Eighteen Months of High Resolution Indoor and Subslab Temporal Observations from an Industrial Building

AEHS West Coast Conference, San Diego CA

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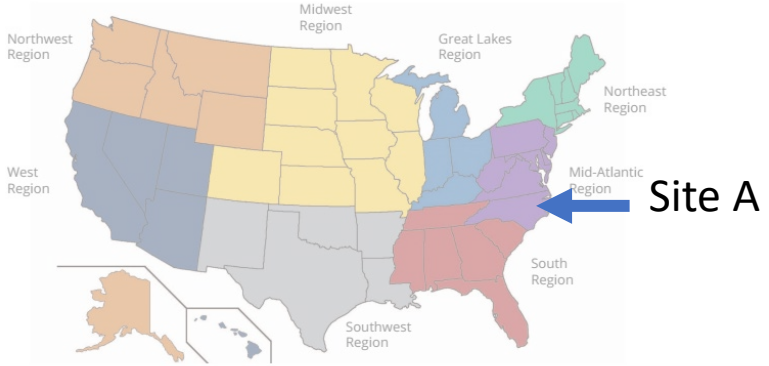
Site Background

- Site located in Mid-Atlantic region
  - Mostly concrete/asphalt-paved industrialized area
  - cVOCs released from damaged industrial wastewater lines
- Medium-to-coarse grain sands in vadose zone
- Depth-to-groundwater: 3 to 8 ft bgs
- Remediation Activities
  - Groundwater extraction and AS/SVE
  - Discontinued in 2012/13 due to limited effectiveness.
  - Additional remediation planned



GW cVOCs Beneath/Near Study Building

cVOCs	Max Concs (2014-16) (µg/L)
1,1-DCE	644
1,2-dichloroethane	7.4
Cis-1,2-DCE	474,000
Trans-1,2-DCE	67,700
TCE	898,000
VC	639,000

VA Site A – Building Characteristics

- ~120,000 ft^2 building constructed of brick with a poured concrete slab and divided into three large bays. The slab is generally 6 to 8 inches thick.
- Heat provided by steam-fired unit heaters with overhead fans in the warehouse/storage bays.
- No centralized cooling system within the warehouse space. During Summer, bay doors are kept open and portable fans provide airflow.
- Various wood-framed office areas constructed separately within the bays with separate ceilings and HVAC units.
  - Separate spaces operate as ”zones within larger zones”

Field Activities

- Detailed Building Survey and Diagnostic Testing
  - HVAC evaluation (e.g., type, zones, makeup air, operational settings)
  - Tracer gas testing to evaluate air exchange rates
- Building Pressure Control Studies (Near Worse-Case VI)
  - Pressure data, measure flow rates, HAPSITE VOC data, discharge rates
  - Evaluate leakage, entry points, background, flux
- *Eighteen Month-Long VOC and Indicator/Tracer Studies*
  - Four sampling zones within industrial building
  - High frequency indoor, subslab, and outdoor air cVOCs and radon
  - IA/OA (continuous) and subslab (monthly) radon
  - Continuous pressure and temperature differential data
  - Meteorological data near building

RadonEye (IA/OA)

http://radonftlab.com/radon-sensor-product/rd200/

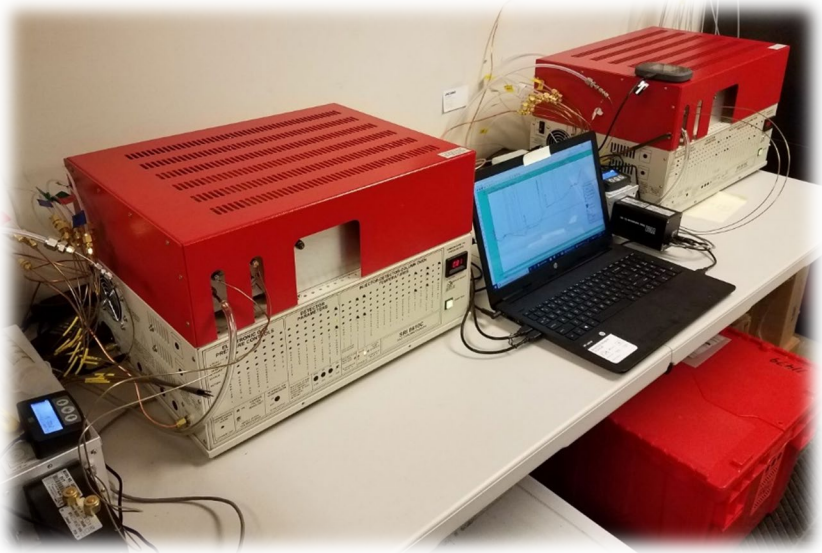
dP and Temp

https://www.omegaeng.cz/ppts_eng/OM-CP-PRTC110.html

RAD7 (subslab Rn)

https://durridge.com/products/rad7-radon-detector/

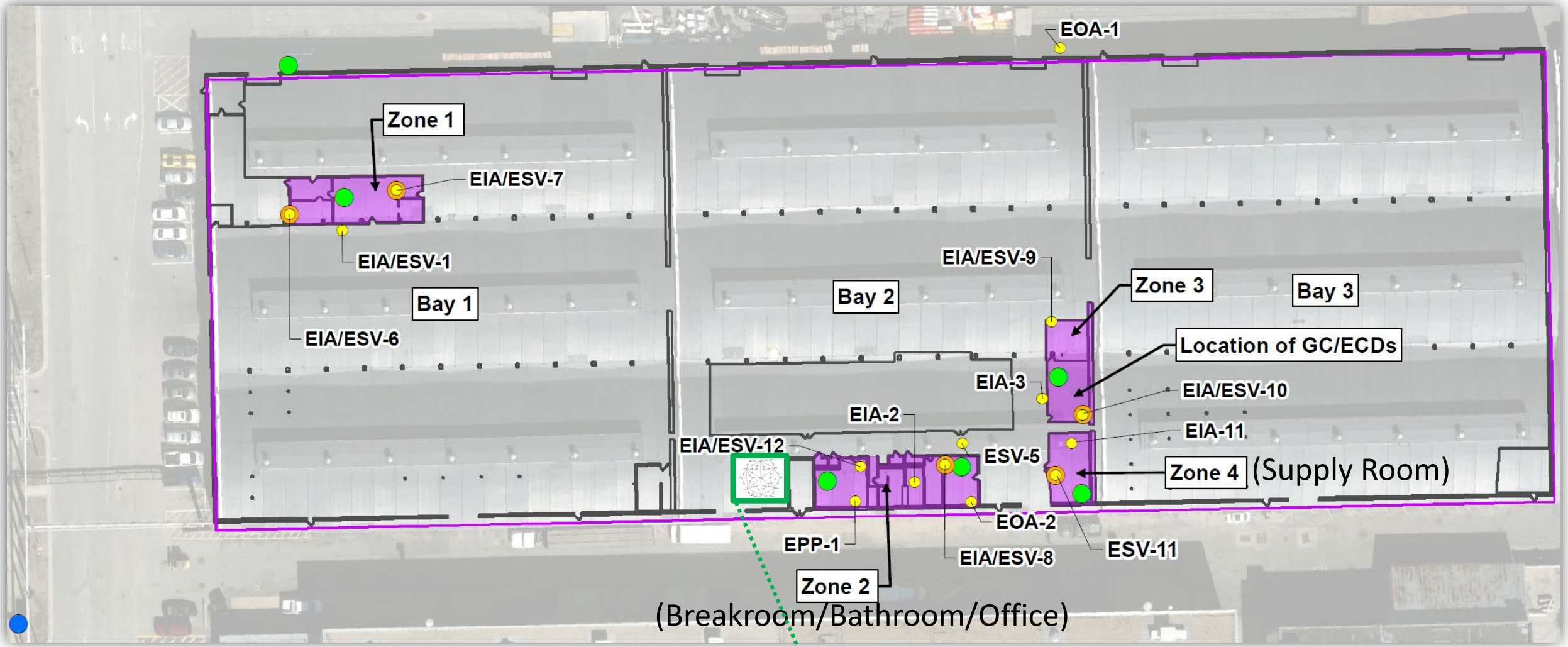
GC/ECD (cVOCs)



Weather Station

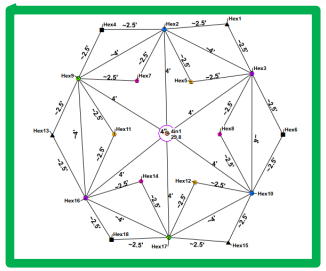
https://www.davisinstruments.com/solution/vantage-vue/

Zones Within Larger Building, Sampling Locations, and Types of Data



- GC/ECD cVOC Sampling Locations
- Differential Pressure & Temp Locations
- Indoor Radon Sampling Locations
- Outdoor Weather Station

EIA-# = Indoor Air ID
ESV-# = Subslab ID

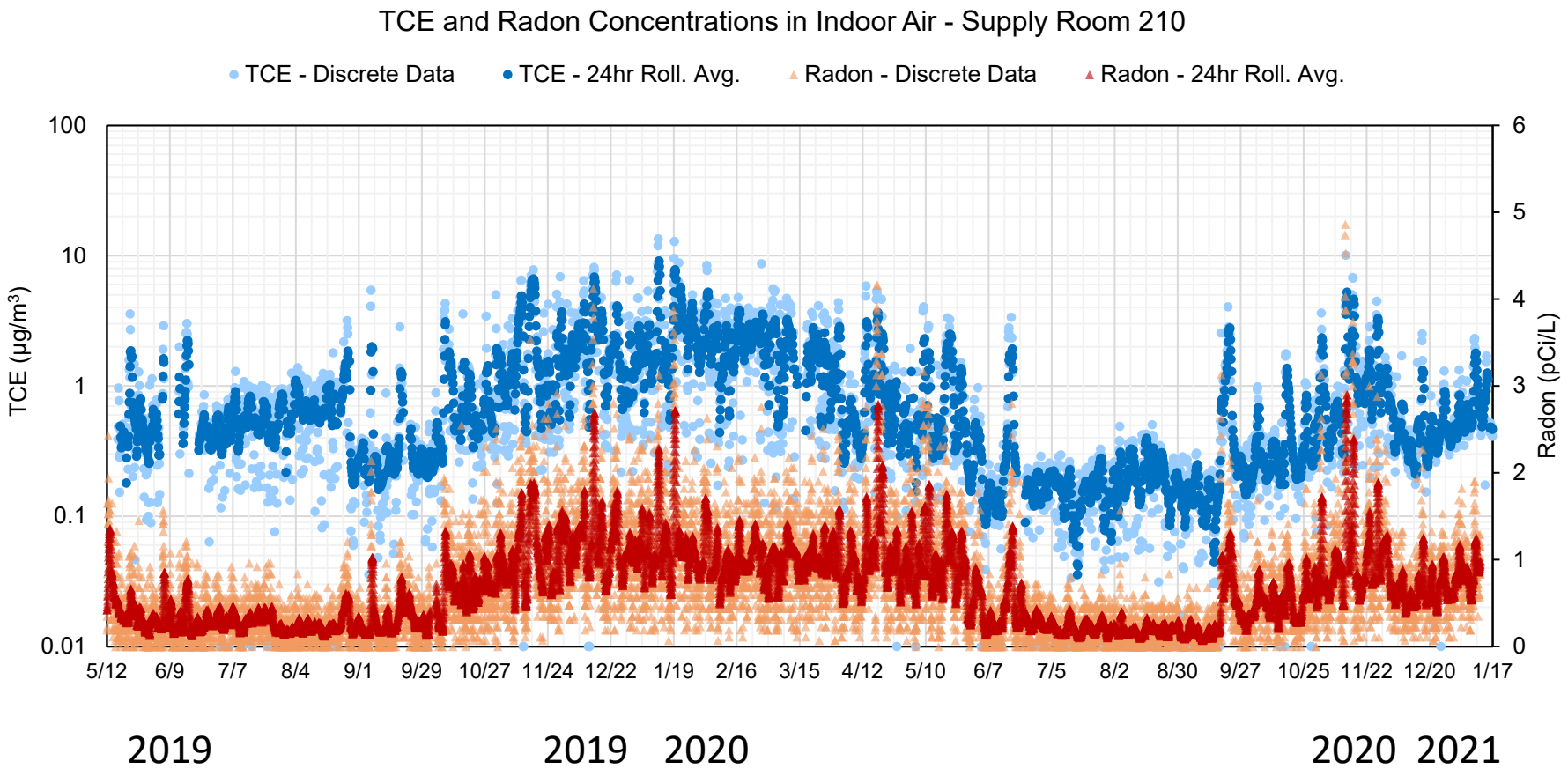


"Hexagon" Intensive Subslab Methods Study Area

- Building Details
- Zones
- Building Footprint

Stack Effect Pattern at Supply Room – Zone 4

The stack effect is when warm air moves upward in the building, potentially drawing in soil gas.

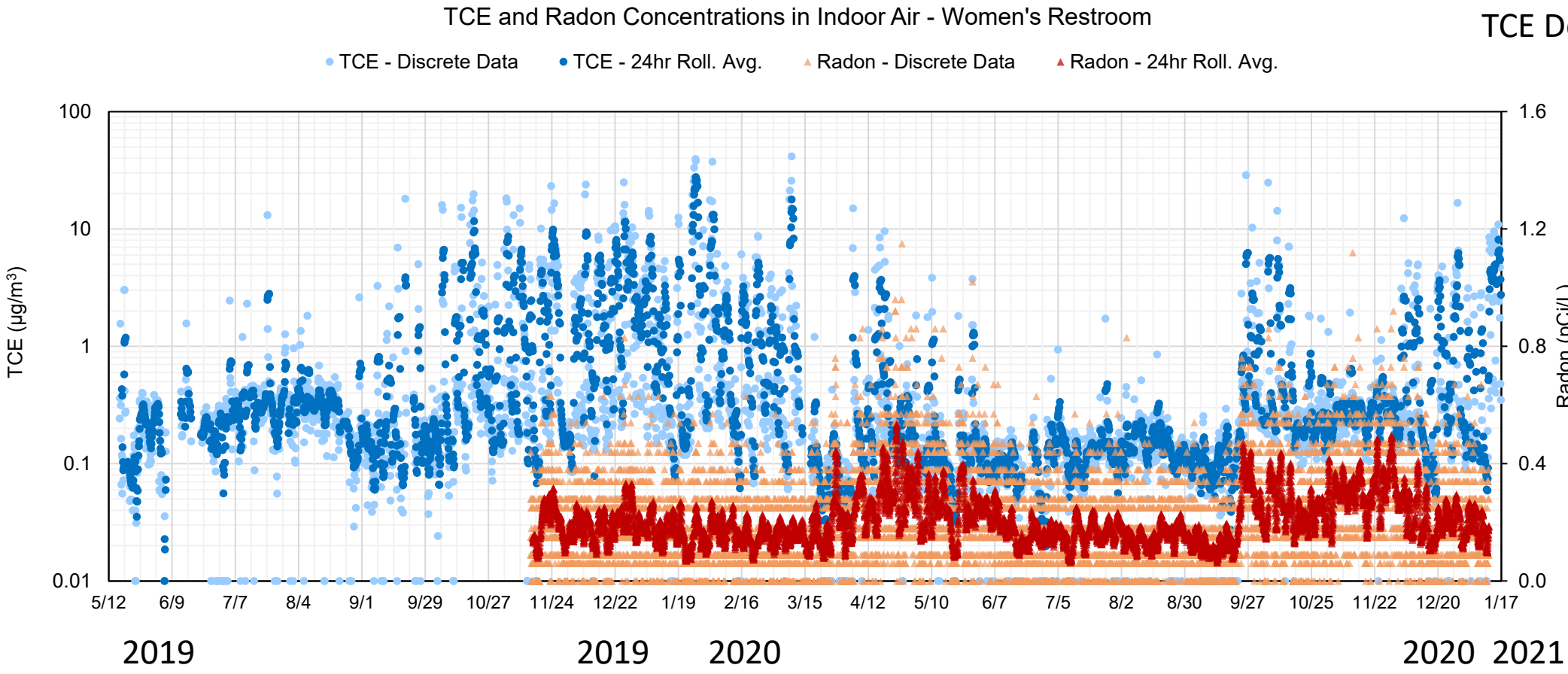


TCE Descriptive Statistics

Sample ID	EIA-11
5 %ile	0.09
10 %ile	0.14
25 %ile	0.25
Median	0.47
75 %ile	1.14
90 %ile	2.60
95 %ile	3.63
Maximum	13.4
Average	0.97
StDev	1.27
Coeff. Var.	1.31
% Detected	98%
Count	3,473

Key Point: Seasonal variation in VI consistent with stack effect pattern at this location.

Seasonal Change at Zone 2 - Bathroom

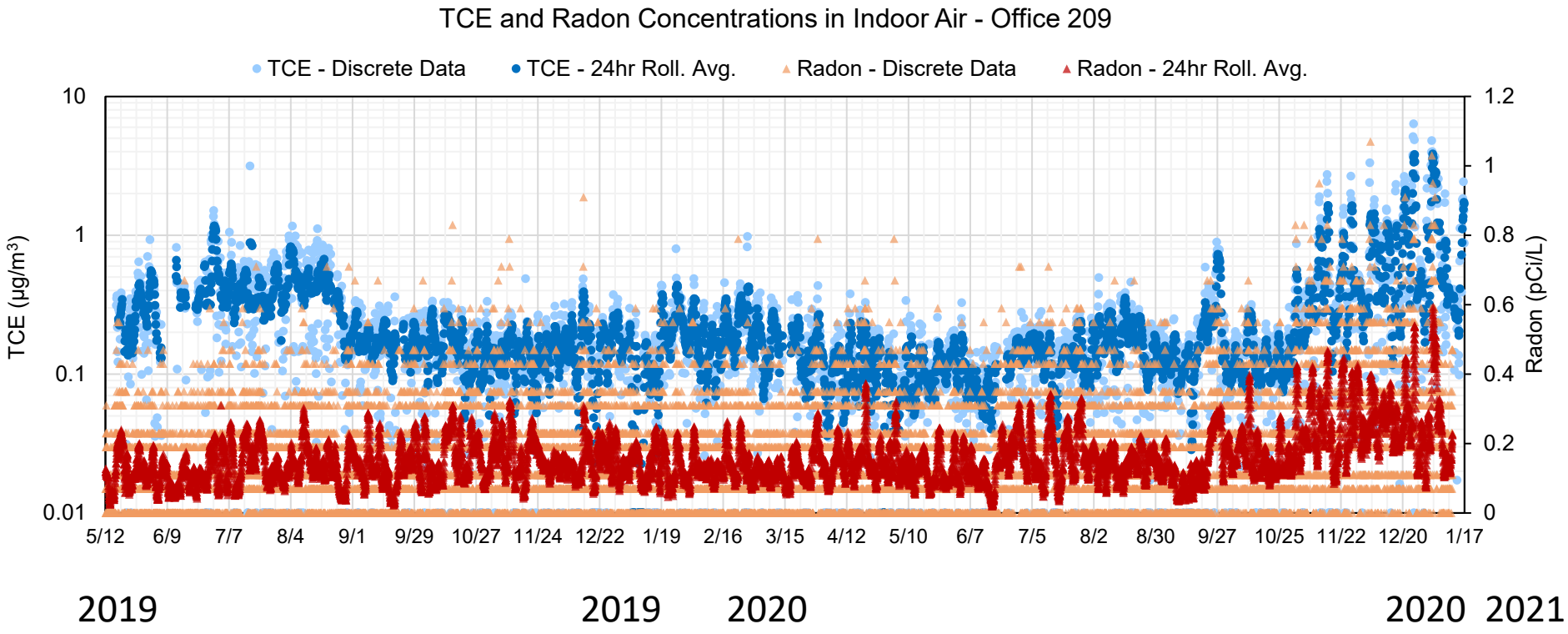


TCE Descriptive Statistics

Location	Restroom
Sample ID	EIA-2
5 %ile	0.04
10 %ile	0.07
25 %ile	0.12
Median	0.20
75 %ile	0.37
90 %ile	2.08
95 %ile	4.42
Maximum	41.4
Average	0.93
StDev	2.9
Coeff. Var.	3.11
% Detected	95.7%
Count	3,478

Key Point: Seasonal shifts at this location are sometimes more pronounced/abrupt and don't follow the standard stack effect model. This suggests a possible role for a preferential pathway and/or shallow water under floor. Radon sometimes correlated with VOCs but not always at this location.

Long Periods of Inactivity at Office Zone 3; Followed By Greater Activity



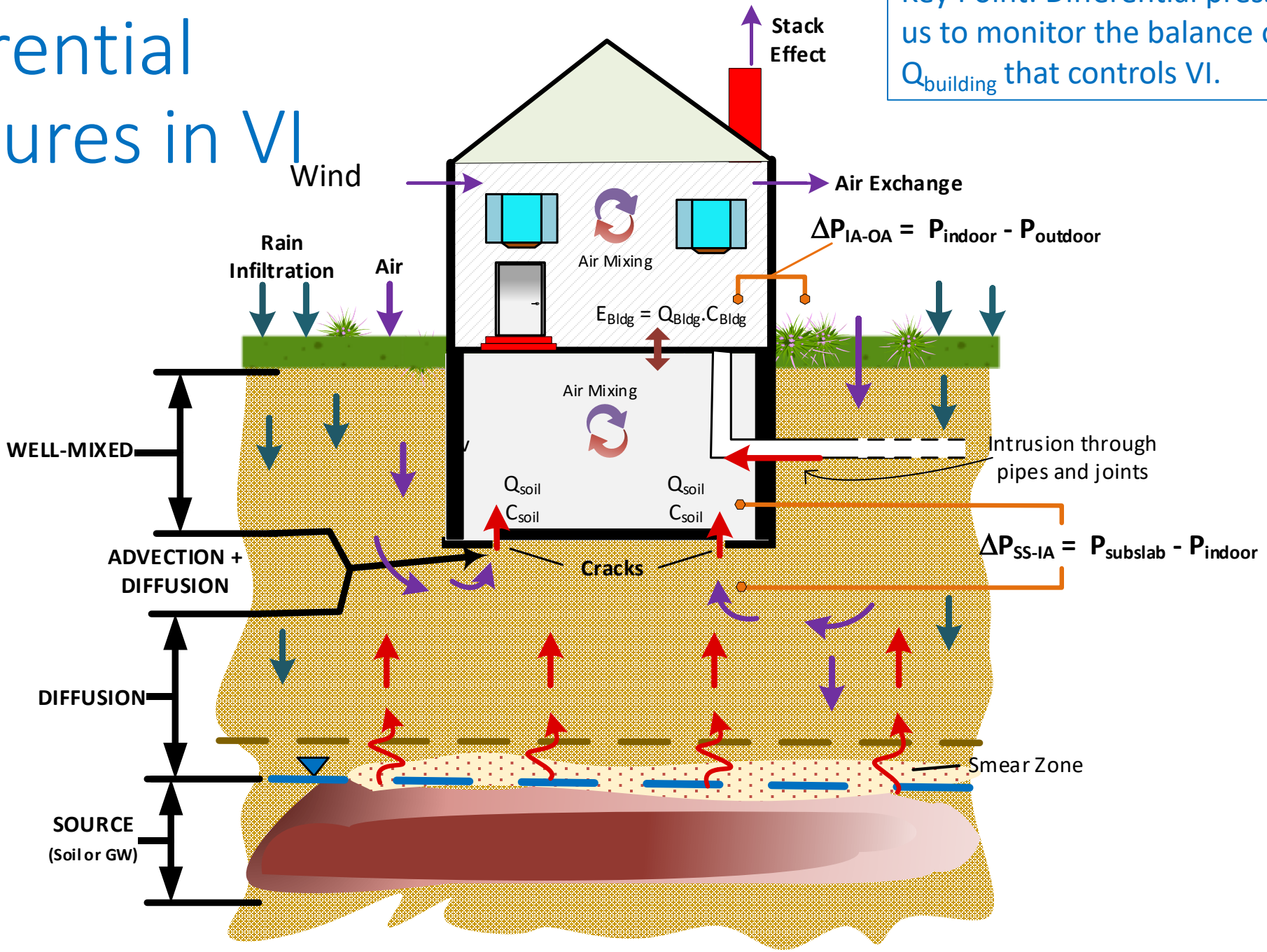
TCE Descriptive Statistics

Sample ID	EIA-10
5 %ile	0.01
10 %ile	0.04
25 %ile	0.10
Median	0.17
75 %ile	0.28
90 %ile	0.49
95 %ile	0.73
Maximum	6.34
Average	0.26
StDev	0.39
Coeff. Var.	1.50
% Detected	93%
Count	3,464

Key point: This location displayed a modest amount of VI (average TCE Nov '20 through Jan '21 = 0.68 µg/m^3 ± 0.8) after more then a year of inactivity (average Sept '19 through Oct '21 = 0.15 µg/m^3 ± 0.10)

Differential Pressures in VI

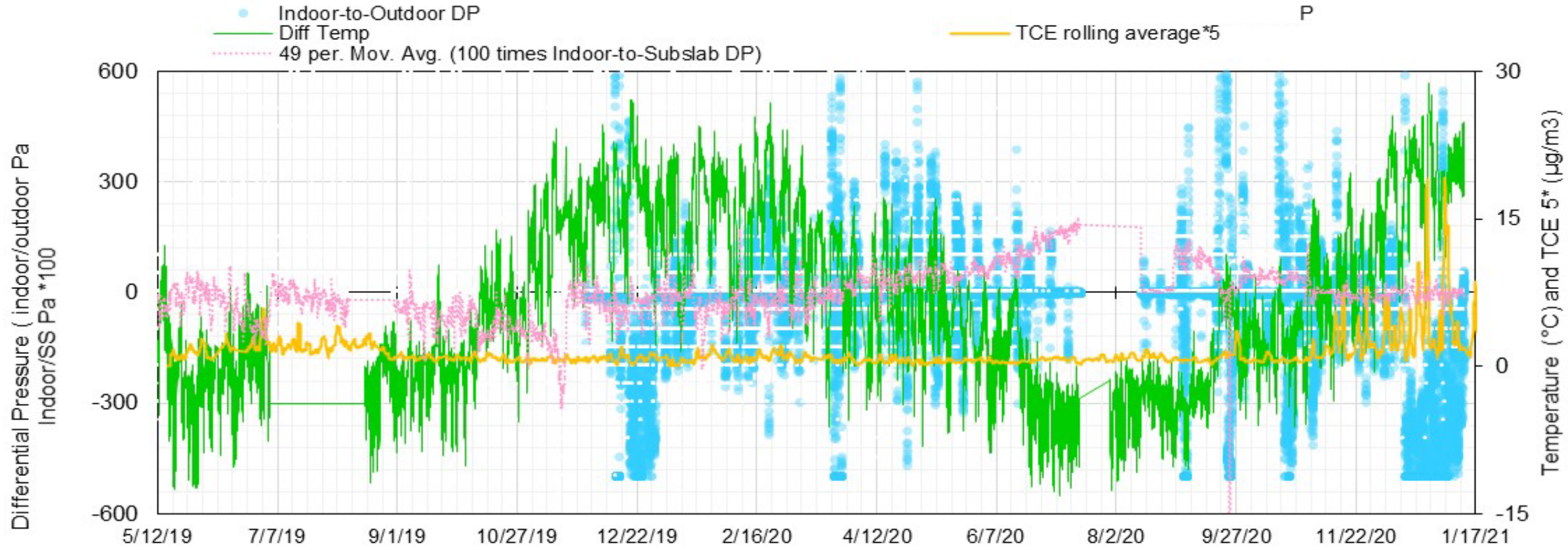
Key Point: Differential pressures allow us to monitor the balance of Q_{soil} and $Q_{building}$ that controls VI.

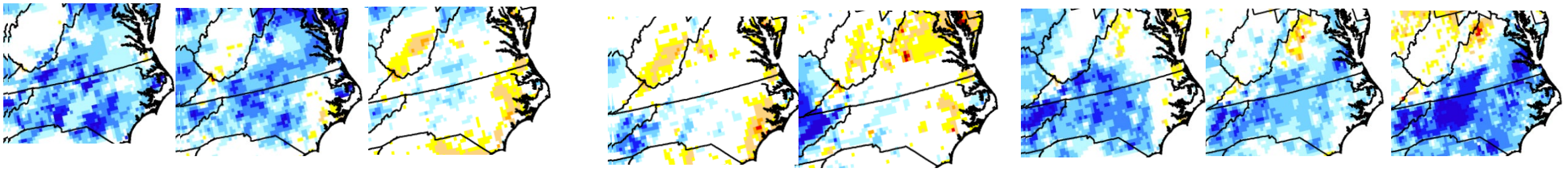


Office 209 – Long Term ΔP, ΔT and TCE with Soil Moisture

Surface soil moisture from https://nasagrace.unl.edu/Archive.aspx

Key point: unexpected VI may have been driven by a combination of soil moisture, wind and stack effect.





5/6/19 7/8/19 9/2/19 1/6/20 4/6/20 8/3/20 10/5/20 12/27/20

Differential Pressure and TCE in Office 209

Detail of late 2020

North > 15 mph

North > 10 mph

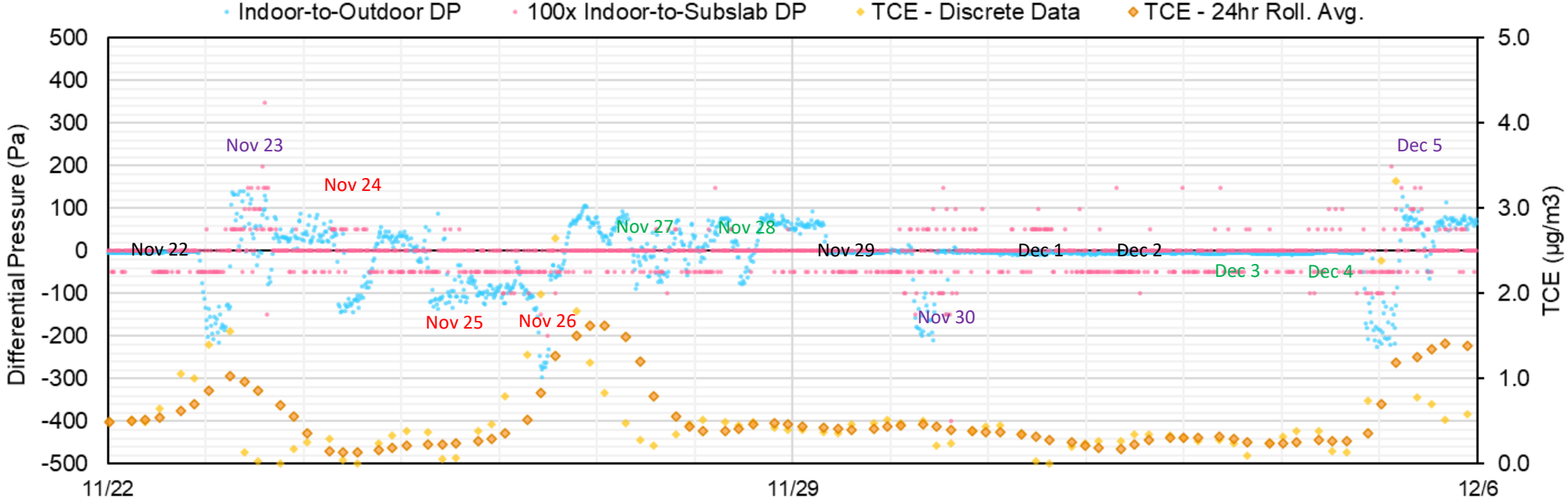
North < 10 mph

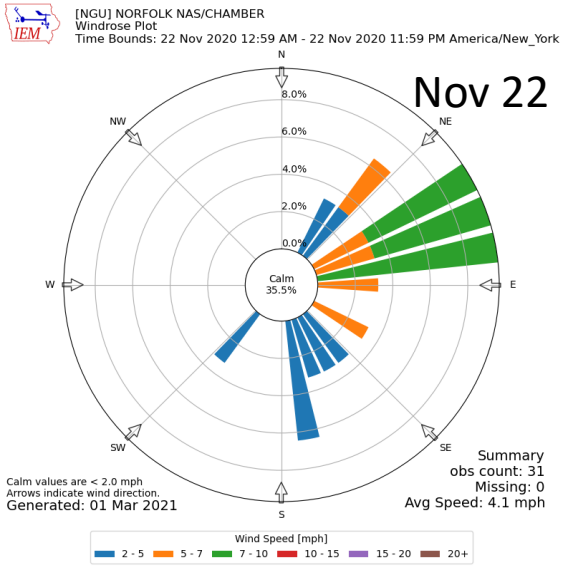
East or West

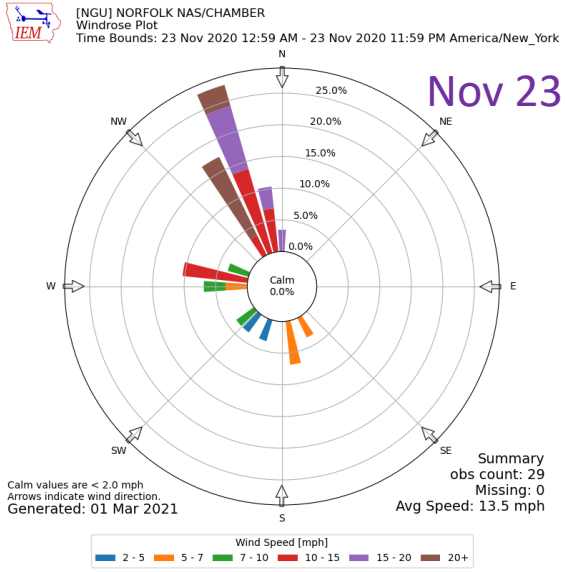
South < 10 mph

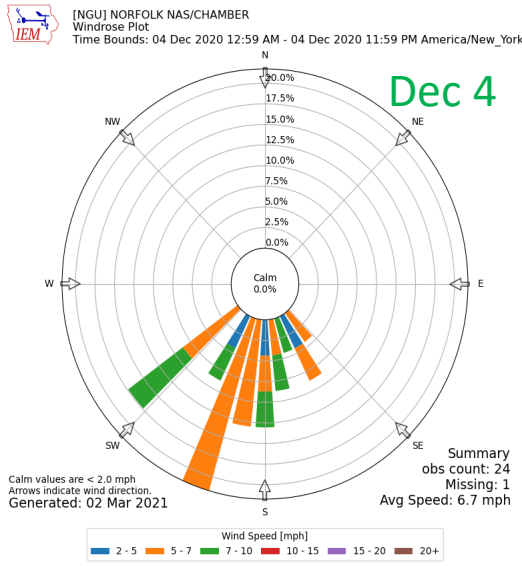
South > 10 mph

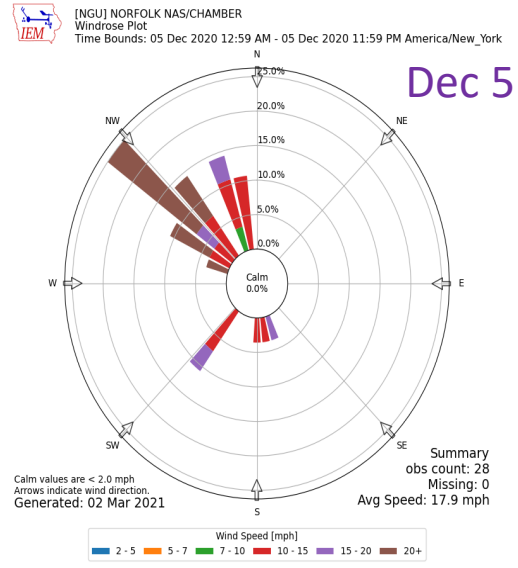
South > 15 mph







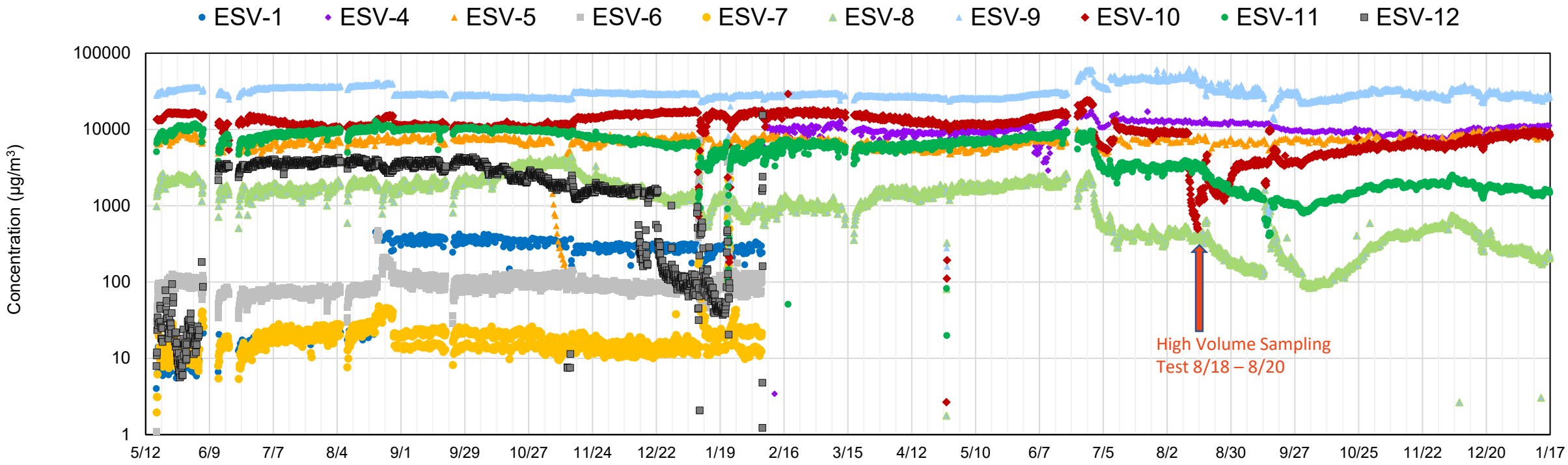


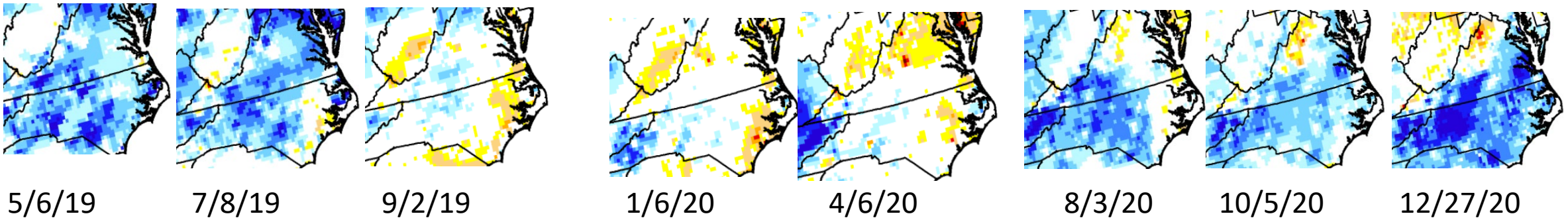


Key Point: Wind speed and direction effects indoor/outdoor differential pressure and TCE.

Results: Long Term Time Series of Subslab Concentrations(May 2019 - Jan 2021)

Surface soil moisture from
https://nasagrace.unl.edu/Archive.aspx





Key Point: Subslab concentrations display a small amount of temporal variability over long periods (CV 0.2 to 0.7), exceptions are gradual weeks long processes.

Example Subslab Port TCE Descriptive Statistics

Key Point: Subslab concentrations show narrow bands of temporal variability and more significant spatial variability.

Location	Office 211		Office 209		Supply Room 210[a]	
	Office	Breakroom	North	South	Conventional	CA-Style
Sample ID	ESV-8	ESV-12	ESV-9	ESV-10	ESV-11	ESV-13
5 %ile	1.5E+02	1.0E-02	2.5E+04	3.5E+03	1.2E+03	2.7E+03
10 %ile	2.5E+02	1.6E+01	2.6E+04	4.8E+03	1.5E+03	3.1E+03
25 %ile	4.9E+02	1.6E+02	2.7E+04	8.7E+03	2.9E+03	3.7E+03
Median	1.4E+03	2.3E+03	2.9E+04	1.1E+04	6.4E+03	5.2E+03
75 %ile	1.9E+03	3.5E+03	3.3E+04	1.5E+04	8.6E+03	6.2E+03
90 %ile	2.3E+03	3.8E+03	3.8E+04	1.6E+04	1.0E+04	7.4E+03
95 %ile	3.1E+03	3.9E+03	4.6E+04	1.7E+04	1.0E+04	8.3E+03
Average	1.3E+03	2.1E+03	3.1E+04	1.1E+04	6.0E+03	5.4E+03
StDev	8.9E+02	1.5E+03	6.9E+03	4.3E+03	3.1E+03	2.5E+03
Coeff. Var.	0.66	0.72	0.22	0.39	0.53	0.46
% Detected	100.0%	92.9%	100.0%	100.0%	99.9%	99.9%
Count	4,126	1,799	4,114	4,112	4,116	1,383

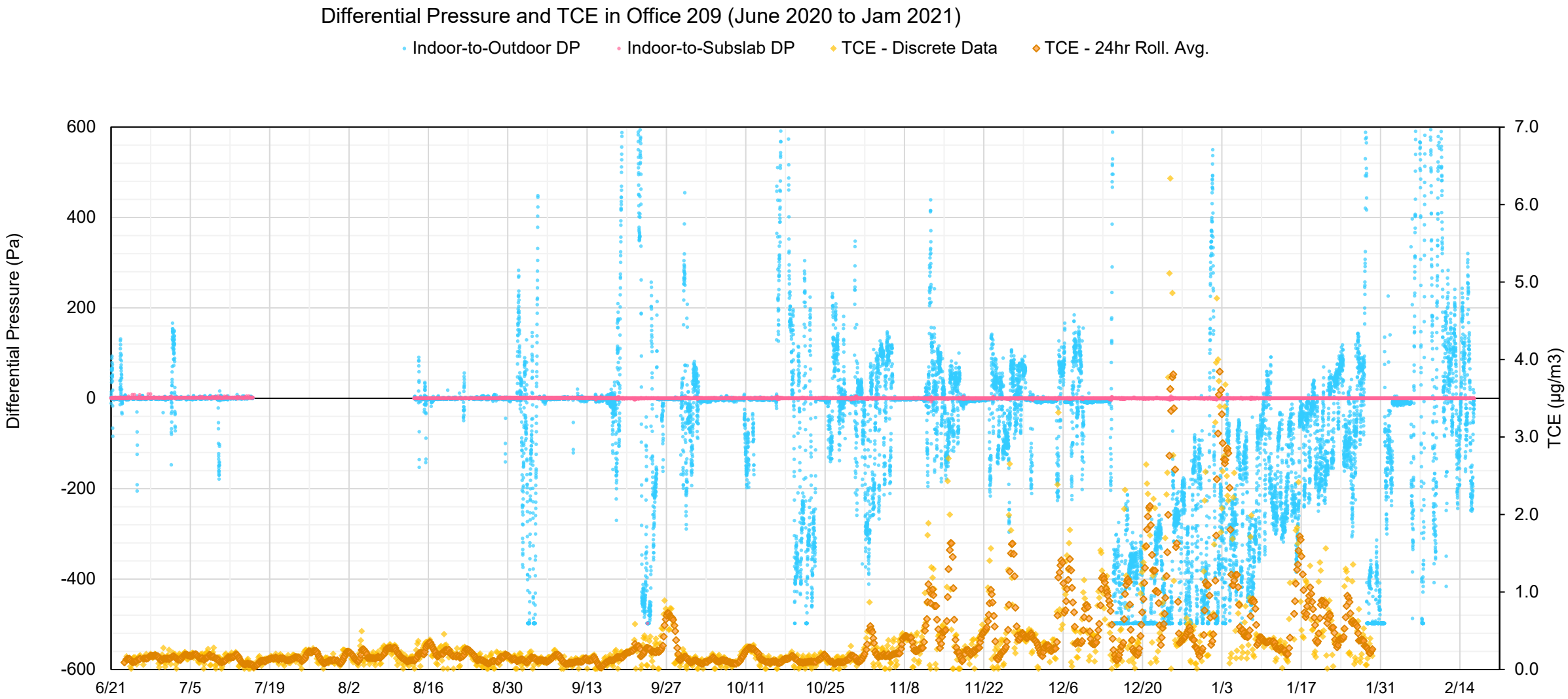
Conclusions

- Temporal variability in indoor air (CV 1.3-3.1) greater than in subslab (CV 0.22-0.72)
- Temporal variability in indoor has different behavioral patterns in different zones within same larger building
- Radon tracks with the temporal pattern at most times/places in building.
- Complex patterns of wind speed, wind direction, temporal variability and human occupancy effect differential pressure.
- Differential pressures control both soil gas entry and air exchange, and thus indoor air concentrations.
- The combination of high soil moisture and high differential temperature may explain VI at one location where it was absent previously.

Acknowledgements

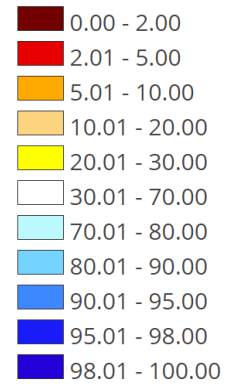
- NESDI Project #554
- US EPA ORD
- Victoria Ciavarra, Travis Pitts, Ben Thompson - Jacobs

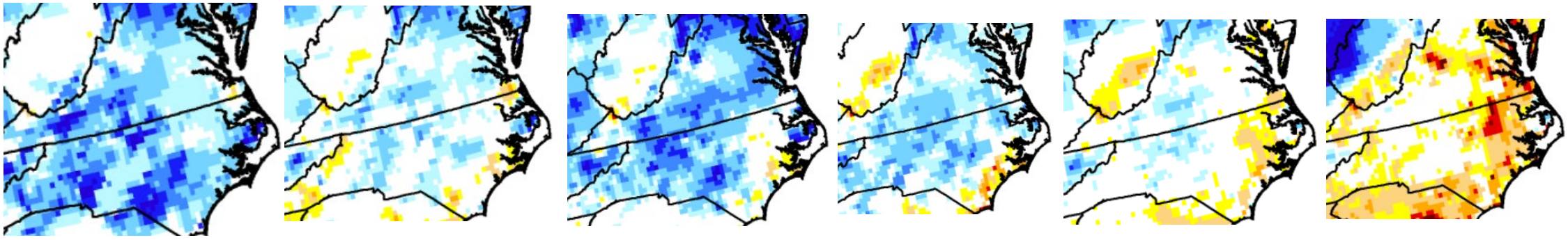
Office 209 Period of Increased Activity



Surface Soil Moisture Percentage

https://nasagrace.unl.edu/Archive.aspx





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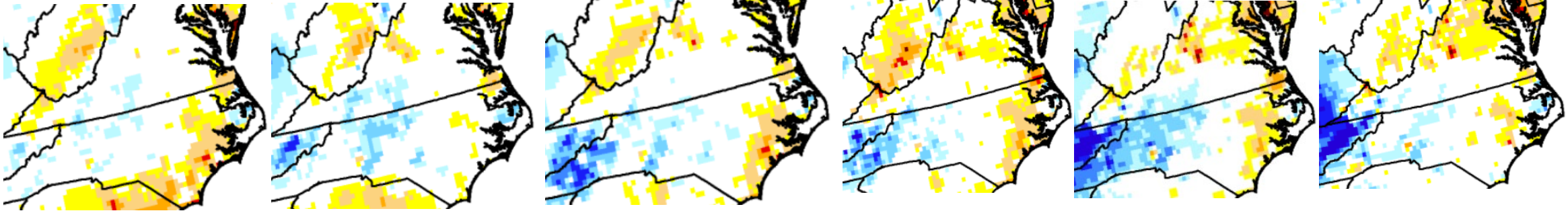
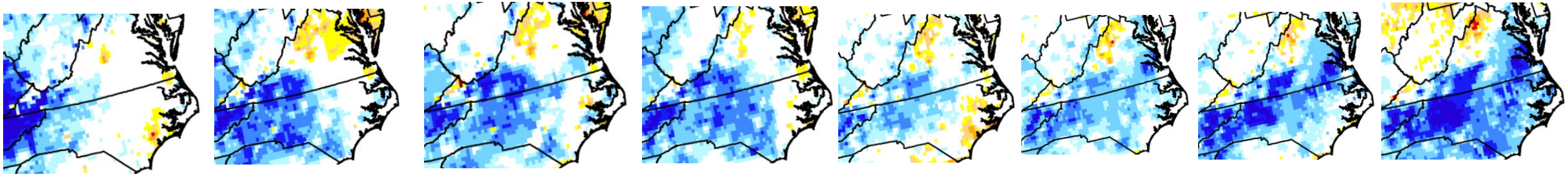


11/4/19 12/2/19 1/6/20 2/3/20 3/2/20 4/6/20



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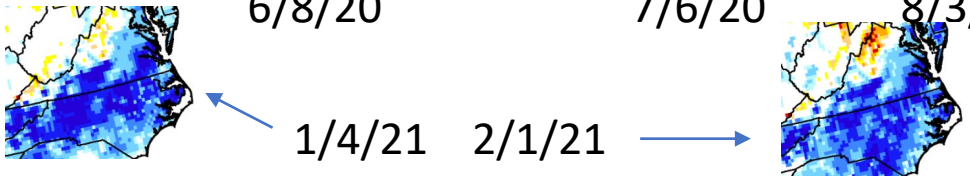
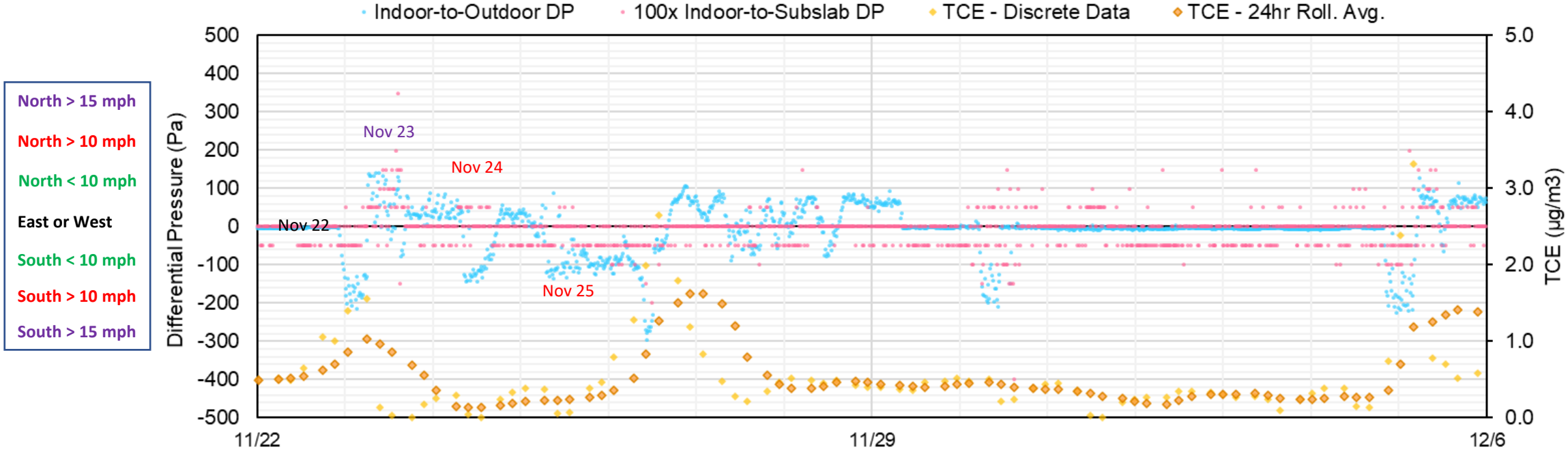
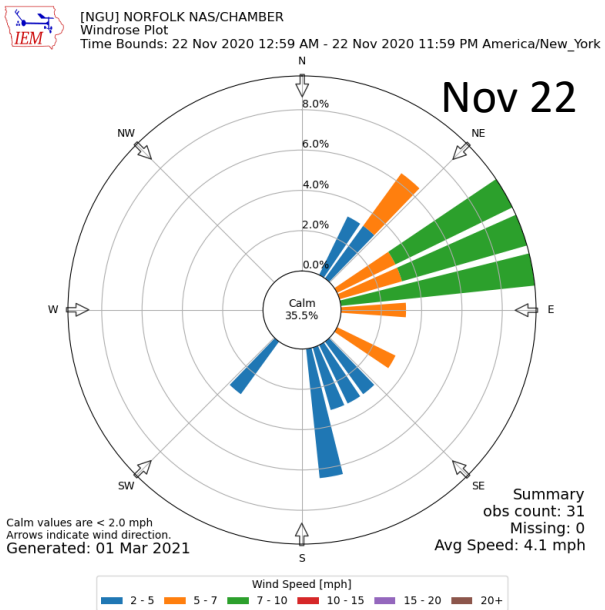
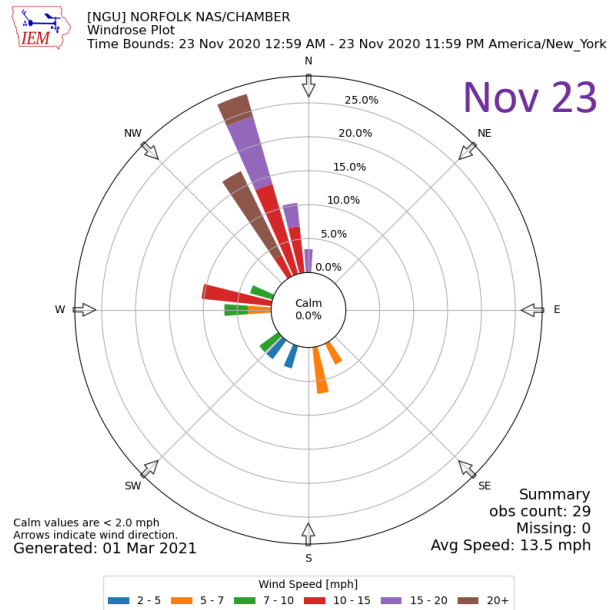


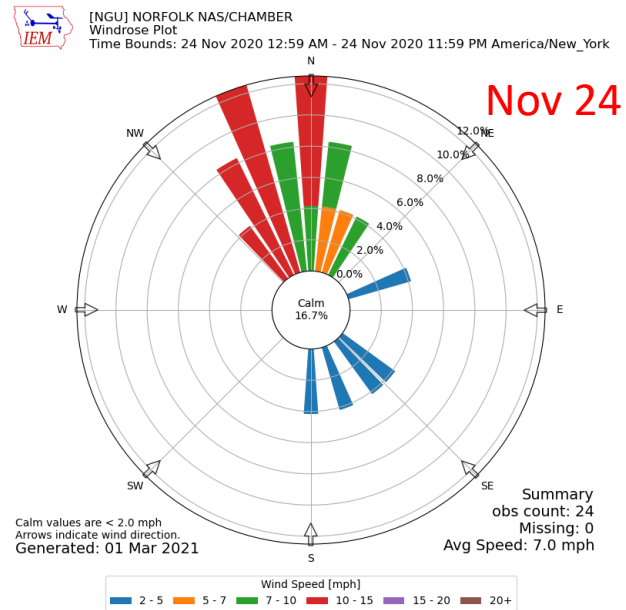
1/4/21 2/1/21

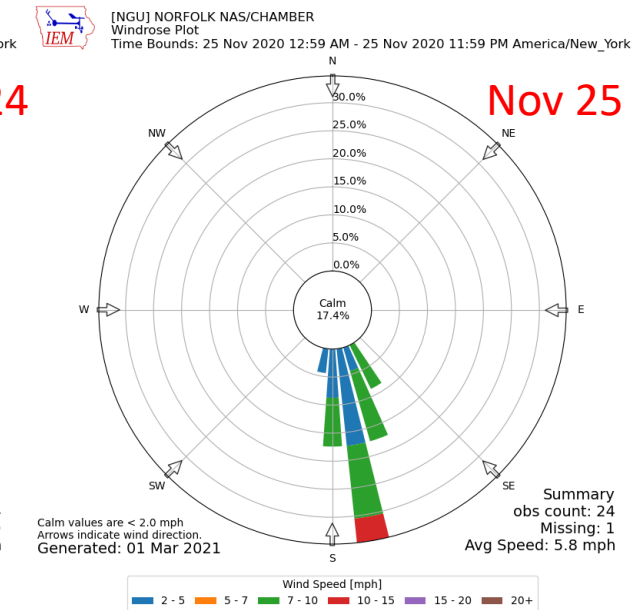
Differential Pressure and TCE in Office 209



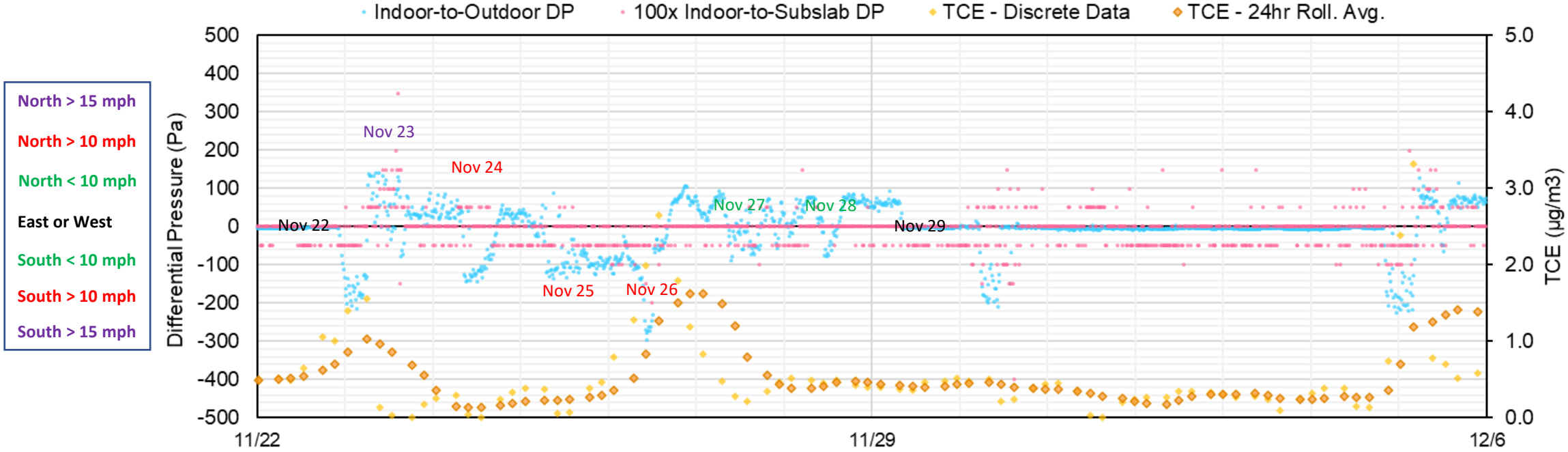


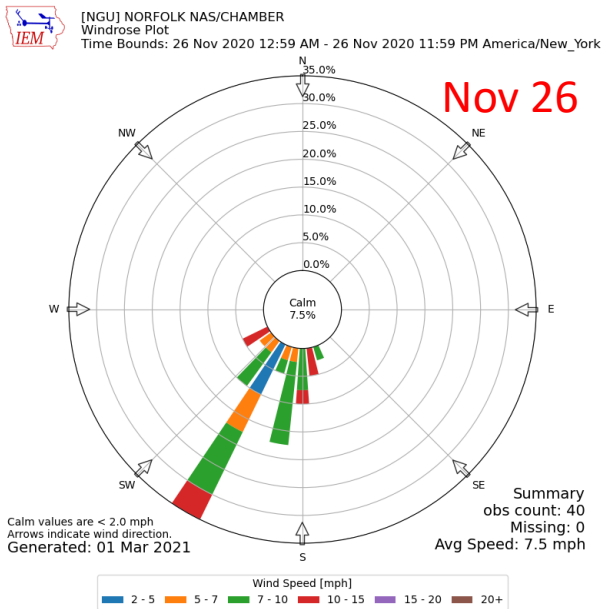


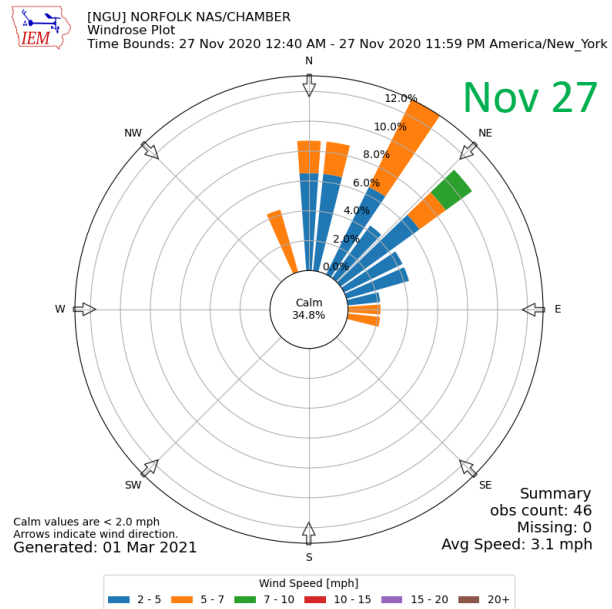


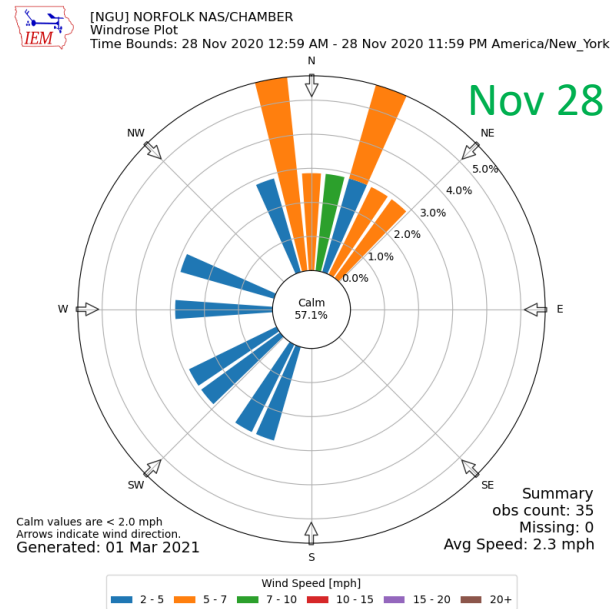


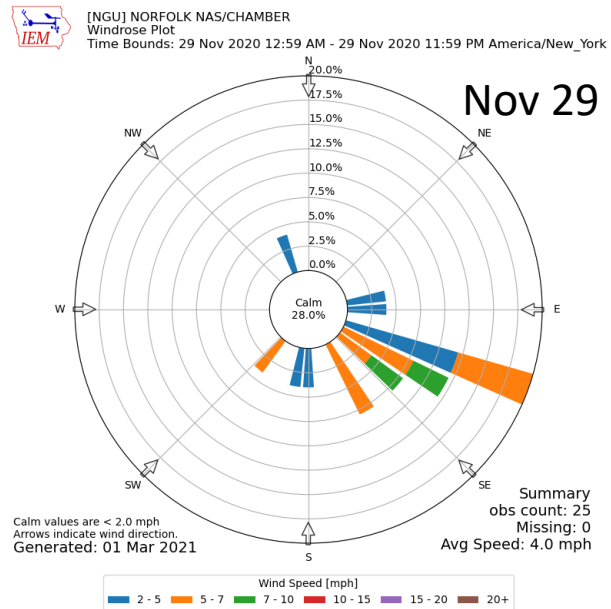
Differential Pressure and TCE in Office 209



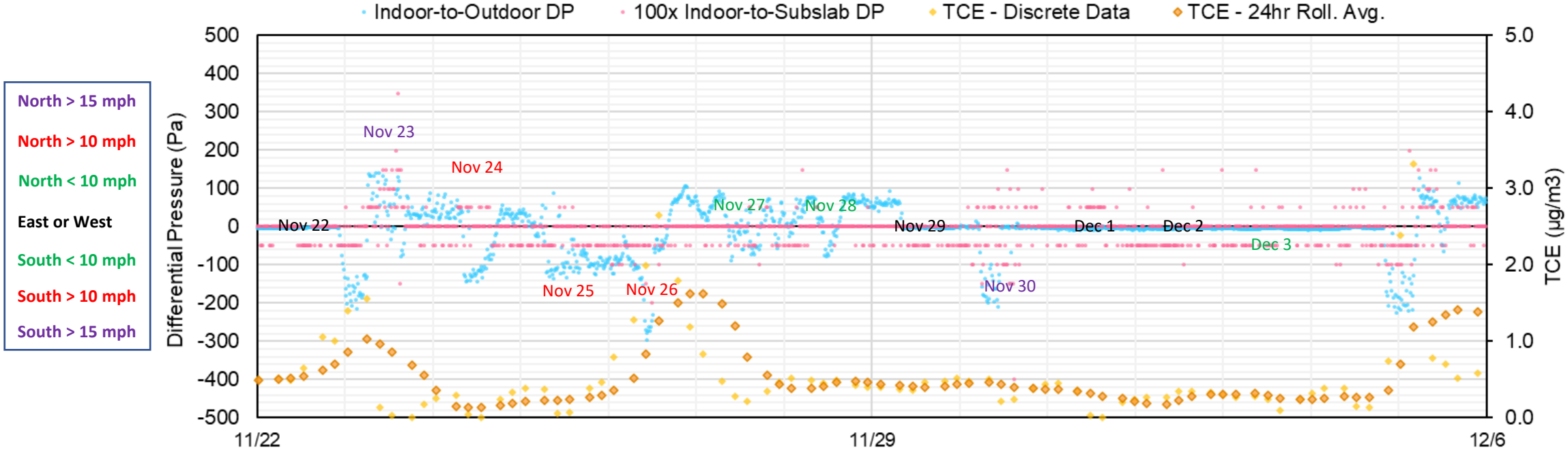


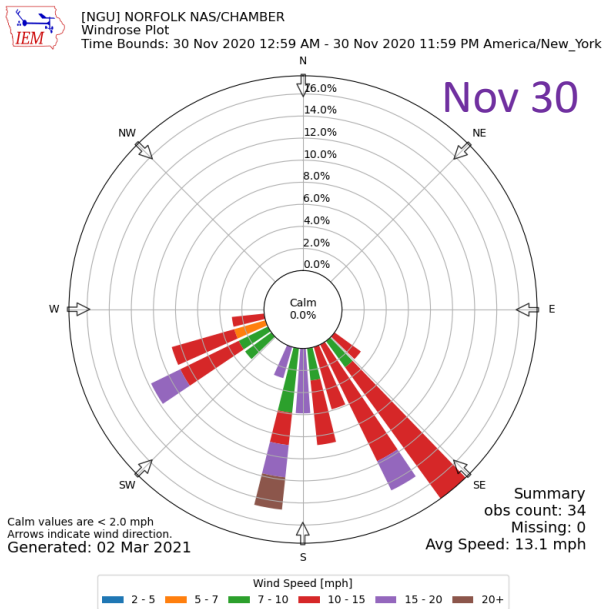


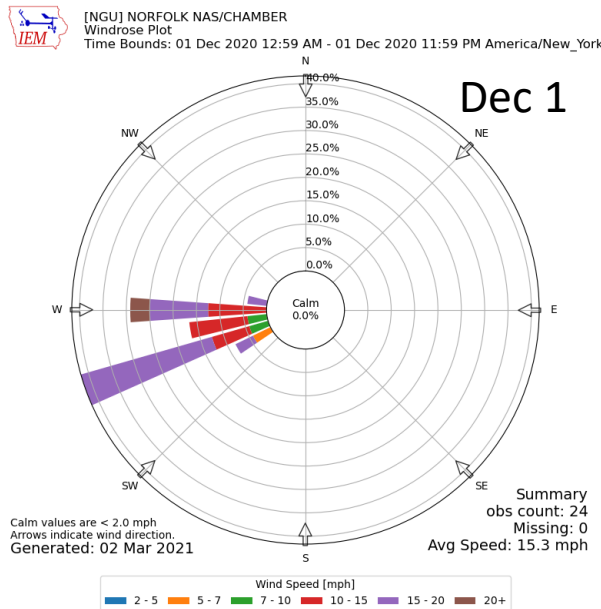


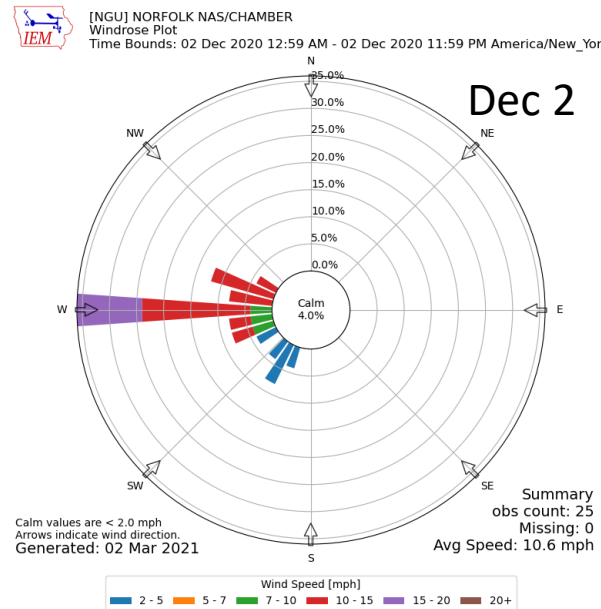


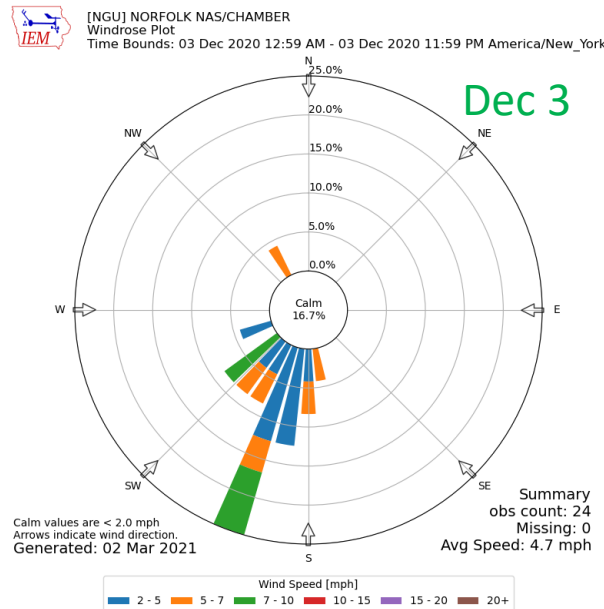
Differential Pressure and TCE in Office 209











Results: Open Warehouse Area