlow sampler, flux chamber, field FID, bag sampling, infrared camera
- **Measured emission rate/flux from 31 wells in Hillman State Park**
  - Mean methane emission rate for wellheads 0.70 kgd/well/day



Legacy Well Methane Emissions



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