Low-cost sensors for informational PM-2.5 monitoring in Oregon

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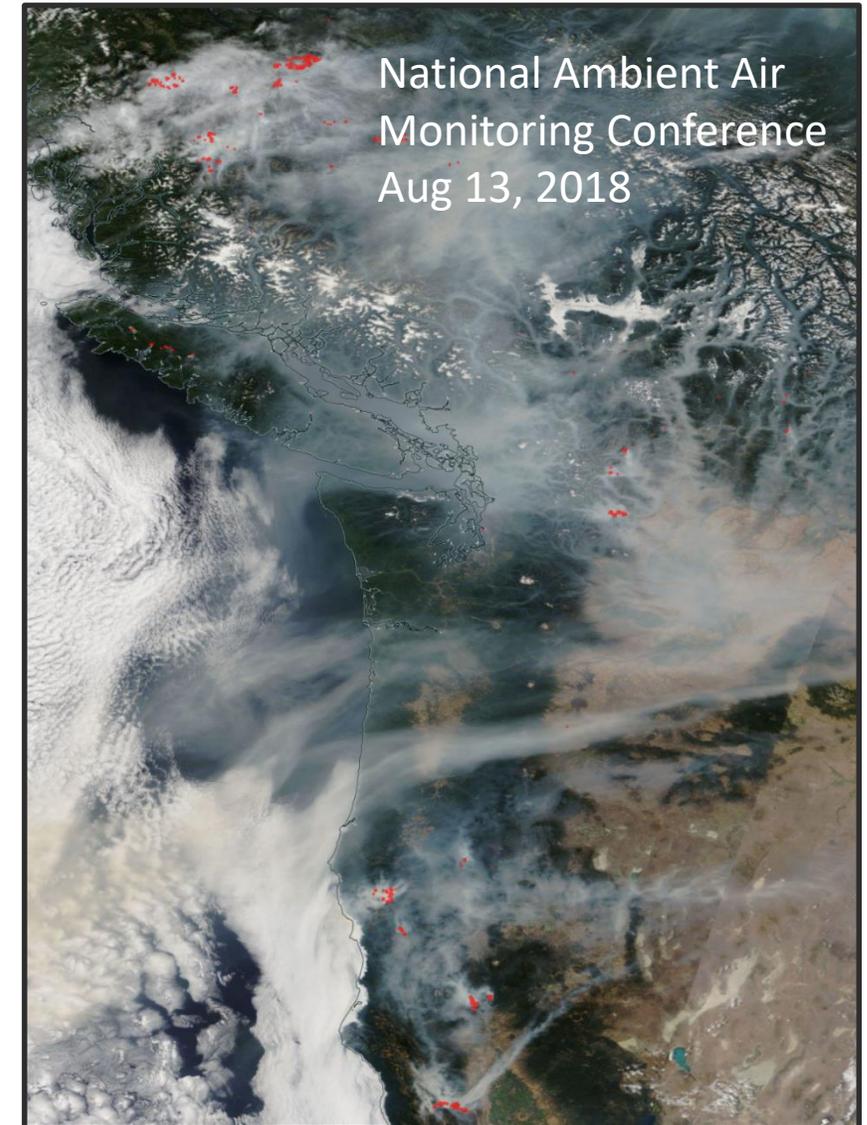Tom Roick

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Evan Bing
Ben Ayres
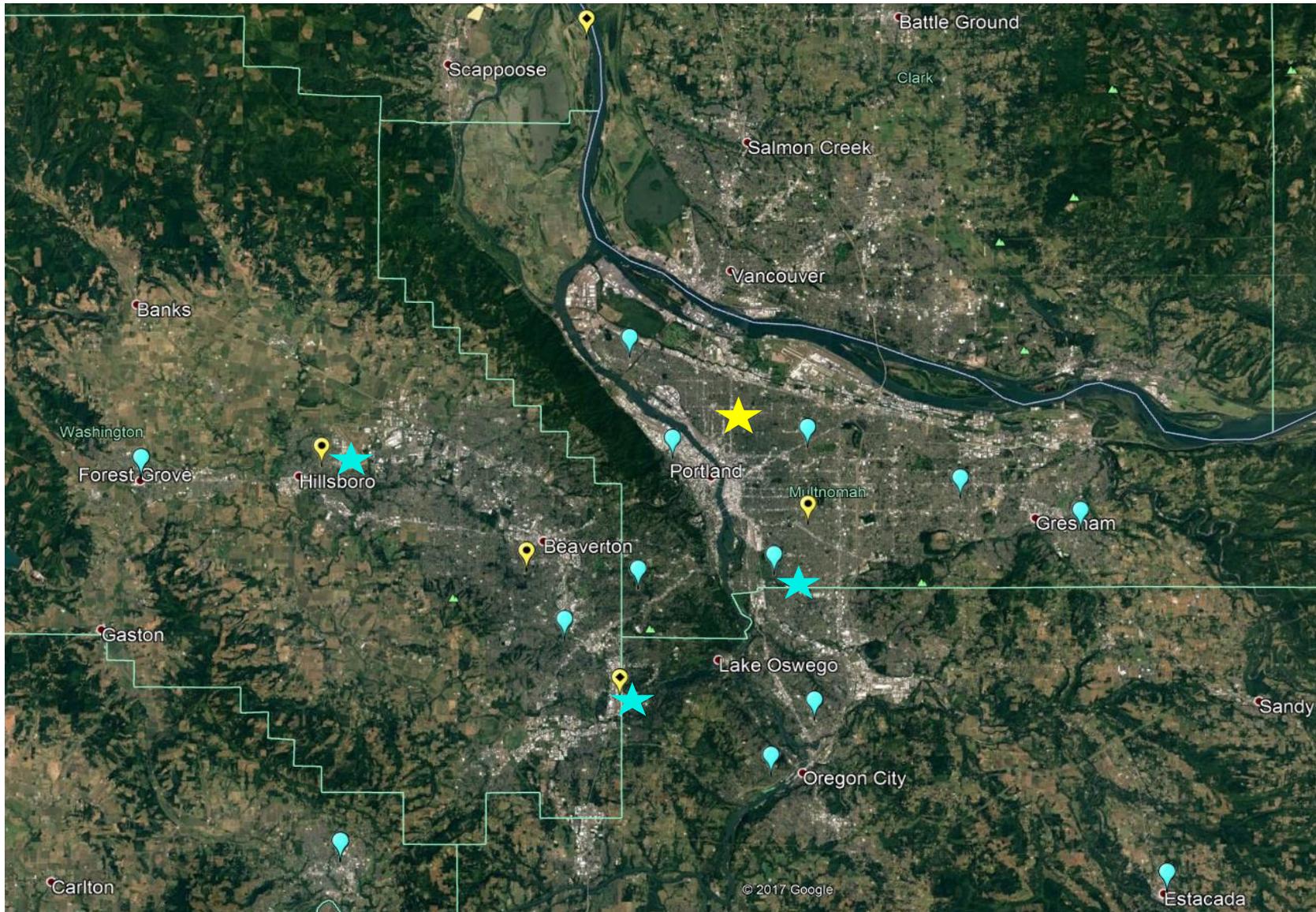
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DEQ

What Do You Know,

and When Do You Know it?

Why build a low-cost PM sensor package at DEQ?

- Received funding in 2017 to add 30 new sites
- Expand PM-2.5 monitoring using an approach
  that is consistent with existing methods in Oregon
  - Measurement & QA/QC approach
  - Use existing IT and AQM network infrastructure
- Provide <u>publicly-owned</u> near real-time data

- Provide data of known quality (e.g., traceable)

- Data should meet DEQ data quality objectives

Key:
Yellow – Existing monitors, Red - existing summer monitors, Blue – New Monitors, Star – Air Toxics

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Oregon DEQ data quality objectives

- Data completeness >= 75%

https://www.oregon.gov/deq/FilterDocs/aqmlowcost.pdf

https://www.oregon.gov/deq/FilterDocs/aqmtargets.pdf

- Air Quality Index data should be within +/- 20% FRM Data

State of Oregon Department of Environmental Quality

Air Quality Monitoring Performance Targets[1]

Application	Pollutants	Precision & Accuracy[2]	Examples	Supporting Documentation
Regulatory or compliance monitoring, Air toxics monitoring[3]	Ozone, PM2.5, CO, NO2, SO2, Lead, VOCs, HAPs[3]	+/- 10%	Filter-based FRM[4] sampler, Continuous FEM[5] PM monitor, FEM ozone analyzer, EPA laboratory protocols	40 CFR parts 50, 53, and 58, National Air Toxics Trend Station Technical Assistance document
Supplemental monitoring, Special studies, Real-time Air Quality Index	Ozone, PM2.5, H2S, VOCs, Meteorology	+/- 20%	Nephelometer, E-BAM, H2S monitor for odors, Calibrated met station, Sensor-based with quality control and validation	Organization's approved quality assurance plan or sampling analysis plan
Area and source surveys, Screening; Fenceline monitoring, Personal exposure	Ozone, PM2.5, NO2, VOCs, Meteorology	+/- 30%	Calibrated sensors, Home met station	EPA Air Sensor Toolbox
Information, Education, Community monitoring	Ozone, PM2.5, NO2, CO, VOCs and others	+/- 50%	Low-cost sensors, Personal monitors	South Coast AQMD Air Quality Sensor Performance and Evaluation Center

1 This document is for informational use only. DEQ makes no claim, warranty or guarantee of instrument performance when operated by users for their specific applications.

2 These guidelines are likely to evolve as technology and science advance.

3 Hazardous air pollutants or air toxics

4 Federal Reference Method

5 Federal Equivalent Method

# Designing the Oregon DEQ PM sensor package

- Sensor selection – Background Research:
  - South Coast AQ SPEC/EPA/academic papers

- Data of known quality
  - Tracking sensor & performance
  - Identify drift & confirm sensor operation
  - Known data pipeline
  - Quality assessment

- Measurement technique
  - Optical PM measurements (composition, RH...)
  - Reduce environmental impacts on sensor
  - Ability to zero

- Provide communities with real time data
  - Cellular communication
  - Community work

2 Parts

Part 1: Inline with Nephelometer (Met One M903)

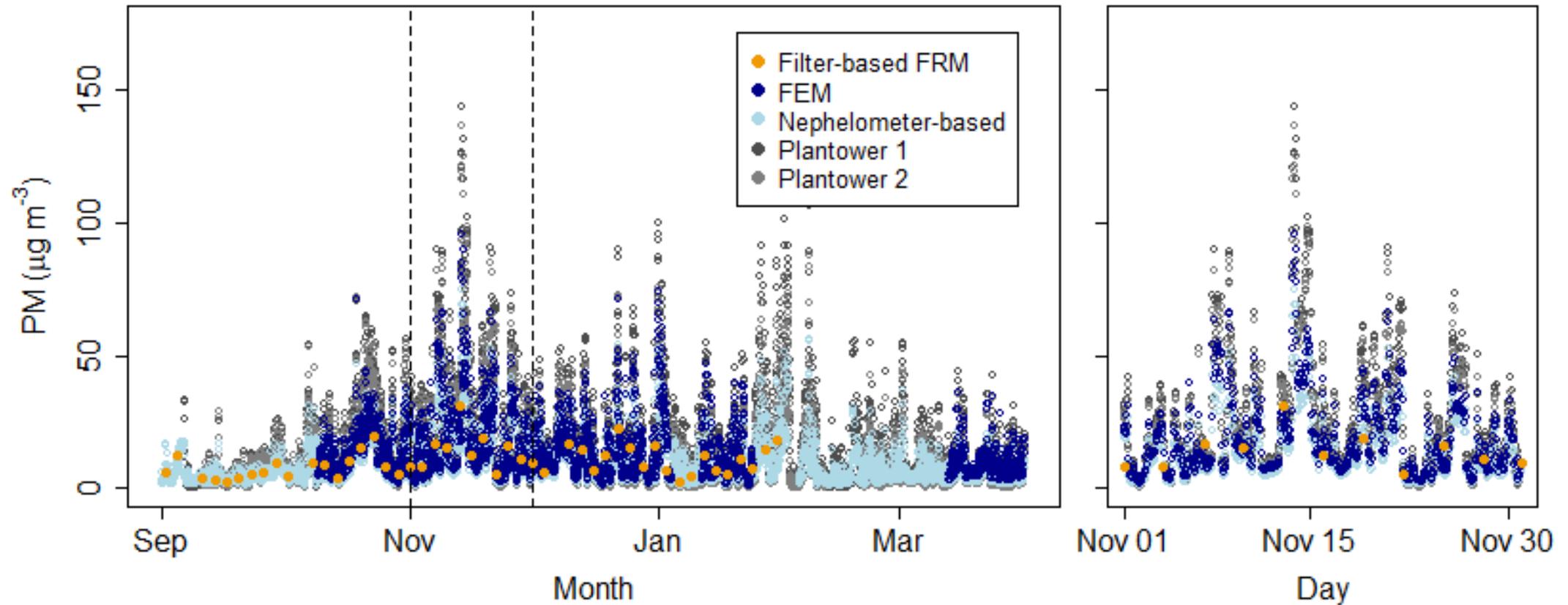Examine Plantower sensor performance across Oregon
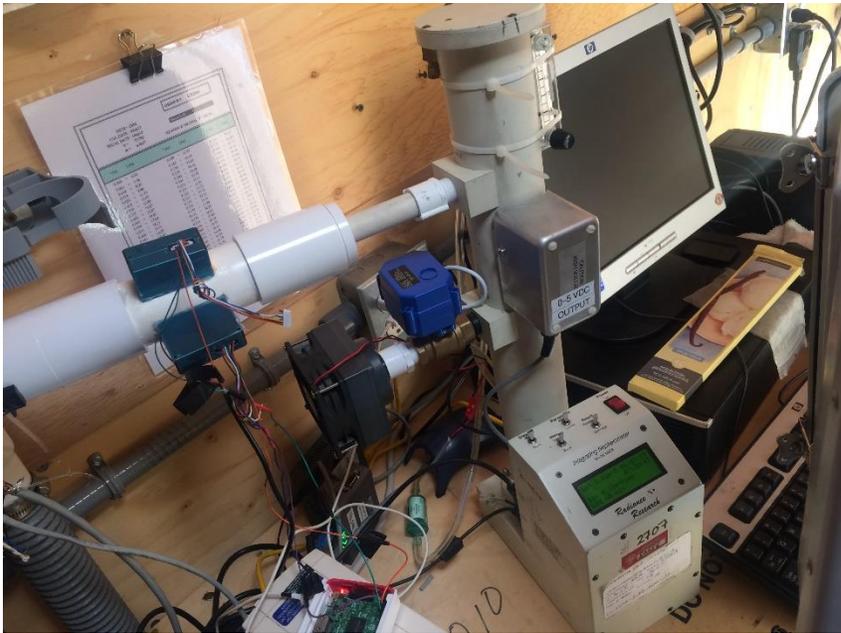
Part 2: SensOR ™

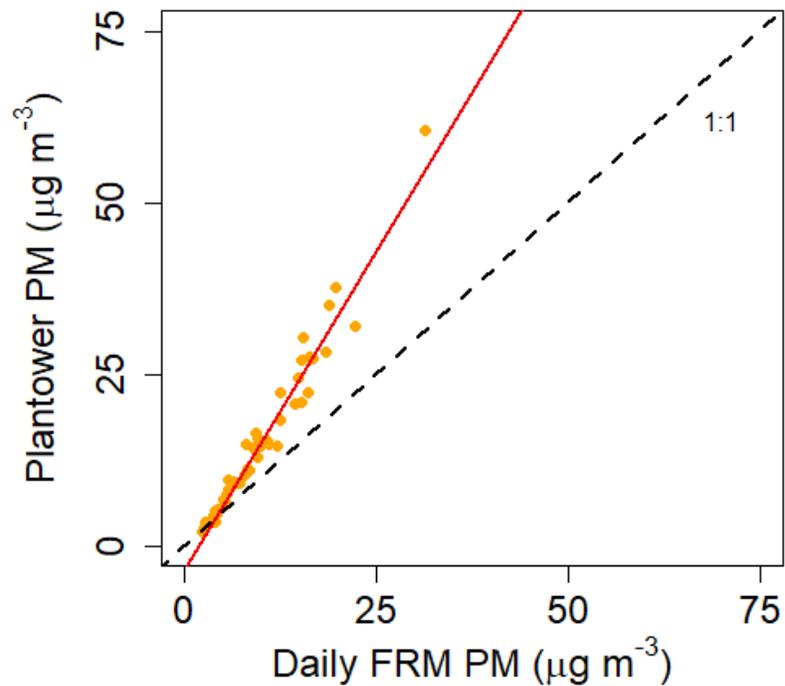Stand-alone package for use in Oregon

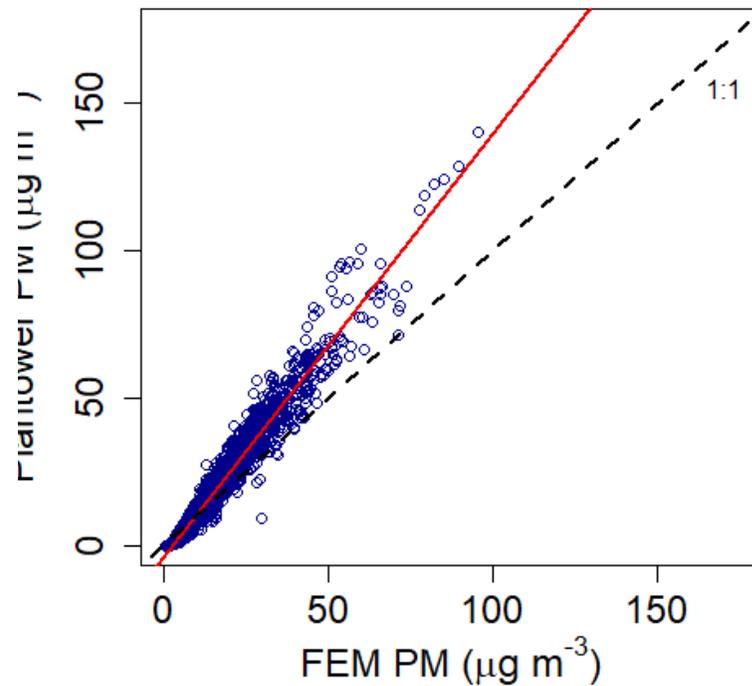# Part 1: Plantower PMS5003ST Vs. Nephelometer Performance

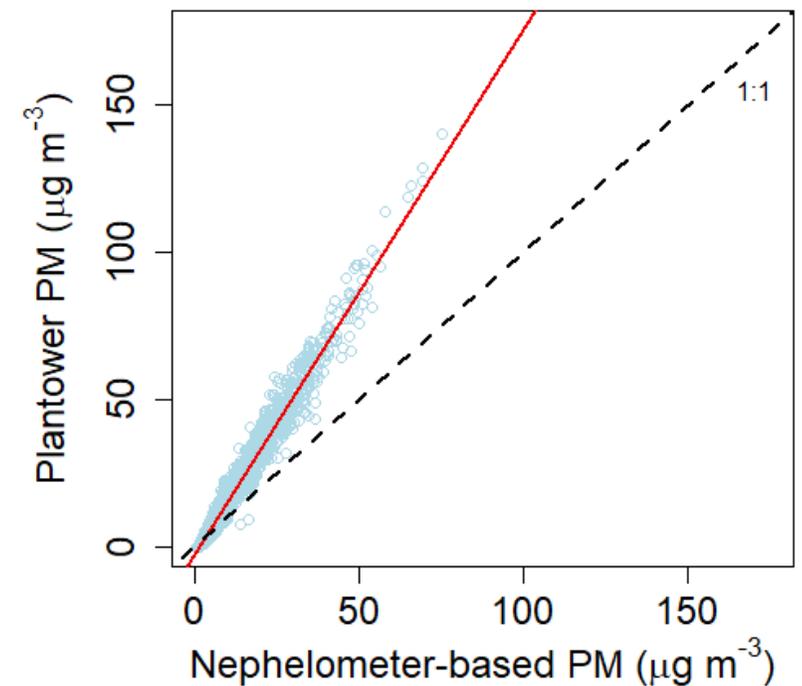# Plantower PMS5003ST comparison with co-located reference and informational-level monitors

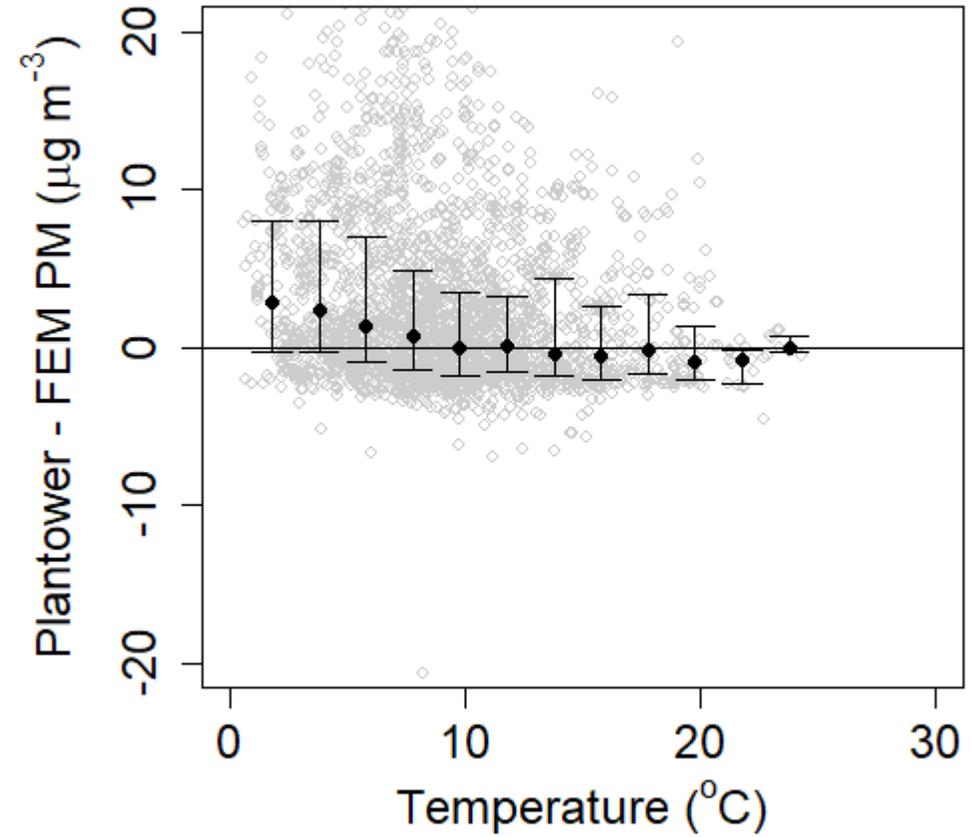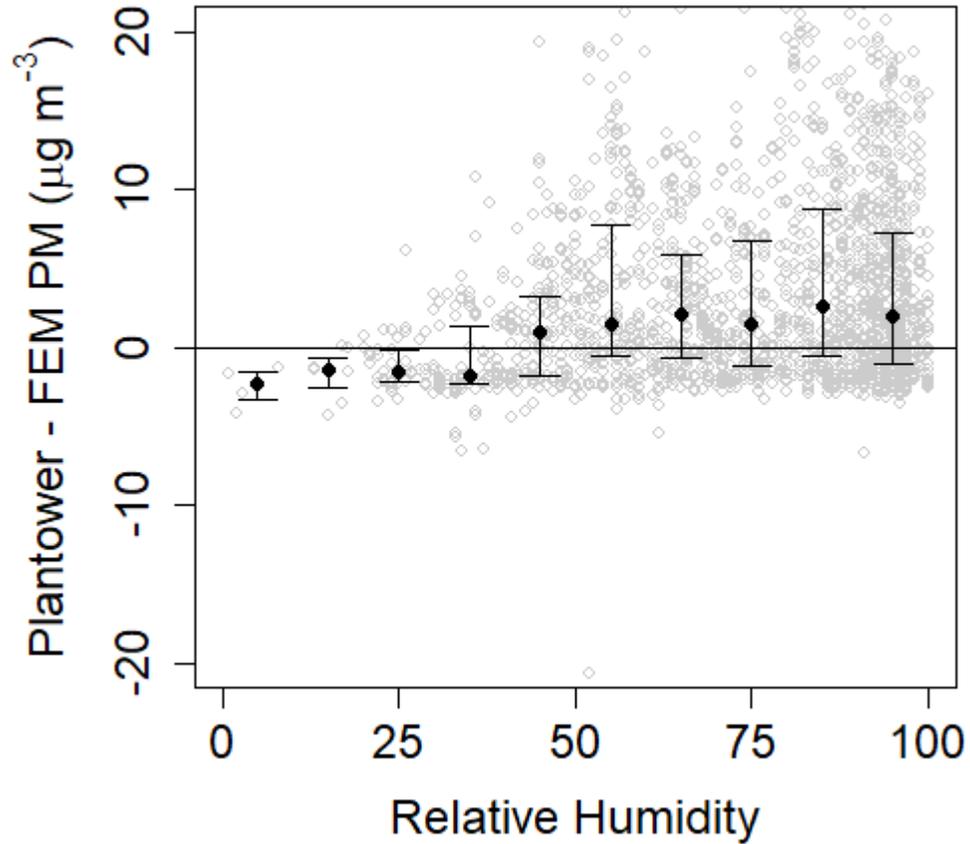Plantower PM-2.5 = 1.86 * FRM PM − 3.33
R^2 = 0.96

Plantower PM-2.5 = 1.44 * FEM PM − 3.70
R^2 = 0.96

Plantower PM-2.5 = 1.79 * FEM PM − 2.38
R^2 = 0.98

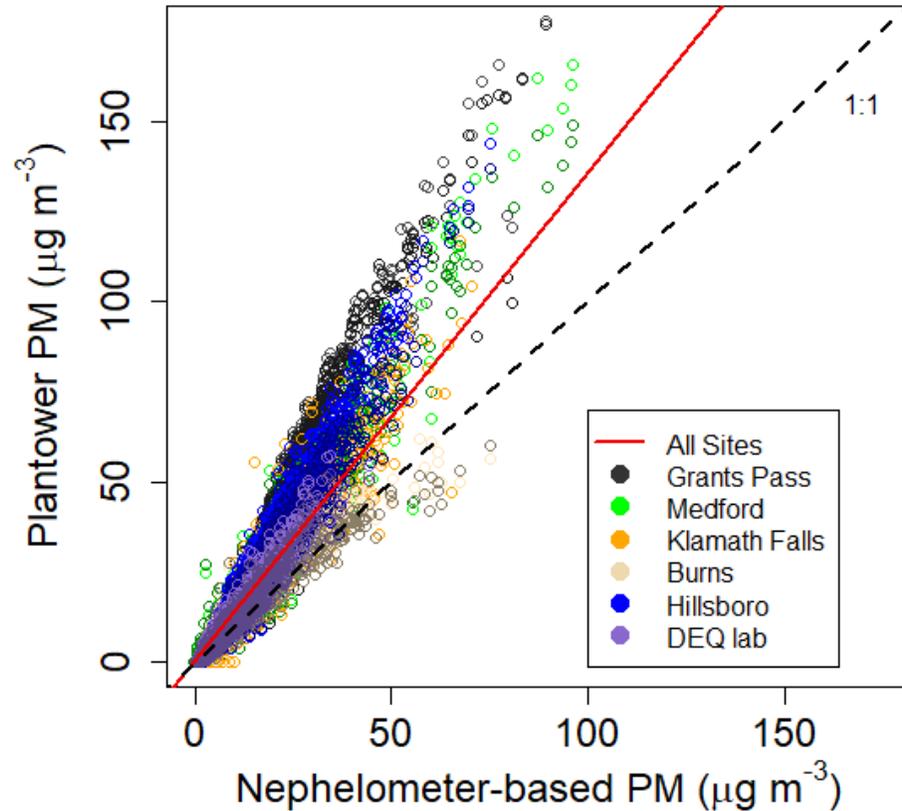# Plantower PM-2.5 Humidity-Temperature Dependence

Sensor-Site Regressions

All sites combined:

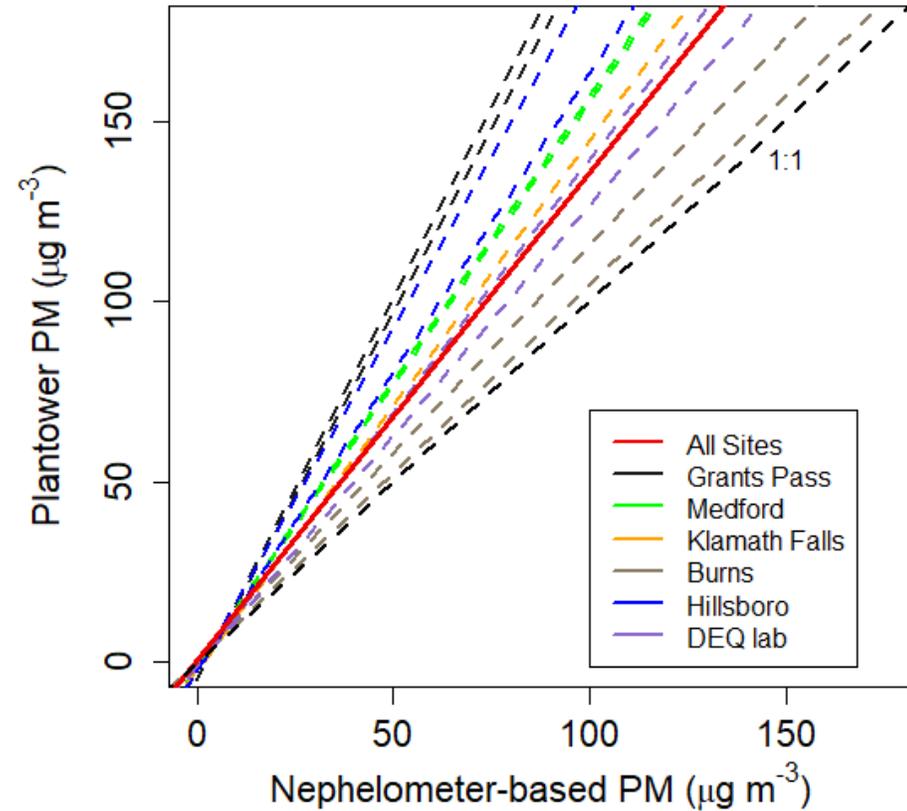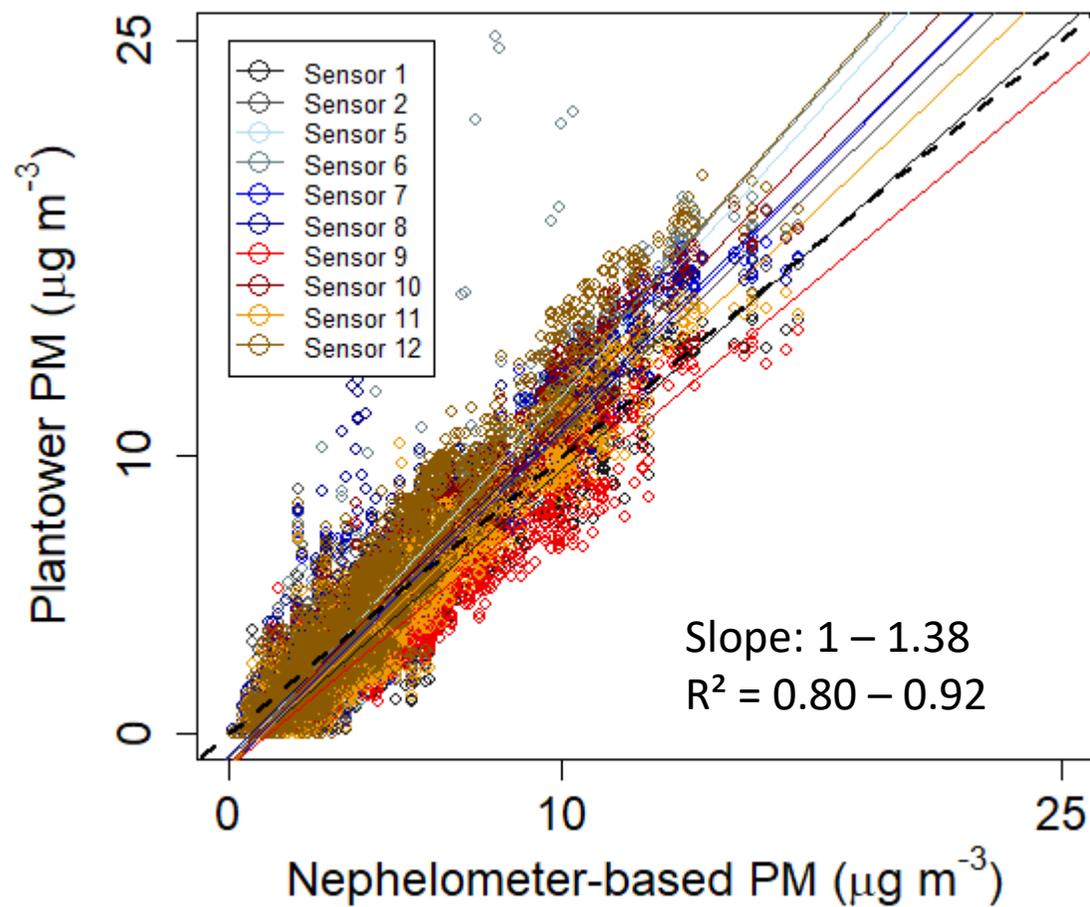Plantower PM = 1.35 * Nephelometer-based PM +0.35

$R^2 = 0.61$

Site specific:

Slope range: 1.04 (Burns) - 2.11 (Grants Pass)

R^2 range: 0.91 (Burns) - 0.98 (Hillsboro)

Group-test
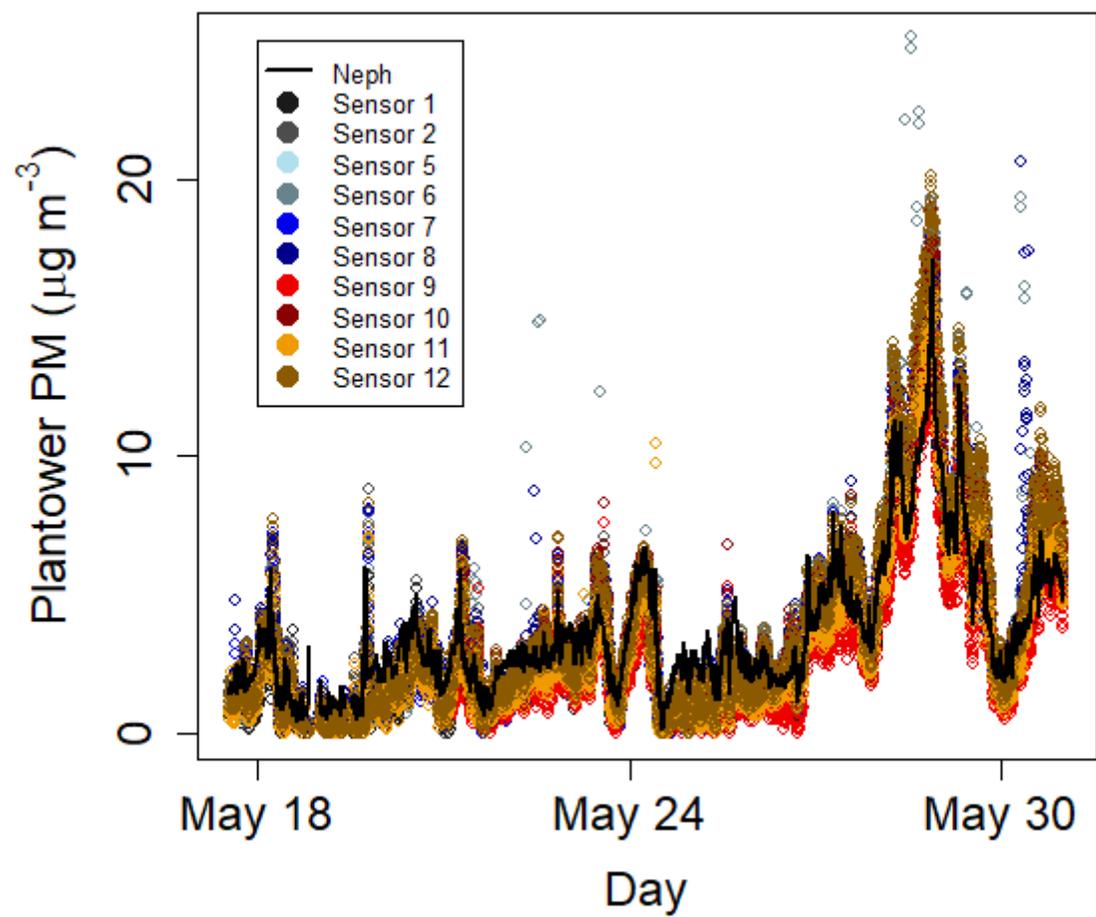
Smoke-test
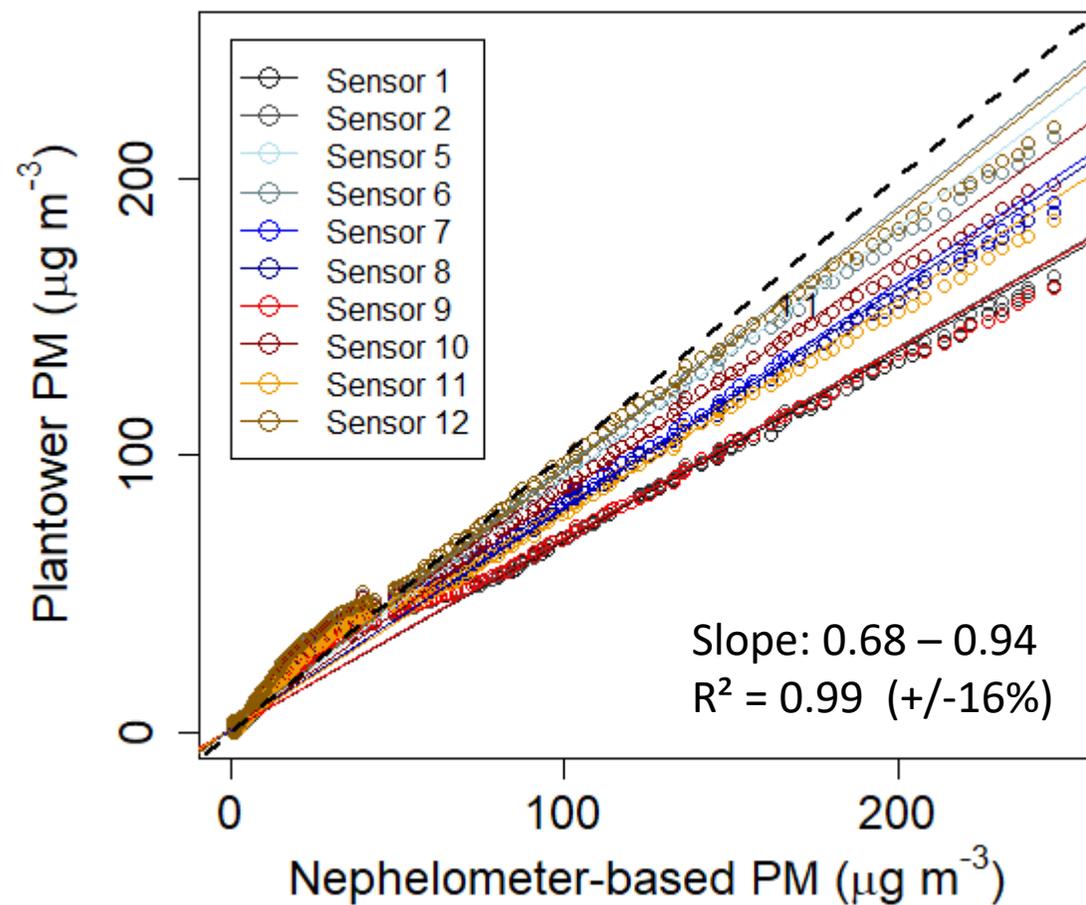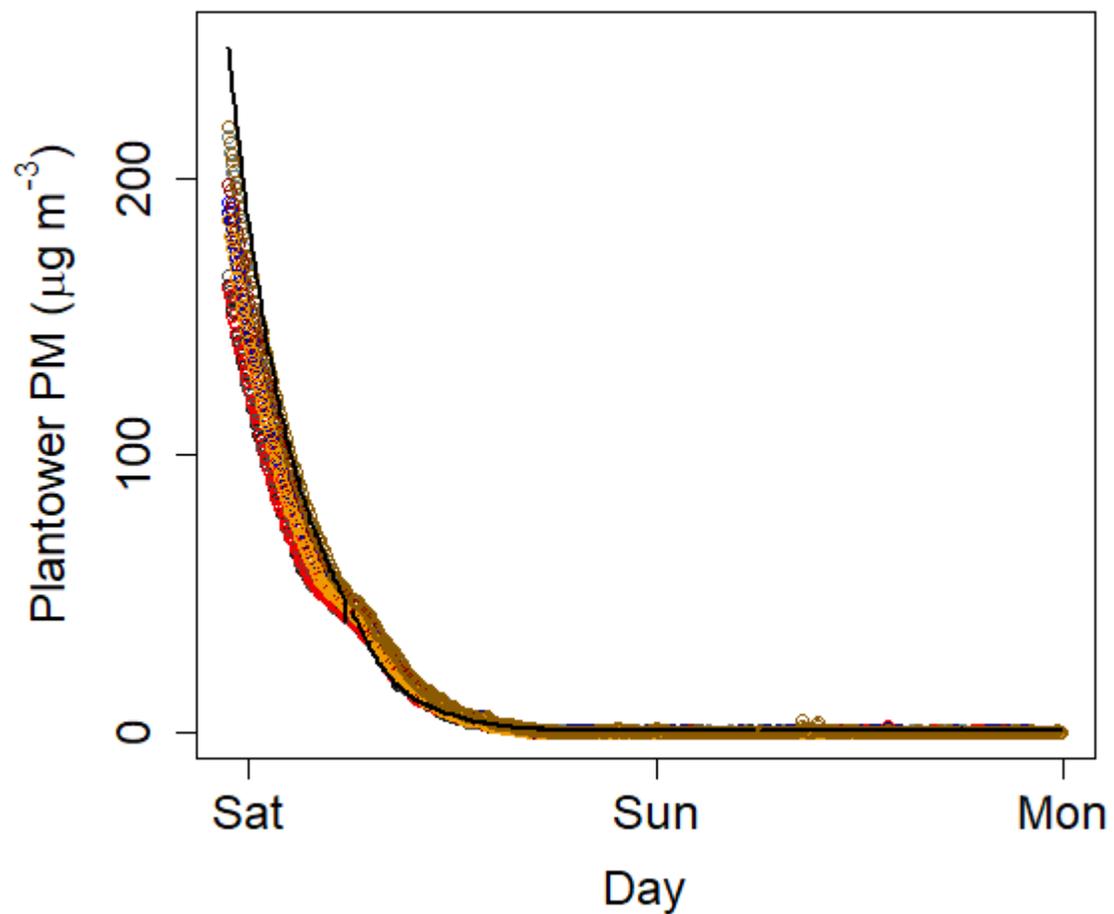
Approach

- Treat SensOR™ similar to the nephelometer
- Inline sensors run at multiple sites for at least 30 days
- Correct Plantower output to Bscat
  - Range of corrections is +/- 20%
- Use Nephelometer to FRM correlations specific to each site as implemented over many years in OR
  - Range of correlations is +/- 15%
  - Wildfire correlation is different from winter time correlations
- Quarterly maintenance checks
  - Doesn't respond to SUVA
- Verify with collocated sites and performance audits

Comparison of inline sensor pair
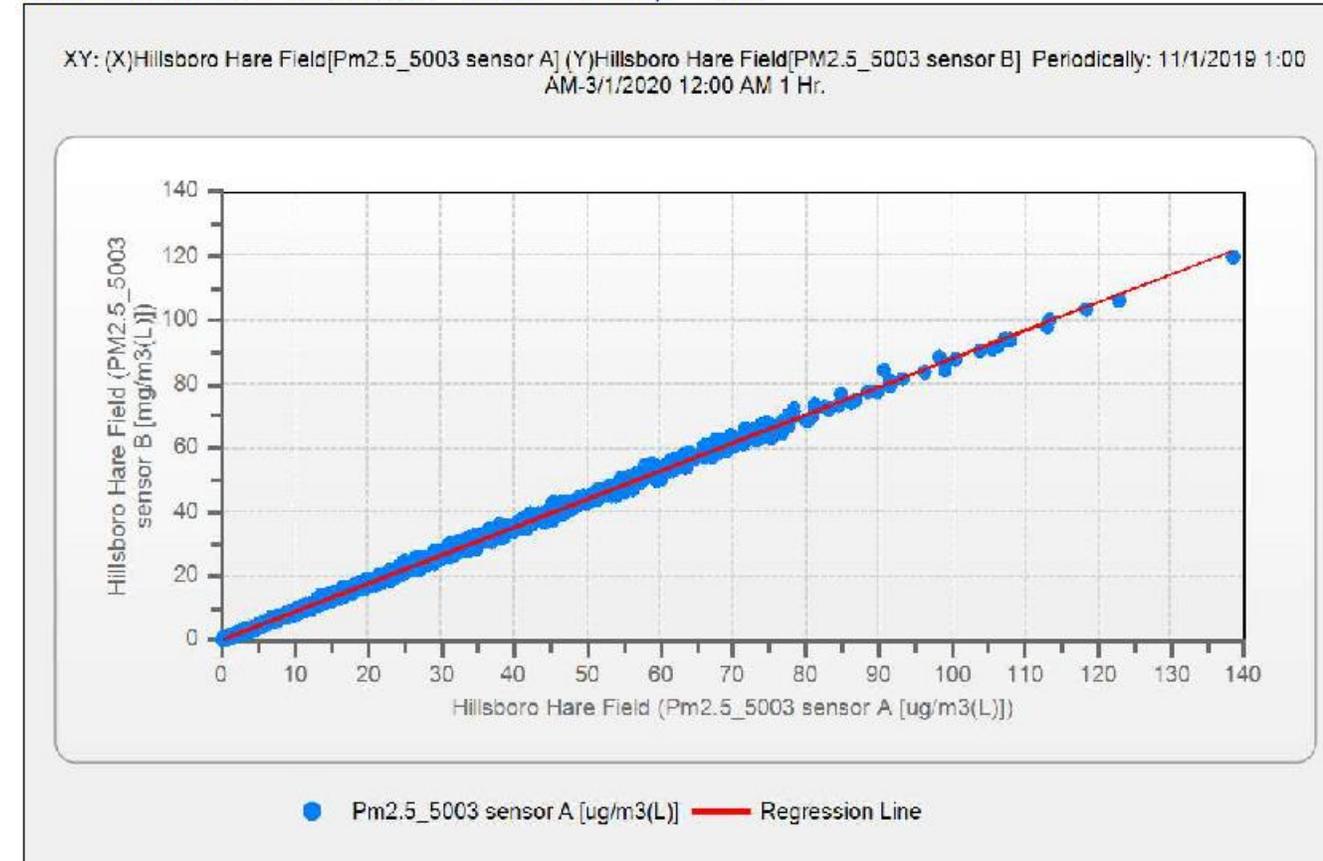
Comparison of inline sensor to Nephelometer Bscat

Nephelometer to FRM correlations – 2016-2018

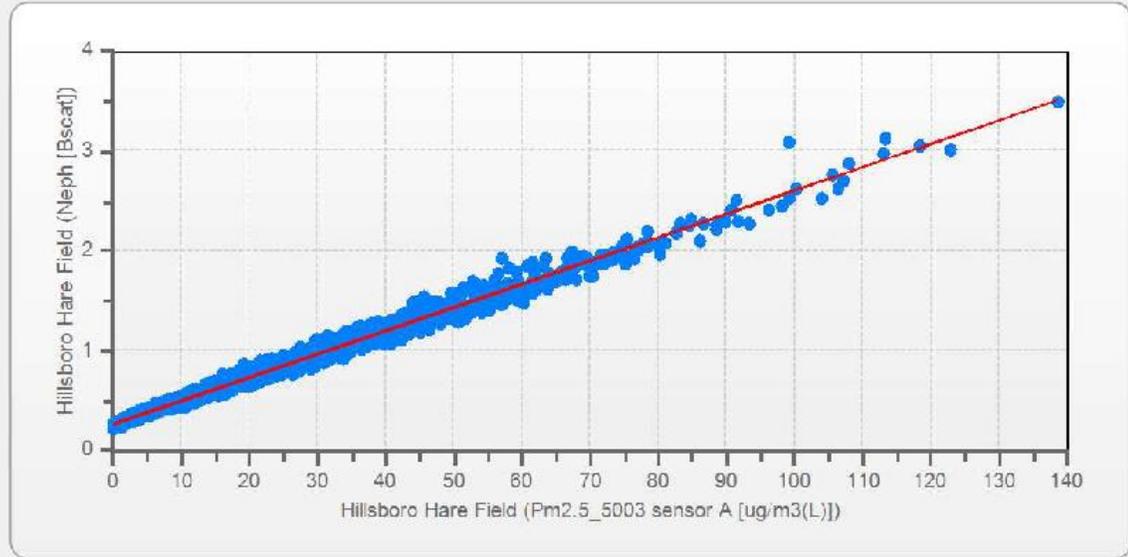| stn_code	stn_id	city	intercept	slope	df	rmse	adj.r2	ff_bscat
PDP	4.1E+08	Prineville	-3.01	17.78	151	1.12	0.98	1.58
BWS	4.1E+08	Burns	-1.6	15.93	169	1.44	0.97	1.67
MGB	4.1E+08	Medford	-2.18	17.38	136	1.16	0.97	1.56
GPP	4.1E+08	Grants Pas	-2.71	16.87	79	0.93	0.96	1.64
KFP	4.1E+08	Klamath Fa	-2.58	17.32	164	1.14	0.97	1.59
LCM	4.1E+08	Lakeview	-2.59	18.98	153	2.14	0.96	1.45
E99	4.1E+08	Eugene	0.41	19.3	257	1.4	0.96	1.27
EAP	4.1E+08	Eugene	0.61	20.8	259	1.11	0.97	1.17
SCH	4.1E+08	Springfield	0.68	21.29	66	1.83	0.85	1.14
OAK	4.1E+08	Oakridge	0.54	16.3	254	1.01	0.98	1.5
CGC	4.1E+08	Cottage Gr	0.61	17.79	260	1.16	0.94	1.37
SEL	4.11E+08	Portland	-2.92	18.84	201	1.14	0.95	1.48
HHF	4.11E+08	Hillsboro	-2.64	17.97	171	1.29	0.95	1.54
TBC	4.11E+08	Tualatin	-3.12	21.39	113	1.36	0.9	1.31
ALL	0	wildfire eq	2.96	13.31	78	25.09	0.78	NA

Method	
1	Download raw data (report AMP501) for the state for parameters 88101 and 11203 for
2	Average hourly bscat data (paramter 11203) to create daily averages.
3	Run regression for each site only using days that do not have a fire flag (IT qualifier).
4	Run regression using all days marked with the IT flag, across all sites to determine the fir
5	For each site, based on the equation, calculate the bscat value corresponding to a PM2.5

Part 2: SensOR™

Heated Aluminum Inlet

Sample Chamber w/ 2 Plantower PMS5003ST Sensors

Zero Air Pump

Fan (Flow ~2 LPM)

SensOR™

Cellular Modem

DC Power Supply

Raspberry Pi

Zero Air Relay

AC Power Input

Data Flow

DEQ/Lab

(1) Automated Data Collection:

Command Center
- Database

Dedicated Computer(s) w/ ENVIDAS
- Data Poll
- Zero Call

Cell Modem

- TCP/IP connection
- Modbus protocol
- n = 30 to 40

Site-level

Cell Modem — Raspberry Pi

Plantower PMS5003st

(2) Single access and troubleshooting:

Workstation w/ Putty & xMing

DEQ lab network

File ▾ | Dynamic | Reports | Operational | Information | Edit | Tools | Setups | Views | Help | Opened Windows List ▾

Tabular ▾ | Multi Station ▾ | Custom | Chart | Dashboard | Dynamic | Network | Received | Calibration | Alerts | Open Startup Items

Tabulars | Visuals | Maps | Last | Alerts | Startup

Date & Time	Sensor RH A	Sensor RH B	Sensor Temp A	Sensor Temp B	Sensor A Pm2.5est	Sensor B Pm2.5est
	%	%	C°	C°	ug/m3(L)	ug/m3(L)
6/5/2020 11:45 PM	40.5	39.8	21.7	21.8	6.1	6.0
6/5/2020 11:40 PM	40.1	39.1	21.8	22.1	6.0	6.3
6/5/2020 11:35 PM	39.7	38.6	22.0	22.3	6.5	6.9
6/5/2020 11:30 PM	39.7	38.8	22.1	22.4	7.2	7.5
6/5/2020 11:25 PM	39.4	38.3	22.2	22.5	5.9	6.1
6/5/2020 11:20 PM	39.0	37.2	22.2	22.8	5.2	5.4
6/5/2020 11:15 PM	38.8	36.6	22.1	22.9	4.0	4.5
6/5/2020 11:10 PM	38.8	36.8	22.1	22.9	3.8	4.2
6/5/2020 11:05 PM	39.0	37.0	22.1	22.8	5.2	5.5
6/5/2020 11:00 PM	39.0	36.8	22.0	22.8	4.7	4.6
6/5/2020 10:55 PM	39.3	36.8	21.8	22.8	4.3	4.9
6/5/2020 10:50 PM	39.5	36.8	21.8	22.9	3.9	4.2
6/5/2020 10:45 PM	39.5	36.9	21.8	22.8	4.1	4.3
6/5/2020 10:40 PM	39.3	37.3	21.8	22.5	4.4	4.4
6/5/2020 10:35 PM	39.2	37.5	21.9	22.5	8.3	8.2
6/5/2020 10:30 PM	39.3	36.9	21.8	22.8	5.8	6.7

■ Invalid   ■ Alarm   ■ Instantaneous Data   ■ Warning
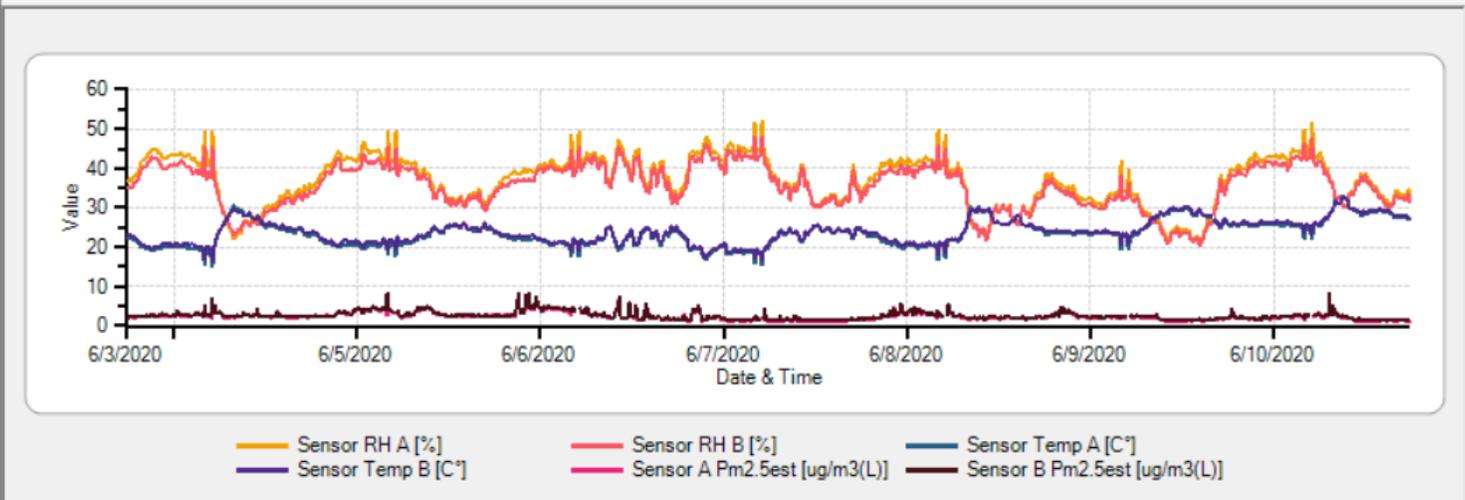
Legend: Sensor RH A [%] — Sensor RH B [%] — Sensor Temp A [C°] — Sensor Temp B [C°] — Sensor A Pm2.5est [ug/m3(L)] — Sensor B Pm2.5est [ug/m3(L)]

Idle | Site Map | SQL Server: deqlead-lims\aqi | DataBase: Enview | User: djohnson | Ver. 7.7.196 | 6/10/2020 7:04 PM

SensOR™ PM 2.5 – 5 minute average

MultiStation: Periodically: 11/20/2019 12:05 AM-3/2/2020 12:00 AM Type: AVG 5 Mins.

Hillsboro Hare Field(PM2.5 Est [ug/m3(L)])   Hillsboro Hare Field Sensor(Sensor A Pm2.5est [ug/m3(L)])   Hillsboro Hare Field Sensor(Sensor B Pm2.5est [ug/m3(L)])

Comparison of SensOr™ Plantower pair

XY: (X)Hillsboro Hare Field Sensor[Sensor A Pm2.5est] (Y)Hillsboro Hare Field Sensor[Sensor B Pm2.5est] Periodically: 11/20/2019 1:00 AM-3/2/2020 12:00 AM 1 Hr.
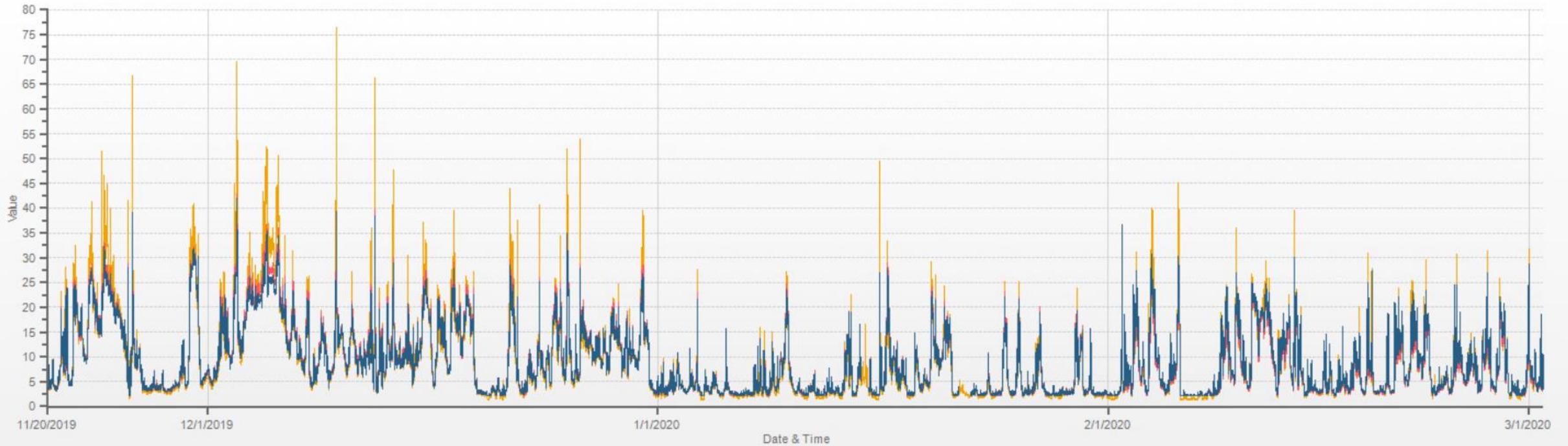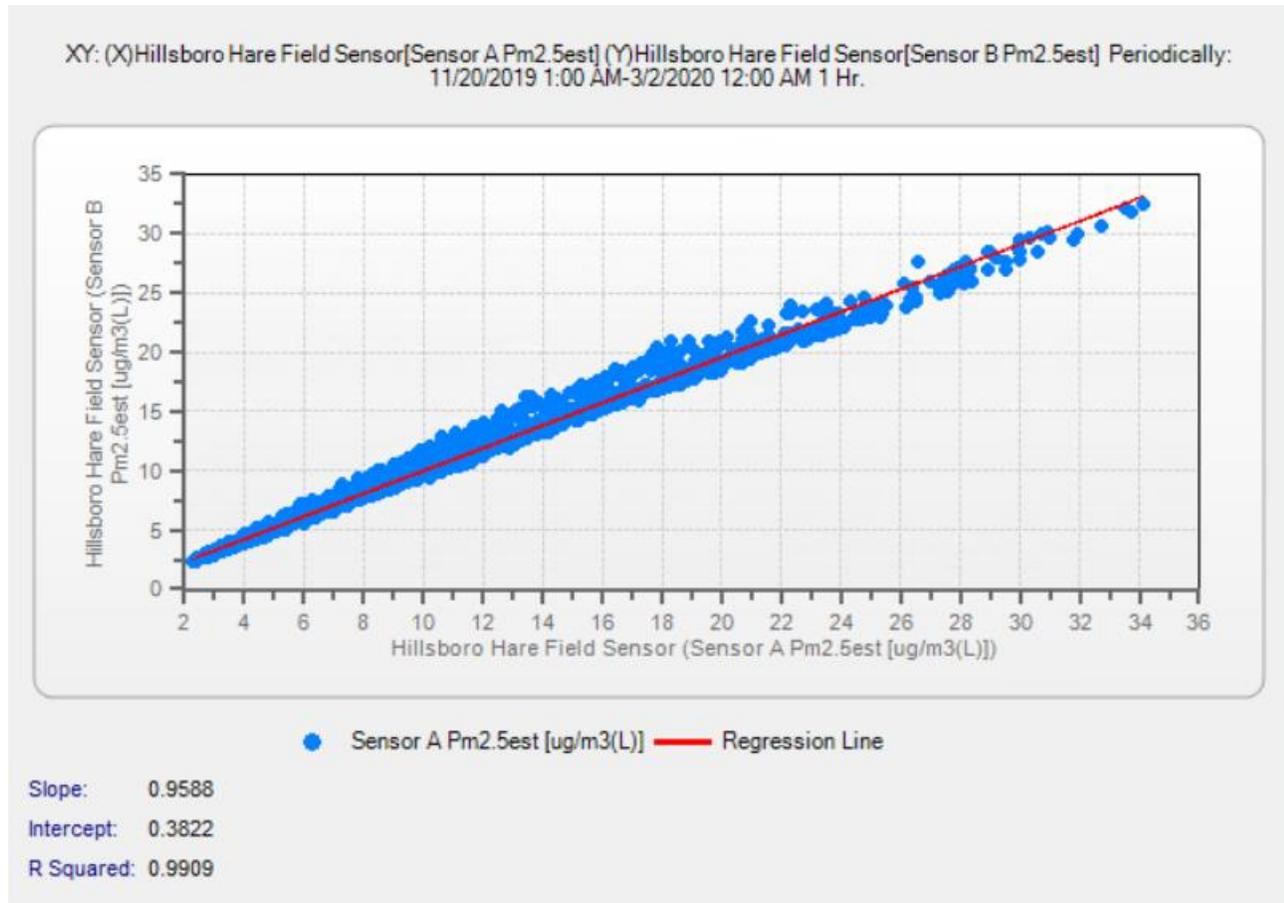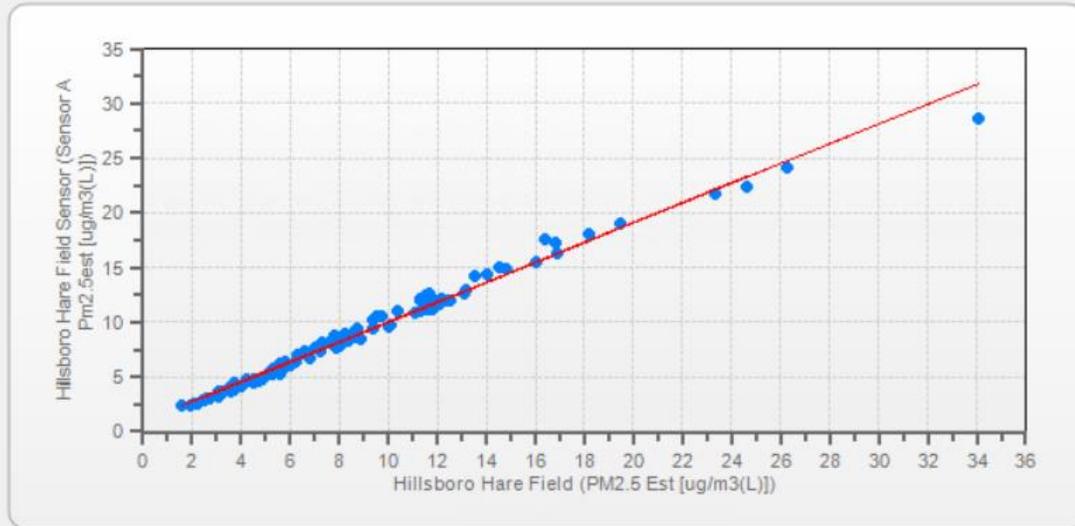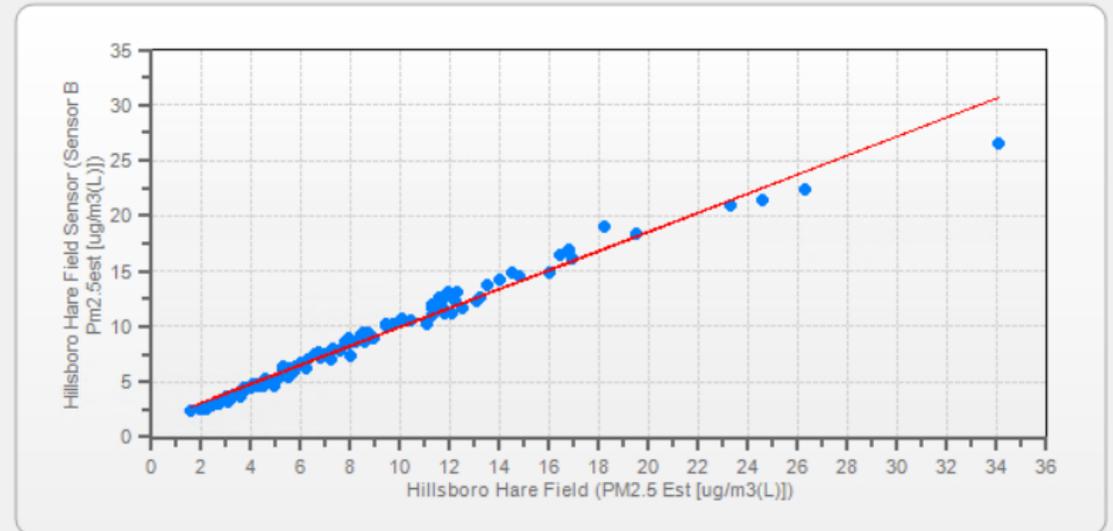
Slope: 0.9588
Intercept: 0.3822
R Squared: 0.9909

Comparison of SensOR™ PM 2.5 to Neph PM 2.5

Next steps

- Current focus
  - 9 sites on line
  - 10 more sites to be added very soon
  - Address network-scale challenges (eg. Maintenance, data QA)
  - Community building/sensor hosting
  - Explore use for PM monitoring during field burning & wildfires
  - Implement QA performance audits

- Long-term possibilities
  - Incorporate other pollutants/meteorology
  - Validate/improve PM forecasting models
  - Feedback/collaboration from the larger community

Community Monitoring

- DEQ is working with several community monitoring groups
- Produce defensible data that supports their monitoring objective
- Offer collaboration and technical support
- Encouraged to follow guidelines presented in EPA's **_Handbook for Citizen Science Quality Assurance and Documentation_**

Pilot Project to Show Sensor Data on AirNow's Fire and Smoke Map

- EPA presented a pilot project which adds data from PurpleAir to the Fire and Smoke Map. Prototype online June 12.

- Collocated PAs compared to FRM

- Would screen for data issues, apply a universal correction equation to concentrations, and present as NowCast AQI.

- $0.534*PA(CF1\ avg) - .084*RH + 5.6$

- Correct within one AQI level 93%

- States & local agencies may opt out

- Comments to sensordatapilot@epa.gov

DEQ

Is this good enough?

Or do we want to know?