Large Scale PM2.5 and Air Toxics Monitoring at Unconventional Natural Gas Development Sites in the Appalachian Basin

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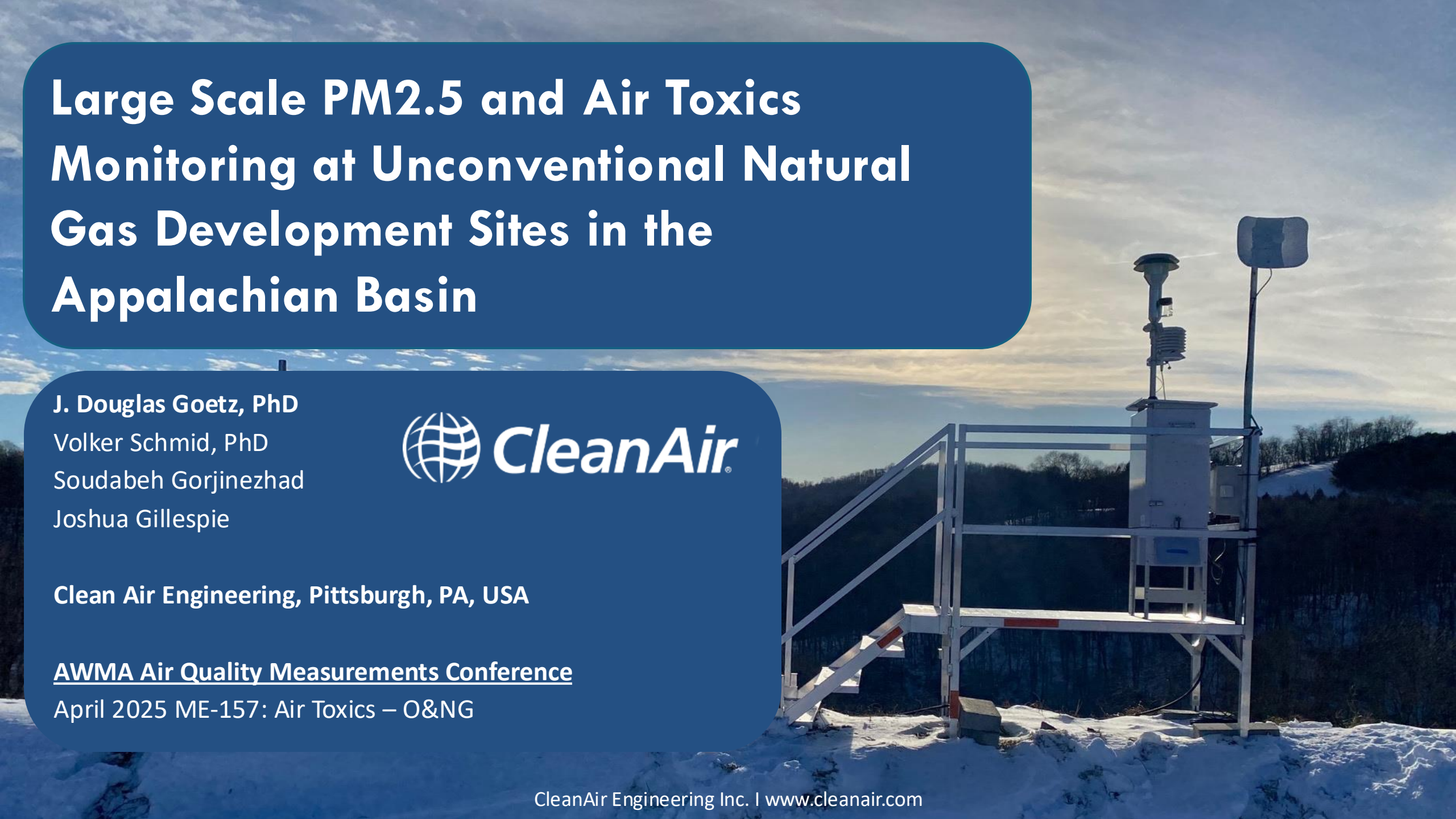


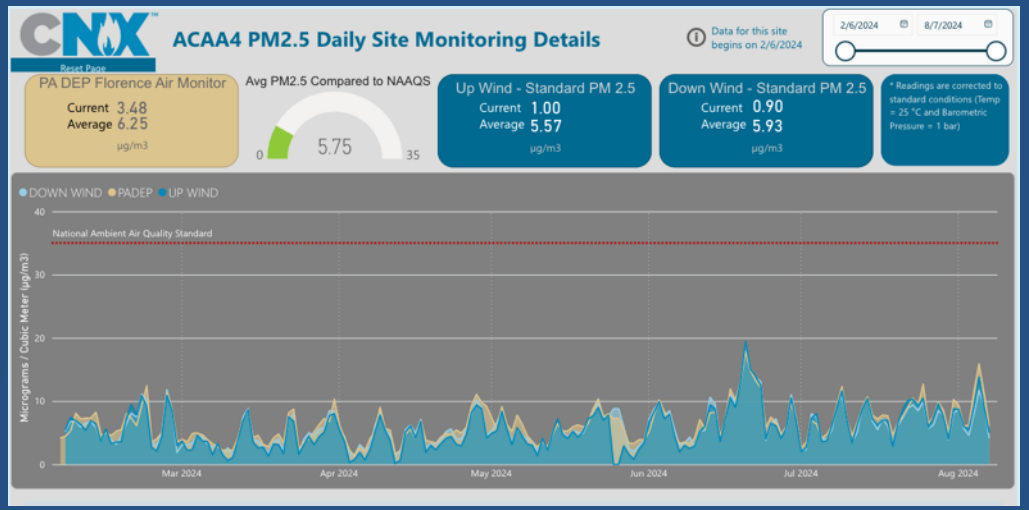
Public-Private AQ Monitoring Collaboration

- CNX Resources – a major NG company located in the Appalachian Basin
- Unconventional NG production and midstream operations
- Radical Transparency program started in late 2023 with a focus on environmental monitoring and public disclosure
- In collaboration with PA Governor's office and PA Department of Environmental Protection (PADEP)
- Fugitive Emissions of PM2.5 and BTEX monitored to investigate human health concerns outlined recent studies

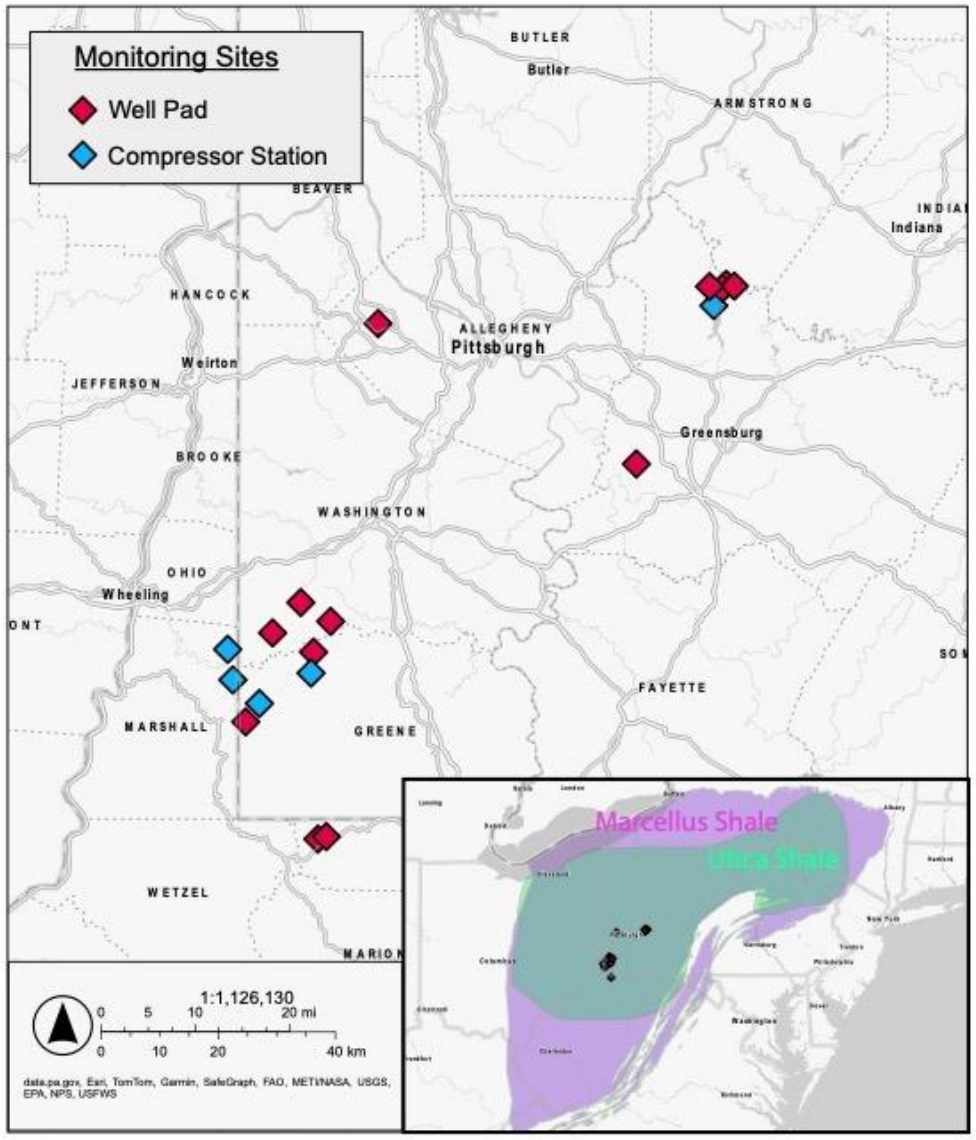
RADICAL TRANSPARENCY OVERVIEW

RADICAL TRANSPARENCY: A NEW ERA OF RESPONSIBLE DOMESTIC ENERGY DEVELOPMENT

www.cnx.com/sustainability-radical-transparency



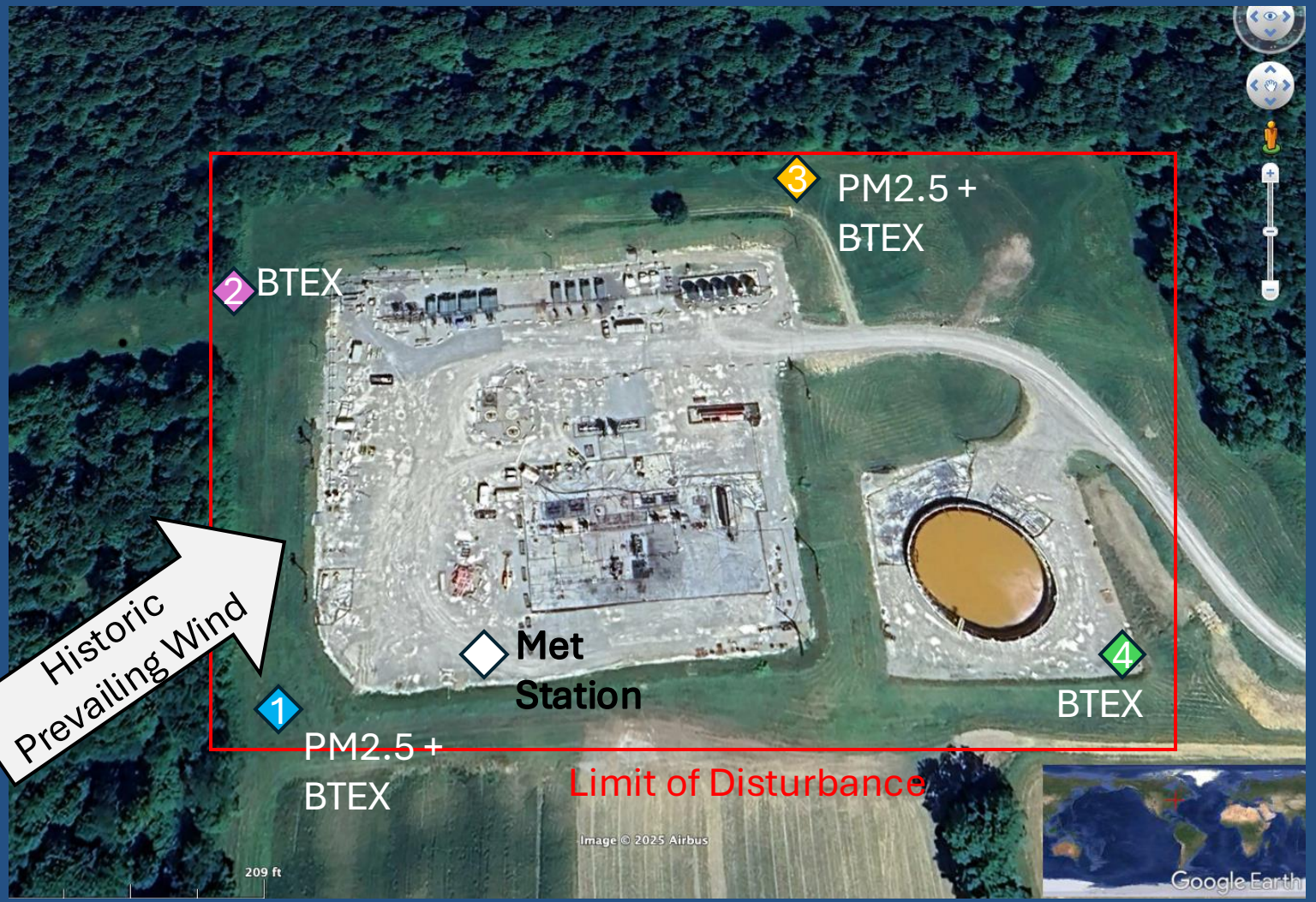
Large-Scale Monitoring Program



- Monitoring started Oct. 2023 w/one production well pad
- 18 monitoring locations w/ >10 years of continuous data
- Monitoring is on-going and the locations are based on real development schedules

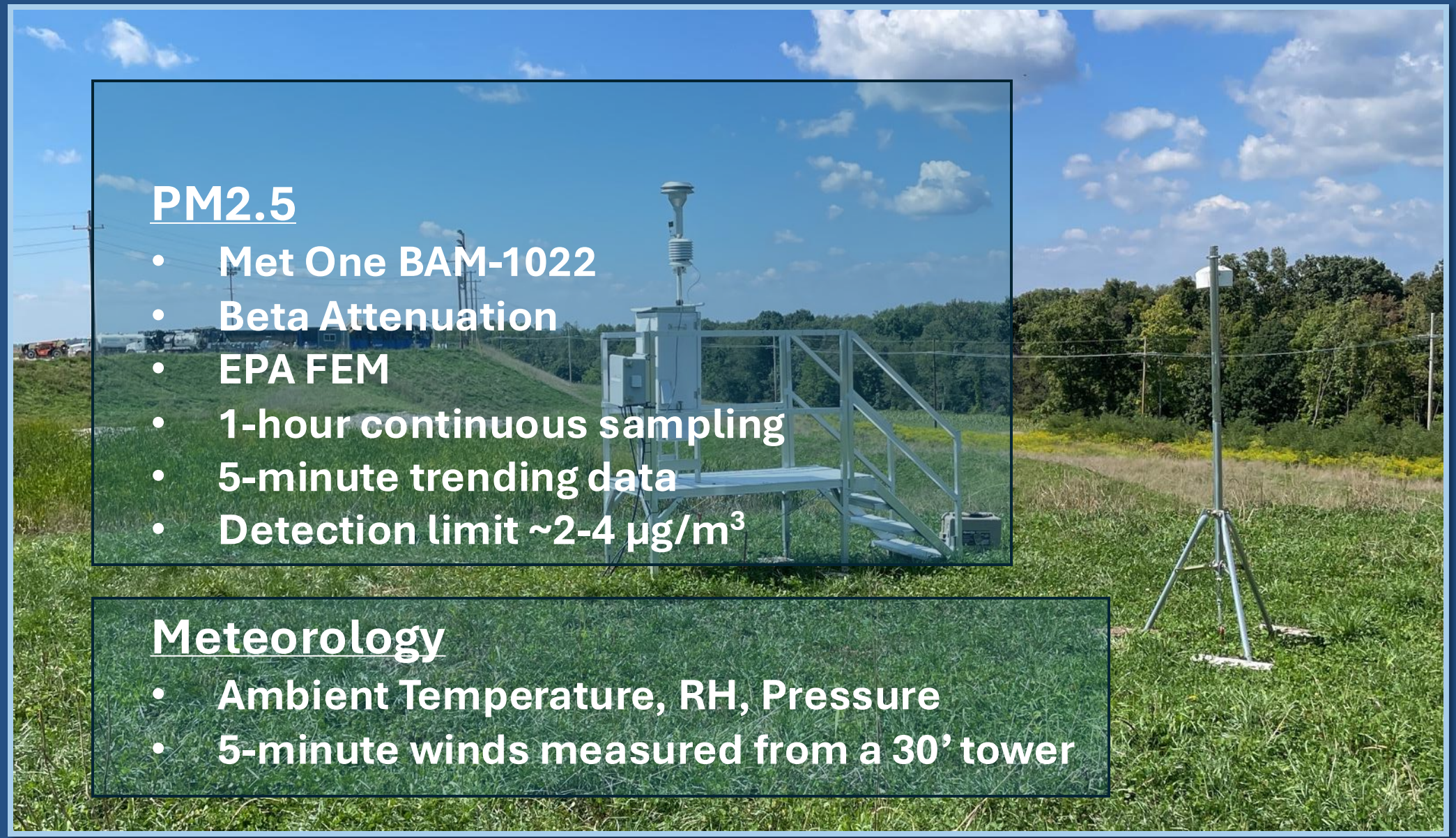
Site Type	Observation Periods	Typical Duration
Pad Construction	1	~9 months
Drilling Operations	6	3-6 months
Completion Operations	9	1-6 months
Production Well Pad	11	≥6 months
Compressor Stations	5	>1 year

Fenceline Monitoring



- The monitoring plan was designed for the capture of fugitive emissions at the fenceline or ~500 ft from the facility center
- An upwind/downwind monitoring scheme was used to optimize the sampling of emissions based on the historic prevailing wind direction (e.g. SCAQMD Rule 1466)
- Other considerations for siting:
  - EPA guidelines for Federal Equivalent Method (FEM) monitoring of PM2.5
  - Lease limit of disturbance (LOD)
  - Topography
  - Site operations

Monitoring Equipment



PM2.5

- Met One BAM-1022
- Beta Attenuation
- EPA FEM
- 1-hour continuous sampling
- 5-minute trending data
- Detection limit ~2-4 µg/m^3

Meteorology

- Ambient Temperature, RH, Pressure
- 5-minute winds measured from a 30’ tower

Monitoring Equipment

Benzene
Toluene
Ethylbenzene
Xylene (BTEX)

Passive Sorbent Trap Sampling w/ CarbopackX

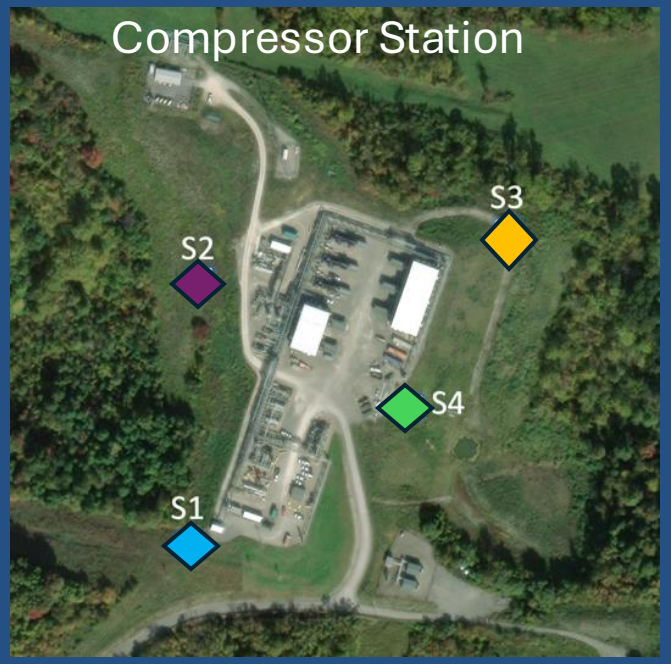
Modified EPA M325A/B*

14-day continuous sampling

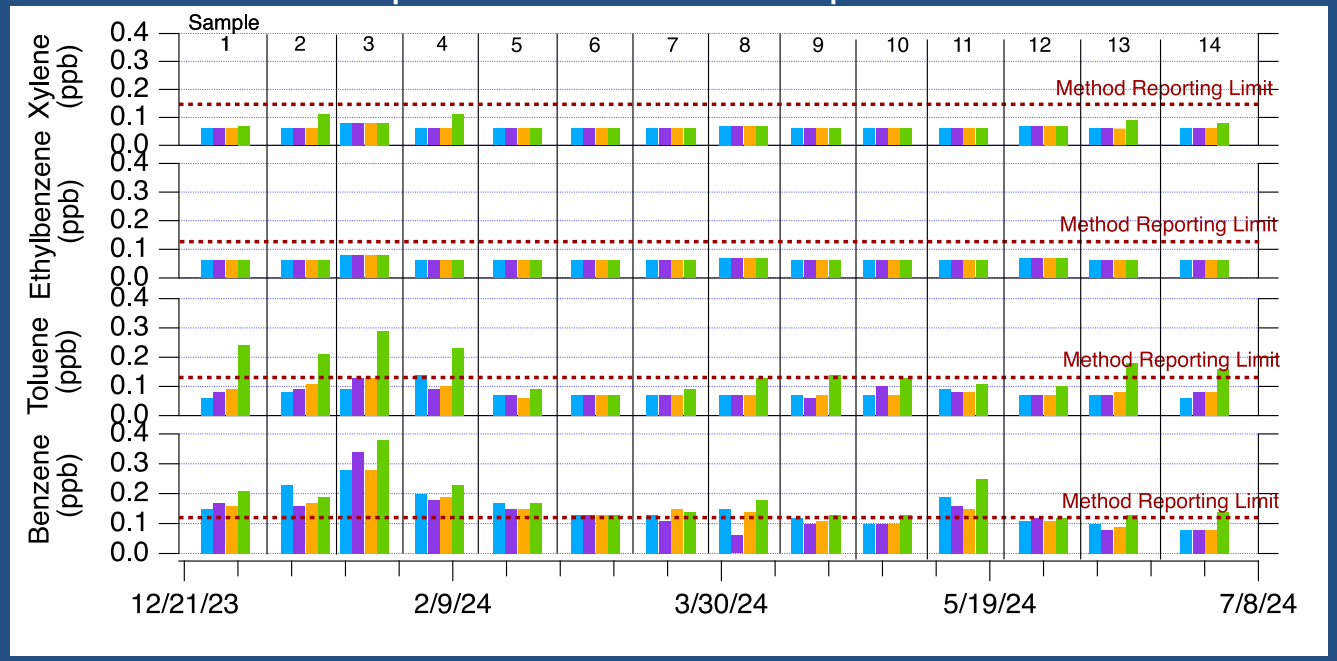
Sensitivity for Benzene <0.1 ppb

*https://www.epa.gov/sites/default/files/2019-08/documents/method_325a.pdf

Preliminary BTEX Results

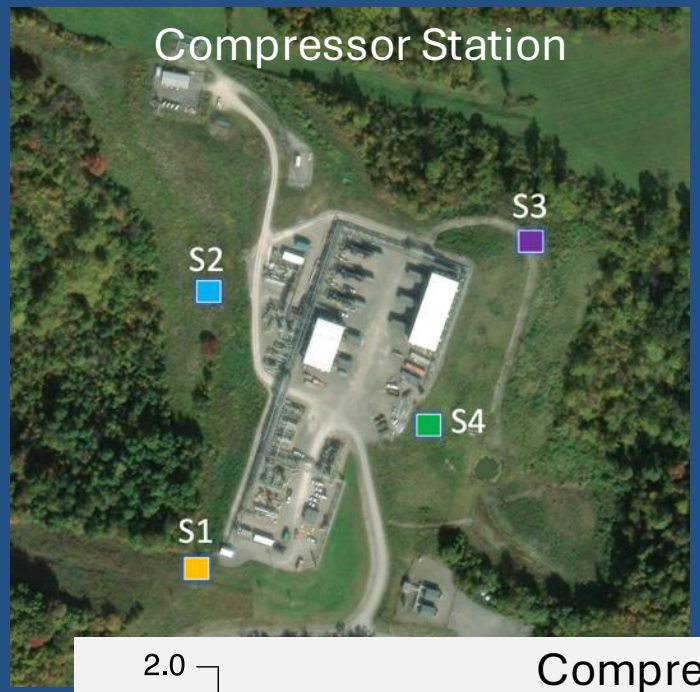


Compressor Station Example Time Series



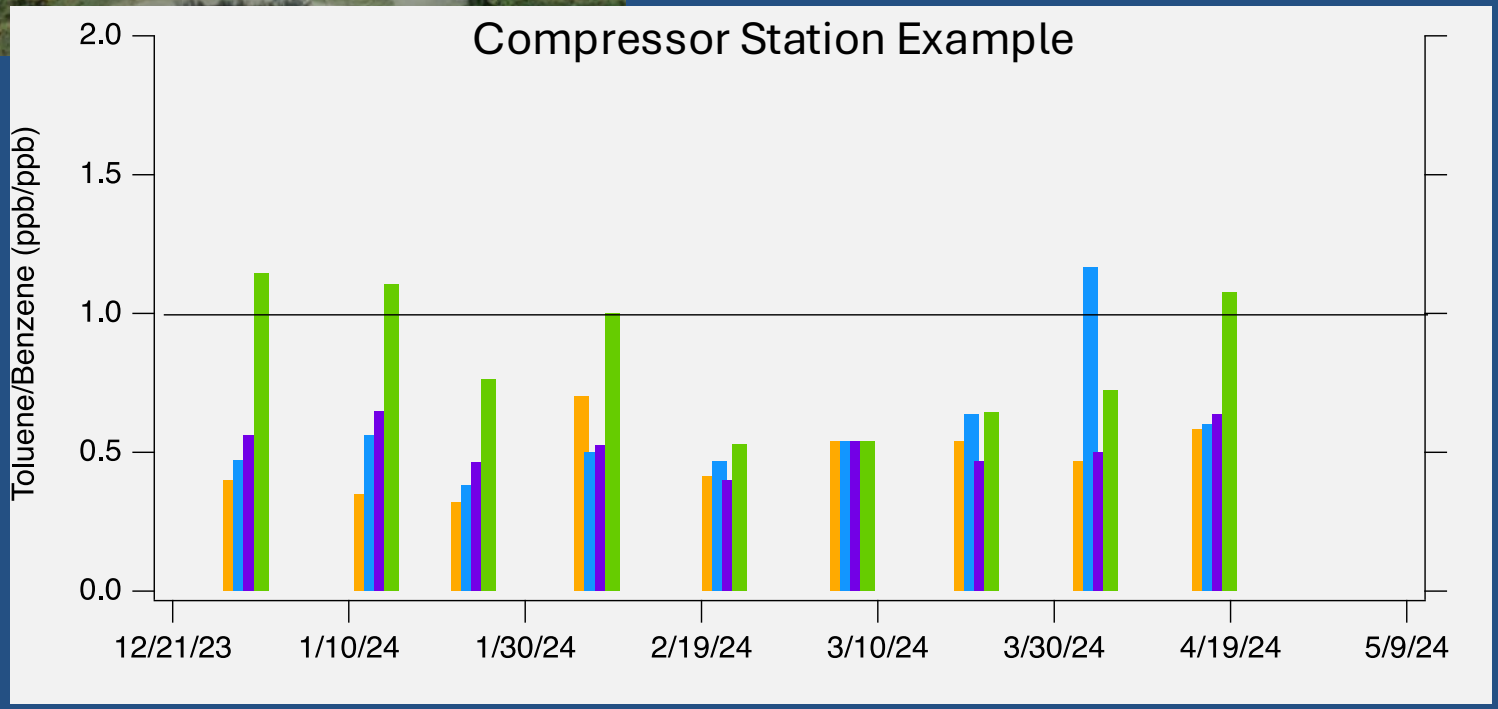
Benzene Inhalation Minimum Risk Level (MRL) [ATSDR, Benzene Toxicological Profile, 2024]		
	Duration (days)	**Level (ppb)**
Acute	<14	9.0
Intermediate	15-365	7.0
Chronic	>365	2.0

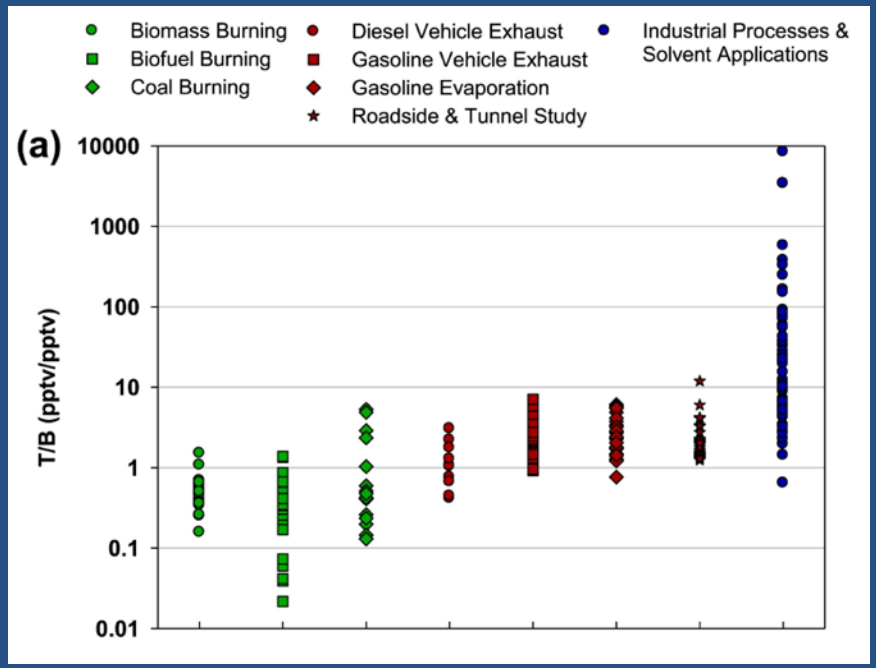
- No observations near U.S. ATSDR Inhalation Minimum Risk Levels for acute or chronic level exposure. (See ATSDR ToxGuides)
- Concentrations at all sites were generally near regional background levels and below laboratory reporting limits, and the highest observed Benzene concentration was 0.63 ppb
- Marcellus Shale is low in NG liquids and is therefore expected to emit lower concentrations of Hazardous Air Pollutants (HAPs) compared to other liquid rich plays



Source Identification w/ BTEX

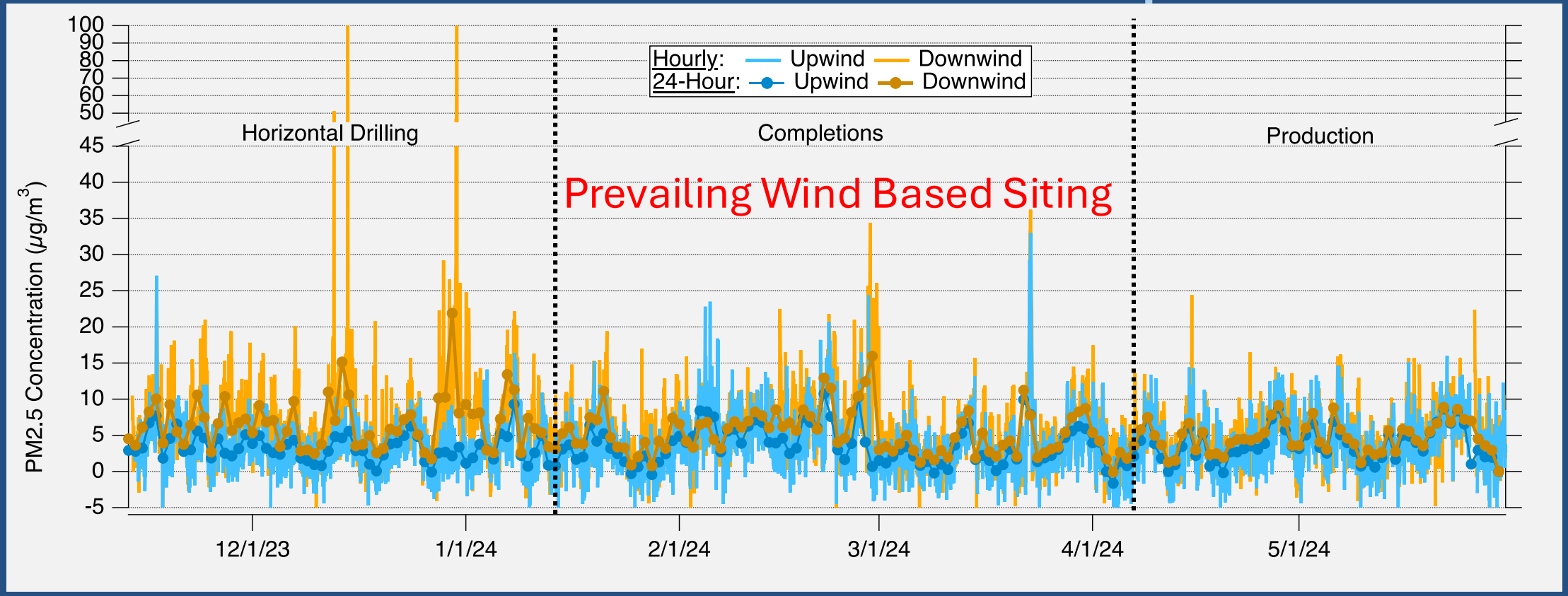
- Toluene:Benzene is a useful tool to estimate the source of air toxic enhancement concentrations at the fenceline
- There are many examples in scientific literature like Zhang et. al., 2016 that can be used as a resource to identify possible sources
- The compressor station example below shows that the S4 air toxic concentrations are likely from liquid fuel combustion or evaporation from vehicle traffic





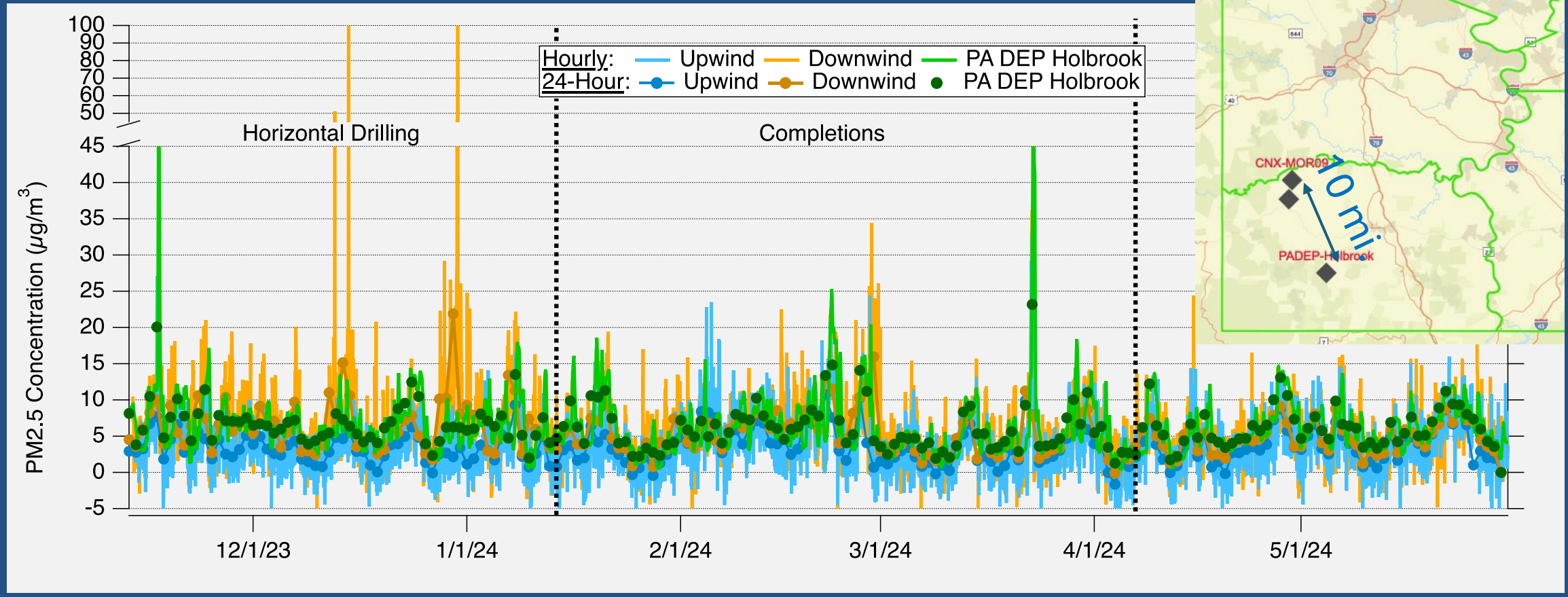
Zhang et al. 2016, JGR Atmospheres

PM2.5 – Well Pad Development



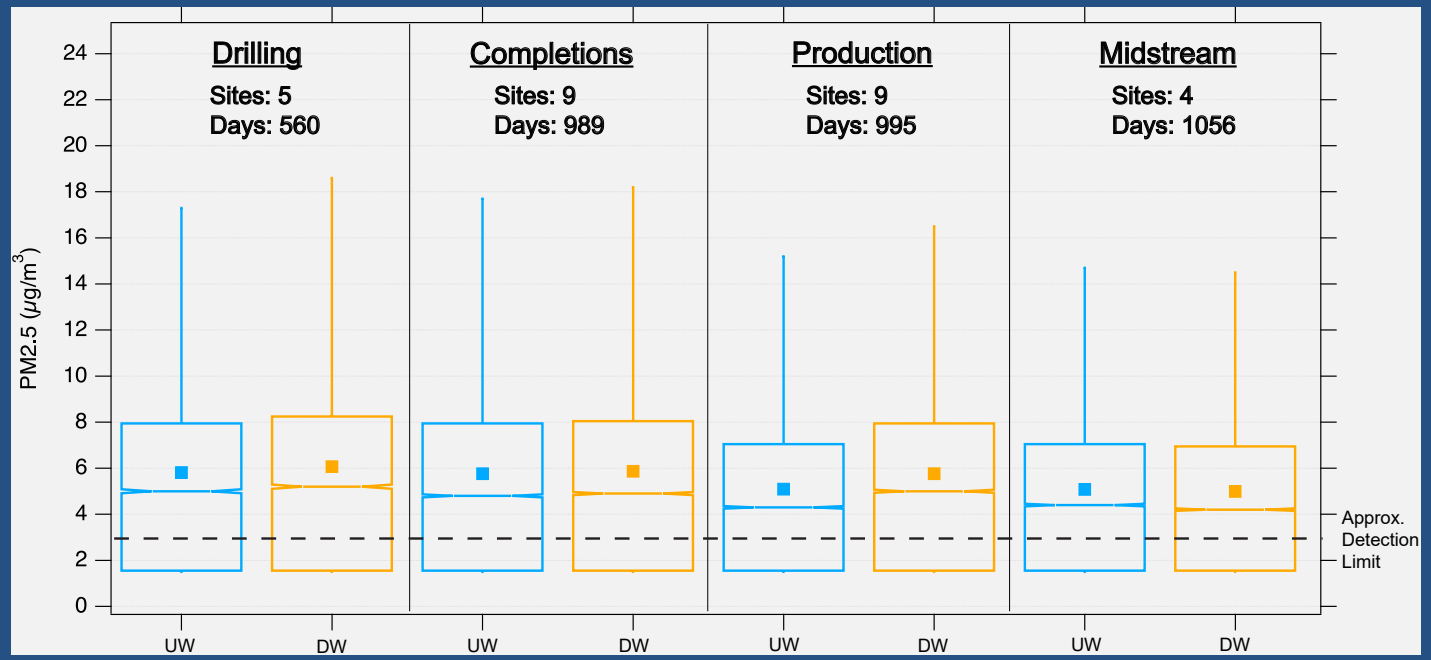
- The above example shows a 6-month time series of hourly and daily PM2.5 concentrations at the MOR09 well pad
- The example results show that there were no daily concentrations above 25 µg/m^3 during any phase
- The MOR09 example is representative of most of the PM2.5 monitoring, with a low frequency of short-duration differences between the upwind and downwind monitors based on prevailing wind siting

PM2.5 – Comparison to Other Sites



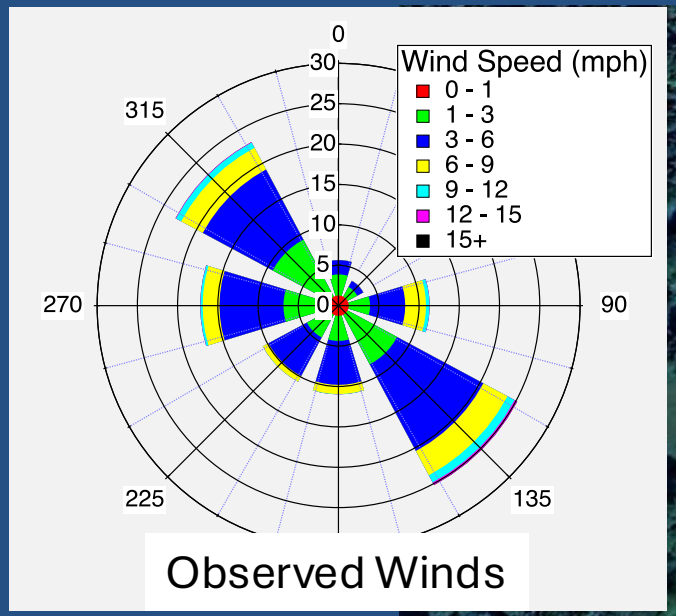
- Local PADEP monitoring sites can be used for comparison to 'regional background' PM2.5 concentrations
- The above example from the MOR09 well pad shows that the daily concentrations at the sites compare well with the PADEP site that is ~10 miles away

Project PM2.5 Concentrations



- Box and whisker plots of the aggregated hourly PM2.5 show the statistics from the upwind and downwind locations based on the prevailing wind siting
- The analysis shows minor differences between the upwind and downwind sites, however, an analysis using the monitored winds is required
- Although not shown in the figure: No exceedances of the primary NAAQS standard for PM2.5 (35 µg/m^3 24-hour avg.) were observed at any of the 18 monitored sites

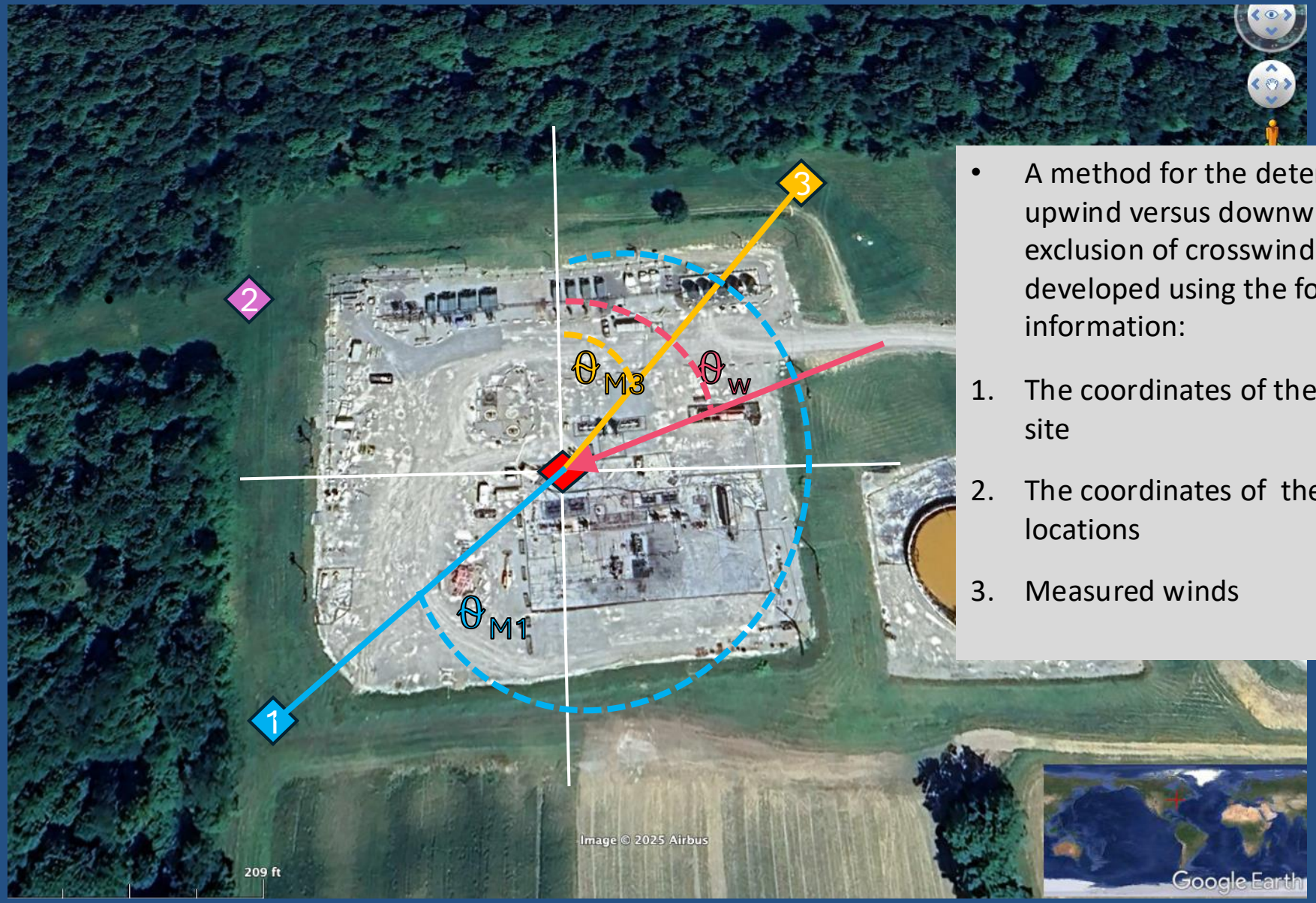
PM2.5 Downwind Enhancement (ΔC)



Observed Winds

- Wind-resolved analysis of the enhancement concentrations at the fenceline is needed to understand the concentration of fugitive emissions leaving the site (ΔC)
- The cumulative wind rose and satellite imagery example from the BP06 well pad shows that the prevailing wind siting does not capture all hourly records where monitoring station 3 is in the downwind position.
- Therefore, a method for determining the hourly upwind and downwind monitoring position is required

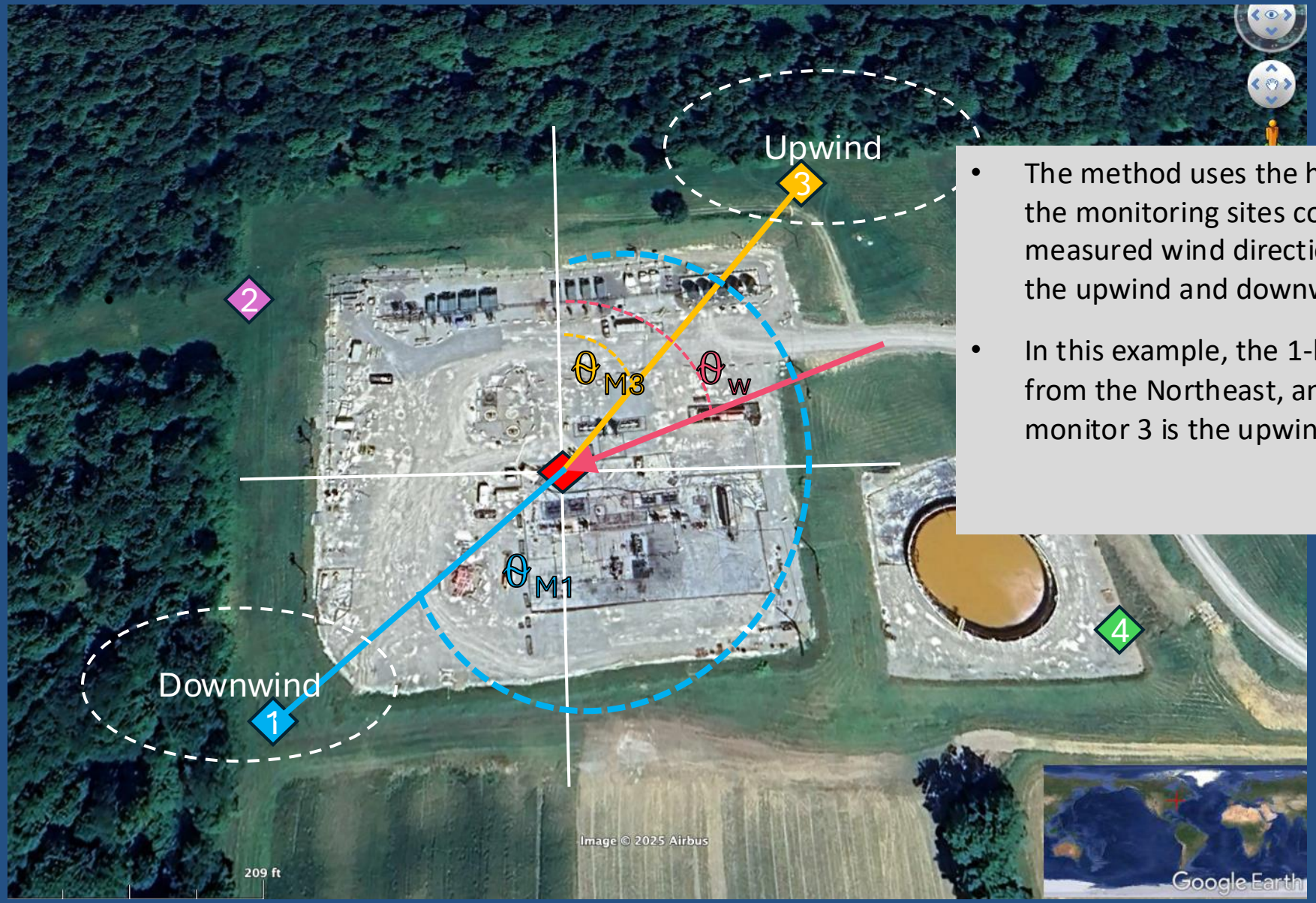
PM2.5 Downwind Enhancement (ΔC)



- A method for the determination of the upwind versus downwind monitor and exclusion of crosswind conditions was developed using the following information:

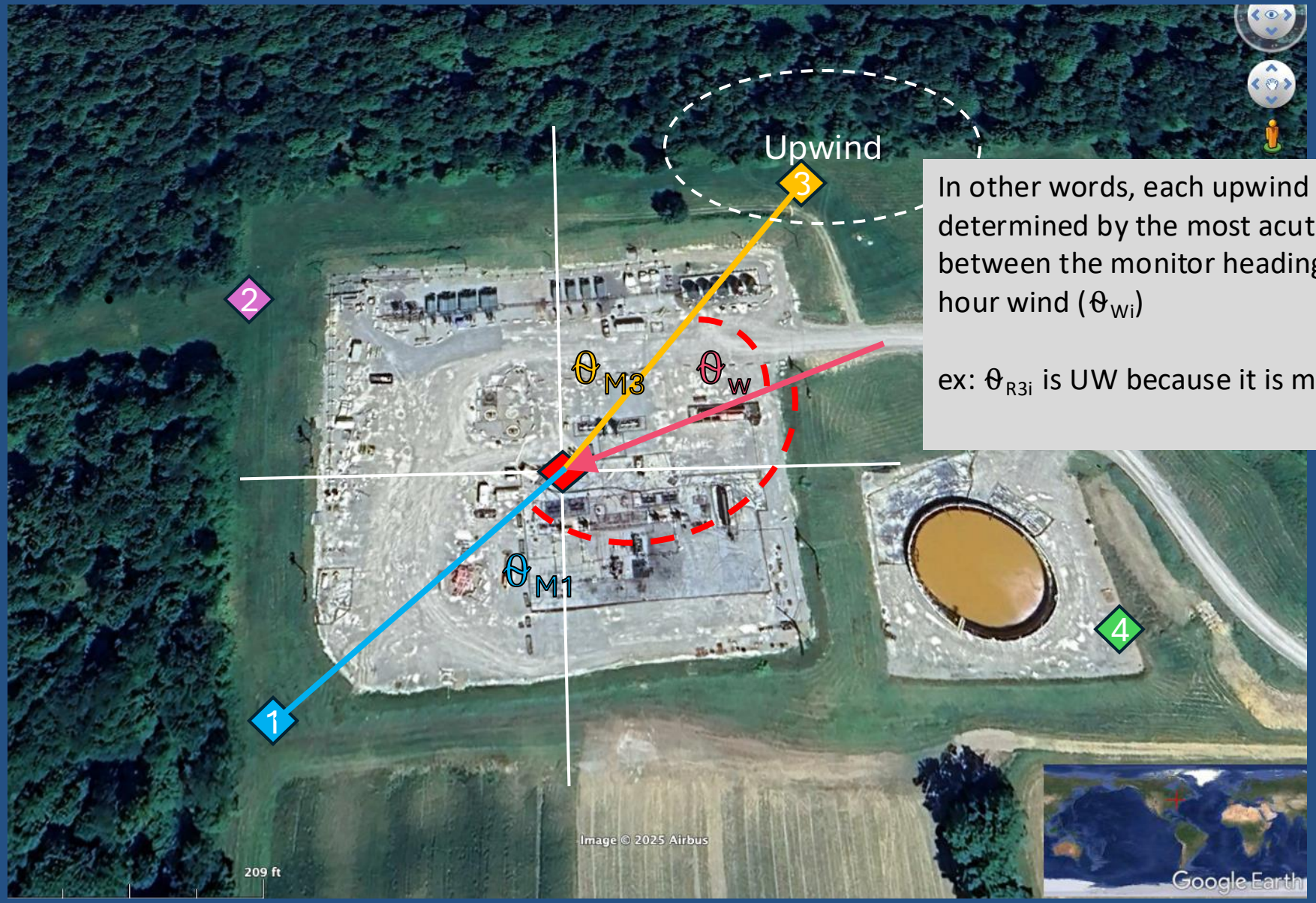
1. The coordinates of the center of the site
2. The coordinates of the monitoring locations
3. Measured winds

PM2.5 Downwind Enhancement (ΔC)



- The method uses the heading angle of the monitoring sites compared to the measured wind direction to determine the upwind and downwind locations
- In this example, the 1-hour wind comes from the Northeast, and therefore, monitor 3 is the upwind location

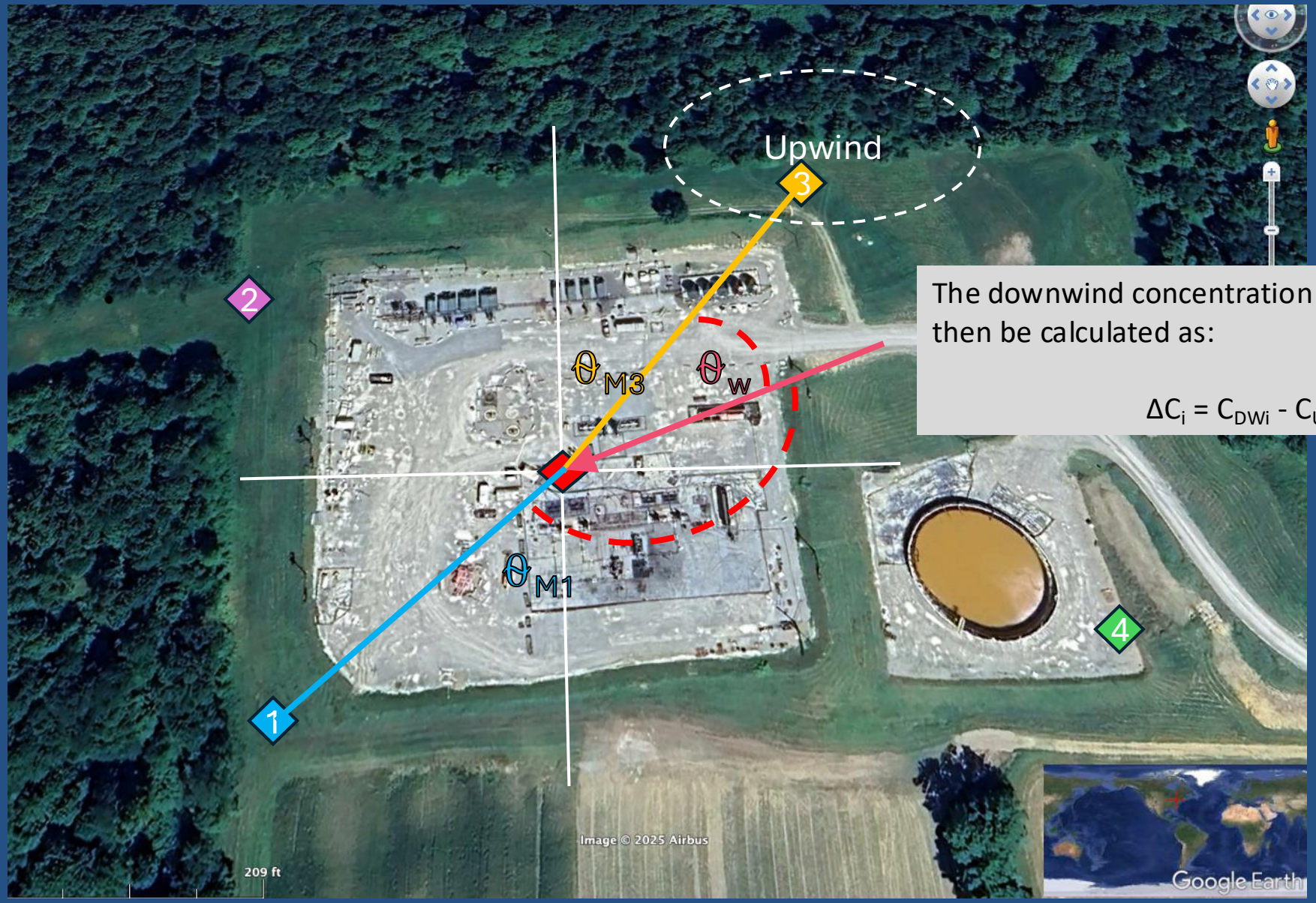
PM2.5 Downwind Enhancement (ΔC)



In other words, each upwind record (X_{UWi}) is determined by the most acute radial angle (θ_R) between the monitor heading (θ_{Mx}) and the 1-hour wind (θ_{Wi})

ex: θ_{R3i} is UW because it is more acute

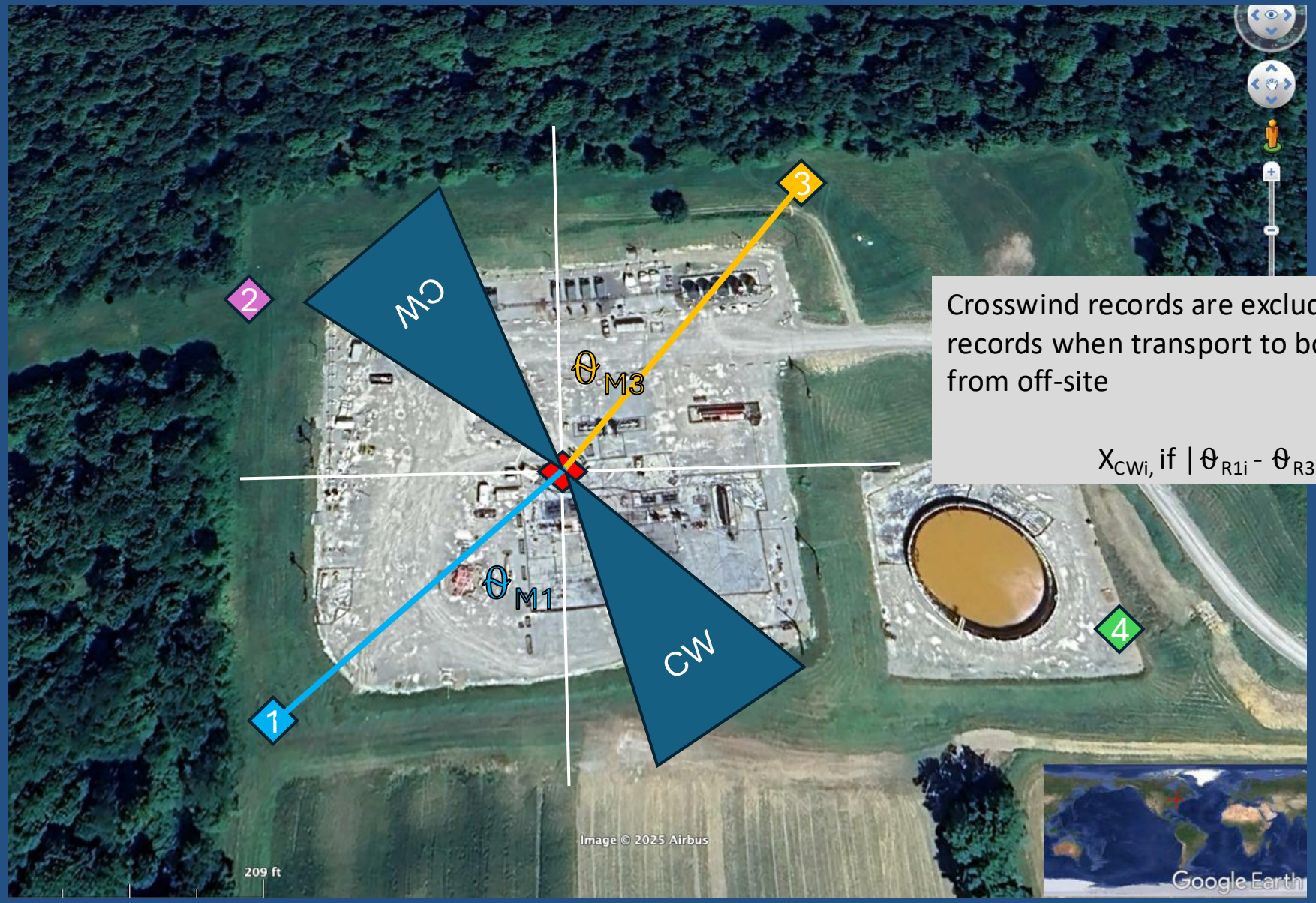
PM2.5 Downwind Enhancement (ΔC)



The downwind concentration enhancement can then be calculated as:

$$\Delta C_i = C_{DWi} - C_{UWi}$$

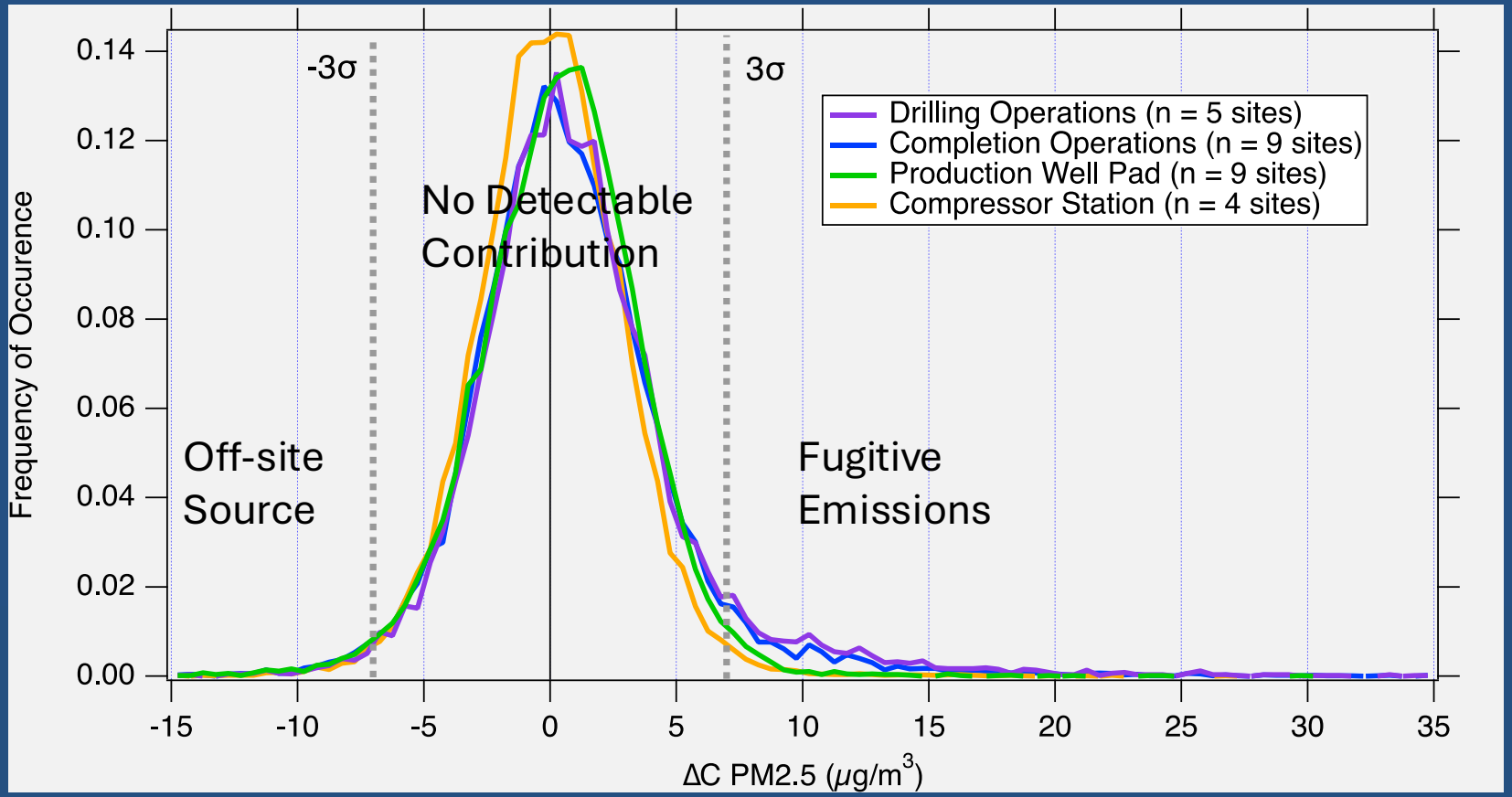
PM2.5 Downwind Enhancement (ΔC)



Crosswind records are excluded to remove records when transport to both monitors is from off-site

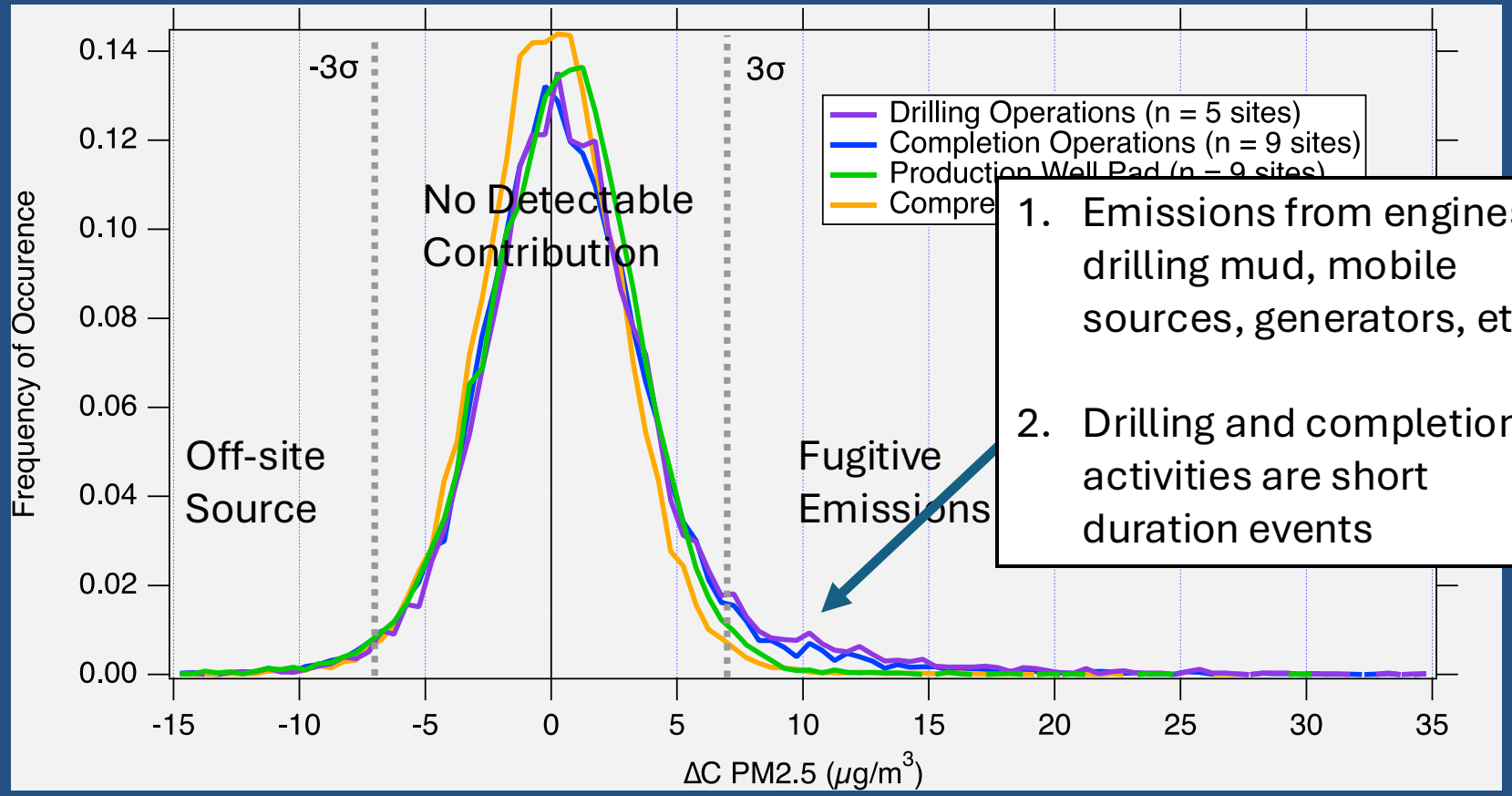
$X_{CWi,}$ if $|\theta_{R1i} - \theta_{R3i}| \leq 30°$

PM2.5 ΔC by Phase



- ΔC can be visualized as a histogram to show the frequency distribution for the various operational phases
- A negative ΔC represents hourly data where the source of enhanced concentrations came from off-site
- The ±3 times the minimum detection of the BAM-1022 (estimated here as 2.3 μg/m^3) is used as a threshold for where there are no detectable differences in concentration between the monitors due to simultaneous variability
- Estimated fugitive emission concentrations are observed when ΔC is greater than 7 μg/m^3

PM2.5 ΔC by Phase



- Based on the analysis, drilling and completion operations were observed to have a larger frequency of observed fugitive emissions of PM2.5 compared to compressor stations and well pads
- The higher frequency of fugitive emissions of PM2.5 from drilling and completions is expected due to the large number of mobile sources and other combustion sources associated with pre-production activities

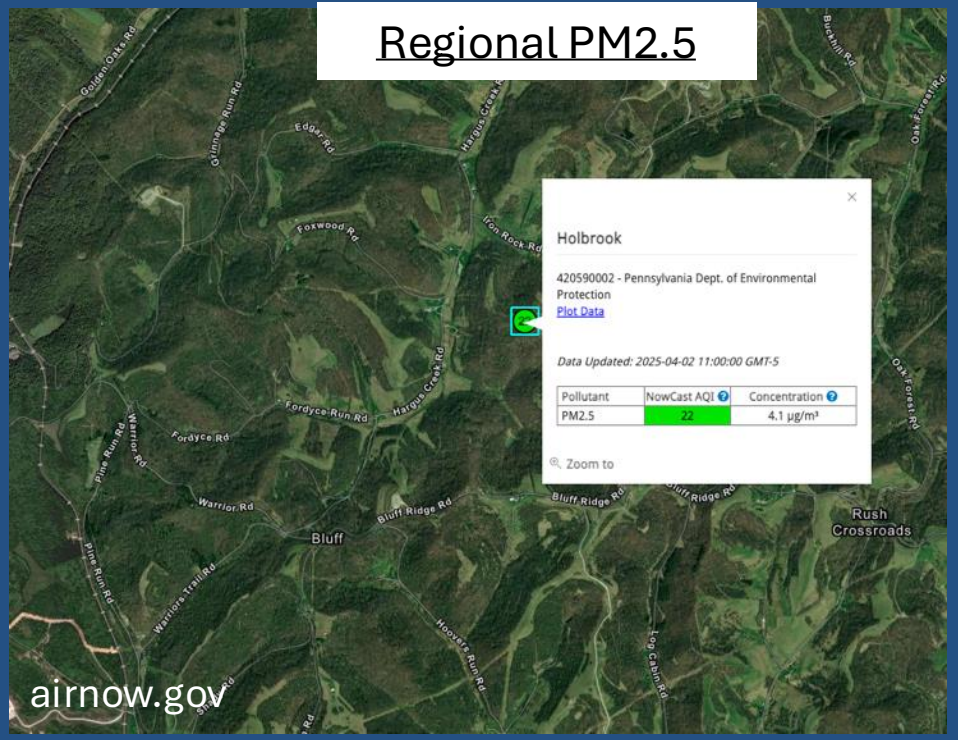
PM2.5 ΔC Context (Preliminary)

- How do the low-frequency fugitive emissions compare to exposure levels at background locations, downwind of other industrial sources, or near other sources?
- A method was developed for determining concentration enhancements at monitoring sites without upwind/downwind information

$$\Delta C = Ci - C_{bck}, \text{ where } C_{bck} = 15^{th} \text{ percentile of C over 48-hrs*}$$

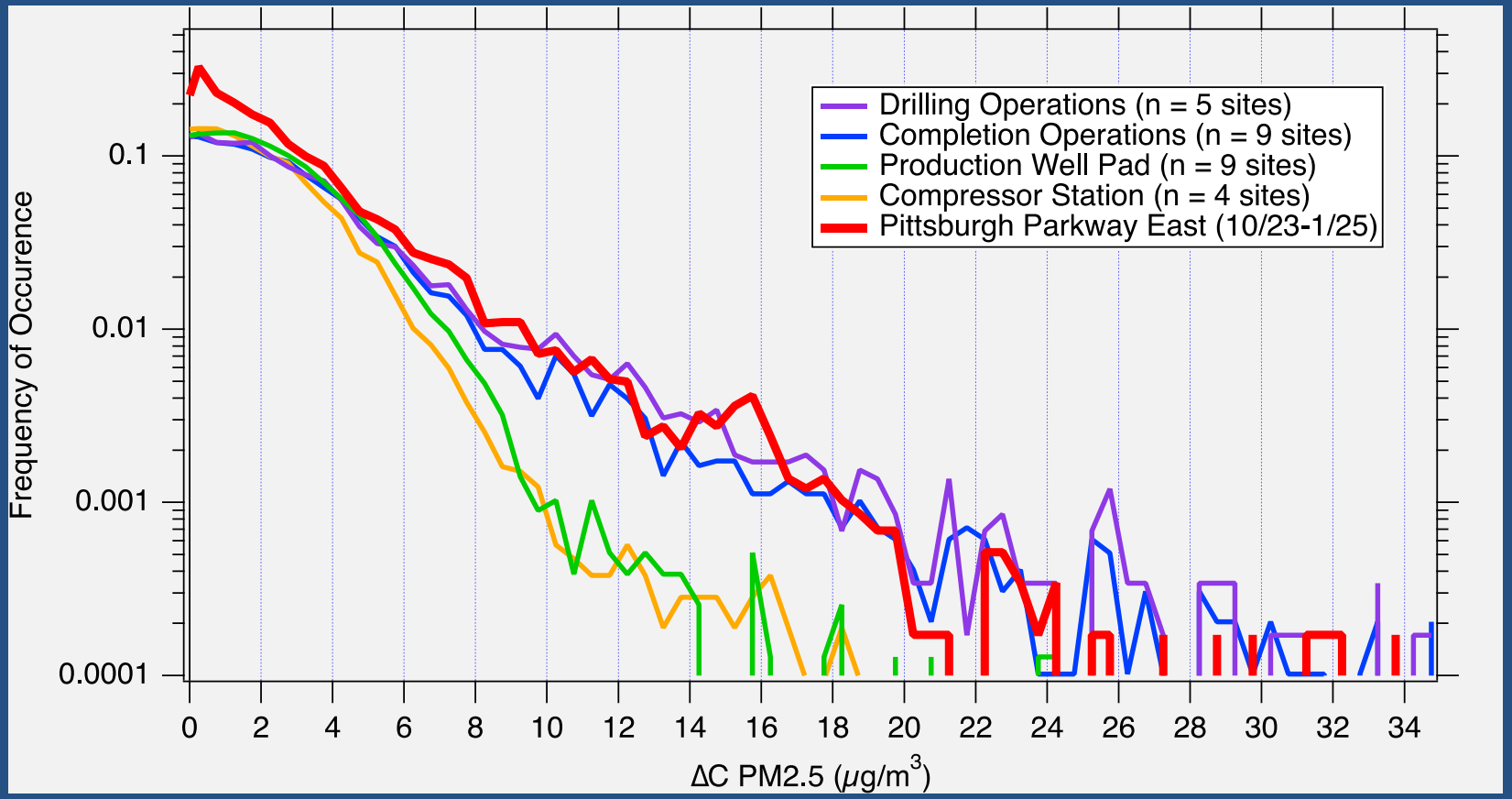
Near-road way PM2.5

Regional PM2.5



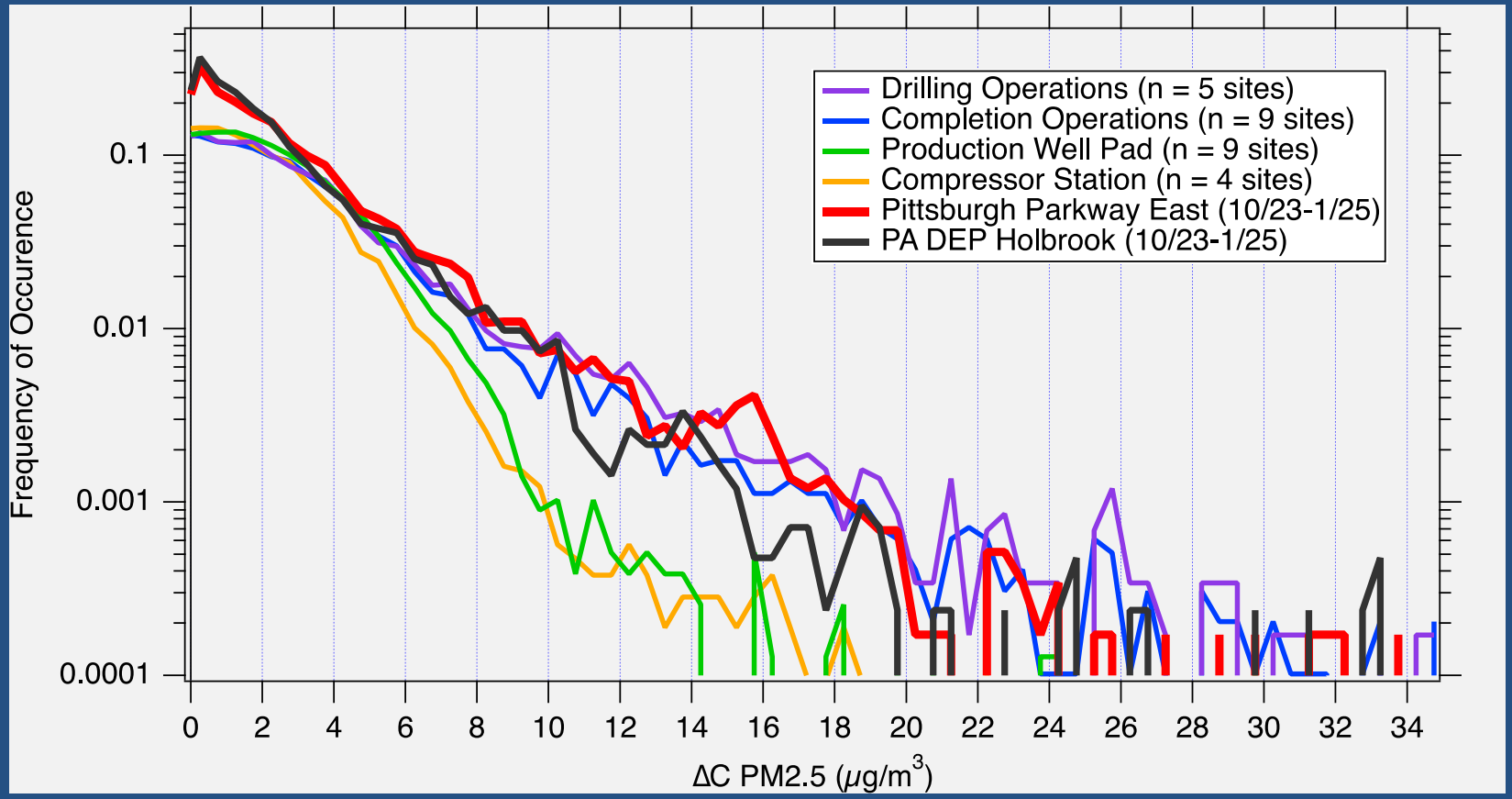
* Goetz et al. 2017, Draper et al. 2023, Actkinson et al. 2021

PM2.5 ΔC Context (Preliminary)



- Near highway ΔC from 10/23 to 1/25 was estimated and compared to an enhanced version of the ΔC results histogram
- Near highway ΔC profile shows similarities to drilling and completions fugitive emission profiles
- The near highway exposure, however, would be considered long duration compared to the weeks to months fenceline exposure of drilling and completion events

PM2.5 ΔC Context (Preliminary)



- Long-duration exposure vs. short-duration exposure is important when determining health impacts

- A comparison to a regional background station also shows some low-frequency enhancements, suggesting:
  1. Uncertainties in the analysis
  2. The PADEP regional background site may have nearby sources of PM2.5

Major Takeaways:

1. A Large-scale air quality monitoring network is established at Appalachian Basin development sites as part of CNX Resource's Radical Transparency program

2. Background level concentrations of BTEX were observed at the fenceline of all facilities monitored, and no exceedances of US ATSDR Inhalation Minimum Risk Levels were observed

3. No exceedances of the US EPA PM2.5 NAAQS were observed

4. PM2.5 ΔC analysis shows evidence of low-frequency fugitive emissions from drilling and completions operations

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