Americium Surrogate Suspension-Resuspension Study

PRESENTED BY

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National Academies of Sciences – Radioactive Sources: Applications and Alternative Technologies

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Introduction

Objective: Perform a resuspension study considering different surfaces in ambient and humid conditions looking at relatively early time resuspension.

Goals and Benefits:

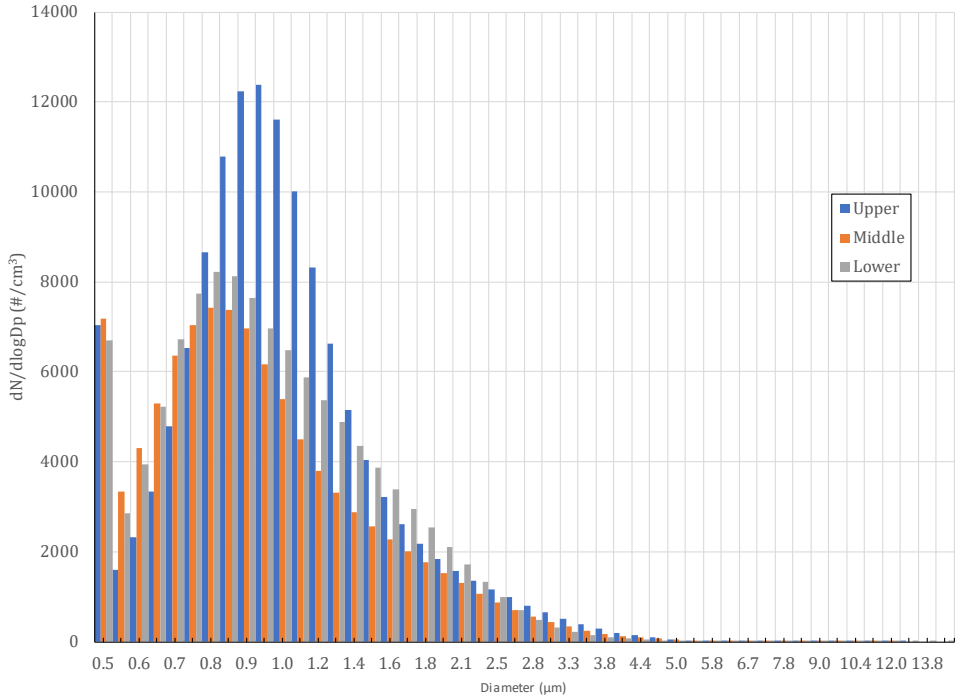
- Provide insight into resuspension methods
- Validation or improvements to resuspension source terms for models such as Turbo FRMAC

Utilizing:

Surrogate Cerium Oxide (CeO_2)

Large Aerosol Dissemination Chamber

Varying substrate types and resuspension methods



Limitations in Current Datasets

Laboratory/Synthetic Experiment Datasets	Event-Based Datasets
Isolated Processes/Experimental Constraints: Well constrained data often addressing only one process of the resuspension mechanism	Meteorology: Uncontrolled meteorological conditions both at event and post-event, including meteorology generated by event, precipitation and wash-out
Simulated Environment: Wind tunnel and environmental chambers have limited heights and do not account for entrainment, mixing or advection of material to upper levels	Lofting: Lofting of material into mid/upper levels of the atmosphere will separate material from the surface boundary layer and inhibit settling
Surrogate Material: Laboratory tests are often limited to using surrogate material with similar but ultimately different physical and chemical properties	Contamination: Advection of contamination from previous tests into area of deposition
Surface Representation: Applying surface substrates to represent real life ground level surfaces	Topographical impacts: Material can be preferentially removed from the boundary layer due to impacts with topography
	Surface Sink: Radionuclide material which is trapped by the surface soils/material
	Initial Deposition vs. Resuspension: Identifying when the initial deposition of radionuclide material is complete as material is initially elevated to unquantified levels. The resuspension process begins while material is still depositing
	Height of Initial Release: The height of initial release impacts the initial deposition rate, which in turn will impact the lateral variability and advection/spread of any radionuclides.

SAND2020-4899 (Table 1-1)

Current Estimates of Resuspension

Marshall et al., reprocessed data from Maxwell & Anspaugh:

- Resuspension factors within first few days to weeks centered around 10^{-6} m^{-1}
- Range spanning 5 orders of magnitude

Maxwell & Anspaugh:

$$K_t = \left(1.0E^{-5} \times e^{-8.1E^{-7} \times t}\right) + \left(7.0E^{-9} \times e^{-2.31E^{-8} \times t}\right) + 1.0E^{-9}$$

Turbo FRMAC has an additional option to utilize the resuspension factors described in NCRP Report No. 129 [6] , which are as follows:

- K = 10^{-6} m^{-1} for near term events < 1 day,
- K = 10^{-6} m^{-1} /t for time > 1day and < 1,000 days, or
- K = 10^{-9} m^{-1} for t > 1,000 days.

SAND2020-4899 (Equation 1)

The Experimental Setup

Chamber Design

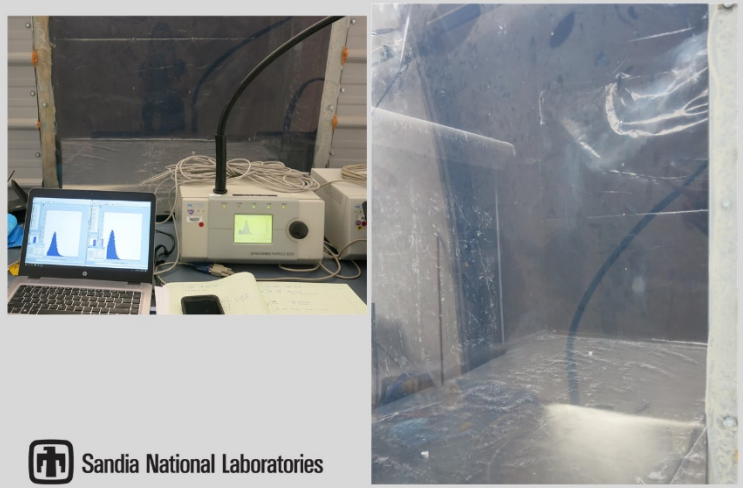
Rolling "garage" doors

Ability to have multiple substrate floors

Black pond liner internal walls

- Provides uniformity and repeatability for experimental series
- Clean down and reset

Chamber service door serves as visual port into chamber (34" x 80")



17 ft x 18ft x 12-15 ft

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SAND2020-4899 (Figure 2-8)

Sampling and Diagnostics

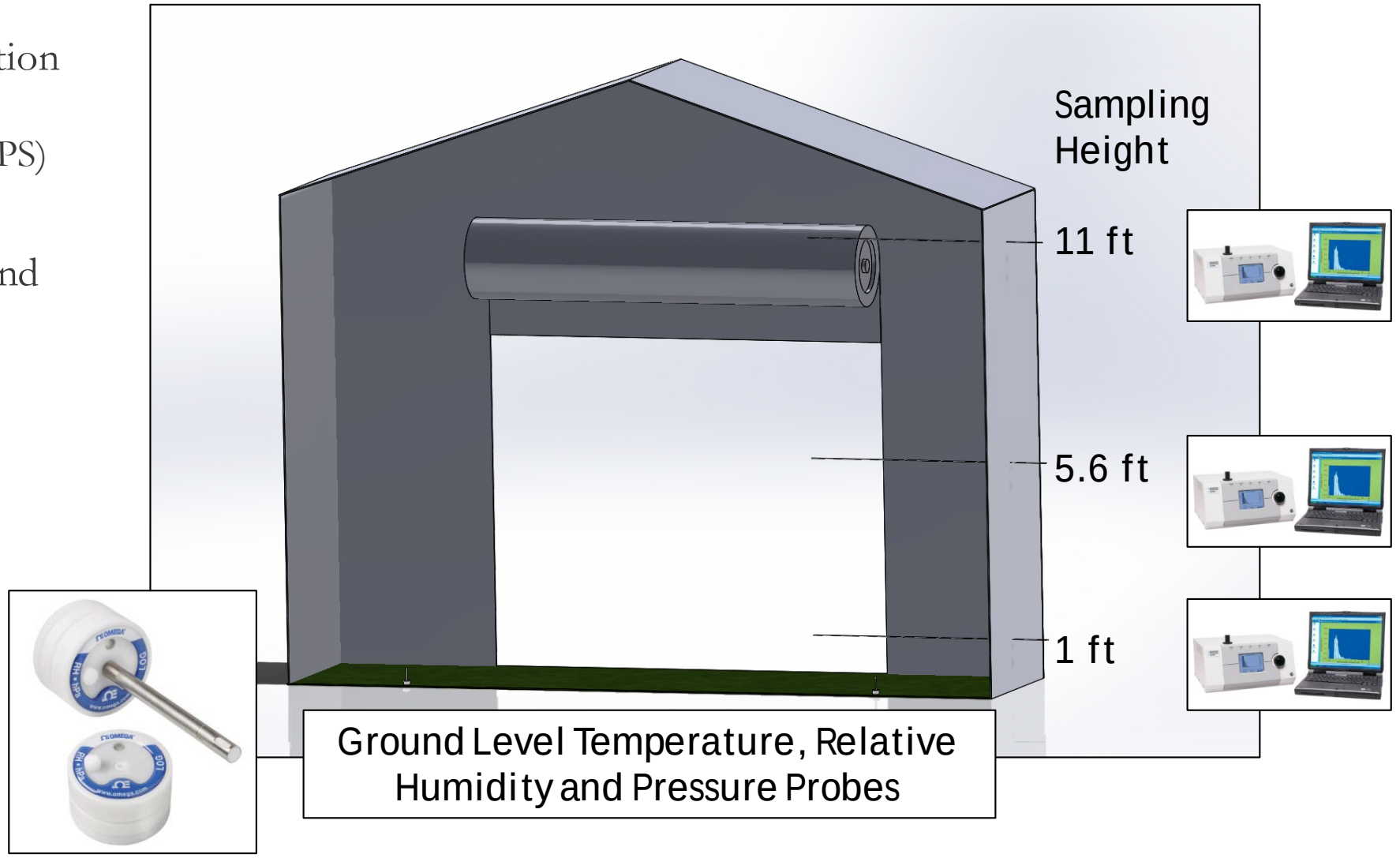
Real time particle size distribution and concentration

- Aerodynamic Particle Sizers (APS) at three different heights

Temperature, relative humidity and pressure probes at ground level

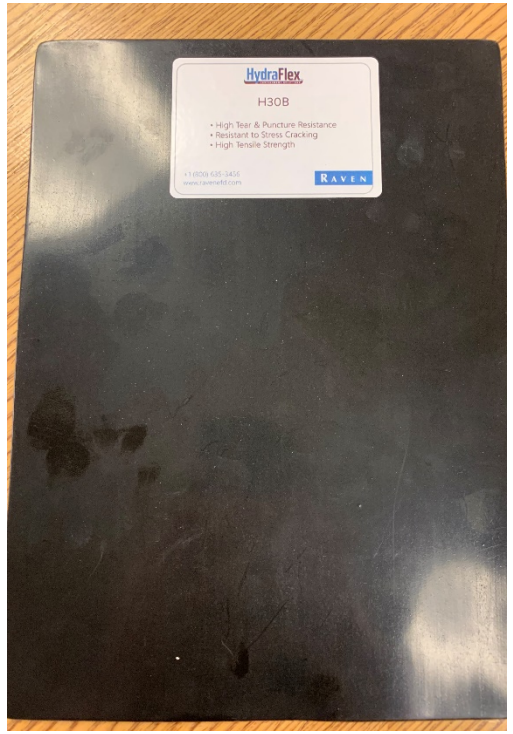
GoPro Cameras

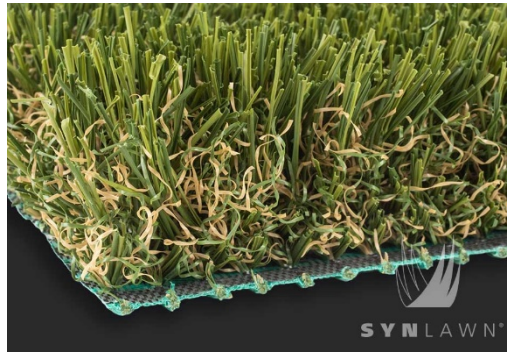
Witness Coupons



SAND2020-4899 (Figure 2-9)

Surface Substrates





Pond Liner

- Manufactured by Raven Engineered Films – HydraFlex H30B
- Thickness = 28.5 Mil
- Protective surface for entire chamber

Artificial Turf

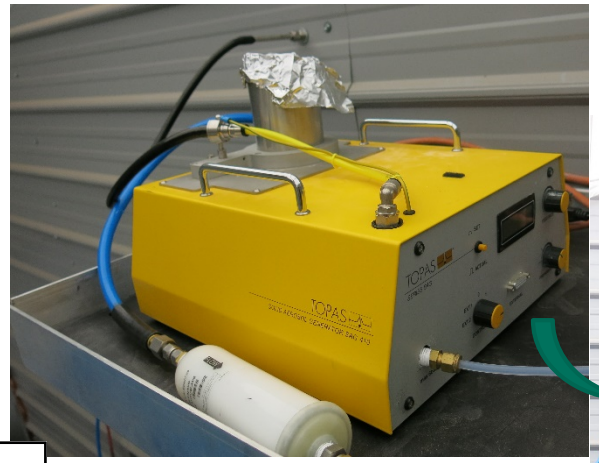
- SynLawn DuraGrass60

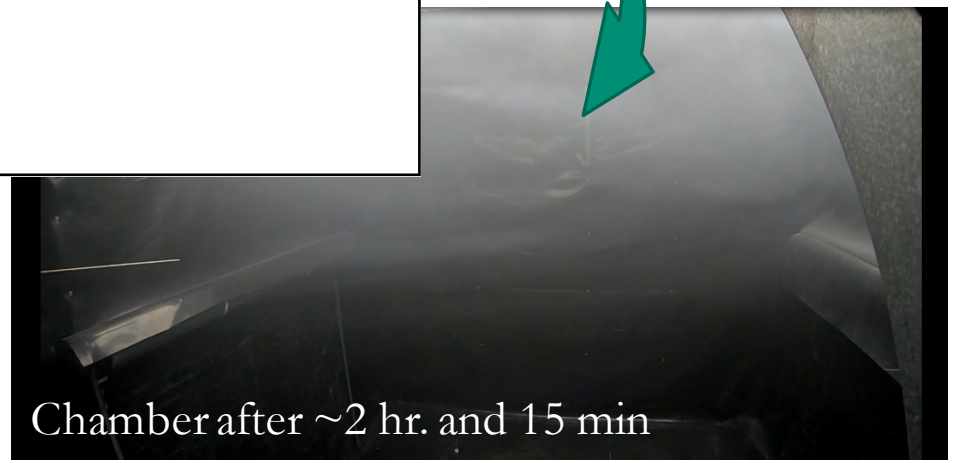
Patio Pavers

- Riccobene Masonary – Concrete Square Pavers
- 18” x 2” Square

Initial Aerosolization

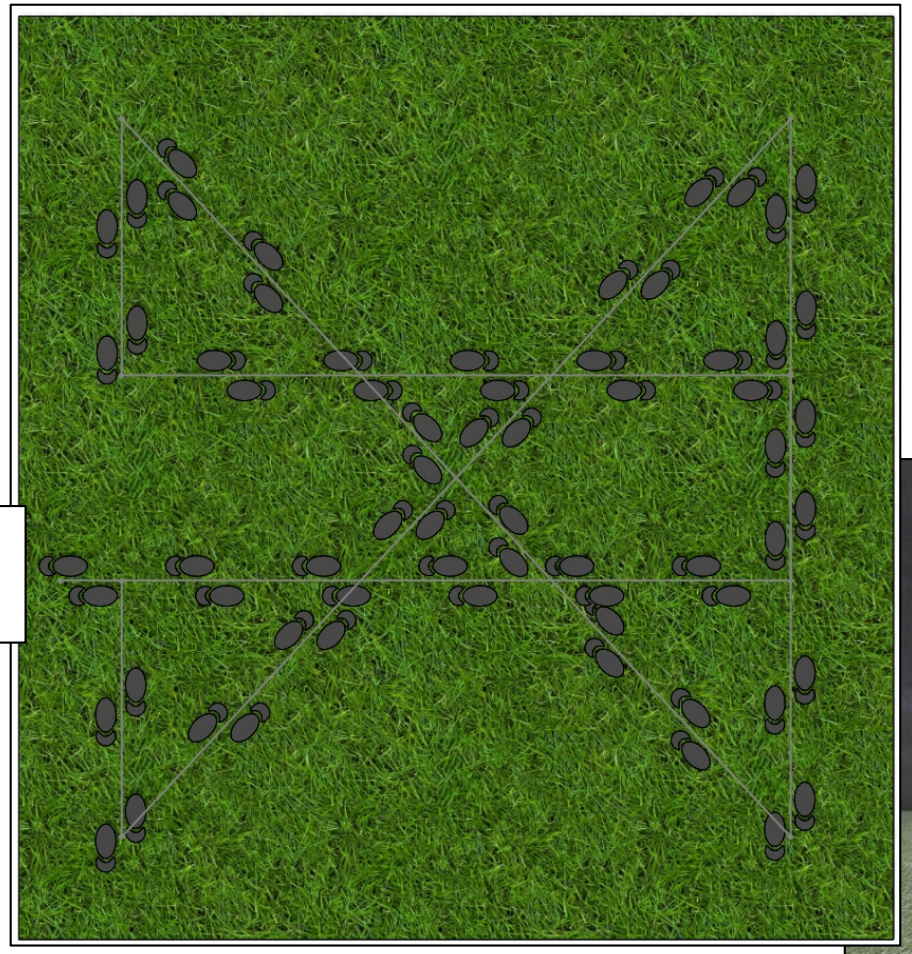
Aerosol enters the chamber via a ~ 12 ft high port on the front of the chamber





SAND2020-4899 (Figure 2-10)

Resuspension Analysis of Walking in Chamber



Fixed Path in Chamber

Each Resuspension Event Consisted of 3 Laps

Approximately 90 - 120 seconds to complete

Resuspension Analysis of Driving in Chamber

Typically One Pass – Forward and Reverse Out

Approximately 120 seconds to complete

Both front and back doors are open

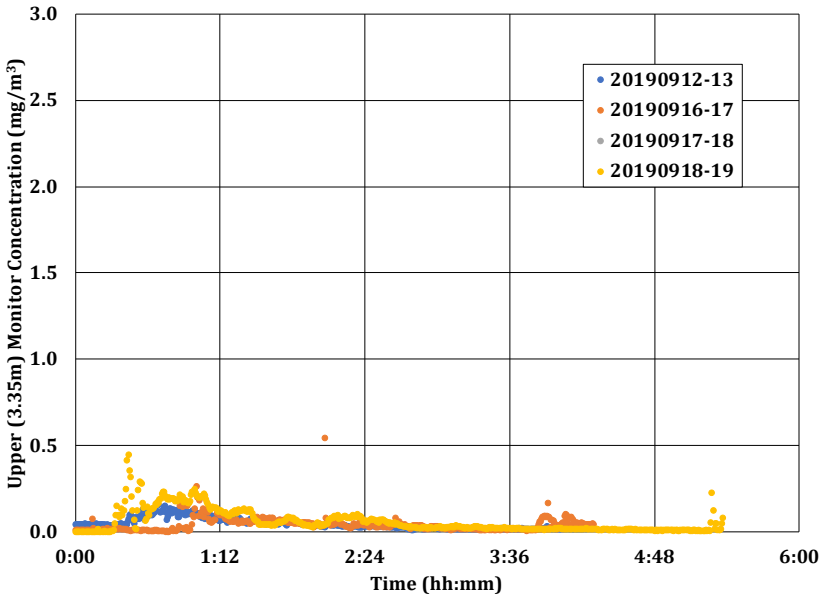
- Expect dilution at higher levels

Results

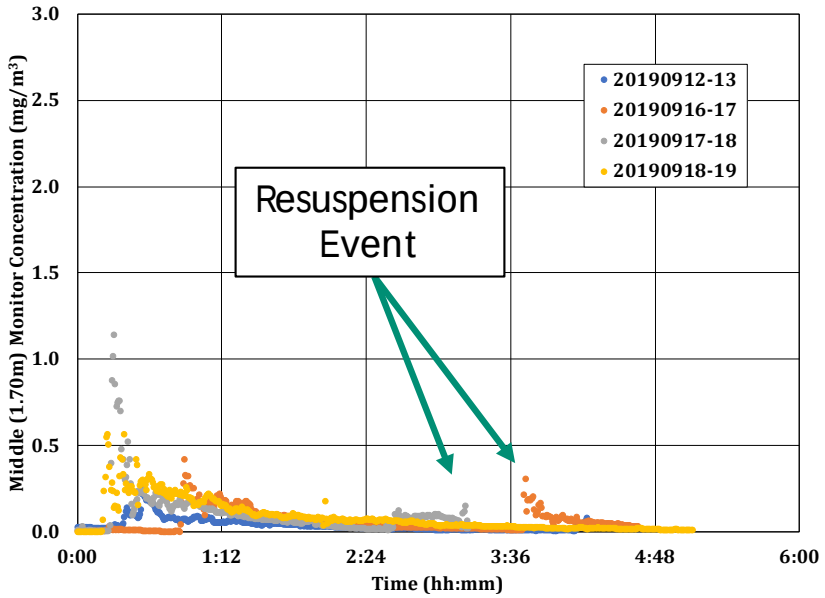
Resuspension Time Series Examples

Resuspension Events occurred after chamber reaches background concentration

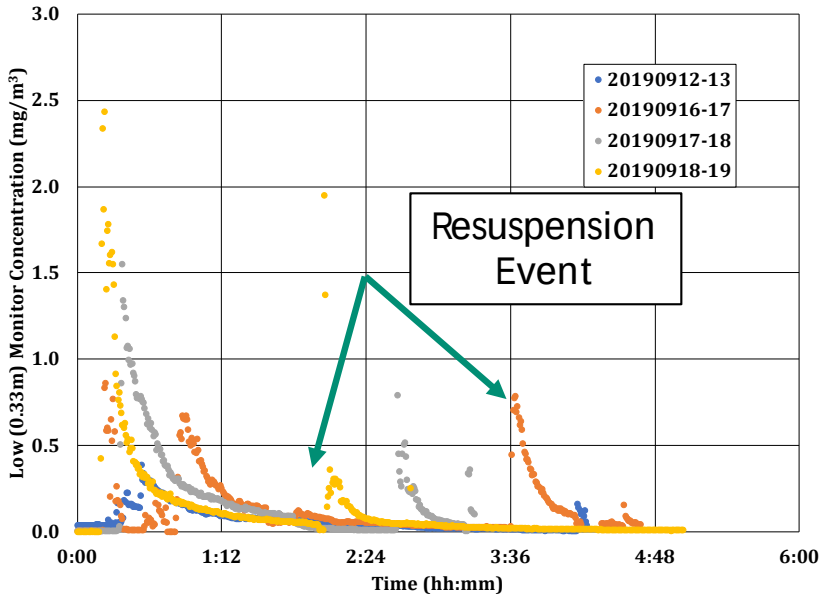
Each Resuspension Event can be seen as a peaks in concentration timeseries



Top Sampler 11 ft

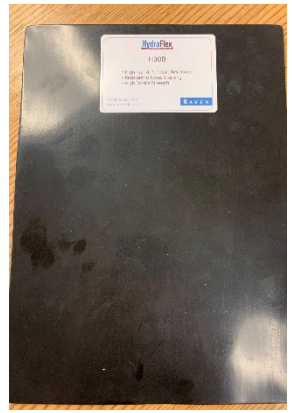


Middle Sampler 5.6 ft



Bottom Sampler 1.0 ft

Size Distributions – Pond Liner – Walking

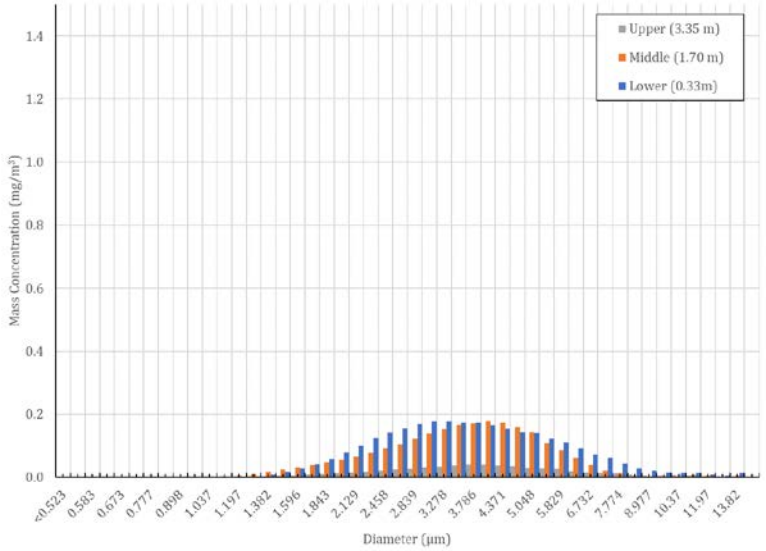


Substrate: Pond Liner

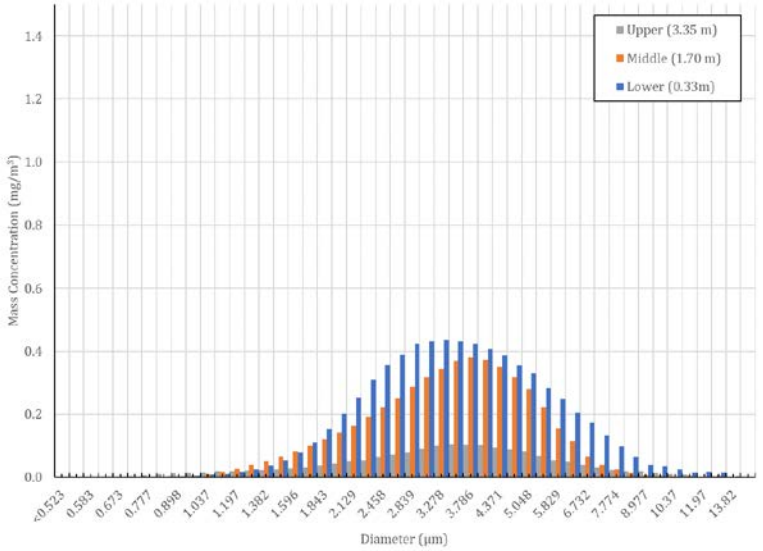
Method: Walking 3 Passes

Nominal Dp = 1 μm

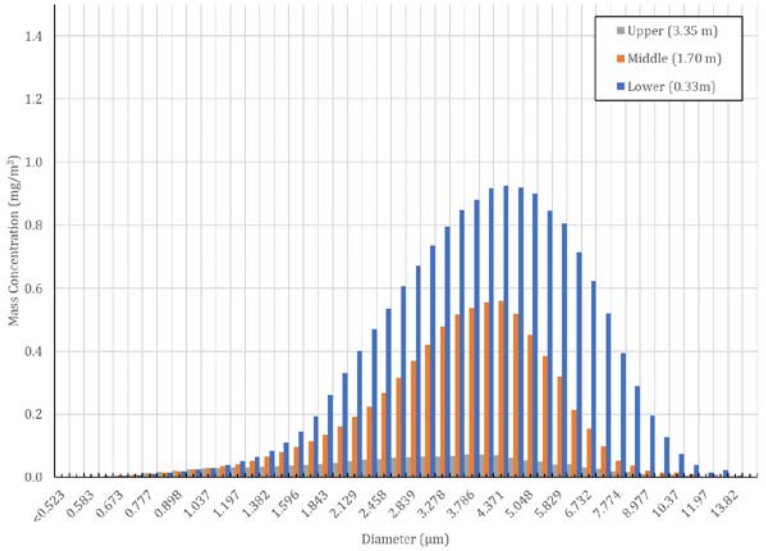
Δtime = 0 (days) – 13:27 (hr:mm)



0 (days) – 13:36 (hr:mm)



0 (days) – 19:27 (hr:mm)



- Increasing concentrations from resuspension with time from deposition

SAND2020-4899 (Figure 3-1, 3-2 and 3-3)

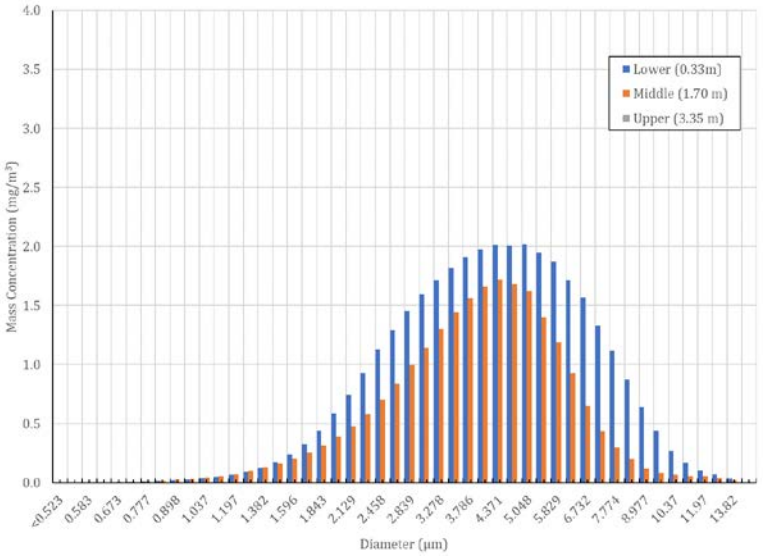
Size Distributions – Grass – Walking

Substrate: Grass

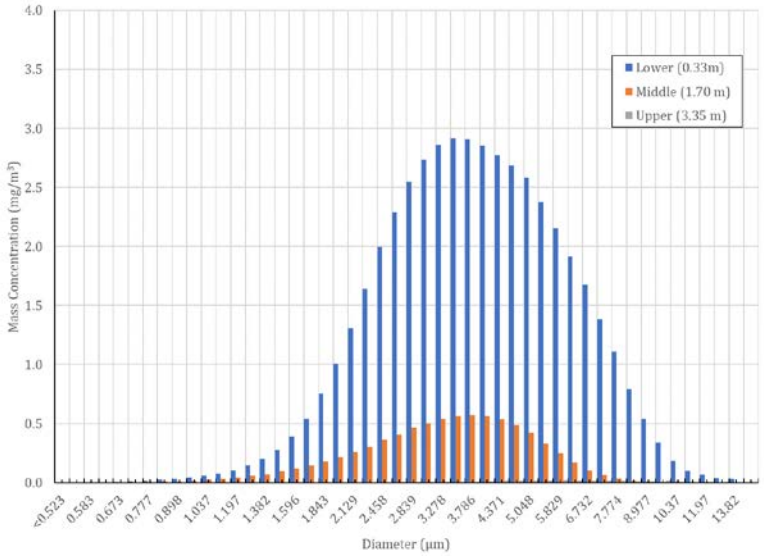
Method: Walking 3 Passes

Nominal Dp = 1 μm

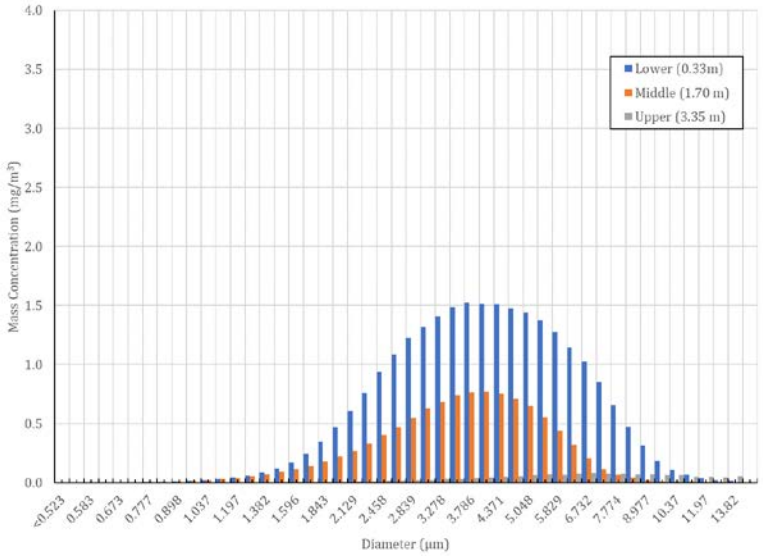
Δtime = 0 (days) – 16:25 (hr:mm)



0 (days) – 16:38 (hr:mm)



0 (days) – 21:29 (hr:mm)



- ~ 3x the aerosol concentration resuspended compared to pond liner

SAND2020-4899 (Figure 3-6, 3-7 and 3-8)

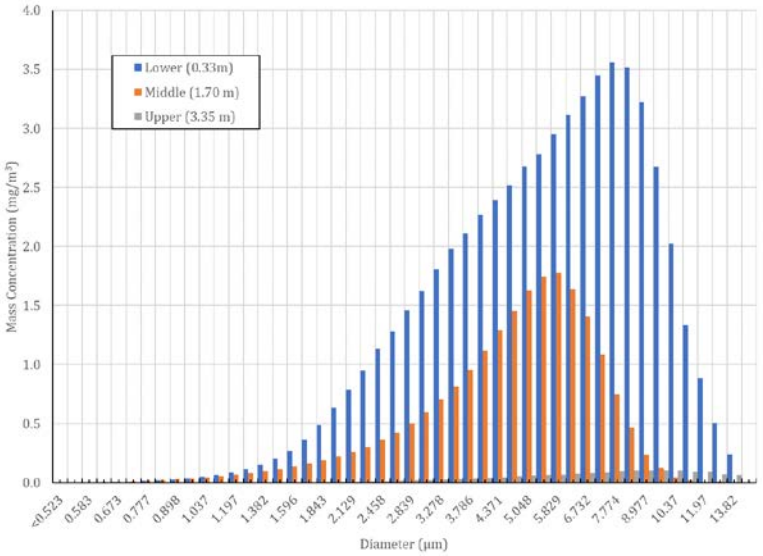
Size Distributions – Grass – Walking

Substrate: Grass

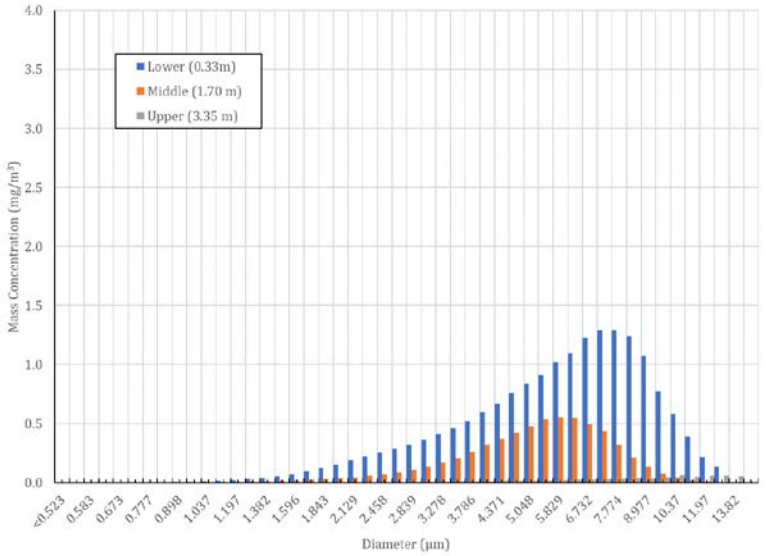
Method: Walking 3 Passes

Nominal Dp = 10 μm

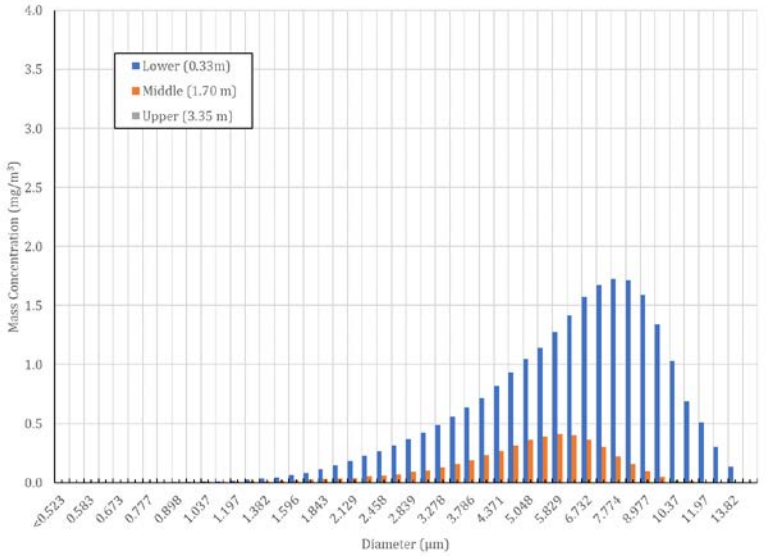
Δtime = 0 (days) – 23:44 (hr:mm)



1 (days) – 20:33 (hr:mm)



1 (days) – 23:05 (hr:mm)



- Decrease in aerosol concentration resuspended over time since initial deposition

SAND2020-4899 (Figure 3-10, 3-11 and 3-12)

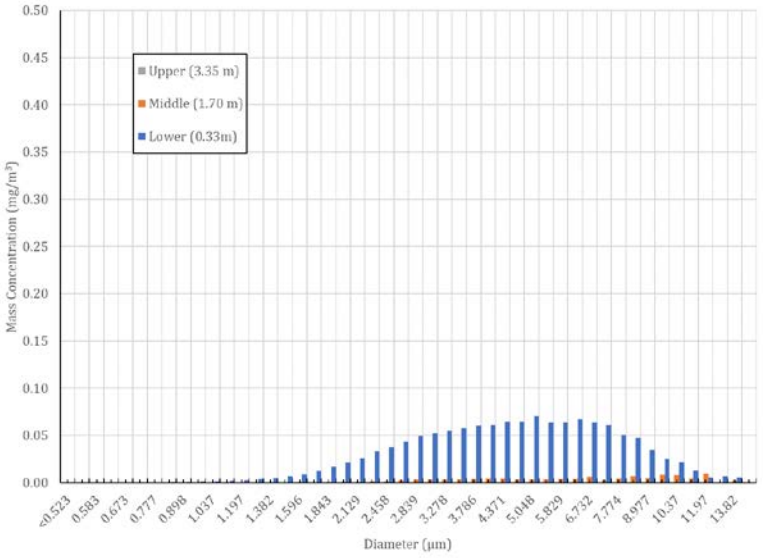
Size Distributions – Pavers – Walking

Substrate: Pavers

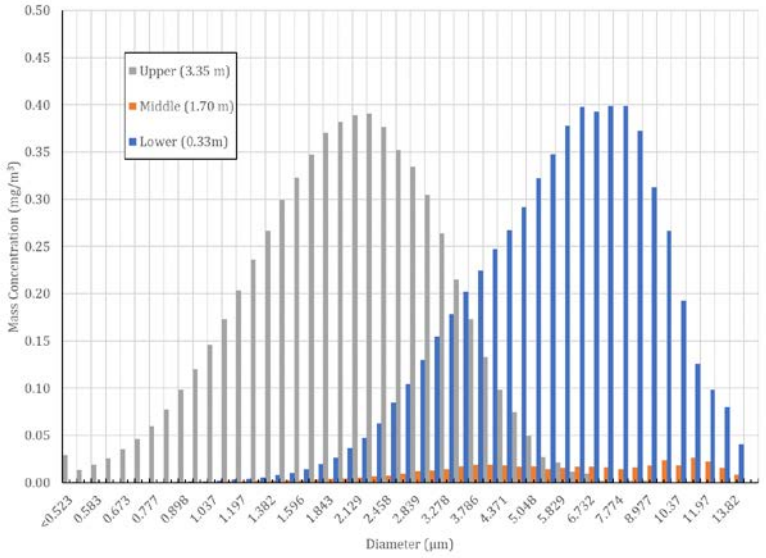
Method: Walking 3 Passes

Nominal Dp = 10 μm

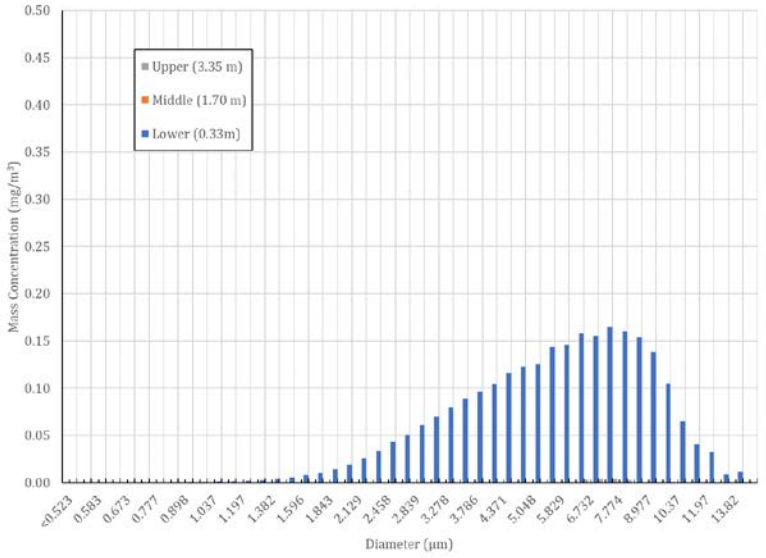
Δtime = 0 (days) – 21:39 (hr:mm)



7 (days) – 22:28 (hr:mm)



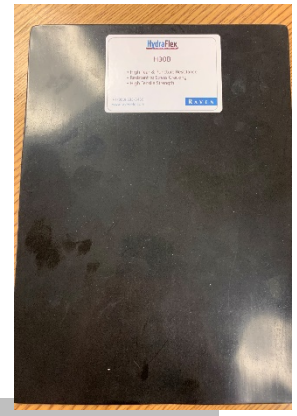
13 (days) – 23:09 (hr:mm)



- Impacts from water vapor condensation at upper level monitor, low resuspension

SAND2020-4899 (Figure 3-19, 3-20 and 3-21)

Size Distributions – Pond Liner – Vehicle

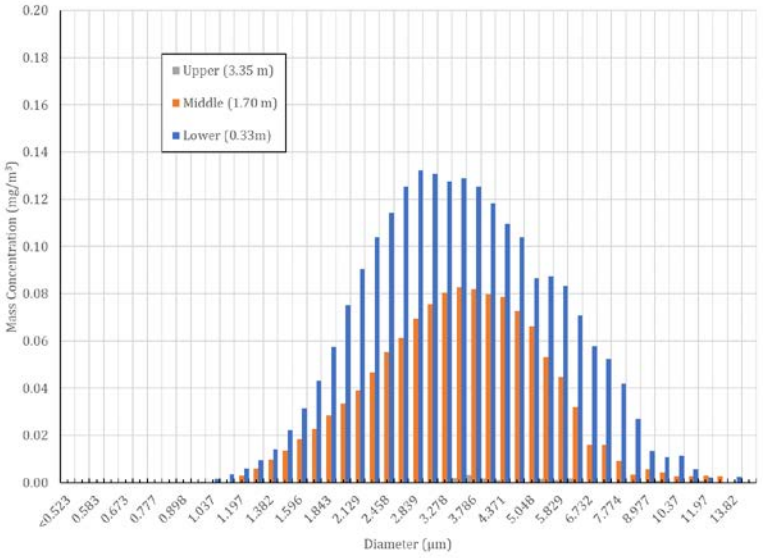


Substrate: Pond Liner

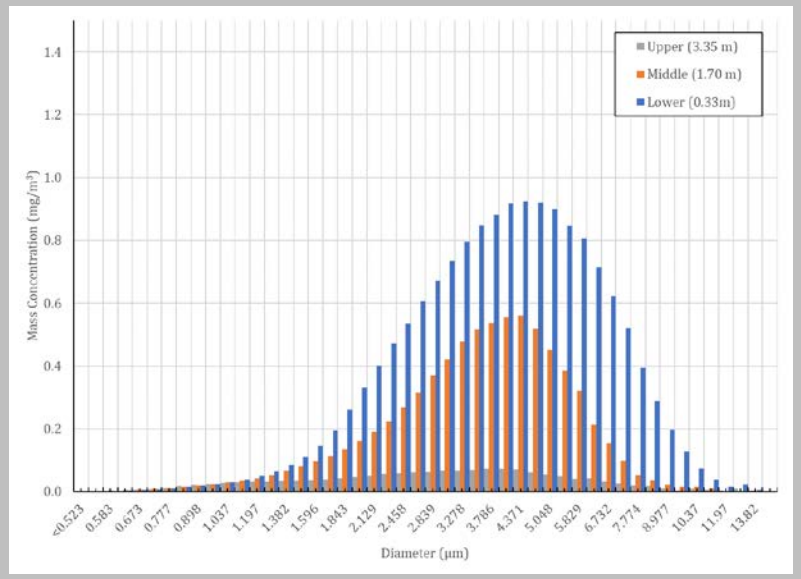
Method: Vehicle

Nominal Dp = 1 μm

Δtime = 0 (days) – 21:39 (hr:mm)



Compare To Walking 0 (days) – 19:27 (hr:mm) :



- Order of magnitude reduction in resuspended concentrations

SAND2020-4899 (Figure 3-5)

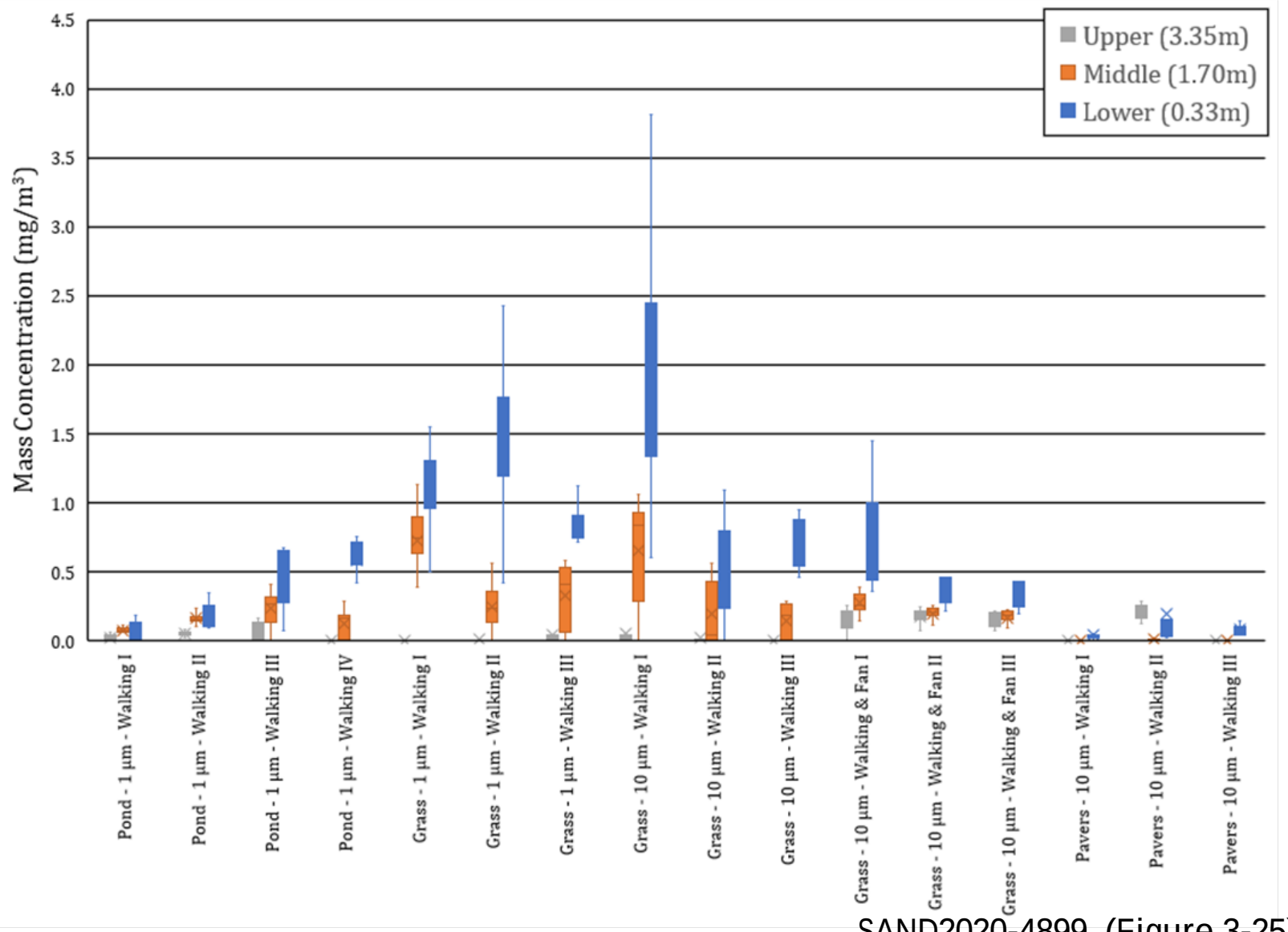
Walking Resuspension Events

Box & Whisker Plot
- Min/Max Values (whiskers)
- 1st, Median, 3rd Quartile (box)
- Mean (x)

Events + 3 min Mixing Window

Lower Monitor (0.33m) shows significant impact and variation

Grass shows higher resuspended concentrations at Mid/Lower levels



SAND2020-4899 (Figure 3-25)

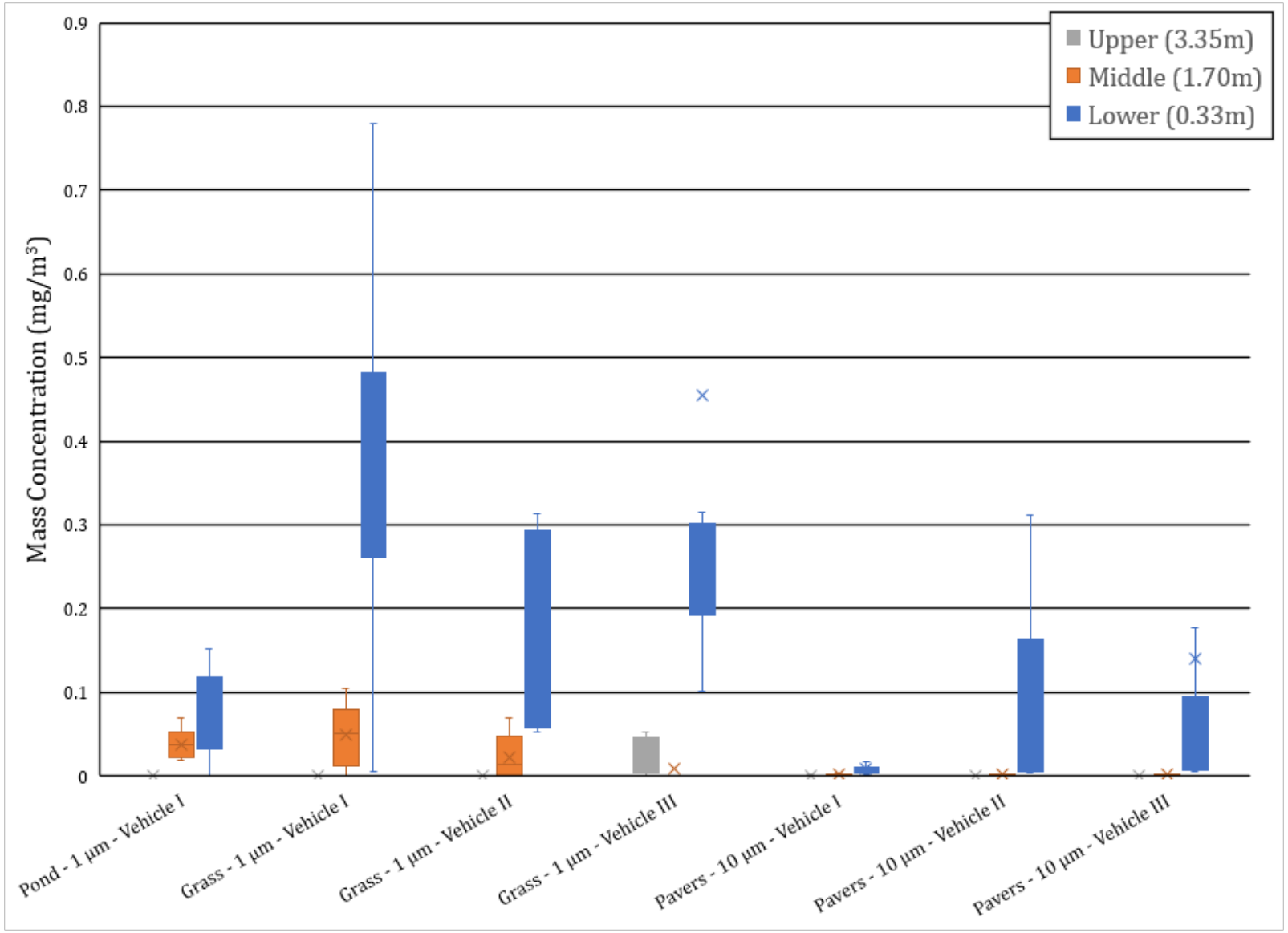
Vehicle Driven Resuspension

Box & Whisker Plot
- Min/Max Values (whiskers)
- 1st, Median, 3rd Quartile (box)
- Mean (x)

Events + 3 min Mixing Window

Lower Monitor (0.33m) shows significant impact and variation

Middle Monitor is impacted but less substantially



SAND2020-4899 (Figure 3-26)

Resuspension Rates as a Function of Substrate, Mechanism and PSD

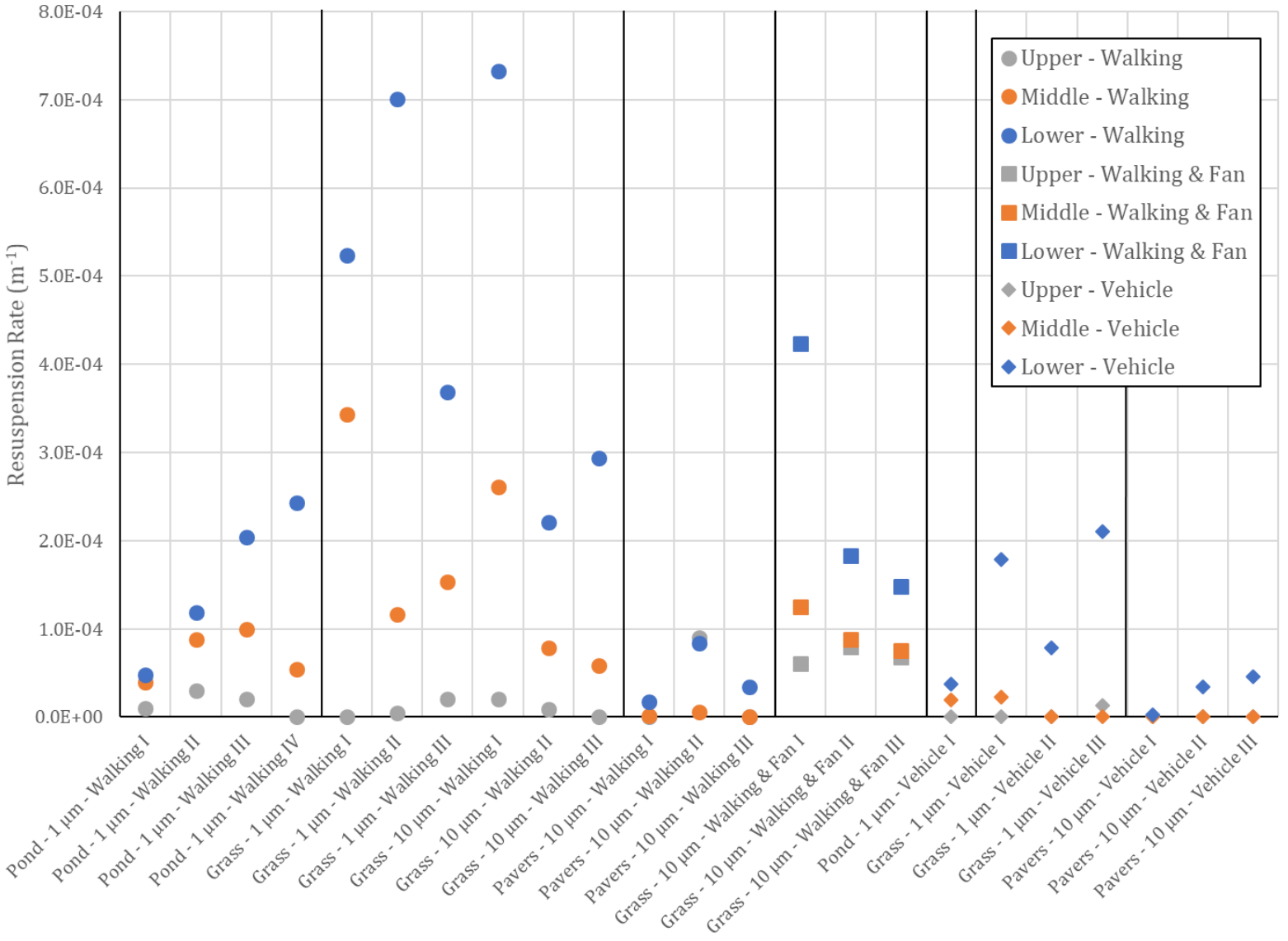
Resuspension Factor, K:

$$K = S_f = \frac{\chi}{D}$$

χ = Measured air concentration: (mg/m^3)

D = Area Deposition Density (mg/m^2)

Urban Setting K is lower than Grass



SAND2020-4899 (Figure 3-27)

Conclusions

Conclusions

- Evaluation of mass concentration, size distribution and resuspension rate under well constrained conditions:
  - Pond Liner, Artificial Grass, Pavers
  - Walking, Vehicle, Walking and Wind Blown

- PSD of resuspended particles can vary as a function of:
  - Height, substrate surface, time from deposition

- Artificial Grass
  - Highest mass concentration and highest resuspension factor for walking ($K = 10^{-4}$ m^{-1}) and vehicle ($K = 10^{-4}$ to 10^{-5} m^{-1}) mechanisms
  - Higher resuspension factor than in literature

- Paved Surface
  - Lower mass concentration and resuspension factors for walking ($K = 10^{-5}$ m^{-1}) and vehicle ($K = 10^{-5}$ to 10^{-6} m^{-1})
  - Resuspension as a function of time from deposition, 5 – 7 days showed highest resuspension rates

Conclusions

- Walking & Windblown
  - More applicable to real life applications
  - Resuspension at lower levels (0.3m) is preferential for larger sized particles ($K = 10^{-4}\ m^{-1}$)
  - Bi-modal at mid level (1.7m) ($K = 10^{-4}$ to $10^{-5}\ m^{-1}$)
  - Small particles at higher levels (3.35 m) ($K = 10^{-5}\ m^{-1}$)

- Evaluation of source terms of aerosol resuspension under constrained conditions
- Near-term dataset (0 to 15 days)
- Does not account for:
  - Complete Deposition
  - Transport
  - Entrainment or maintenance of lofted aerosol
  - Aerosolization and dissemination methods

- Using one number for modeling doesn't cross the breadth of surfaces and mechanisms

Questions?

Additional Slides

Material

^{241}Am specific activity of 3.428 Ci/gram

Material Properties	AmO_2	CeO_2
Density (g/cm^3)	7.65	11.68
Bulk Modulus (GPa)	213.7	217.7

Typical Uses	Form	Activity (Ci)		
		Min	Max	Typical
Calibration Facilities	Am	5	20	10
Research reactor startup	AmBe	2	5	2
Well logging	AmBe	0.5	23	20
Thickness gauges	Am	0.3	0.6	0.6
Fill level gauges	Am	0.012	0.12	0.06
Moisture detectors	AmBe	0.05	0.1	0.05
Moisture/density gauges	AmBe	0.01	0.1	0.05
Bone densitometry	Am	0.027	0.27	0.14
Static eliminators	Am	0.03	0.11	0.03

[a] *First-principles LDA+U and GGA+U study of cerium oxides: Dependence on the effective U parameter*, Christoph Loschen, Javier Carrasco, Konstantin M. Neyman, and Francesc Illas; The American Physical Society, 035115, 2007

[b] *Electronic, mechanical, and thermodynamic properties of americium dioxide*, Yong Lu, Yu Yang, Fawei Zheng, Bao-Tian Wang, and Ping Zhang; Journal of Nuclear Materials, 441 (411-420), 2013.

Summary of Results

Max Value
Min Value

	Nominal Particle Diameter (µm)	Resuspension Event	Time Since Deposition (day - hr:min)	Conditions During Resuspension		Mode Diameter (µm)			Average Concentration (mg/m^3)			Resuspension Factor (m^{-1})		
				Temperature (°C)	Relative Humidity (%)	Upper (3.35m)	Middle (1.70 m)	Lower (0.33m)	Upper (3.35m)	Middle (1.70 m)	Lower (0.33m)	Upper (3.35m)	Middle (1.70m)	Lower (0.33m)
Pond Liner	1	Walking I	0 - 13:27	27.7	36.3	4.07	4.07	3.05	0.019	0.073	0.089	1.03E-05	3.96E-05	4.82E-05
	1	Walking II	0 - 13:36	28.4	37.0	3.52	3.79	3.28	0.054	0.162	0.219	2.95E-05	8.75E-05	1.19E-04
	1	Walking III	0 - 19:27	27.0	42.8	4.07	4.37	4.37	0.048	0.239	0.490	2.00E-05	9.95E-05	2.04E-04
	1	Walking IV	0 - 22:07	30.1	36.8	12.86	3.79	4.70	N/A	0.130	0.584	N/A	5.40E-05	2.43E-04
Grass	1	Walking I	0 - 16:25	27.6	44.6	0.54	4.37	5.05	0.000	0.723	1.101	0.00E+00	3.43E-04	5.23E-04
	1	Walking II	0 - 16:38	28.3	51.0	5.83	3.79	3.52	0.009	0.253	1.516	4.36E-06	1.17E-04	7.01E-04
	1	Walking III	0 - 21:29	30.2	57.9	6.73	4.07	3.79	0.044	0.331	0.797	2.01E-05	1.53E-04	3.68E-04
	10	Walking I	0 - 23:44	25.9	17.3	8.98	5.83	7.77	0.051	0.658	1.847	2.02E-05	2.61E-04	7.32E-04
	10	Walking II	1 - 20:33	18.8	10.0	10.37	5.83	7.77	0.022	0.198	0.556	8.70E-06	7.85E-05	2.21E-04
	10	Walking III	1 - 23:05	22.7	7.8	11.97	5.83	7.77	0.001	0.147	0.740	3.70E-07	5.82E-05	2.94E-04
	10	Walking & Fan I	0 - 20:09	13.7	22.3	5.05	13.82	7.77	0.134	0.277	0.938	6.04E-05	1.25E-04	4.23E-04
	10	Walking & Fan II	1 - 16:35	10.2	57.1	5.43	11.97	7.77	0.177	0.196	0.405	7.99E-05	8.82E-05	1.83E-04
	10	Walking & Fan III	15 - 21:00	7.7	27.3	5.43	11.97	7.77	0.150	0.168	0.327	6.76E-05	7.57E-05	1.48E-04
Pavers	10	Walking I	0 - 21:39	13.7	23.2	0.84	11.97	5.05	N/A	0.004	0.040	N/A	1.55E-06	1.73E-05
	10	Walking II *	7 - 22:28	9.5	50.7	2.29	11.14	7.77	*	0.014	0.196	*	6.01E-06	8.37E-05
	10	Walking III	13 - 23:09	10.2	34.1	7.77	0.54	7.23	and	0.000	0.081	N/A	0.00E+00	3.44E-05
Pond Liner	1	Vehicle I	0 - 17:13	30.5	41.2	3.79	3.52	2.84	N/A	0.037	0.070	N/A	1.98E-05	3.76E-05
Grass	1	Vehicle I	0 - 18:45	29.6	44.7	0.54	4.37	3.28	0.000	0.048	0.375	0.00E+00	2.29E-05	1.78E-04
	1	Vehicle II	0 - 19:21	29.6	43.3	0.54	4.70	4.07	0.000	N/A	0.164	0.00E+00	N/A	7.81E-05
	1	Vehicle III	0 - 18:26	28.3	51.0	7.77	5.05	3.52	0.028	N/A	0.454	1.28E-05	N/A	2.10E-04
Pavers	10	Vehicle I	1 - 1:13	13.6	38.1	5.43	13.82	5.43	0.001	0.002	0.009	2.30E-07	6.18E-07	2.89E-06
	10	Vehicle II	5 - 0:37	10.7	19.4	5.83	3.79	6.73	0.000	0.002	0.104	4.58E-08	5.16E-07	3.44E-05
	10	Vehicle III	5 - 0:44	10.7	19.2	4.37	11.97	7.23	0.000	0.002	0.139	7.77E-08	5.40E-07	4.60E-05

* Data collected during this test was impacted by water droplets nucleating in the resuspension chamber at the upper level. As such this data was excluded from the analysis.

SAND2020-4899 (Table 3-1)

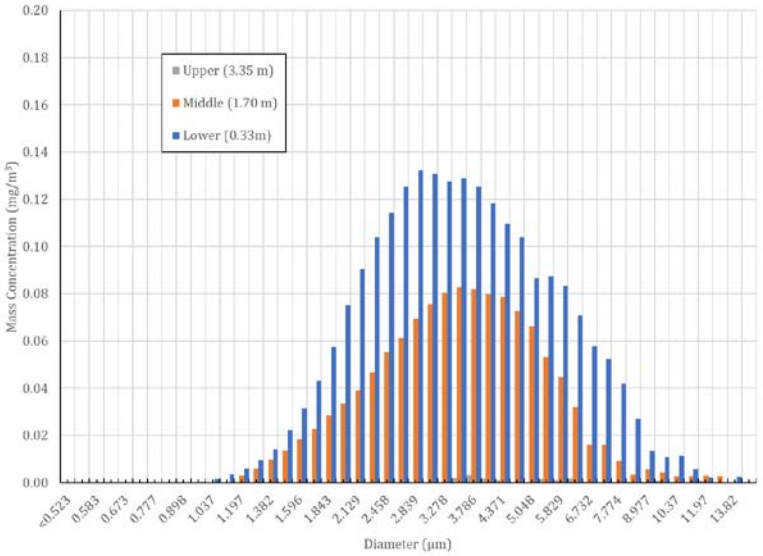
Size Distributions – Grass – Vehicle

Substrate: Grass

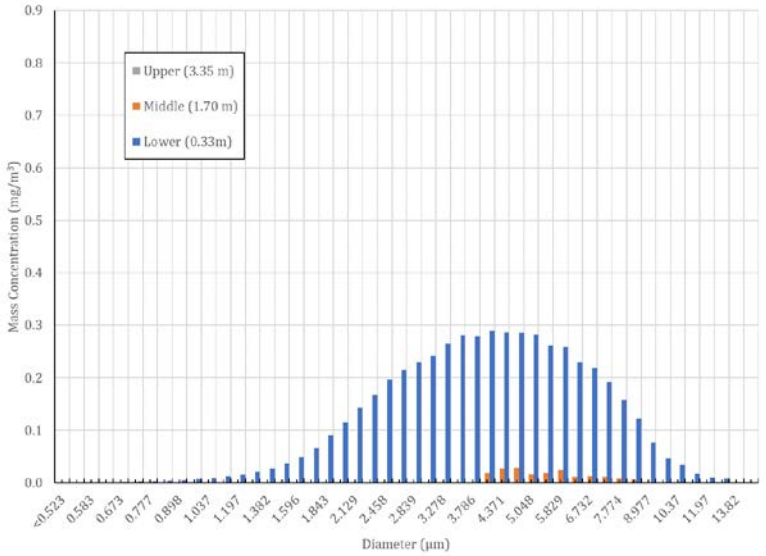
Method: Vehicle

Nominal Dp = 1 μm

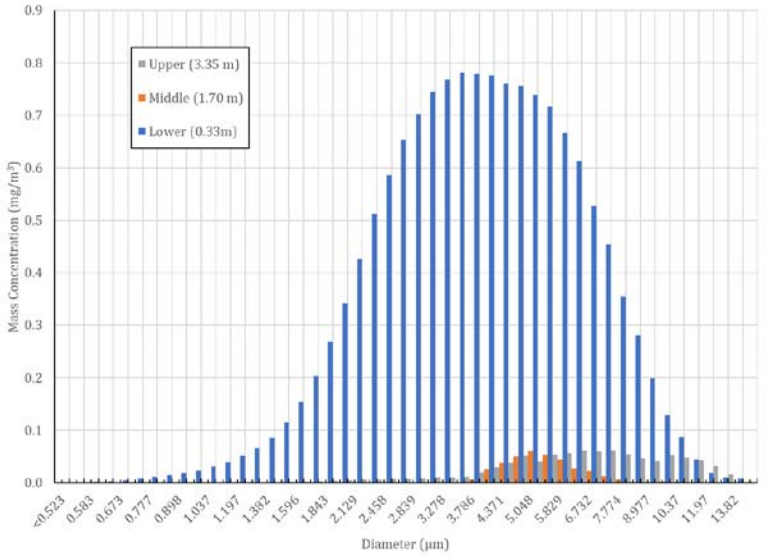
Δtime = 0 (days) – 18:45 (hr:mm)



0 (days) – 19:21 (hr:mm)



0 (days) – 18:26 (hr:mm)



- Mid-level concentrations are reduced over time

SAND2020-4899 (Figure 3-13, 3-14 and 3-15)

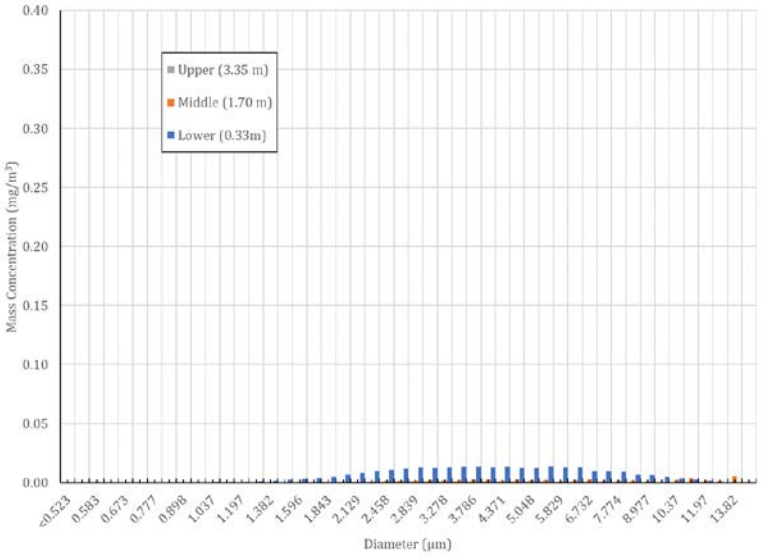
Size Distributions – Pavers – Vehicle

Substrate: Pavers

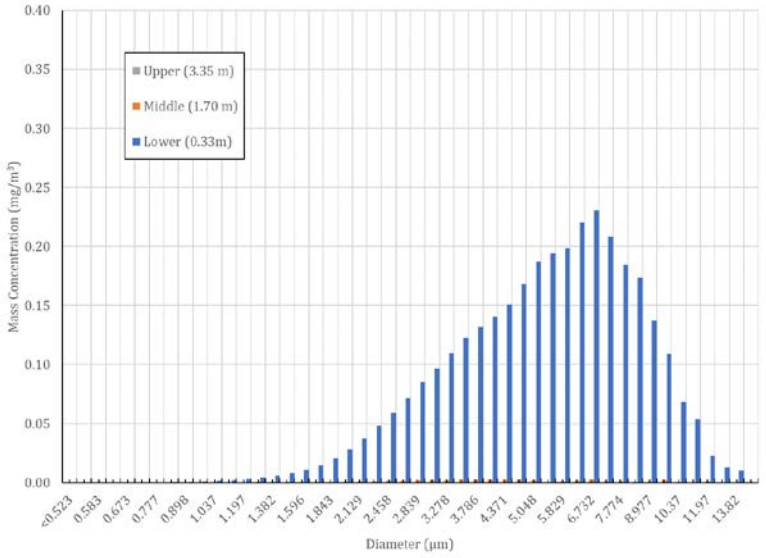
Method: Vehicle

Nominal Dp = 10 μm

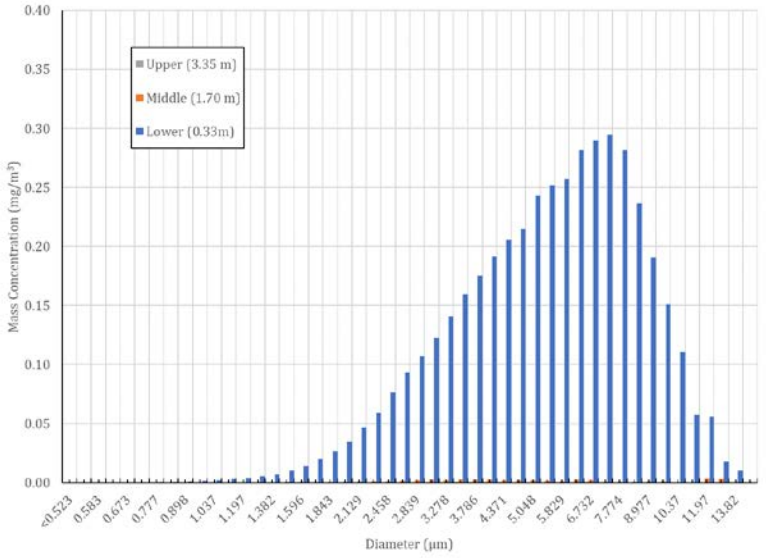
Δtime = 1 (days) – 01:13 (hr:mm)



5 (days) – 00:37 (hr:mm)



5 (days) – 00:44 (hr:mm)



- Lower concentrations than grass. Increased resuspension with time from deposition

SAND2020-4899 (Figure 3-22, 3-23 and 3-24)

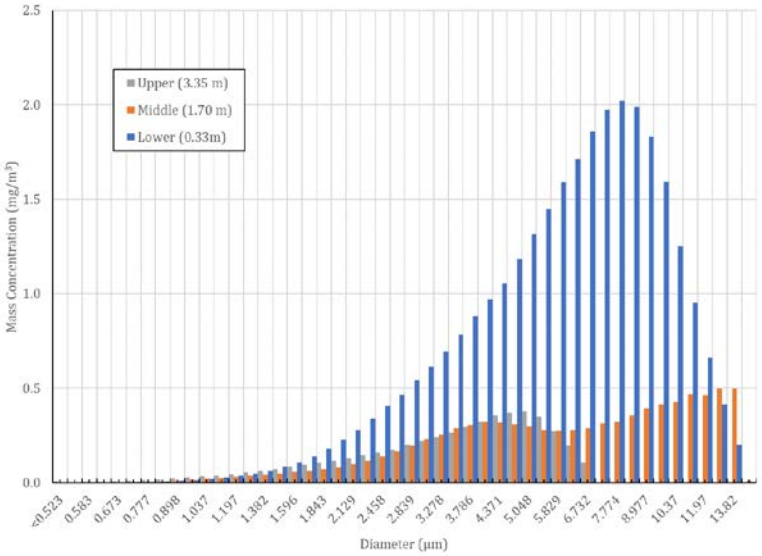
Size Distributions – Grass – Wind Blown

Substrate: Grass

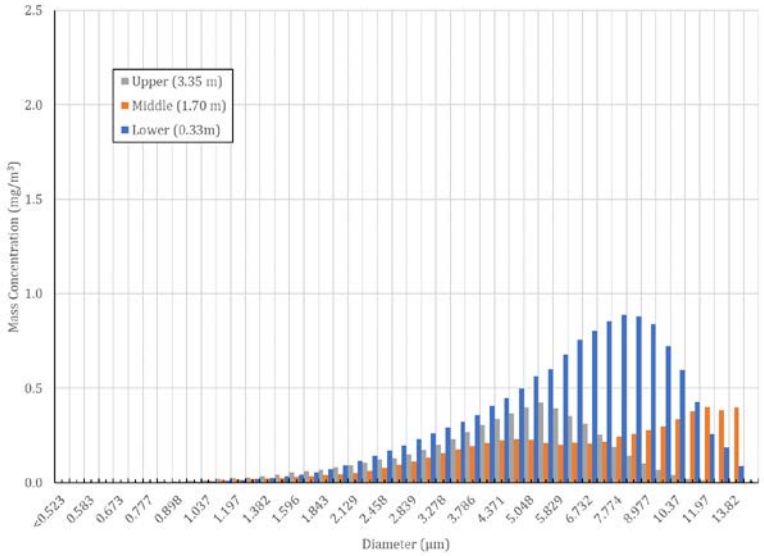
Method: Walking and Wind Blown

Nominal Dp = 10 μm

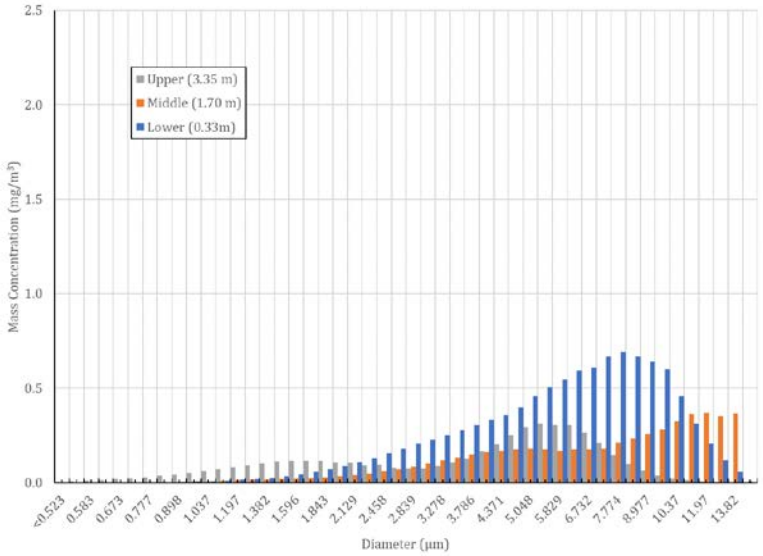
Δtime = 0 (days) – 20:09 (hr:mm)



1 (days) – 16:35 (hr:mm)



15 (days) – 21:00 (hr:mm)



- More representative of real world. Well mixed with agglomeration

SAND2020-4899 (Figure 3-16, 3-17 and 3-18)