Ambient NO_2 AERMOD Performance Assessment & Model Improvement Project Modeled to Observed Comparison

12th Conference of Air Quality Models

EPA-Research Triangle Park

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Project Participants

- **PRCI is directing and managing this research initiative**
  - PRCI – Pipeline Research Consortium International
  - Trade Associations
  - Member Companies and OEMs
- **PRCI's current membership includes companies operating in the United States, Canada, South America, Europe, Australia, China, and Japan**
  - 38 pipeline operating companies
  - 4 pipeline industry organizations
    - *American Petroleum Institute*
    - *Association of Oil Pipe Lines*
    - *Electric Power Research Institute*
    - *Operations Technology Development*
  - 31 associate members (service suppliers and manufacturers)

Study Objectives

- **The purpose of this project was to complete one year of comprehensive field measurements to develop a dataset from a representative transmission compressor station**
  - Collect concurrent hourly ambient nitrogen oxide and ozone, meteorological, and reciprocating engine PEMs data
  - Typical stations include multiple aligned stacks
  - Stack height typically similar to compressor house eave or ridge (implications for plume “downwash”)
- **Use data to evaluate AERMOD model performance and assess opportunities for model improvement**
  - Emphasis on potential model over-prediction of “near field” impacts from sources with shorter stacks, such as compressor stations

Project Host Site

- **Balko, Oklahoma Compressor Station**
- **Largest nearby cities:**
  - Perryton, TX: 10 miles (S)
  - Liberal, KS: 40 miles (N)
  - Guymon, OK: 45 miles (WNW)
  - Amarillo, TX: 142 mi (SSW)

- **Isolated flat site with no nearby major highway/NO2 sources**
- **Approximate Prior Station Utilization:**
  - 2013 - 47%
  - 2014 - 63%
  - Similar or higher utilization was expected in 2016 – actual use was marginally lower
- **Stacks aligned N/S with predominant wind direction**

Project Host Site: Balko, Oklahoma Four Reciprocating Engines

- Three compressor drivers and one emergency engine
- One hot water boiler with capped release

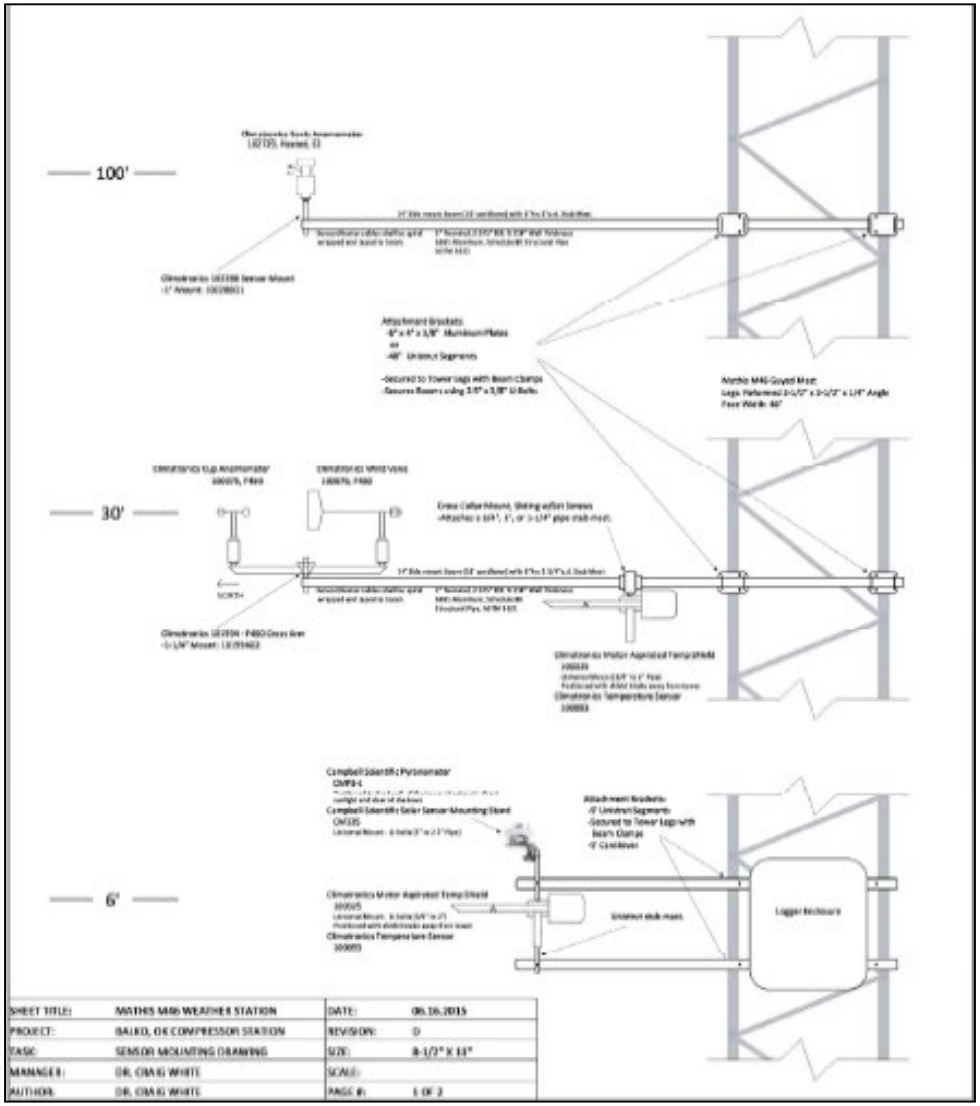
	Engine 8*	Engine 9	Engine 10	Emergency Engine
Engine Manufacturer & Model Number	Clark TCV-10	Clark TCV-12	Cooper-Bessemer 12W330C2	Caterpillar G3406
Approximate Horsepower	3,400	4,000	6,900	375
Stack Height (ft)	33.0	34.5	68.0	27.7
NO_x Emission Rate (g/hp-hr)	12	15.5	2.0	12.0
Permitted NO_x Emission Rate (lb/hr)	89.95	136.69	30.20	9.90

* Engine 8 did not run during study period

Engine Exhaust Stacks

* Looking Northeast

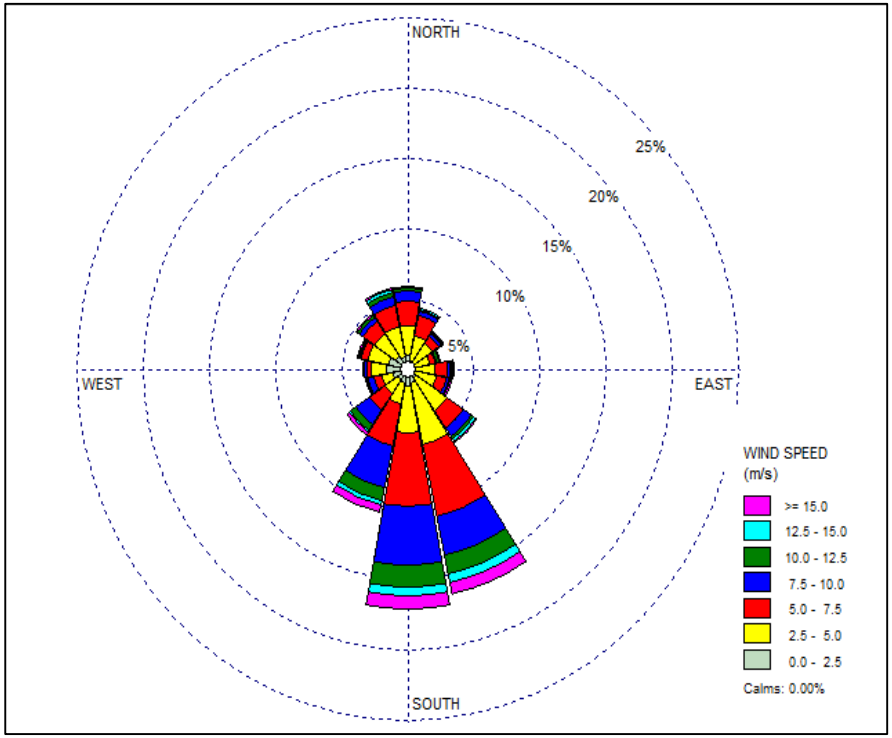
Met Data: 3-Levels of Instrumentation Using Fabricated Cross Arms



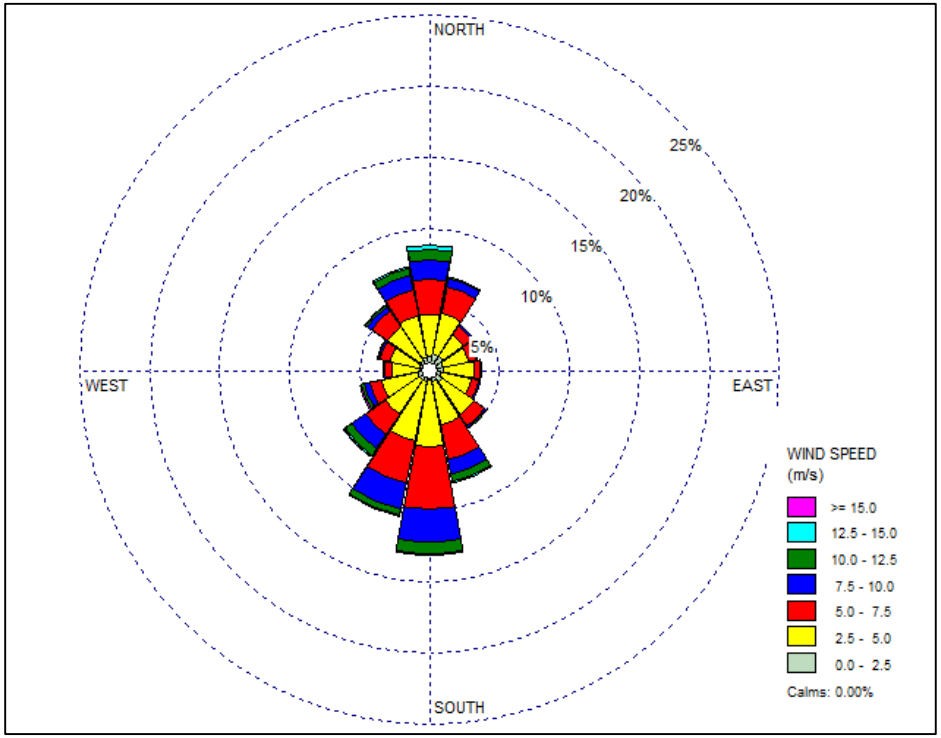
Comparison of Onsite Wind Rose to NWS Used for Siting

- Nearby (~45 mi NW) NWS Hooker OK used for monitor siting study
- Onsite minimally supplemented with Guymon ASOS data

10-meter site wind rose for Dec 1, 2015 – Dec 31, 2016



Wind rose for Hooker, OK station Dec 1, 2015 – Dec 31, 2016



Monitor Locations

- **Four monitor locations**
  - 3 “impact” and one “background”
- **2 north monitors are in alignment with the stacks**
  - Monitors 1 (Far North/Field) and 2 (North Fence) approximately 900’ apart
  - EPA (and OK) requested this configuration to assess downwind dispersion (predominant S wind)
- **East monitor sited primarily to assess downwash events**
  - Monitor 3 (East Fence) approximately 350’ east of sources
- **Southwest “Tower” monitor placed upwind of sources**
  - Monitor 4 (Tower)

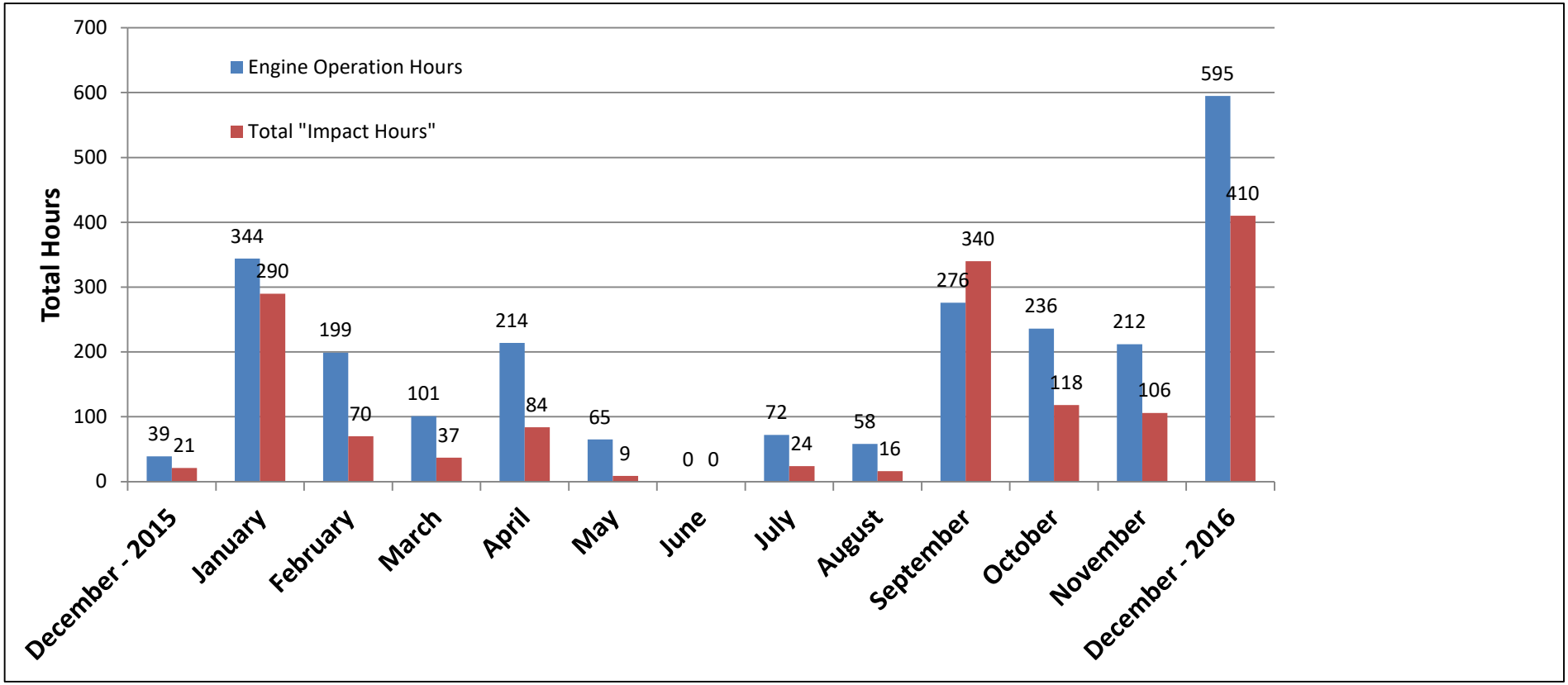
Ambient Monitoring Hours [A]

Parameter	Monitor 1 Field		Monitor 2 North Fence		Monitor 3 East Fence		Monitor 4 Tower	
Analyzer	Ozone	NOx	Ozone	NOx	Ozone	NOx	Ozone	NOx
Total Hours	9,528	9,528	9,528	9,528	9,528	9,528	9,528	9,528
Invalid Hours [B]	557	2,577	428	428	1,627	605	476	473
Valid Hours	8,971	6,951	9,100	9,100	7,901	8,923	9,052	9,055
Percent Valid Hours	94.2%	73.0%	95.5%	95.5%	82.9%	93.7%	95.0%	95.0%

[A] During 13-Month Period (Dec. 2015 – Jan. 2017)

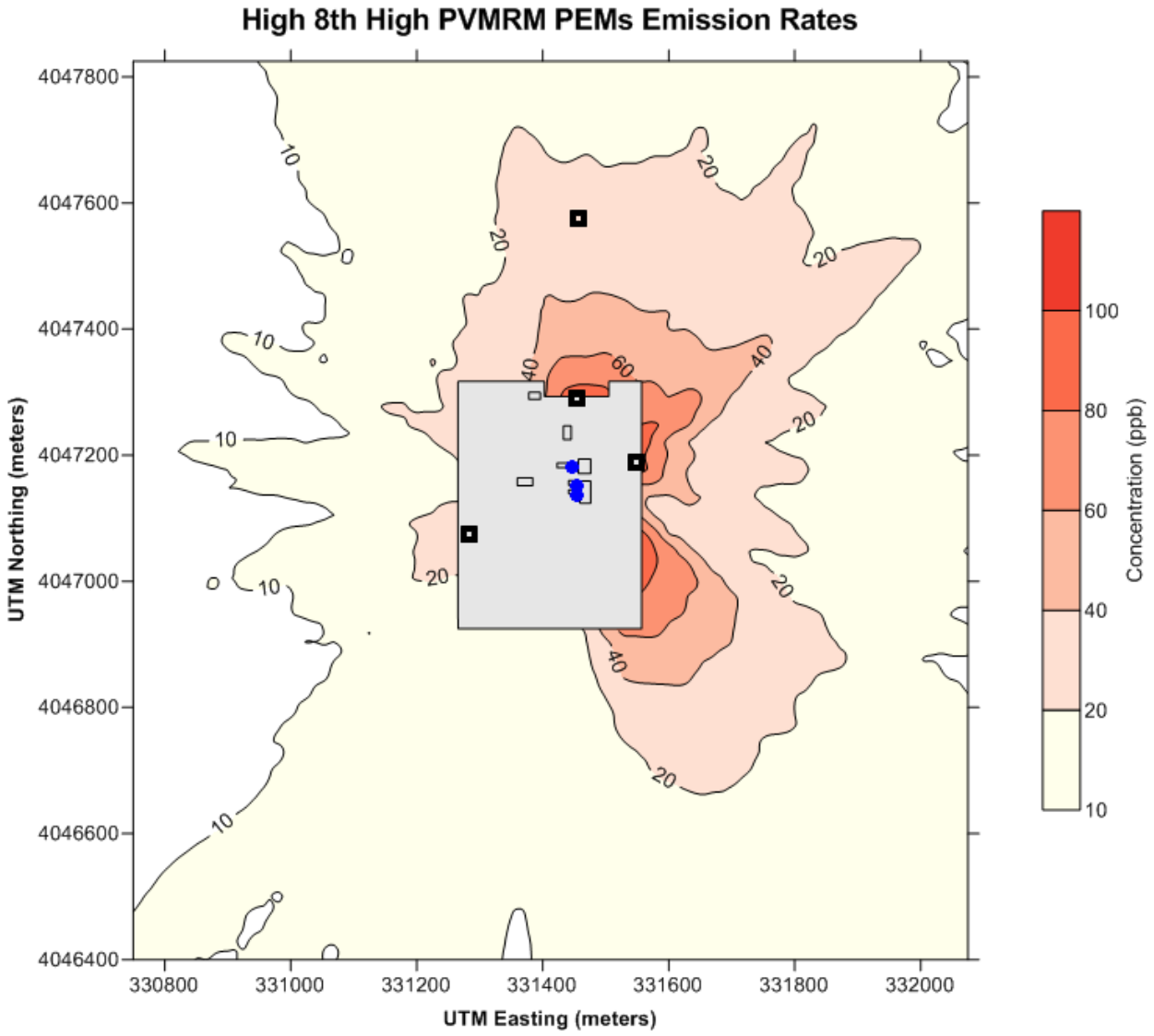
[B] Invalid hours include missing hours, calibration hours, and hours where the monitor was out of service.

Station 102 Utilization & Impact Hours (1-hour if both engines are running)



- 45 deg. sector (Alignment between one or more exhaust stacks and one or more monitors
- September data highlights double-count of impact from 2 north monitors
- Significant additional run time (and favorable winds resulting in measured impacts) in last 4 months and in 13th month

Monitor Siting – Model Concentration Isopleth using *Site Met Data & PEMs*



Evaluate Siting…

- Monitors *sited* using met data available from Hooker, OK
- Using *onsite* met data, AERMOD demonstrates that the monitors have been correctly sited

Summary of Monitored Data

- **Overall High 8th High of 91.1 ppb occurred at the North Fence monitor**
  - Facility passes NAAQS based on **1 year** of monitoring data
  - Facility failed AERMOD modeling analysis (5 years offsite data and PVMRM) H8H = 207.9 ppb

Monitor Location	Maximum 1-Hour NO_2 (ppb)	H8H NO_2 (ppb)	Minimum 1-Hour NO_2/NOx Amb. Ratio	Average NO_2/NOx Ratios for Top 10 1-hour NOx Measurements
Field (#1)	53.3 September 2016	32.9	0.11	0 .16
North Fence (#2)	**109.8** December 2016	**91.1**	0.05	0.08
East Fence (#3) [A]	57.7 December 2016	18.5	0.04	0.10
Tower (#4)	62.3 December 2016	20.2	0.08	0.11

[A] The East Fence monitored values are adjusted for interference using the methodology detailed in a technical memorandum released February 2018.

Permitting Analysis Results

- **Model over-predictions occur at monitor locations with the East Fence over-predicted by a factor of 11.5 likely due to downwash**
  - Modeled NAAQS exceedances predicted at 3 of the 4 monitors
- ***Removing TCV-10 from analysis reduces impact but still provides large over-prediction***

Monitor Location	High 8th High Observed (NO_2 ppb)	Tier 1	Tier 2	Tier 3	
		Full Conversion (NO_2 ppb)	ARM 2 (NO_2 ppb)	OLM (NO_2 ppb)	PVMRM (NO_2 ppb)
Field	32.9	418.0	224.4	190.2	102.6
North Fence	91.1	1015.5	522.6	254.4	192.0
East Fence	18.5	1286.1	657.9	244.2	211.2
Tower	20.2	460.6	245.2	174.8	82.9

Refined Analysis: Onsite Data

- **Uses actual emissions data from PEMS**
  - Boiler and Emergency Generator tracked as on/off and averaged over 1-hour
- **Uses on-site meteorology data (SRDT), with minimal substitutions from ASOS station in Guymon, OK**
- **Hourly background Ozone and NO_2 files developed by selecting upwind monitor**
  - Typical background NO_2 at Balko was <5 ppb
- **Model performance greatly improves, with slight over-predictions in the near-field**

Monitor Location	High 8th High Observed (NO_2 ppb)	Tier 1	Tier 2	Tier 3	
		Full Conversion (NO_2 ppb)	ARM 2 (NO_2 ppb)	OLM (NO_2 ppb)	PVMRM (NO_2 ppb)
Field (#1)	32.9	154.5	76.5	66.0	32.7
North Fence (#2)	91.1	434.9	205.7	103.1	107.5
East Fence (#3)	18.5	531.7	99.1	114.6	105.2
Tower (#4)	20.2	232.9	81.1	76.4	33.5

AERMOD Chemistry Analysis Utilizing EPA Debug Options

- **Additional analysis of AERMOD plume chemistry, plume growth, and ozone mixing into plume – key issue for near field impacts**
  - Conduct additional investigation into NOx (relative dispersion) and NO_2 (chemistry) PVMRM impacts at both the north fence and field monitor locations
- **Analyses underway to better define:**
  - Plume dimensions at each downwind receptor location
  - Plume assumptions: available O_3, NO, and NO_2 at each downwind location
  - Explore unexpected results in PVMRM (2015) vs 2017 PVMRM update
    - Slight increase using 2017 update in nearfield model predictions

Utilize Debug File to Investigate NO_2 Dispersion and Chemistry

- **Selecting 1-hour "events" with ideal conditions**
  - Focusing on difference in modeled to observed for the north fence and field monitor locations
  - South wind alignment between stacks and monitors
  - Clark TCV-12 engine running
  - Cooper, boiler, emergency generator are NOT running
- **Run model with and without downwash**
- **Run model for NOx and NO_2**
- **Investigate underlying 1-minute data for changes in emissions, meteorology, or ambient monitored impacts**
- **Investigate plume rise using Briggs calculations in EXCEL**

Example 1-Hour Investigation

		North Fence	Field
Monitored Met Data	WindSpeed_30m (m/s)	7.1	7.1
	WindSpeed_10m (m/s)	5.3	5.3
	WindDir_30m (degrees)	177.7	177.7
	Sigma Theta (30m)	4.8	4.8
	PG Stability Class (30m)	D	D
	WindDir_10m (degrees)	174.7	174.7
	Sigma Theta (10m)	6.2	6.2
	PG Stability Class (10m)	D	D
	Temp_10m °C	30.4	30.4
	Temp_2m °C	30.2	30.2
	10m-2m Delta T (°C/m)	0.0	0.0
	% Humidity	36.0	36.0
	Solar Rad (watts/m2)	31.9	31.9
Surface and Profile Met Data	U*, m/s	0.387	0.387
	W*, m/s	-9.0000	-9.0000
	MONIN-OBUKHOV, m	153.1	153.1
	THSTAR	0.0698	0.0698
Model Debug File	Plume Height Center of Mass, m	35.3	55.4
	Sigma-z Estimate, m	8.6	16.9
	Ueff, m/s	6.78	7.46
	Sveff, m/s	0.73	0.72
	Sweff, m/s	0.49	0.49
SFC to ZI	U, m/s	14.70	14.70
	Sig-V, m/s	0.62	0.62
	SigW, m/s	0.42	0.42
Value at ZI	U, m/s	20.17	20.17
	Sig-V, m/s	0.50	0.50
	SigW, m/s	0.40	0.40
	VPTG, K/m	-9.0000	-9.0000

Example 1-Hour Investigation Continued

	Receptor	North Fence	Field
	Time Stamp (mm/dd/yy hh:mm)	9/20/16 18:00	9/20/16 18:00
Monitored Ambient Data	O3_1 (ppb)	18.1	34.3
	NO_1 (ppb)	120.7	18.7
	NO2_1 (ppb)	39.3	14.5
	NOx_1 (ppb)	160.0	33.2
	NO2/NOx Ratio	0.25	0.44
PEMS Data	U10_NOx (lb/hr)	0.0	0.0
	U9_NOx (lb/hr)	101.0	101.0
Modeling Results	Modeled NO2 (ppb)	73.9	25.1
	Modeled NOx (ppb)	359.6	106.2
	Modeled NO2/NOx ratio	0.21	0.24
Model Over/Under Prediction Factor	Error NO2	0.88	0.73
	Error NOx	1.25	2.20
	Error NO2/NOx Ratio	-0.16	-0.46
PVMRM Debug File	MAXCONC_NOX (ug/m3)	676.40	199.84
	MAXCONC_NOX (ppb)	359.60	106.24
	O3CONC (ug/m3)	85.18	85.18
	O3MOLES	0.23	1.17
	NOXMOLES	5.07	15.40
	PLUMEVOL (m3)	130,350	659,470
	PERCENT NO2	21%	24%

Beta Downwash Model Option Analyses

1. P2SHS: PRIME2 with stack height wind speed for concentration calculations (includes ORD cavity fix) – PRIME2 with stack height wind speed used for concentration calculations
2. P2PHS: PRIME2 with plume height wind speed for concentration calculations (includes ORD cavity fix) – Official PRIME2 Options
3. P2AVGS: PRIME2 with speed at average between receptor and plume height for concentration calculations (includes ORD cavity fix)
4. ORDAVGS: ORD version with speed at average between receptor and plume height used for concentration calculations.
5. ORDAERS: ORD version with AERMOD defaults used for concentration calculations.
6. Current AERMOD Version

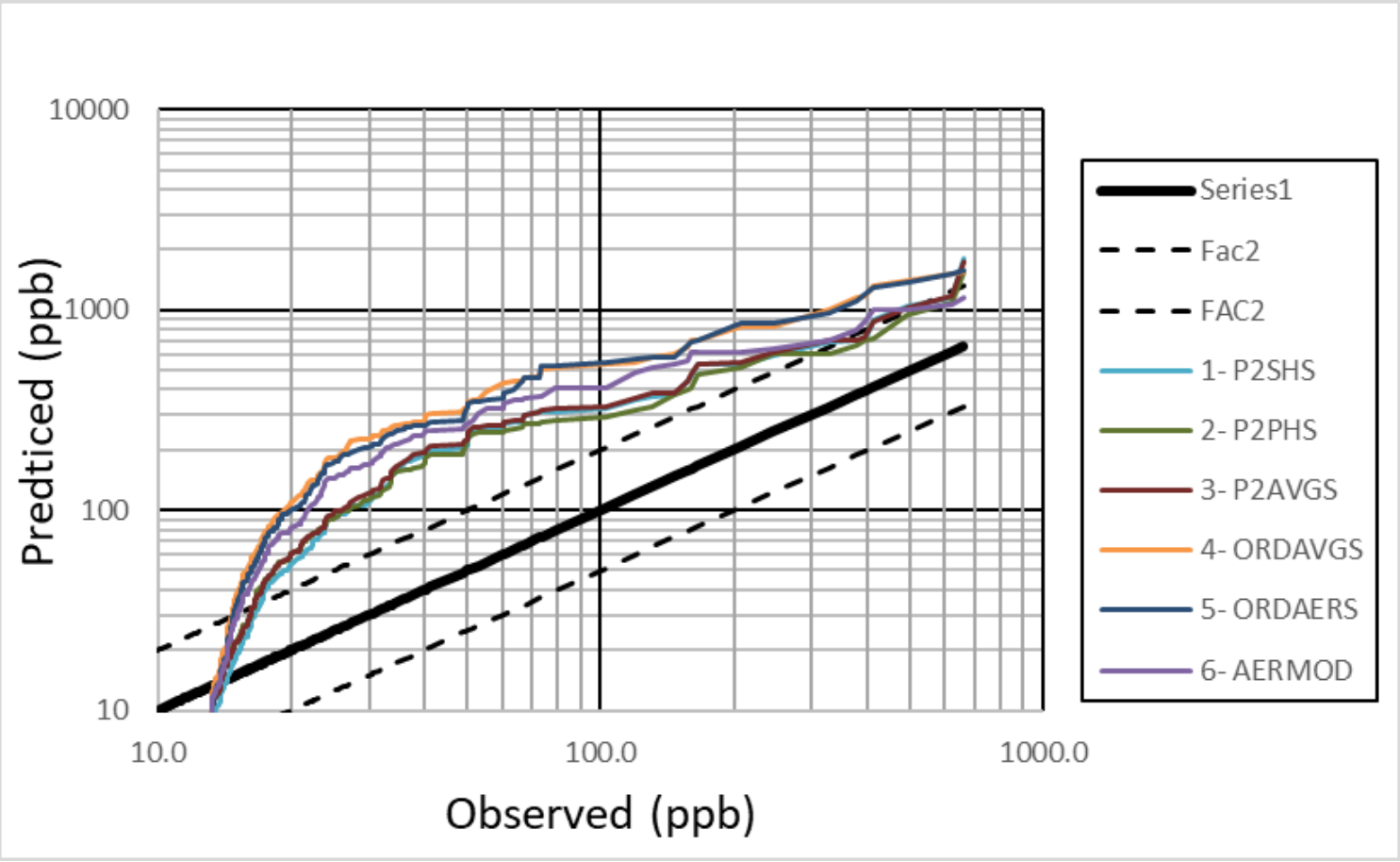
Downwash Analyses
Monitor 3 – East Fence

- **Robust high concentration - NOx (to eliminate chemistry) predicted to observed**
- **NOx is over predicted by a factor of 1.8 to 3.25**

Model Scenario	RHC_{pre} (ppb)	RHC_{obs} (ppb)	RCH_{pre}/RCH_{obs}
1- P2SHS	1312.0	637.0	2.06
2- P2PHS	1156.1	637.0	1.82
3- P2AVGS	1294.5	637.0	2.03
4- ORDAVGS	1855.1	637.0	2.91
5- ORDAERS	2070.8	637.0	3.25
6- AERMOD	1600.1	637.0	2.51

Preliminary results

NOx Q-Q Plot for Monitor 3 East Fence



Preliminary results

Conclusions: Opportunities to Improve AERMOD

- **Model conservatism**
  - Simplistic model chemistry and ozone entrainment assumptions
    - PVMRM over estimation of NO_2/NOx ratios
    - Ambient ratio monitored at north fence during impact hours and in-stack ratio almost identical (~400 ft. separation)
    - O_3 uniformly distributed within plume for immediate conversion of NO to NO_2
  - 1-hour invariant meteorological and emission data are used to predict a 1-hour average ambient concentration
  - Downwash for the compressor station configuration is over predicted
  - 1-hour invariant meteorology used to predict 1-hour impacts contributes to opportunities for over predictions

Additional Data Available

- **Further analysis and monitoring dataset can be found on the PRCI website for a nominal fee (*www.prci.org*)**
  - *Balko, OK Compressor Station 102 Data Summary and Initial AERMOD Performance Assessment*
  - *Isopleths and QQ plots of various model options*
    - *Model performance paired/unpaired in time*
  - *Investigation into model sensitivity to various parameter changes (e.g. ozone, emission rates, downwash, etc.)*
  - *Influence of wind speed on model performance*
  - *Includes an analysis of near field modeled to observed chemistry*
    - *Downwind dispersion and NO to NO2 conversion between North Fence and Field monitors*
- **PR-312-12208-Z04 Summary of NO2-NOx Ratio Test Data Compilation for Reciprocating Engines and Combustion Turbines**

Ongoing 2019 PRCI Activities and Project Focus

- **Evaluation of EPA changes to downwash**
  - Petersen Research and Consulting – evaluation of PRIME2 with and without the new ORD enhancements using Balko dataset
- **Near-field chemistry and use of debug file**
- **Sub-hourly "event" analyses using higher resolution meteorological and emissions data (e.g., 10-minute, 1-minute,)**

Project Contacts

- **Gary Choquette - Pipeline Research Council International**
  402-915-5565
  gchoquette@prci.org

Innovative Environmental Solutions, Inc.

- **Jim McCarthy**
  847-543-0226
  jamesmccarthy@comcast.net

Adrian Huth
715-579-2500
azhuth@the-ies-inc.com

- **Jeff Panek**
  847-516-3658
  japanek@ameritech.net