1-Hour SO_2 Modeling in Complex Terrain in Southwestern PA

MARAMA Modeling Case Histories Webinar
April 28, 2017

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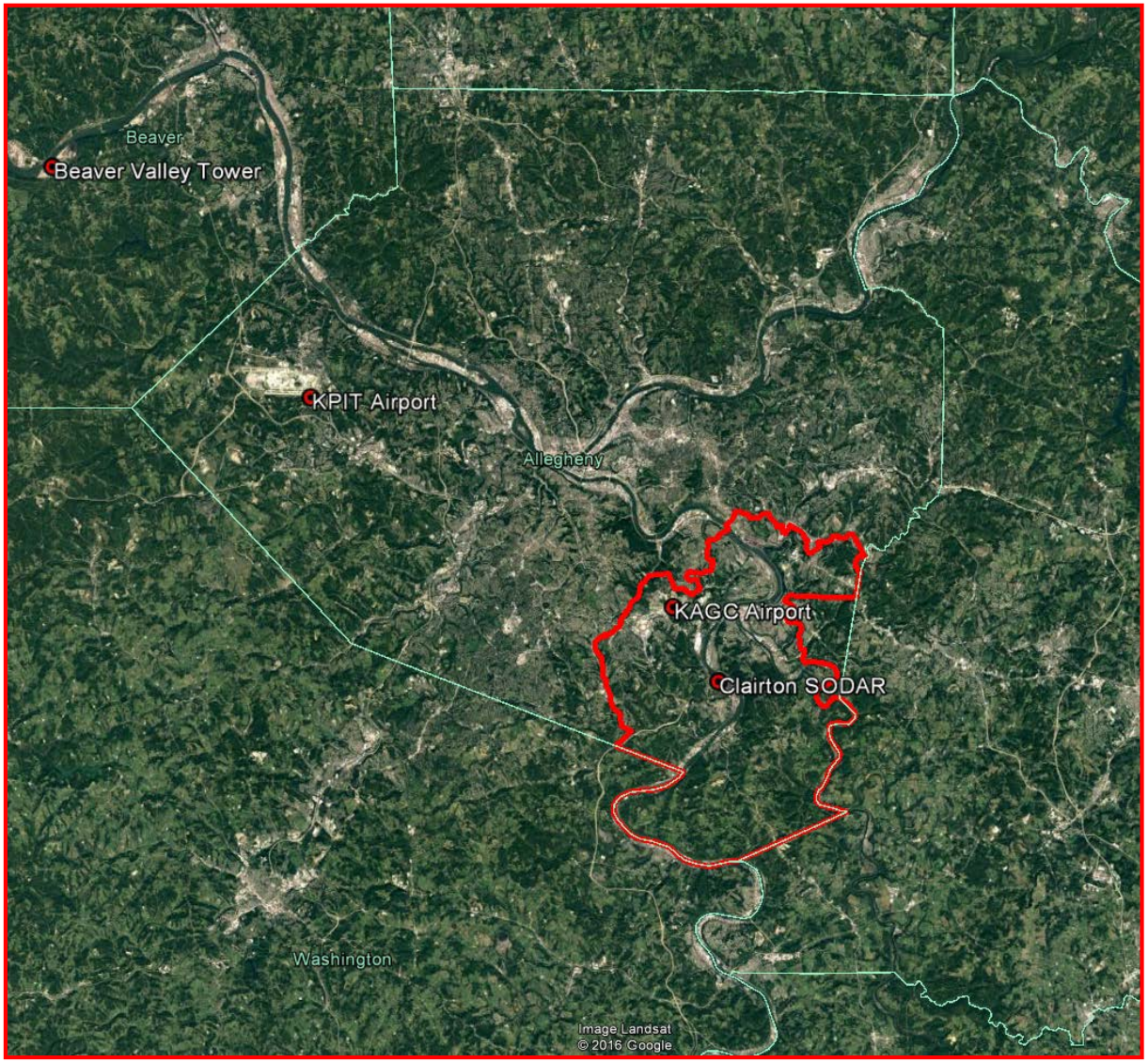
Summary of Problem

- Allegheny, PA SO_2 Nonattainment Area (NAA), 2010 1-Hour NAAQS
  - Monongahela River valley in Southwestern PA (SWPA)
    - Complex terrain (difference of about 140 m, river-to-hilltop)
    - Industrial sources in-valley; populated areas throughout area
  - Sub-hourly emissions, non steady-state conditions
    - Max concentrations during stable conditions, low winds, strong inversions
- ACHD has utilized a number of models over the years
  - See 2014 R/S/L presentation for history
- What is the most appropriate modeling approach, while still regulatory
  - Model, meteorology, source characterization, options
- Case-by-case: SWPA may differ from other areas (flat or complex)

Allegheny, PA SO_2 Nonattainment Area (NAA)

Southwestern PA,
EPA Region III



Allegheny County and Surrounding, w/Key Met Sites

3-D Stacks/Buildings in Google Earth

Met and Monitor Sites in General

- Airport met data
  - Can be representative for some scenarios (tall stacks, plateau flow)
  - For most applications, wind speeds are too high (and/or wrong directions)

- Local met sites (surface-based)
  - Can be too specific to areas (microscale)
  - Can be appropriate for some modeling cases, depending on source/location
  - Probably best used for directional analysis, pollution roses, etc.

- Multi-level towers/acoustic
  - Most site-specific, but very few locations in SWPA
  - SODAR equipment was problematic (low recovery, operational errors)

- Monitors
  - Modeled hotspots are often not suitable for monitoring
  - Like source-oriented monitoring TAD for SO_2
  - Examples: cliffs, dense wooded areas, golf course

SO_2 SIP Development

- ACHD contracted Ramboll Environ for assistance for SO_2 SIP
  - Model “shoot-out”
    - Including puff models (CALPUFF, SCICHEM)
    - Different met, options
    - Model performance
  - Development of WRF/MMIF met for area
    - Can be used as site-specific data for any grid cell in modeling domain

- Shoot-out results:
  - AERMOD with MMIF showed best overall response
  - CALPUFF showed underprediction
  - SCICHEM (test version of 3.1) had problems completing full-year runs

- Selection: AERMOD with MMIF met as most appropriate model
  - MMIF in AERMET-ready met mode

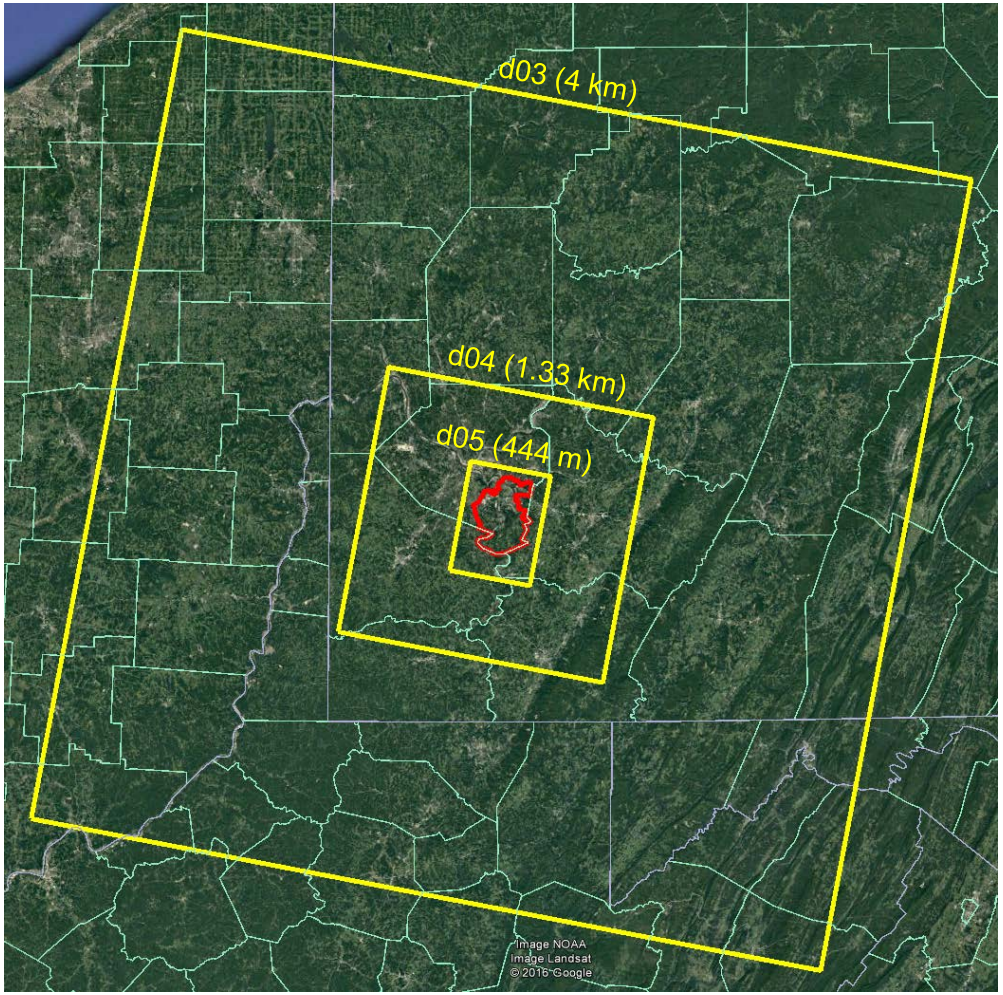
- SIP in public comment in May-June (schedule: Finding of Failure to Submit)

WRF/MMIF Domains

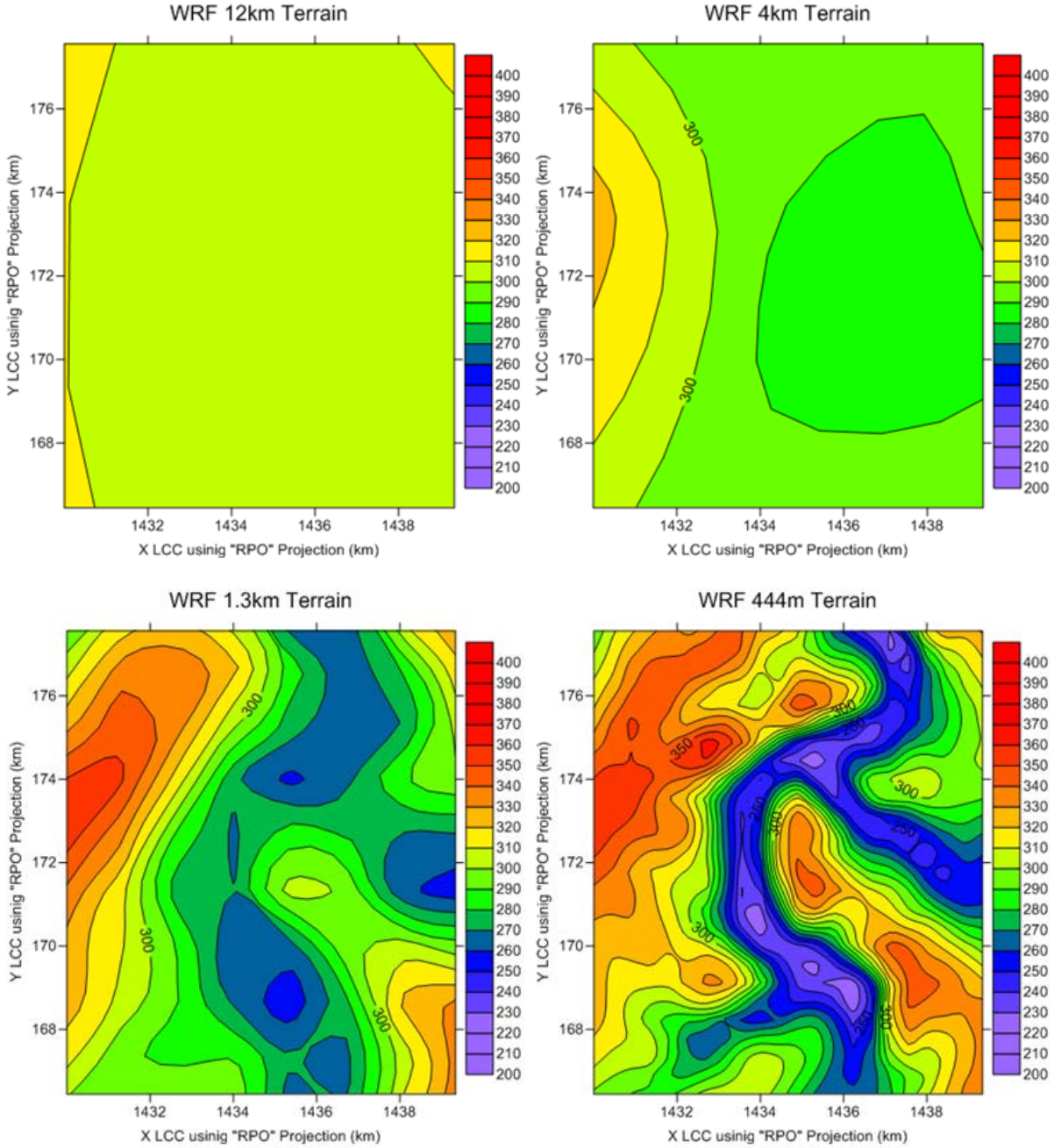
- MMIF domains/resolution
  - D01 (36 km)
  - D02 (12 km)
  - D03 (4 km)
  - D04 (1.33 km)
  - D05 (0.444 km)

- Examine model performance for different domains
  - Based on available airport and/or local site data
  - Test different domains in AERMET/AERMOD

- D03 and D04 showed best met performance, but D05 shows the most valley influence

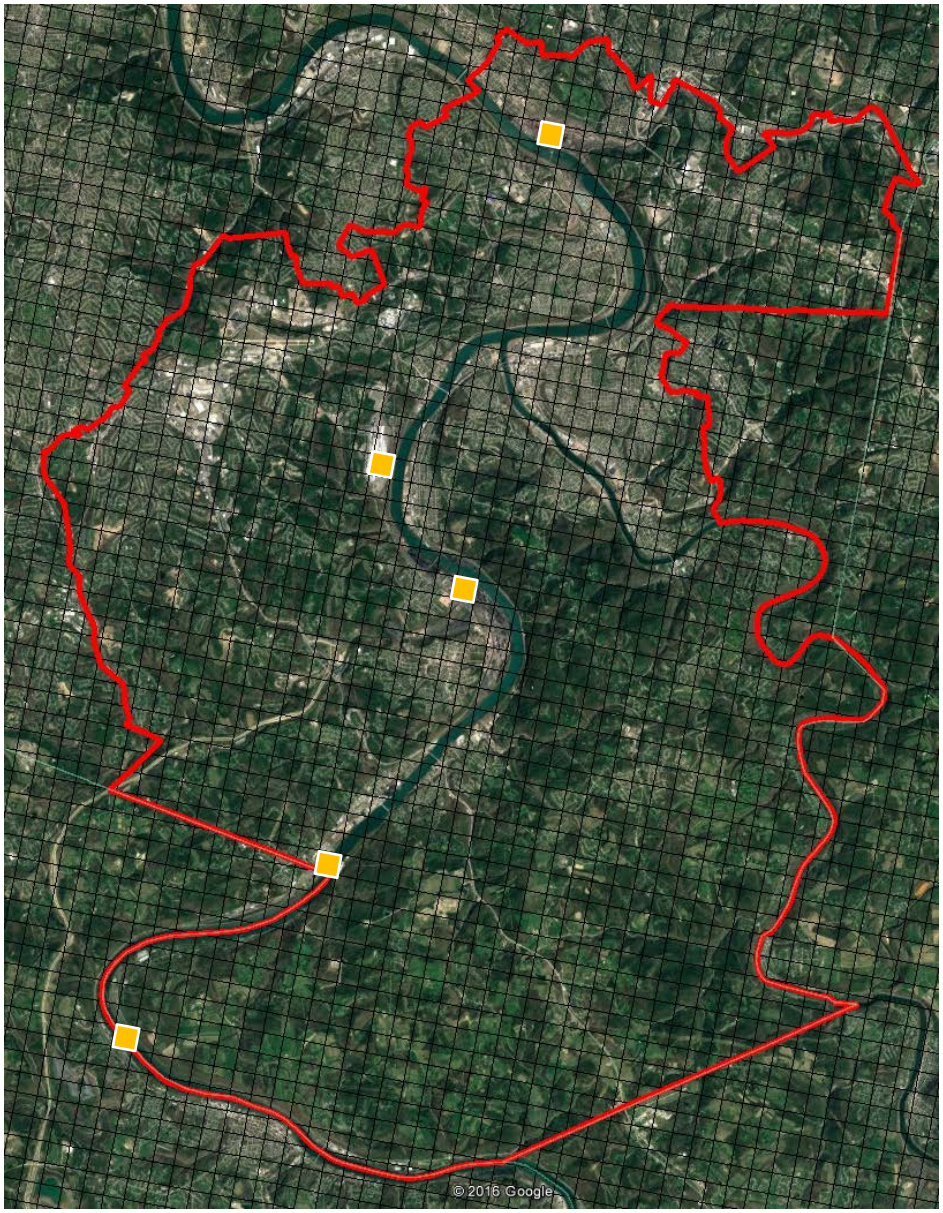


WRF Terrain by Resolution

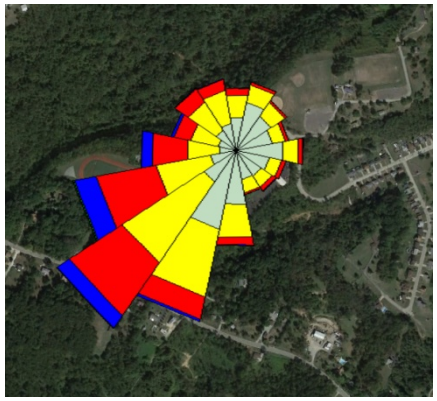


MMIF Cells, D05 (444 m) Domain

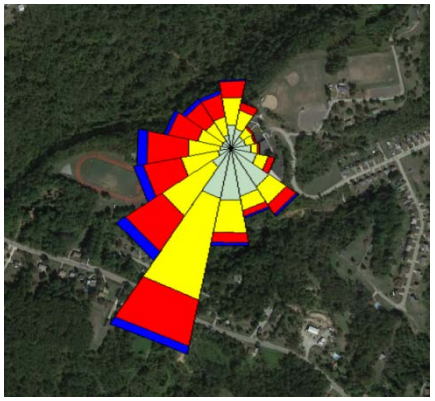
- MMIF generates prognostic onsite data (or “virtual towers”)
  - Any individual grid cell (source location)
- Separate AERMOD runs are done for each source
  - Hourly impacts are combined in post-processing by receptor)
- Each MMIF cell contains unique:
  - Wind/temp profiles
  - Upper air soundings
  - Additional
    - Mixing height
    - Solar radiation
    - Pressure
    - Precipitation



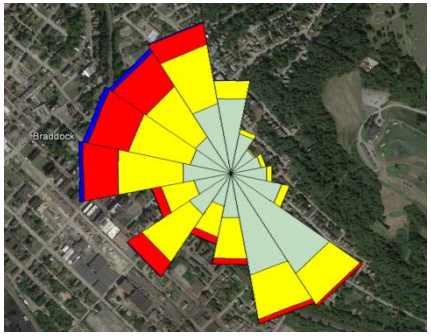
Actual Site and MMIF Wind Directions, D05 Domain, 2014



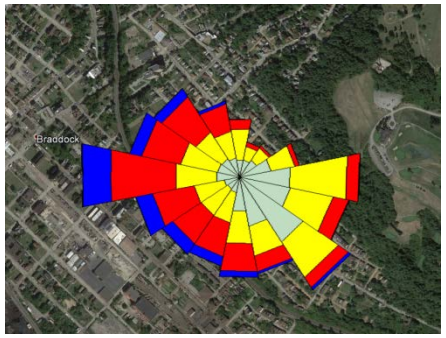
Liberty (actual)



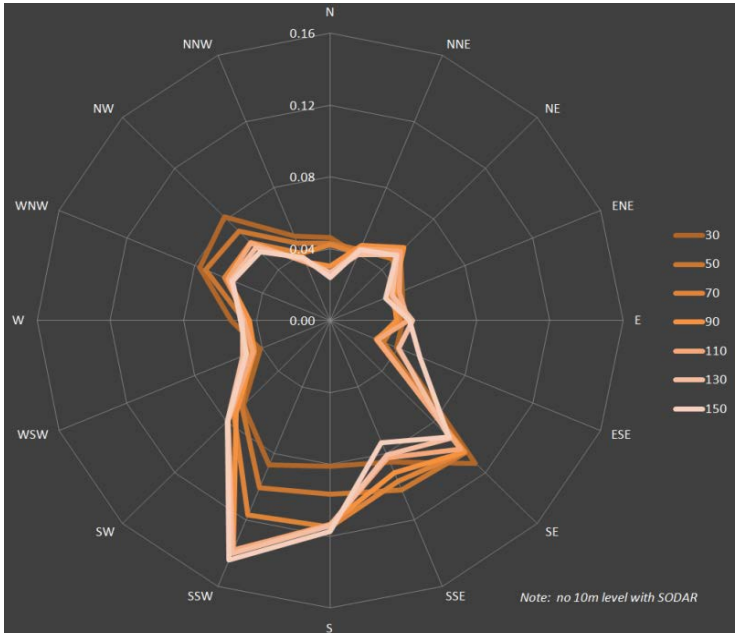
Liberty MMIF D05



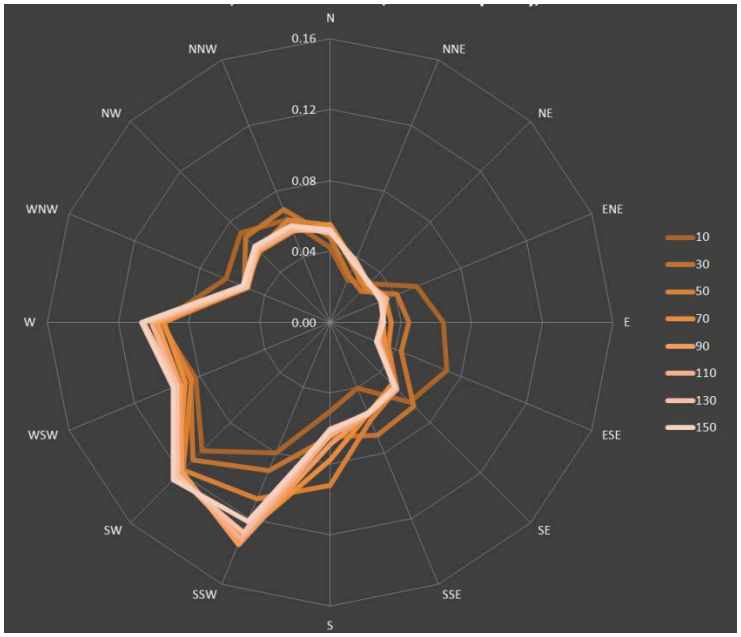
North Braddock (actual)



North Braddock MMIF D05



Clairton SODAR



MMIF D05

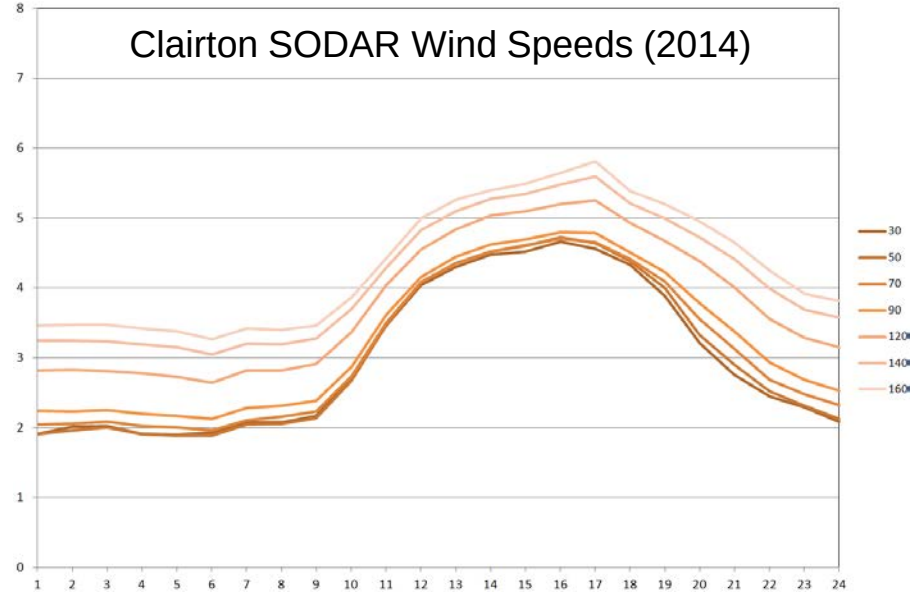
MMIF D05 Direction Frequencies in Relation to River Valley

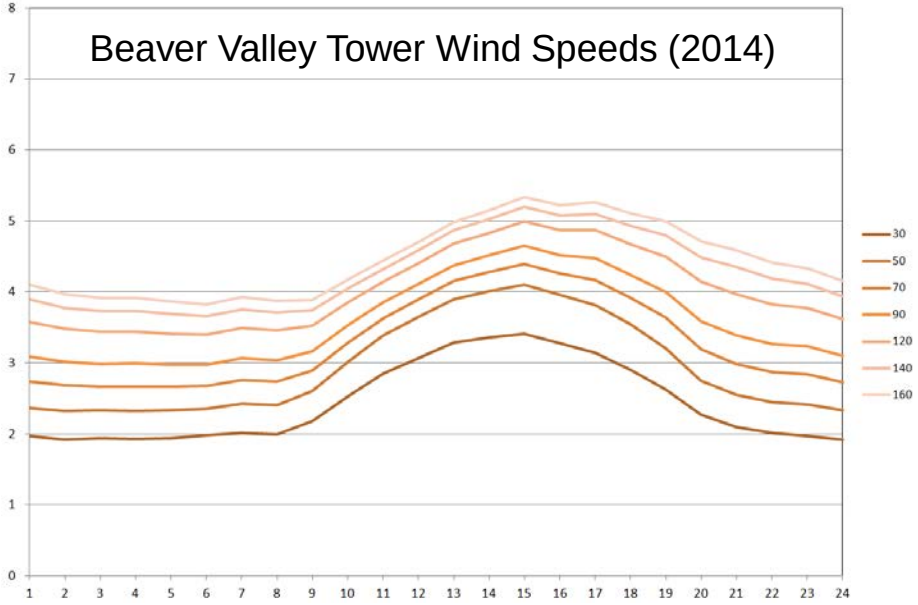
MMIF D05 2014 stacked wind direction frequencies in blue (lighter shades are higher levels)

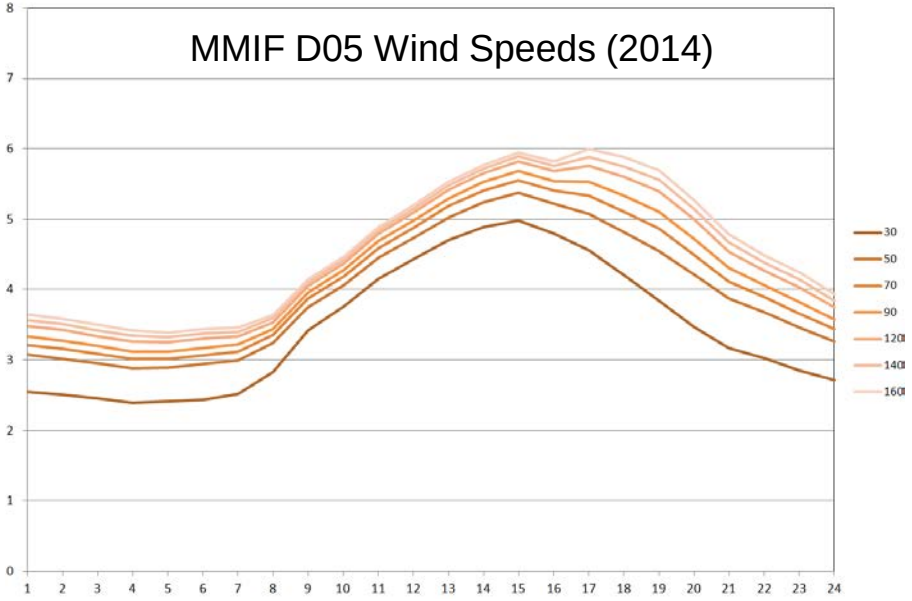
MMIF shows good combination of valley + regional flow

Airport wind roses shown for reference (surface nudging)

AERMOD Avg Hourly Speeds, Measured and Predicted (to 160 m)

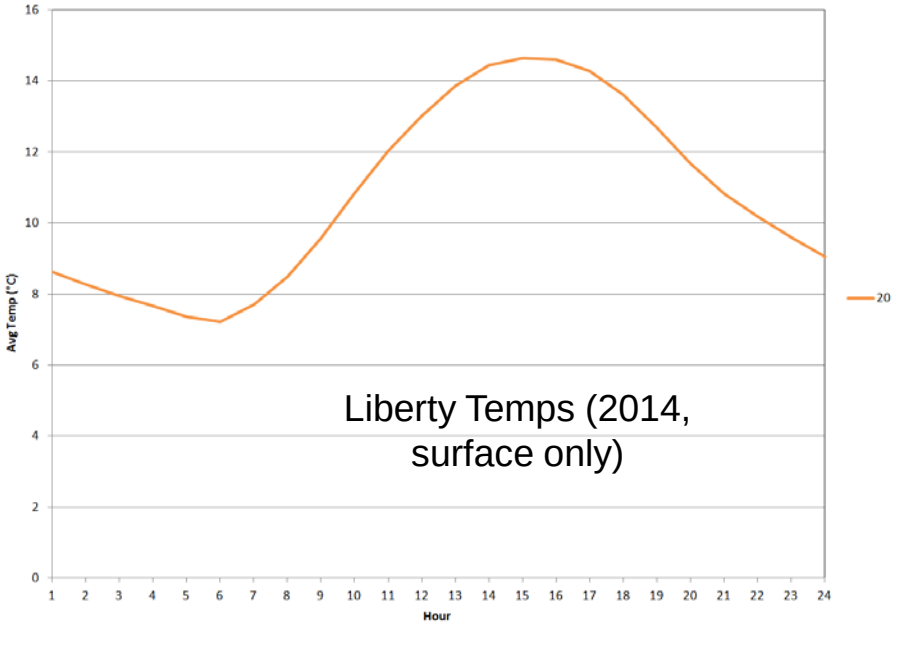


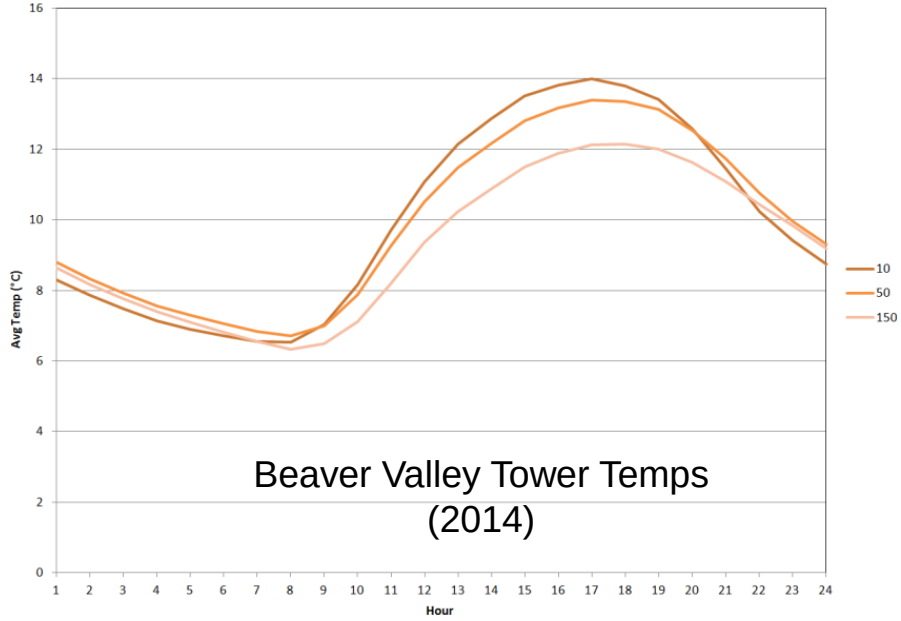


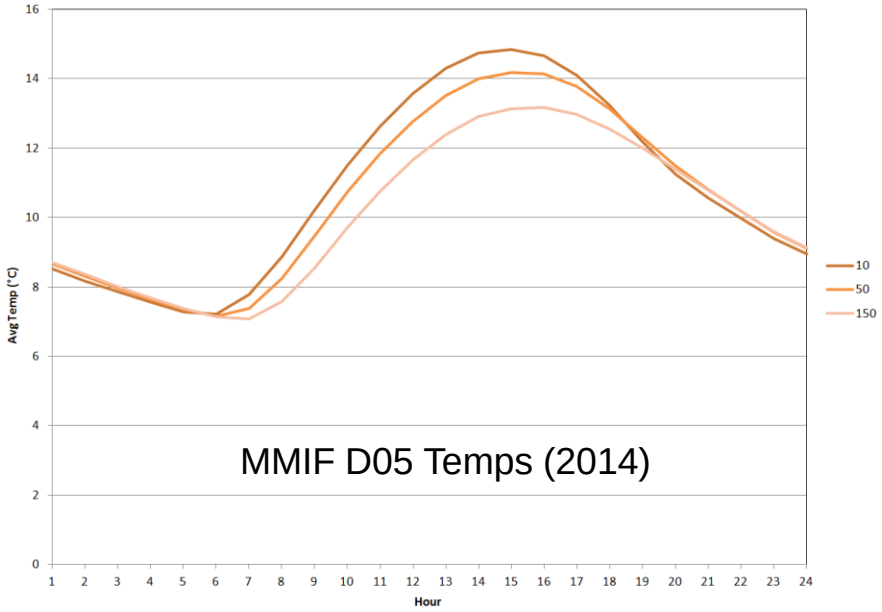


MMIF shows similar wind speeds to multi-level sites

AERMOD Avg Hourly Temps, Measured and Predicted (to 150 m)







MMIF shows similar diurnal pattern to Liberty (surface only) and Beaver Valley (tall tower)

MMIF Analysis

- MMIF is adequately reproducing known met, with some smoothing
  - AERMOD debug output used for comparisons
  - MMIF shows valley flow for in-valley locations
  - Realistic temps/gradients, stable/unstable (night/day) transitions
- Some speed bias at vertical levels above surface
  - Airport/plateau flow is carried through from WRF
- Outperforms any other met data with AERMOD for the NAA
  - Very stable nighttime conditions (matches real-life)
  - Best daily maximums throughout area
    - Airports – overprediction
    - Local sites – underprediction
- D05 domain (444 m resolution) showed best results
  - Less resolution may also be adequate for some cases

AERMOD/AERMET Options (Summary)

Option	Effects in SWPA (in general)
ADJ_U*	For surface-based met: reductions in impacts overall • Almost “corrects” airport to make more localized • Modifies not only u* but also H, M-O L, Zim For MMIF-based met: less change in impacts, not all sources • WRF/MMIF is already “adjusting” friction velocities to an extent • Better overall met parameters, also modifies cloud cover
LOWWIND 1/2/3	• Reduce overprediction at near-field hillsides • LOWWIND3 shows least reductions of the three options • Difficult to evaluate without more robust met/monitor network
URBAN Mode (and half-life)	• Can derive an effective population for industrial heat islands • Difficult to estimate populations, requires assumptions to formula • Affects entire boundary layer throughout domain, potentially removes terrain/rural influences • Likely better with source characterization for heat island • Half-life (w/wo urban) leads to slight reductions
Wind Speed Threshold	• Little change in impacts using < 0.5 m/s threshold • Recommended threshold is adequate
POINTHOR/ POINTCAP	• Can lead to overprediction • Also changes location of impacts • Likely better characterized as vertical stacks

Model Evaluation in Complex Terrain

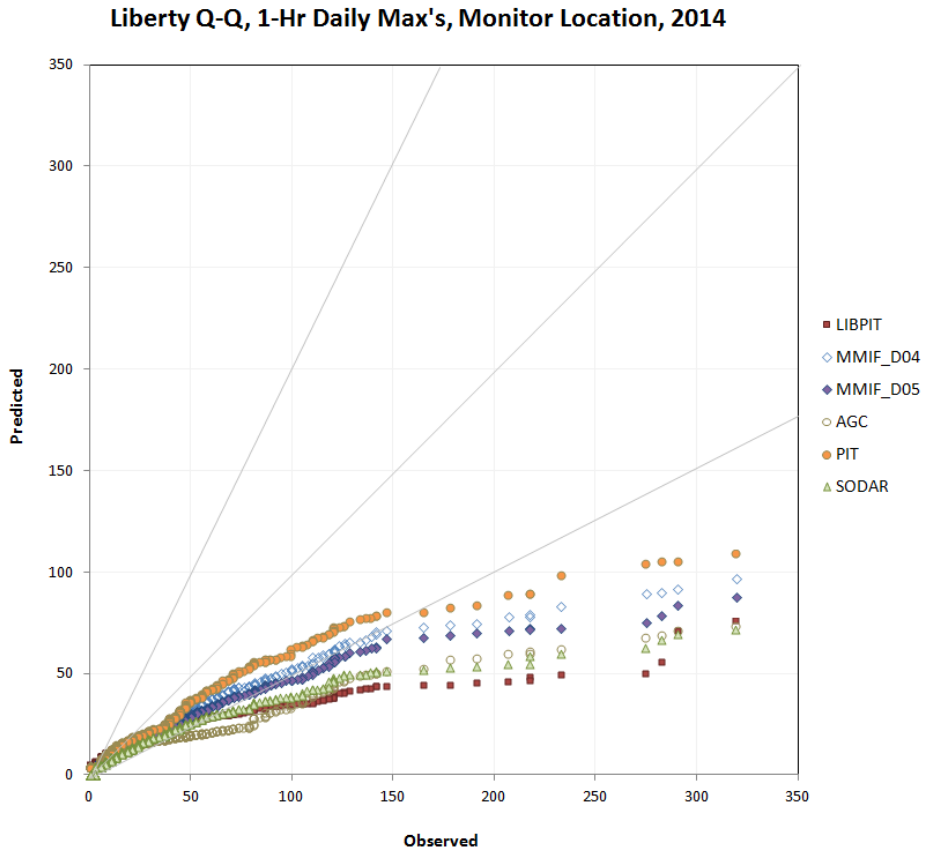
- Difficult in complex terrain on a 1-hour basis
  - May be unique to types of sources in NAA
  - Case-by-case basis

- Real-life conditions
  - Non-steady-state, sub-hourly SO_2 peaks, strong nighttime inversions

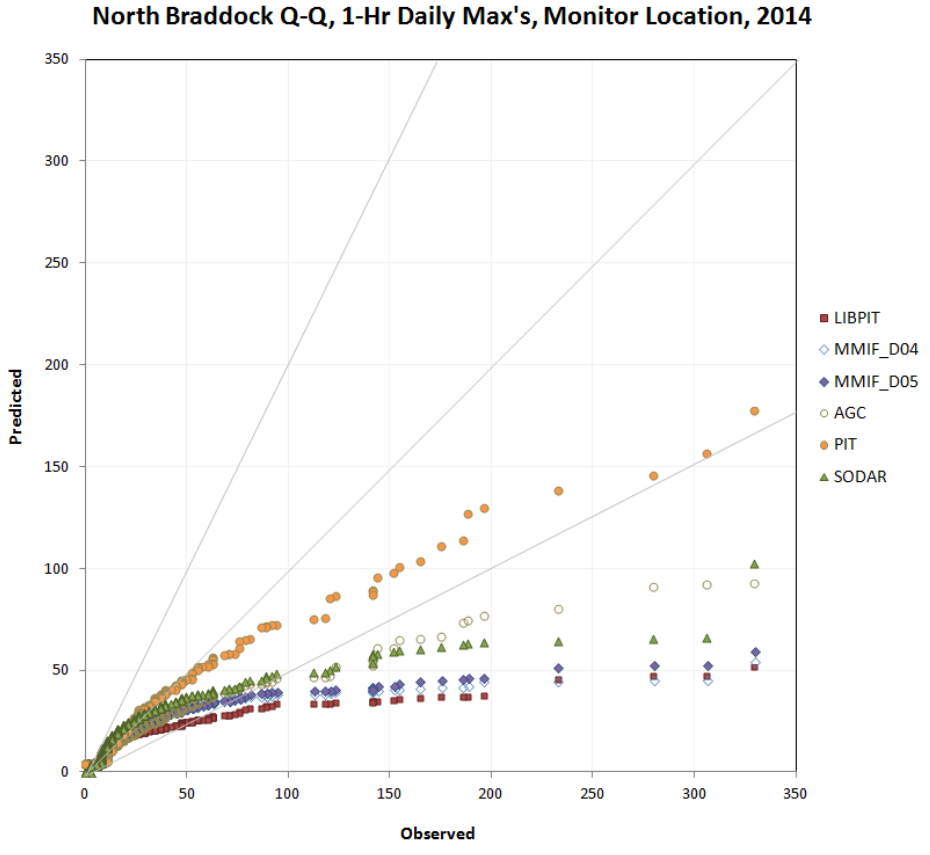
- Modeled simulation
  - Steady-state, hourly plumes, conditions driven by PBL parameters (M-O length, mixing heights, etc.) and profiles

- As a way to “normalize” modeled to monitored:
  - Relax time and space, based on monitor scales
  - Examine terrain and wind directions for further analysis

Monitor Sites Q-Q Plots (Exact Location), Daily Max's, 2014



Liberty Site



North Braddock Site

Runs using all available met
(impacts shown in µg/m³)

Monitor Scales for SO_2

40 CFR Part 58 – "…spatial scale of representativeness is described in terms of the physical dimensions of the air parcel nearest to a monitoring site throughout which actual pollutant concentrations are reasonably similar."

"Monitors sited at the microscale, middle, and neighborhood scales are suitable for determining maximum hourly concentrations for SO_2."

(1) *Microscale* – close proximity to SO_2 point and area sources, typically represents an area impacted by the plume with dimensions extending up to approximately 100 meters.

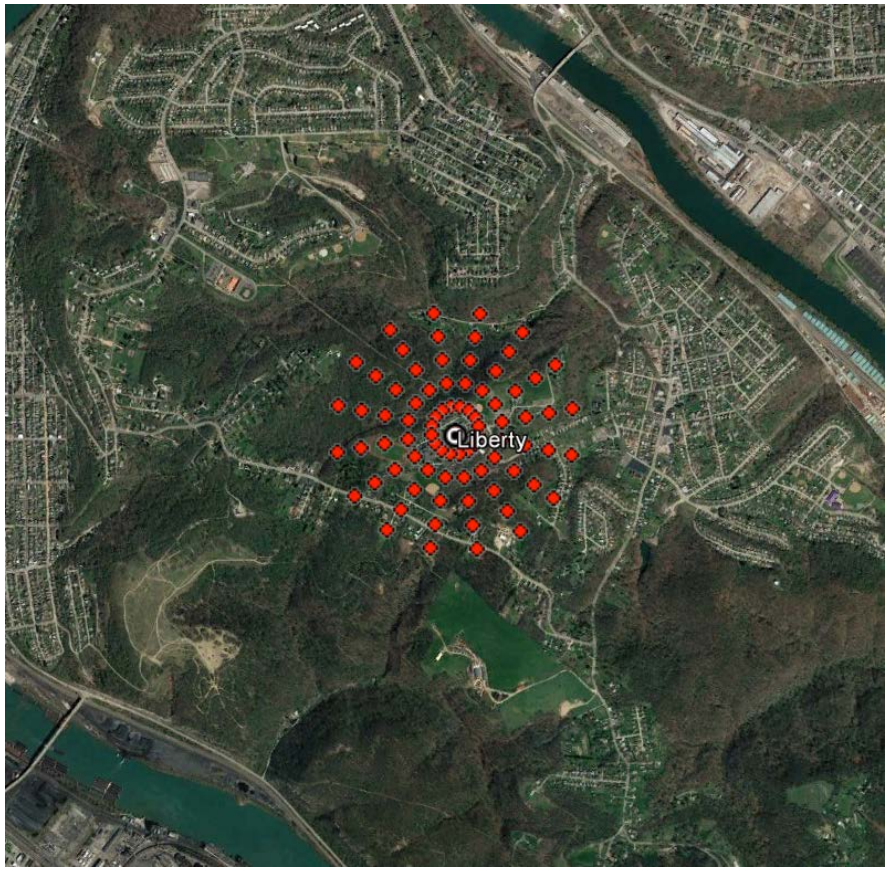
(2) *Middle scale* – generally represents air quality levels in areas with dimensions on the order of approximately 100 meters to 500 meters

- Usually the locations of expected maximum short-term concentrations from major SO_2 sources

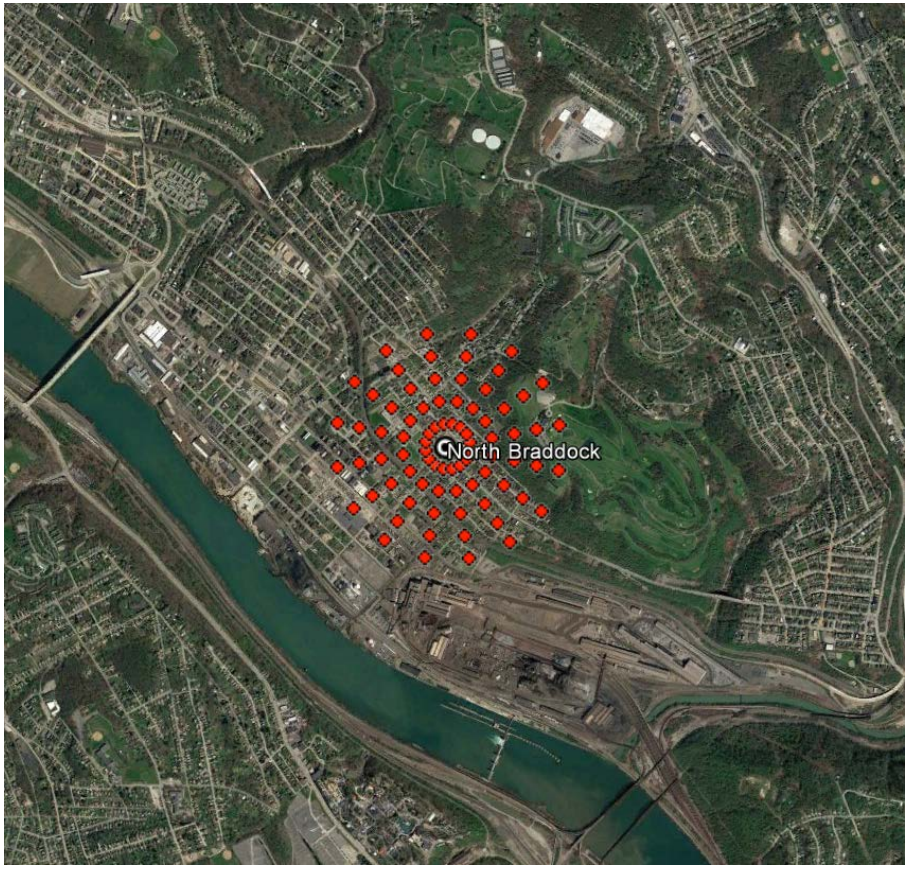
(3) *Neighborhood scale* – characterize air quality conditions throughout some relatively uniform land use areas with dimensions in the 0.5 to 4.0 kilometer range

- Under certain plume conditions, shows high SO_2 concentrations from stationary sources

Monitor Receptors at Middle Scale (to 500 m radius)

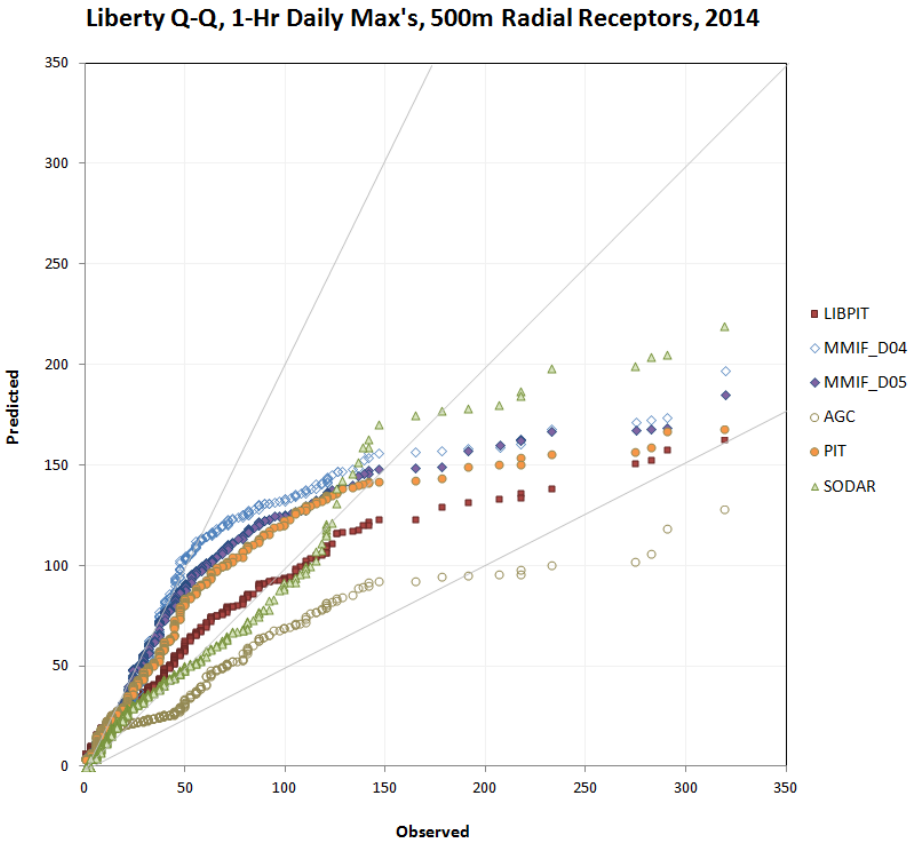


Middle Scale
(500 m radius)

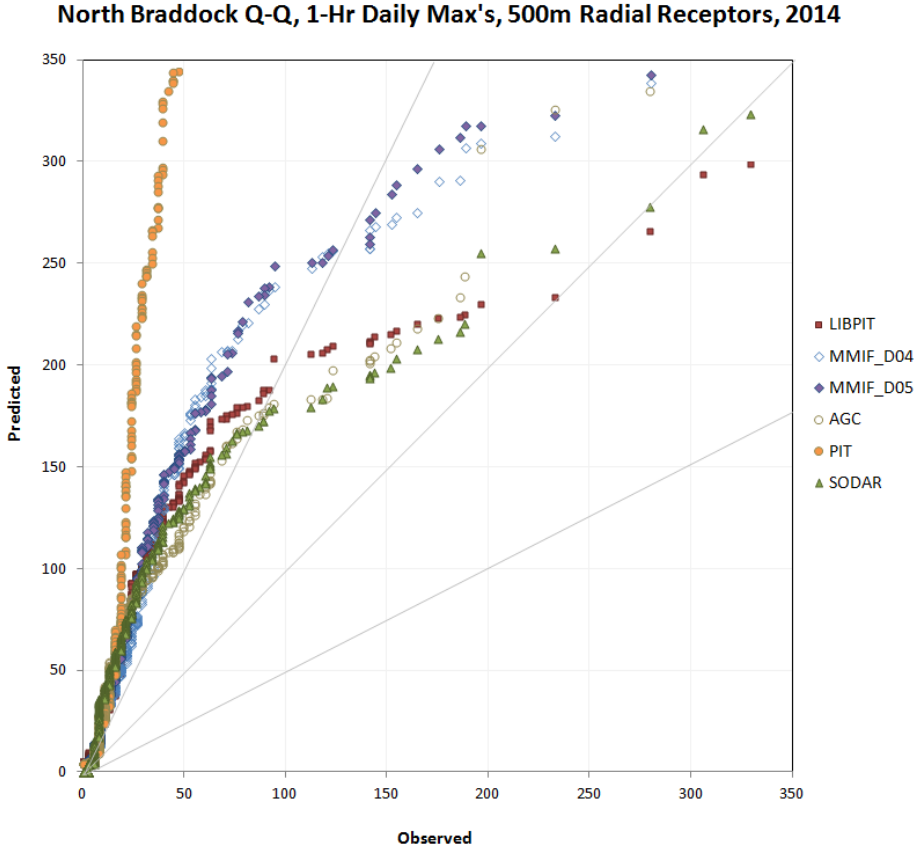


Middle Scale
(500 m radius)

Monitor Sites Q-Q Plots, Middle Scale, Daily Max's, 2014



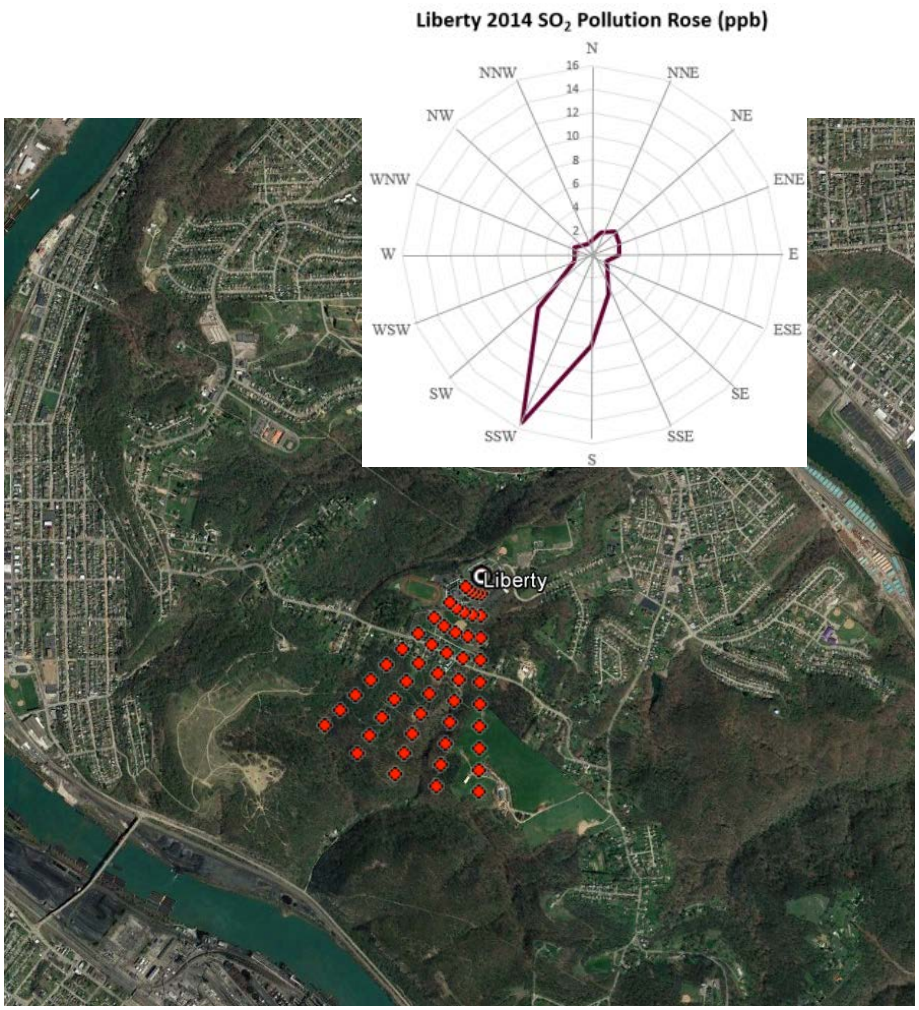
Liberty Site



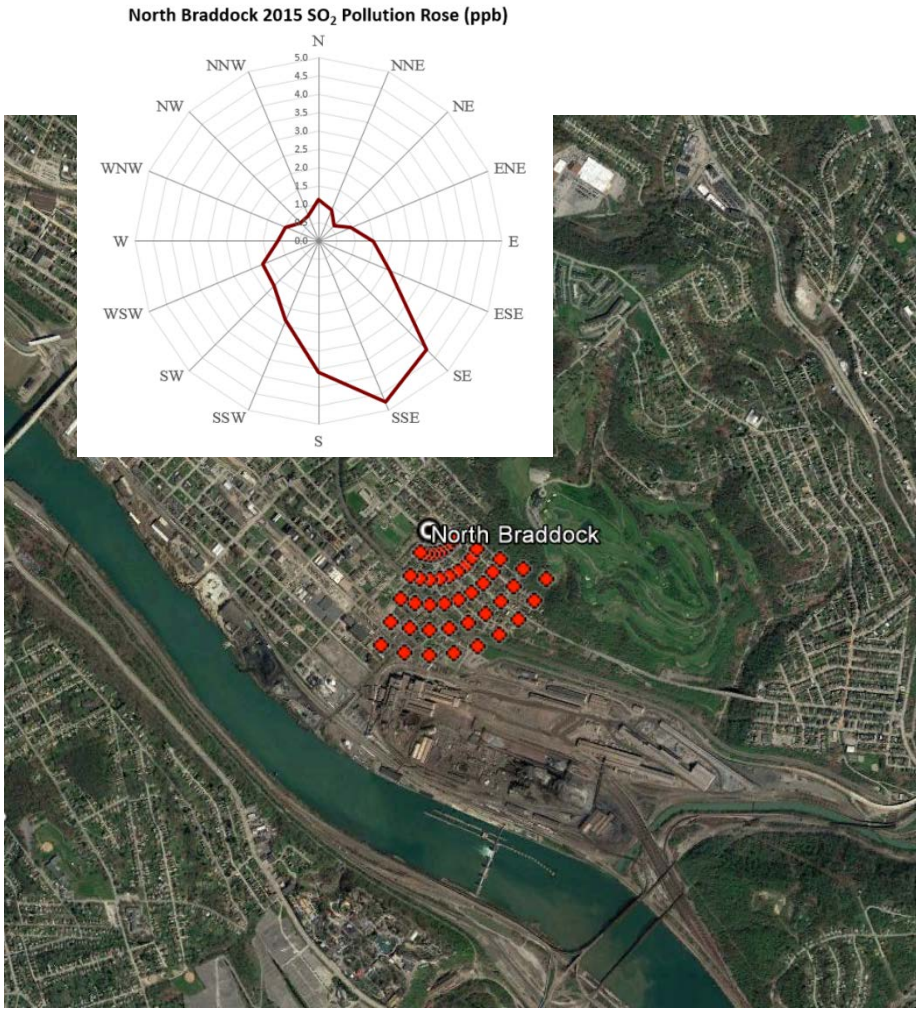
North Braddock Site

Runs using all available met
(impacts shown in µg/m³)

Monitor Receptors, “Sector-Based” Scale (500-1000 m radius)

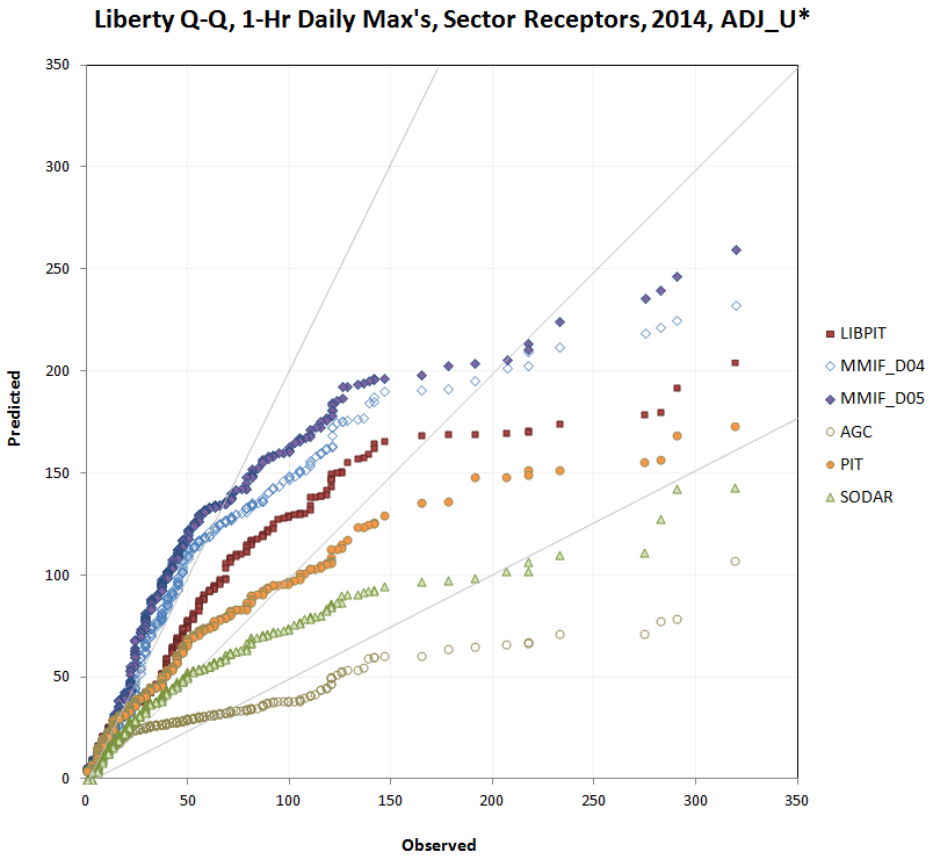


Neighborhood Scale
(1 km sector)

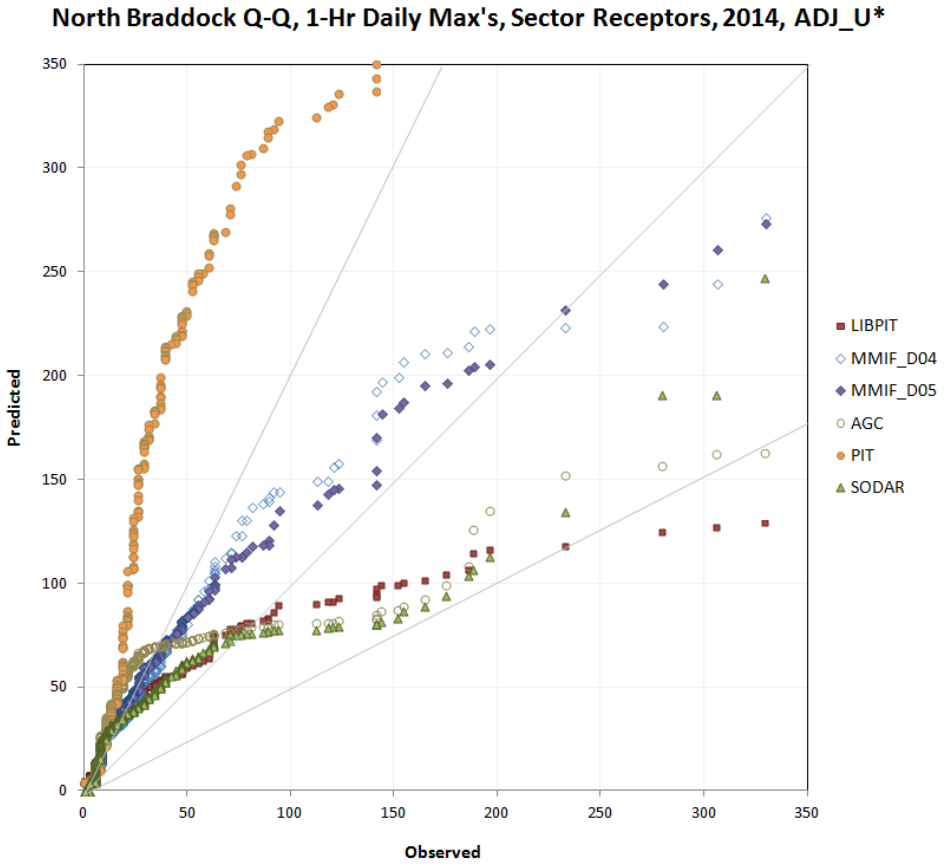


Middle Scale
(500 m sector)

Monitor Sites Q-Q Plots, Sector-Based Scales, Daily Max's, 2014



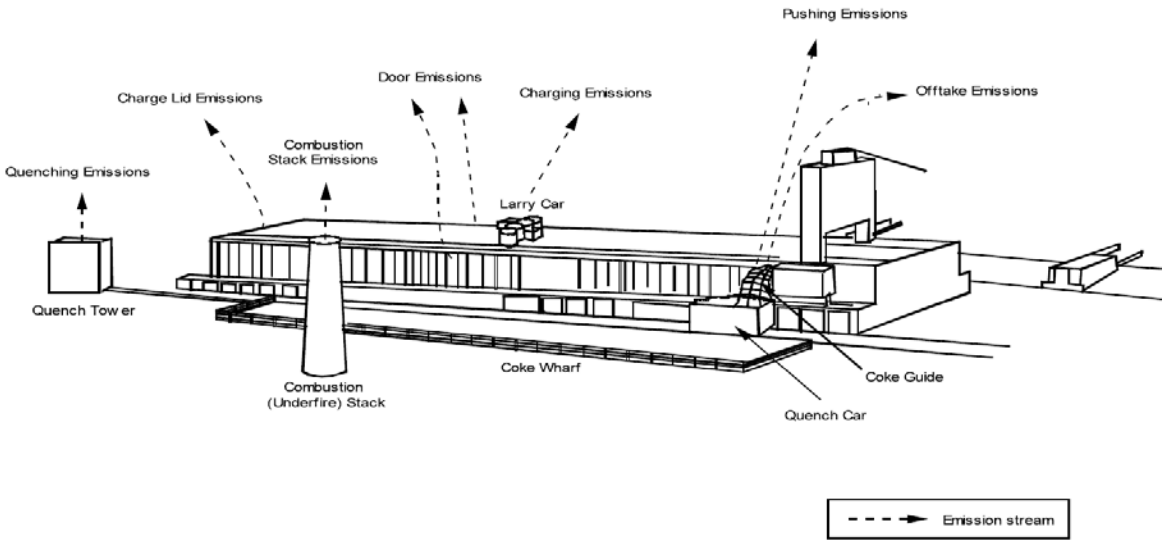
Liberty Site

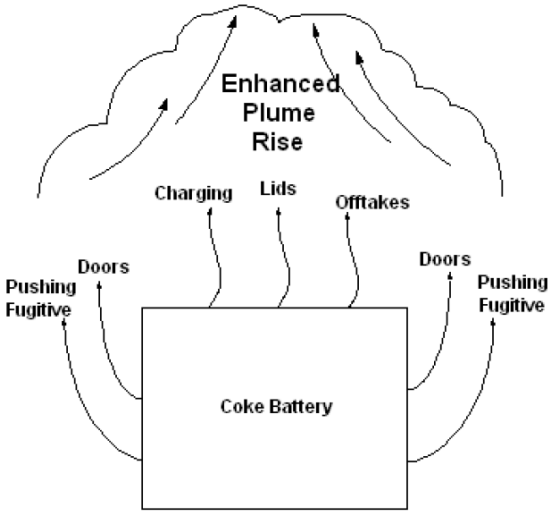


North Braddock Site

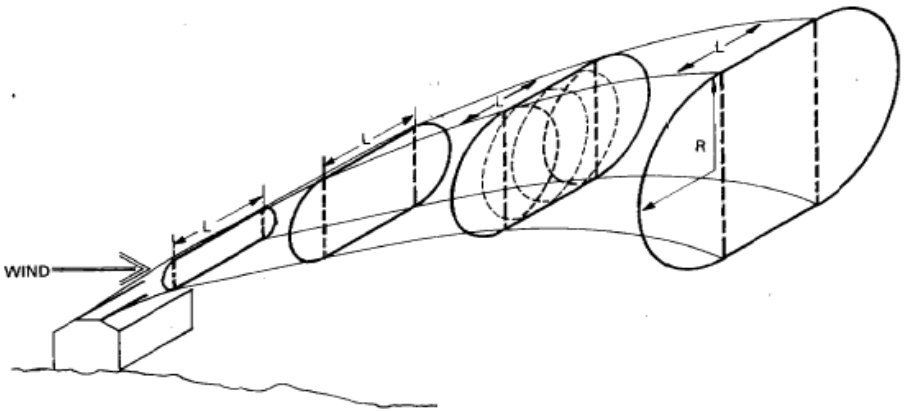
Runs using all available met, w/ADJ_U* selected (w/o turbulence for SODAR)
(impacts shown in µg/m³)

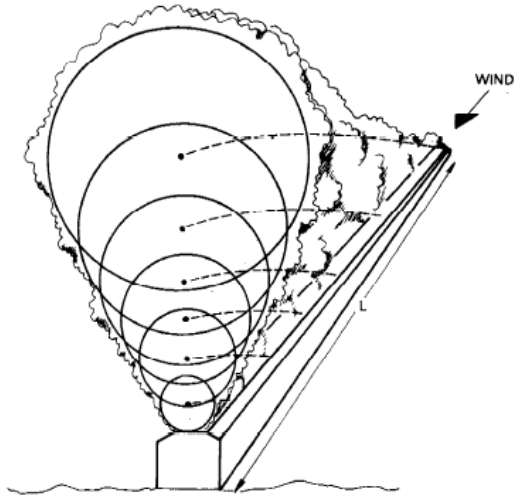
Buoyant Fugitive Sources





Coke battery emission points and plume rise(taken from EPA's Risk Assessment Document for Coke Ovens…, 2003)



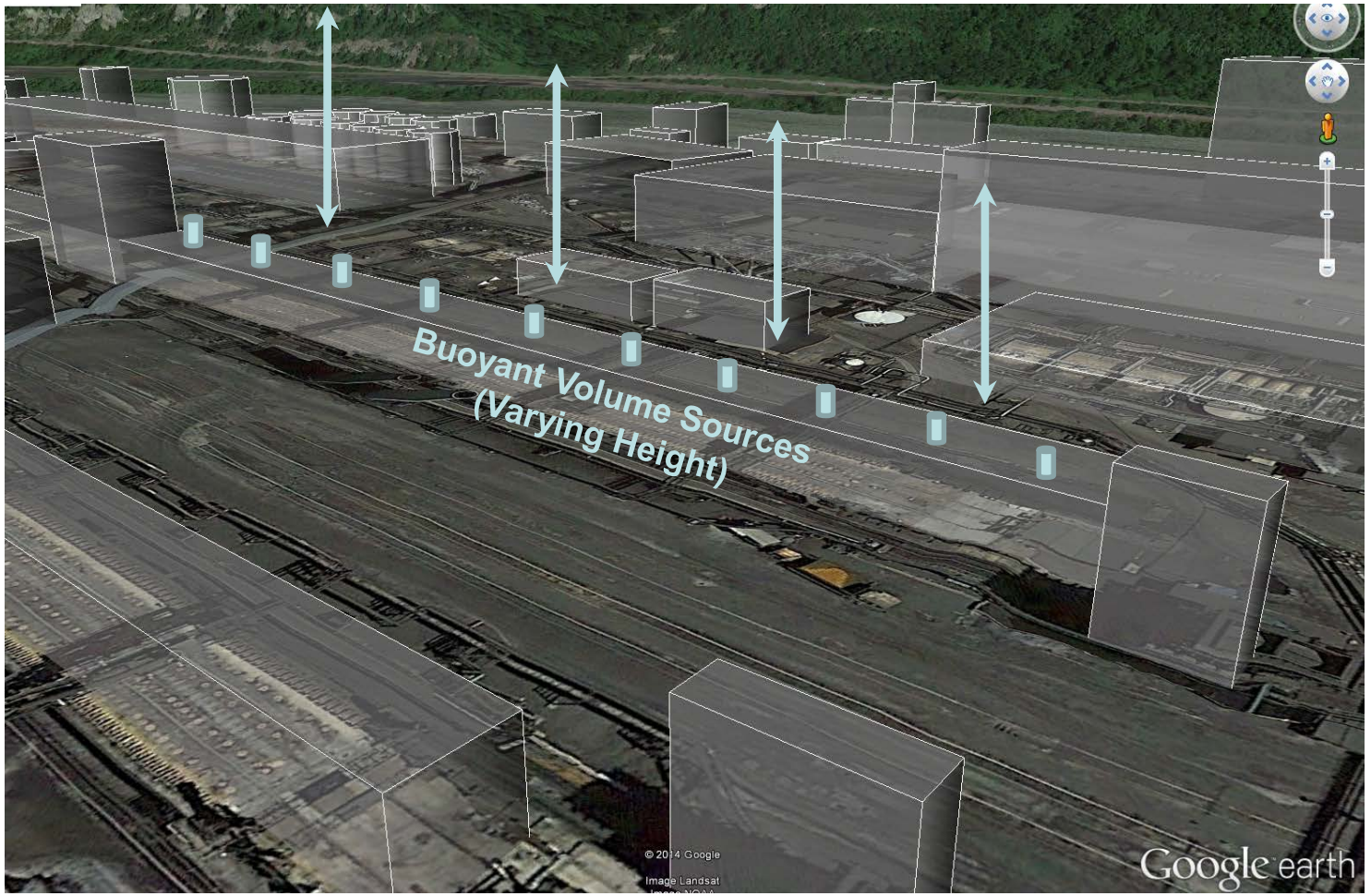


Buoyant line source plumes (taken from BLP user's guide)

Buoyant Fugitive Sources in AERMOD

- Fugitives with substantial heat
  - Observed plume rise, localized heat island effect
  - No definitive way to characterize
- BUOYLINE in AERMOD since v15181 shows questionable results
  - Many processing errors
  - Large line plumes do not disperse easily in complex terrain
- Series of high-temp stacks
  - Leads to overprediction in NAA
  - Release height is important factor in complex terrain with AERMOD
- Series of volumes with fixed release heights
  - Too arbitrary, need to account for buoyancy and atmospheric conditions
- Used for model: series of variable-height volume sources
  - Uses original BLP model to generate hourly plume rises

Buoyant Line as Variable-Height Volumes



HOUREMIS is used to vary the release heights and vertical dimensions (sig-z)

Hourly release height = plume rise + bldg height

Optimal Model Configuration

- AERMOD
  - Point sources for stacks
  - Fixed-height volumes for roof monitors or other ambient fugitives
  - Varying-height volumes for buoyant fugitives
    - Heights based on plume rises generated from BLP

- AERMET
  - Using MMIF D05 (444 m resolution) inputs, developed from WRF
  - MMIF ONSITE, UPPERAIR, and SURF characteristics
  - ADJ_U* for most representative met parameters
  - Each source modeled with unique MMIF (as separate AERMOD runs)
  - Results from different runs combined in post-processing

- Years selected: 2012-2014
  - Based on available WRF runs

- Best science + regulatory approach (case-specific)
  - Makes steady-state modeling more non-steady-state, more realistic

Summary and Future Work

- AERMOD
  - Continued evaluations
  - SO_2 SIP in public comment
- $PM_{2.5}$ SIP
  - CAMx with Plume-in-Grid (PiG)
  - Hybrid of CAMx and AERMOD (for locals) is another option
- Emerging models or techniques
  - CFD: CMU is currently developing a CFD study for the area
  - SCICHEM testing
  - WRF/MMIF enhancements
- Installation of additional met/monitor sites
  - Multi-level tower(s) with collocated SODAR/RASS

Questions?

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