EPA United States Environmental Protection Agency

SENTINEL (Sensor Intelligent Emissions Locator): A Quality Assurance Application for Sensors

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Presentation Outline

- Next Generation Emissions Measurements (NGEM)
  - Fenceline vs. community deployments
  - VOC fenceline sensors (SPods)
  - Sensor pre-deployment and in-field QA
- SENTINEL fenceline sensor data analysis app
  - Manual & automatic QA
  - Visualization and analysis
  - Metadata integration (canisters, meteorological data)
  - QA tables
- SENTINEL App Status

Next Generation Emissions Measurements (NGEM)

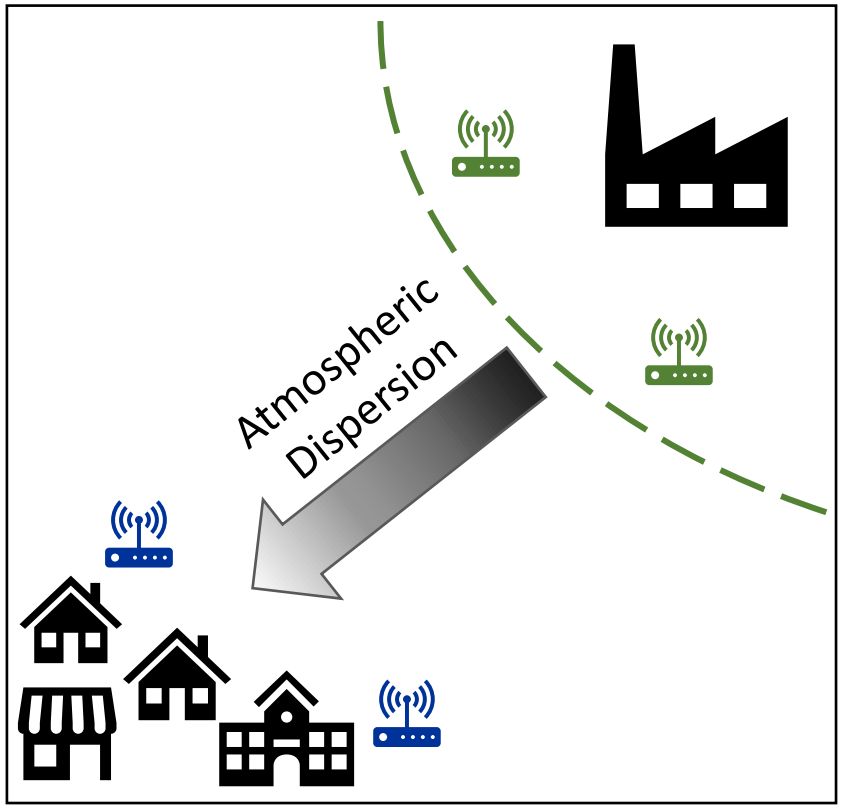
Use new measurement technologies to reduce emissions, enhance worker safety, improve air quality, and support community wellbeing

Fenceline/In-plant vs. In-community Deployment

Application	Purpose	Sensor/Instrument Needs
Fenceline/ In-plant	Detect and characterize VOC emissions	• Fast sensor response is important • Application-specific accuracy/ precision • VOC chemical speciation not as important
In-Community	Quantify ambient VOC levels	• Fast sensor response not as important • Precise and accurate VOC measurements required • Speciation is helpful to understand source contributions

VOC = Volatile Organic Compound

Fenceline/In-plant Sensors
Higher, faster source signal



In-Community Sensors
Lower, slower source signal

In-community Monitoring

2021 Sensor Comparison Presentation

Fenceline Monitoring

South Coast Fenceline Air Monitoring Rule 1180

In-plant Leak Detection

Emission
(Not a real emission)

Leak Detection and Repair Report

VOC Sensor Side by Side Comparisons

How accurate and precise does your VOC sensor need to be?

- 5 sensor manufacturers
  - No baseline correction applied
- VOC sensors can vary by >100 ppb
- Baseline drift is a key factor
- Analysis approaches can depend on proximity to source:
  - **Fenceline** can use simple baseline correction to eliminate drift and isolate emission plumes
  - **In-Community** deployments contain lower VOC signal levels, so accuracy and precision are more important

Sensor Comparison Webinar

Mean Values:

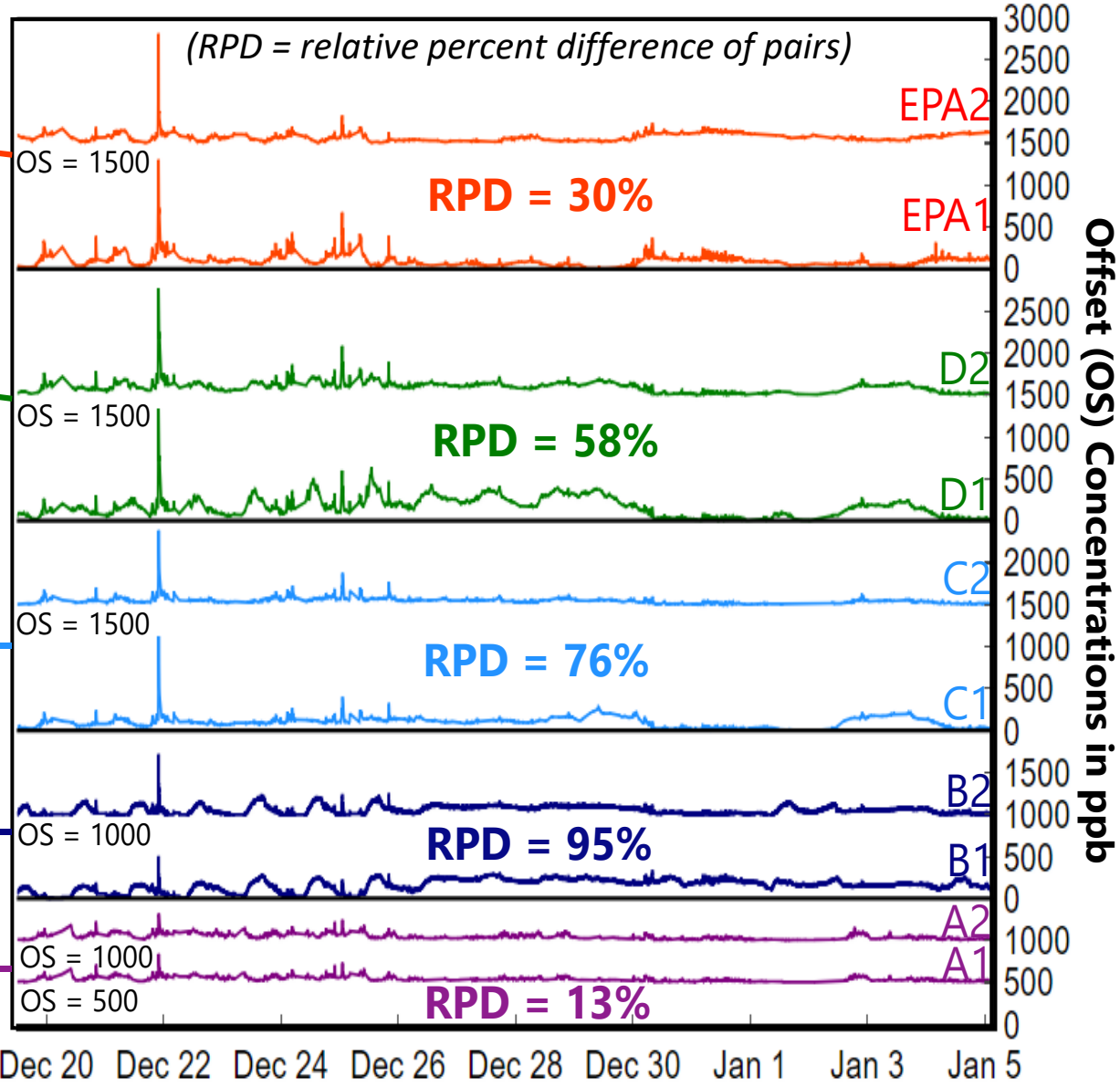
EPA 2 = 91 ppb
EPA 1 = 67 ppb

D2 = 91 ppb
D1 = 165 ppb

C2 = 98 ppb
C1 = 44 ppb

B2 = 62 ppb
B1 = 173 ppb

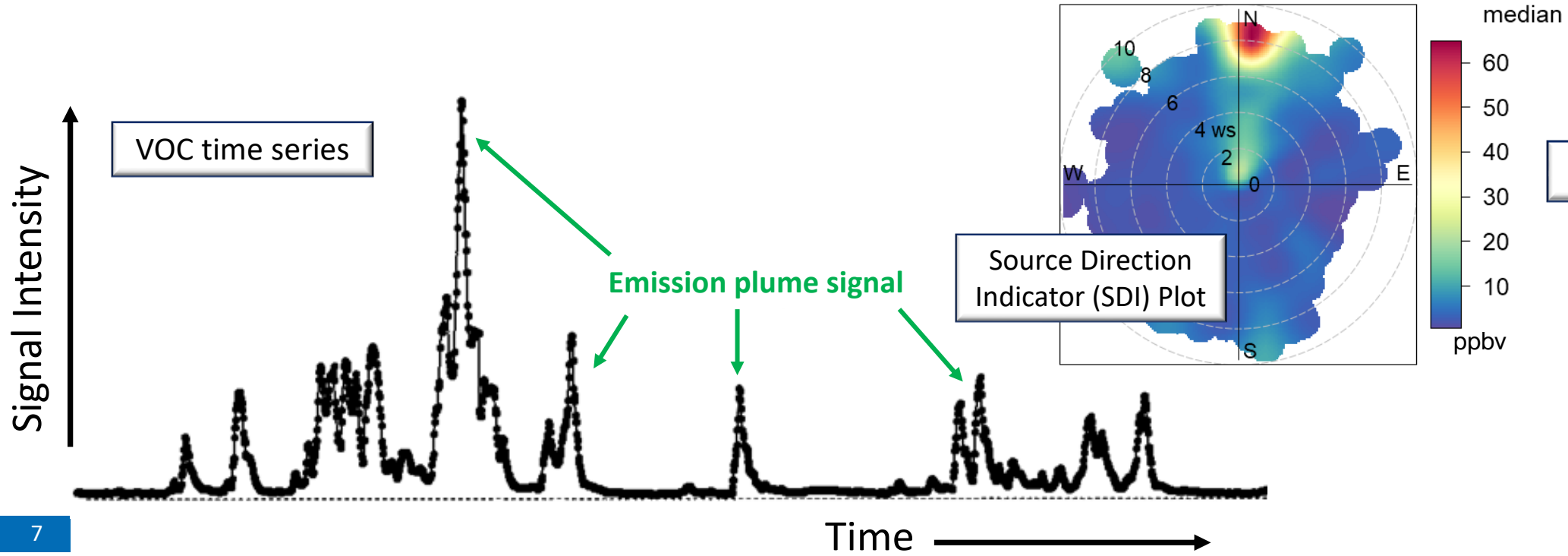
A2 = 41 ppb
A1 = 36 ppb



VOC Fenceline Sensor Pod (SPod)

- SPods collect data as a time series of VOC signal and wind direction
- Signal events occur when emission plume passes over SPod
- Signal disappears when the wind direction shifts slightly
- Combined VOC and wind data inform source location
- Baseline VOC levels are less important (focus on emission plume signal)

EPA Prototype SPod



Commercial SPods

Sensor Pre-deployment and In-field QA

- EPA SPod SOP describes setup and use
  - Full calibrations
  - In-field bump tests
- Compound Response Factors (RF)
  - Can the sensor detect the nearby source?
  - Isobutylene is a reference gas (RF = 1)
  - Higher RF = lower sensor sensitivity to that compound (more difficult to detect)
  - Many emission plumes are a mixture of RFs
  - Triggered canister acquisitions can confirm the compounds in an observed VOC plume

Example of SPod 10.6eV Response Factors

Chemical Name	Ionization Energy	10.6 eV RF
Benzene	9.24	0.5
Xylenes	8	0.5
1,3 Butadiene	9.07	0.8
Isobutylene	9.24	1
Cyclohexane	9.98	1.3
Vinyl chloride	9.99	2.1
Methane	12.51	Zero Response

Complete list of RF values

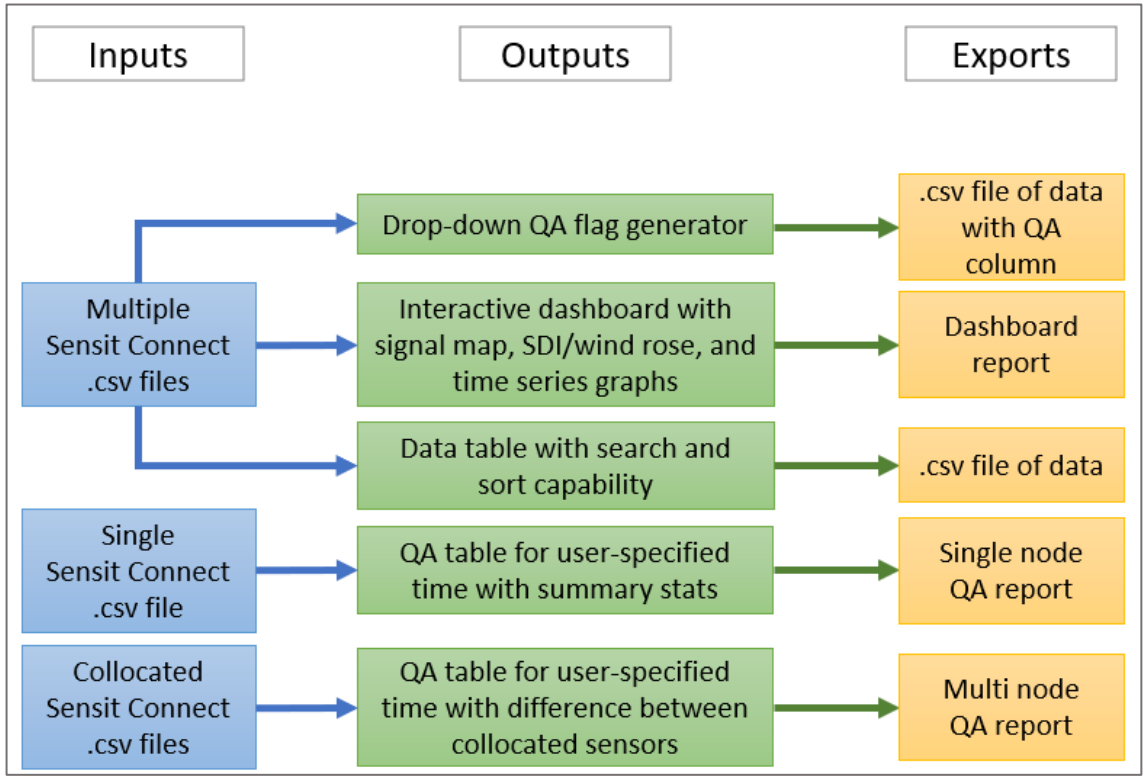
2019 SPod Research Study

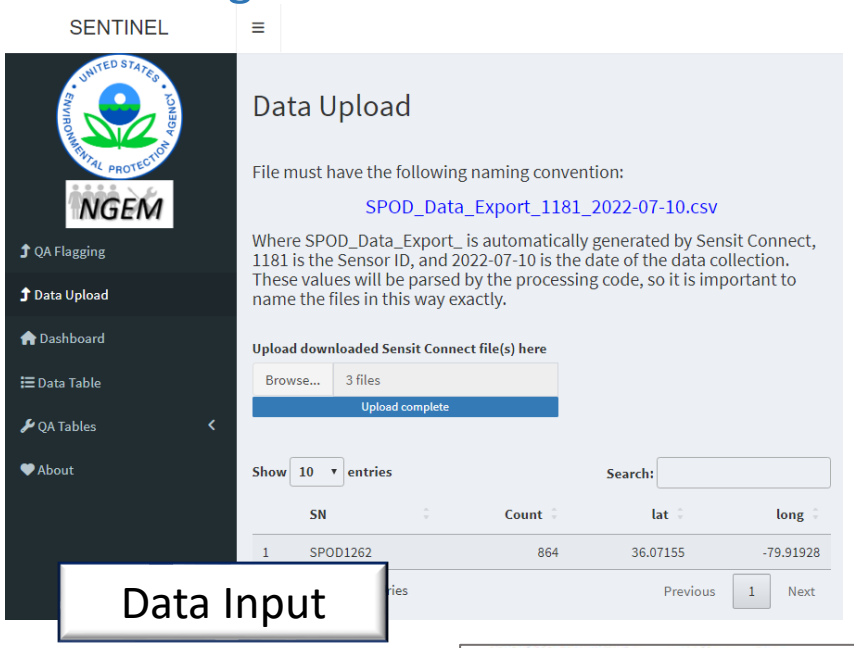
2022 SPod Research Study

SENTINEL App

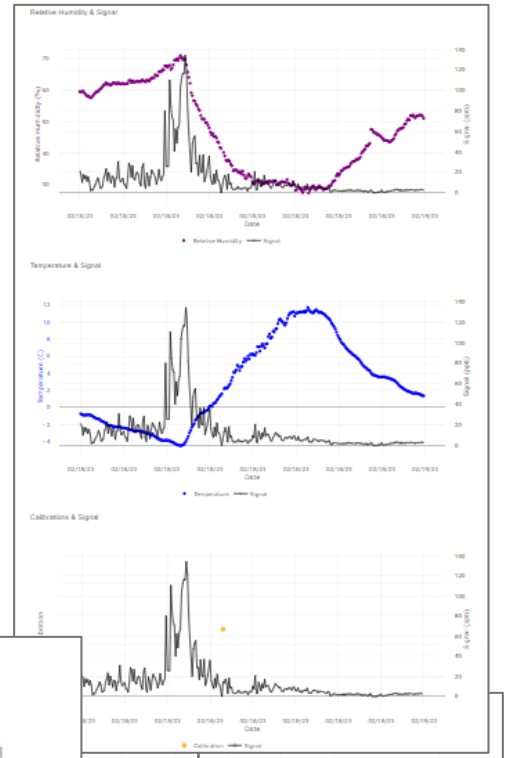
SENTINEL = SEnsor NeTwork INtelligent Emissions Locator

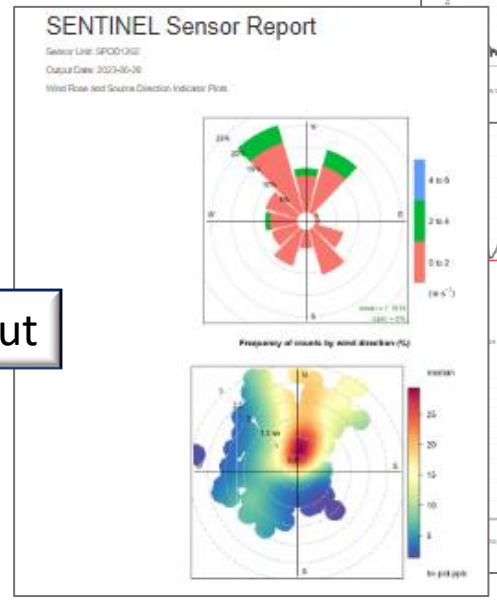
- R Shiny App
- Input raw files for QA or Analysis
  - Multiple or single day
- Output reports and processed data files



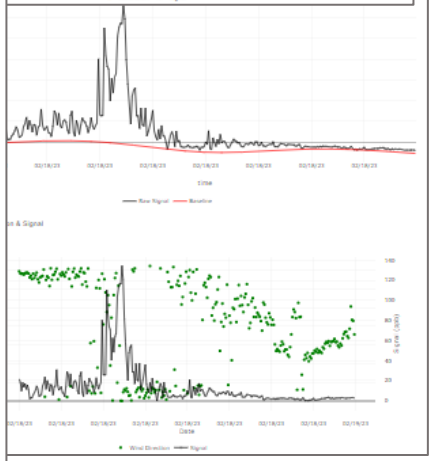


Data Input



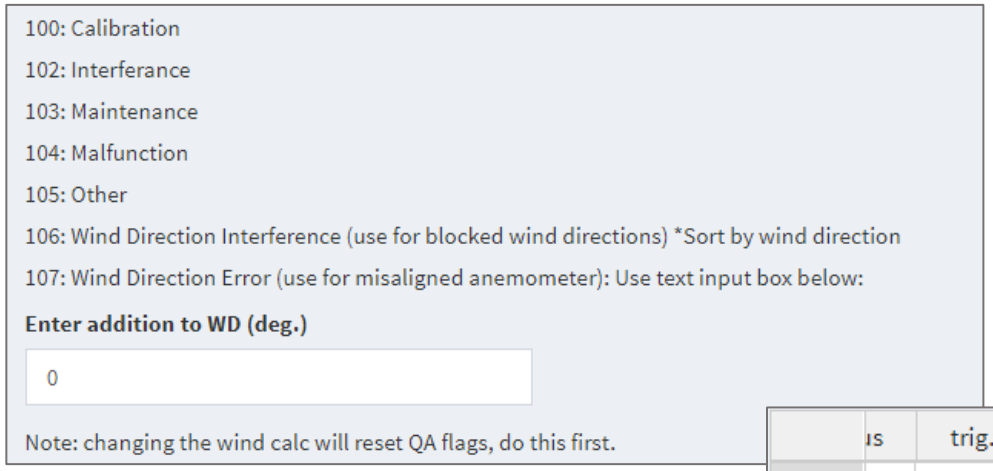


Report Output



Manual & Automatic QA Features

➡ QA column appended to data files that contain a flag if there is a QA issue



- Manual Flags (100 – 107)
  - Flag user defined events that code can't detect
  - Option to input wind corrections to WD column
  - Add lat/long values

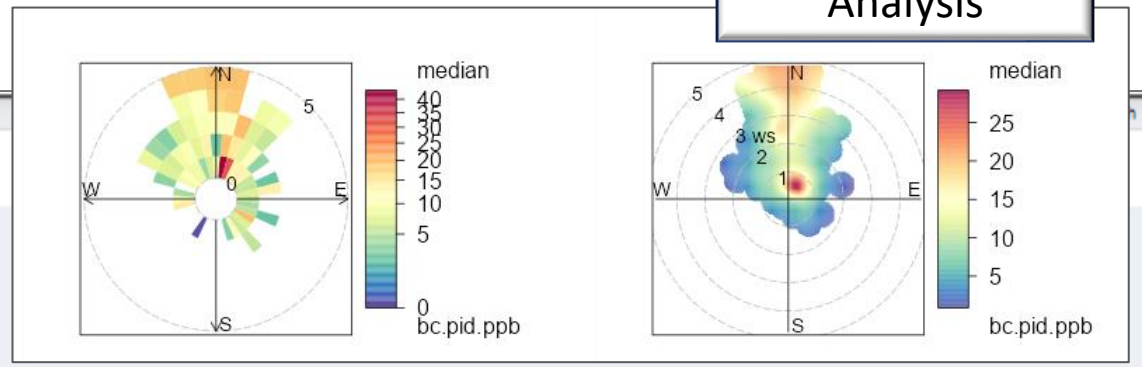
- Automatic Flags (108 – 115)
  - Missing values
  - Repeated values
  - Humidity swings
  - Off-screen high/low values

	ıs	trig.trig_value	trig.trig_activeFlag	trig.trig_eventFlag	lat	long	time	QA	SN
19	207			204	0.00	0.00	2023-03-07 00:03:09	0	1261
20	207			204	0.00	0.00	2023-03-07 00:03:19	0	1261
21	207			204	0.00	0.00	2023-03-07 00:03:29	100	1261
22	207			204	0.00	0.00	2023-03-07 00:03:39	102	1261
23	207			204	0.00	0.00	2023-03-07 00:03:49	103	1261
24	207			204	0.00	0.00	2023-03-07 00:03:59	104	1261
25	207			204	0.00	0.00	2023-03-07 00:04:09	105	1261
26	207			204	0.00	0.00	2023-03-07 00:04:19	106	1261
27	207			204	0.00	0.00	2023-03-07 00:04:29	107	1261
28	207			204	0.00	0.00	2023-03-07 00:04:39	0	1261
29	207			204	0.00	0.00	2023-03-07 00:04:49	0	1261
30	207			204	0.00	0.00	2023-03-07 00:04:59	0	1261

Export files with QA column updated, can subset out these columns in analysis

Visualization and Analysis

Met-integrated Analysis



Tabular Results

Table Results

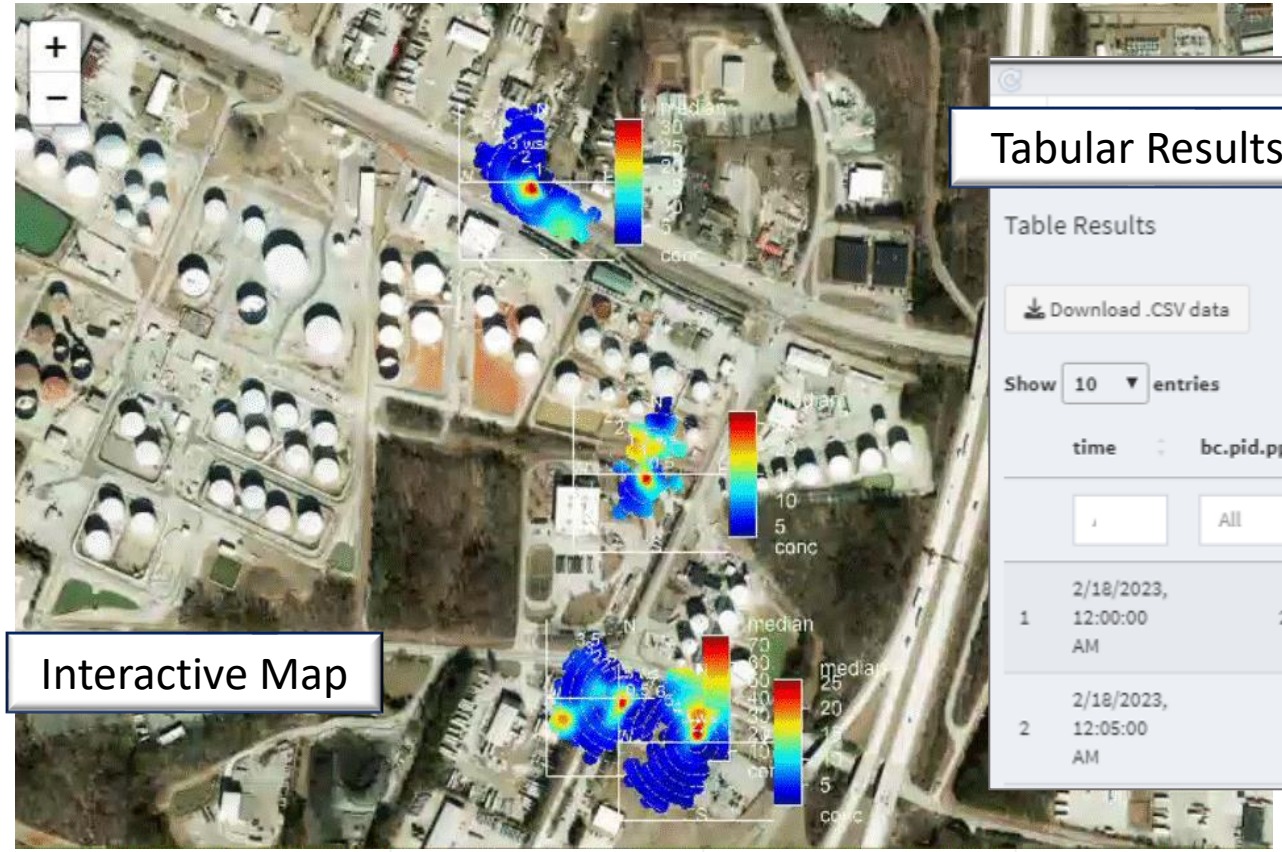
Download .CSV data

Show 10 entries

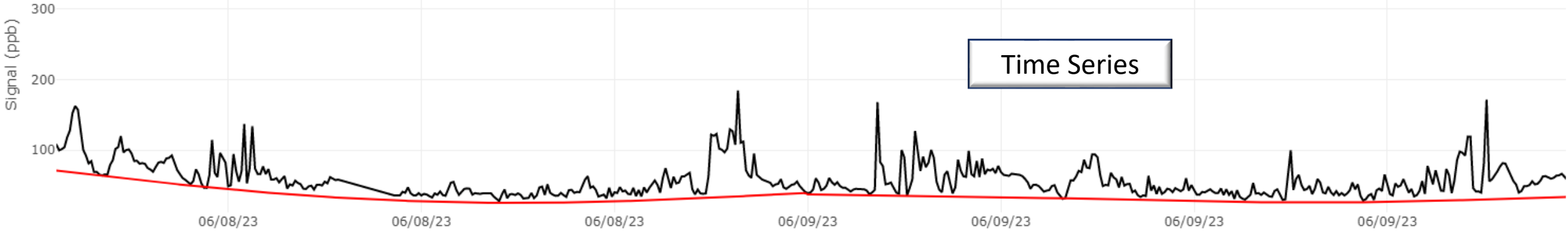
Search:

	time	bc.pid.ppb	pid.sd	rawPID.ppb	temp	rh	pressure	u.wind	v.wind	s1temp	s1heat	
			All		All			Al				
1	2/18/2023, 12:00:00 AM	21.53	16.96	20.44	-0.74	59.44	989	-0.56	-1.54 2.71			1.1
2	2/18/2023, 12:05:00 AM	18.3	18.47	17.28	-0.8	59.39	989	-0.78	2.18	1602.54	41.57	1

Interactive Map



Time Series



SENTINEL QA Tables

- QA check of data quality and sensor operation
  - Values out of range highlighted in red
  - QA ranges determined by recent sensor studies
- Single sensor QA table
  - Confirm bump checks/calibrations
  - Ensure sensor operation is normal
- Collocated Sensors QA table
  - Check difference between sensor values

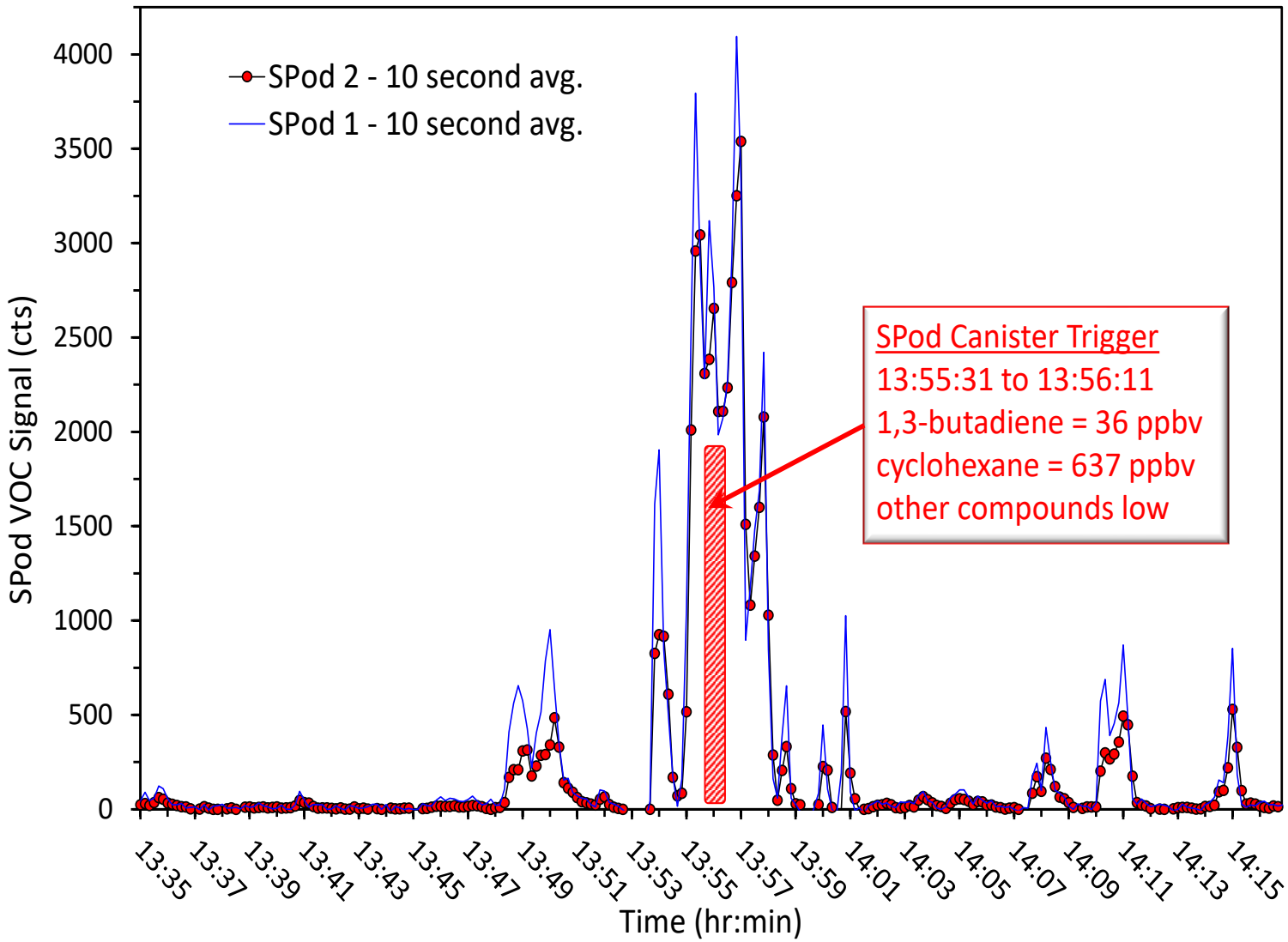
2023-03-28 01:00:00 to 2023-03-28 02:00:00

Time periods with canister collections: FALSE

	Mean	Median	StdDev	Min	Max	DataComp
Data Quality QA:						
Raw PID (ppb)	82.4	82.6	25.5	45	139.6	85
BC PID (ppb)	40.9	40.7	25.1	4.1	97.2	85
Raw PID (mV)	141.6	141.7	17.2	116.4	180.2	85
Temp (Deg C)	13.5	13.5	0.3	12.8	14.1	85
RH (percent)	53.4	53.3	1	51.4	55.4	85
Pressure (mBar)	981	981	0.1	981	982	85
WS (mph)	0.5	0.5	0.3	0	1.5	85
WD (deg)	236.7	240.4	68.8	0	345.3	85
Operational QA:						
S1 temp (arb)	2168.4	2171	13.1	2142	2198	85
S1 Heat (0-255)	18.1	18	1.1	16	21	85
S1 Set (arb)	2168.3	2170	12.9	2140	2196	85
Bat volt (V)	13.9	13.9	0.1	13.8	14.1	85
Charge Current (mA)	114.8	10.1	176.8	0.1	508.5	85
Operate Current (mA)	102	102	4.1	90.4	115.1	85

* Values determined by a location at 892 ft above sea level

Metadata Integration – Canister Data



- Lower-cost VOC sensor measurements are typically not speciated
- Triggered canister samples with laboratory analysis provide context to elevated signal
- SENTINEL detects canister trigger events and combines with VOC signal time series data

2022 SPod Research Study

SENTINEL Development Status

- Pilot user groups are currently testing SENTINEL Version 1.0 as part of an EPA Region 4 VOC Fenceline Sensor Loan program
- Possible app improvements:
  - Additional sensor types (i.e., methane)
  - Source back trajectory analysis
  - Source emission rate estimation
- For more SENTINEL info, contact: macdonald.megan@epa.gov

NGEM website

NGEM Tools & Training Webinar

NGEM Advancements Webinar (ORISE Meets the World)

United States Environmental Protection Agency

Additional Slides Below:

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Regulations are Starting to use NGEM

EPA Refinery Fenceline Monitoring

Optical Gas Imaging in Oil and Gas Applications

South Coast AQMD Fenceline Air Monitoring Rule 1180

Government of Canada Regulation on release of VOCs

California Air Pollution Assembly Bill

Bay Area AQMD Petroleum Refining Emissions Tracking

Colorado Act Concerning Emission of Air Toxics

Ontario Regulation on Air Pollution and Local Air Quality

AQMD = Air Quality Monitoring District

SPod and Leak Detection Sensor Development

EPA United States Environmental Protection Agency

EPA Initial SPod Research

SPod Fact Sheet

In-plant Leak Detection Sensors CRADA*

EPA Prototype SPod Research

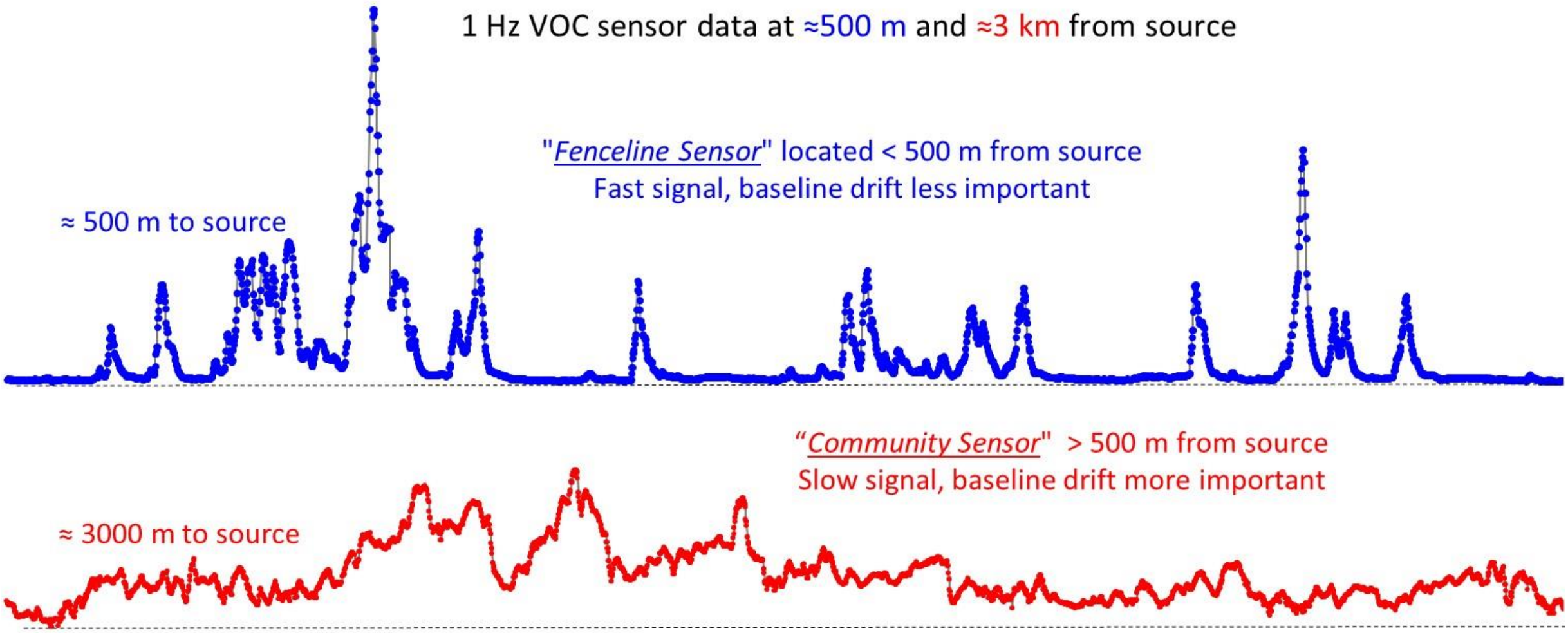
Ongoing SPod Research and Analytics

2014 2015 2016 2017 2018 2019 2020 2021 2022

Time (years)

*CRADA = Cooperative Research and Development Agreement

Sensor Data Analysis Changes with Distance



VOC = Volatile Organic Compound

Environmental Conditions Impact Baseline Drift

Adapted from: Thoma, et al. "Rubbertown next generation emissions measurement demonstration project." Int. J. Environ. Res. Public Health 16.11 (2019): 2041.

Simple Time-based Baseline Correction