Reconciling Fugitive Dust Emissions with Ambient Measurements: Along the Unpaved Road

V. Etyemezian*, J. Gillies, H. Kuhns, D. Nikolic
Division of Atmospheric Sciences
Desert Research Institute
Las Vegas, NV

and

G. Seshadri, J. Veranth
University of Utah
SLC, UT

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Outline

- Background
  - What is the phenomenon being examined?
  - Why is it important?
- Modeling approaches
  - Gaussian plume model (ISC style)
  - Box Model (Gillette style)
  - Deposition velocity
- Model results
  - What do initial results tell us?
  - How does this compare with measurements?
  - Where do we need improvements?
- Conclusions and Future Work

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Relevance to Fug Dust Emissions

- Not accounting for near-field deposition ⇒
  - Overestimate fug dust regional contribution (e.g. Chow and Watson, 2000; Countess, 2001)
  - Erroneous estimate of size distribution of regionally transportable fraction (important for visibility)
  - Cannot resolve PM_{10} contributions from varying fug dust sources
    - Is it the nearby unpaved road, the farm 5 km upwind, or China?
- Over-accounting for deposition ⇒
  - Similar problems

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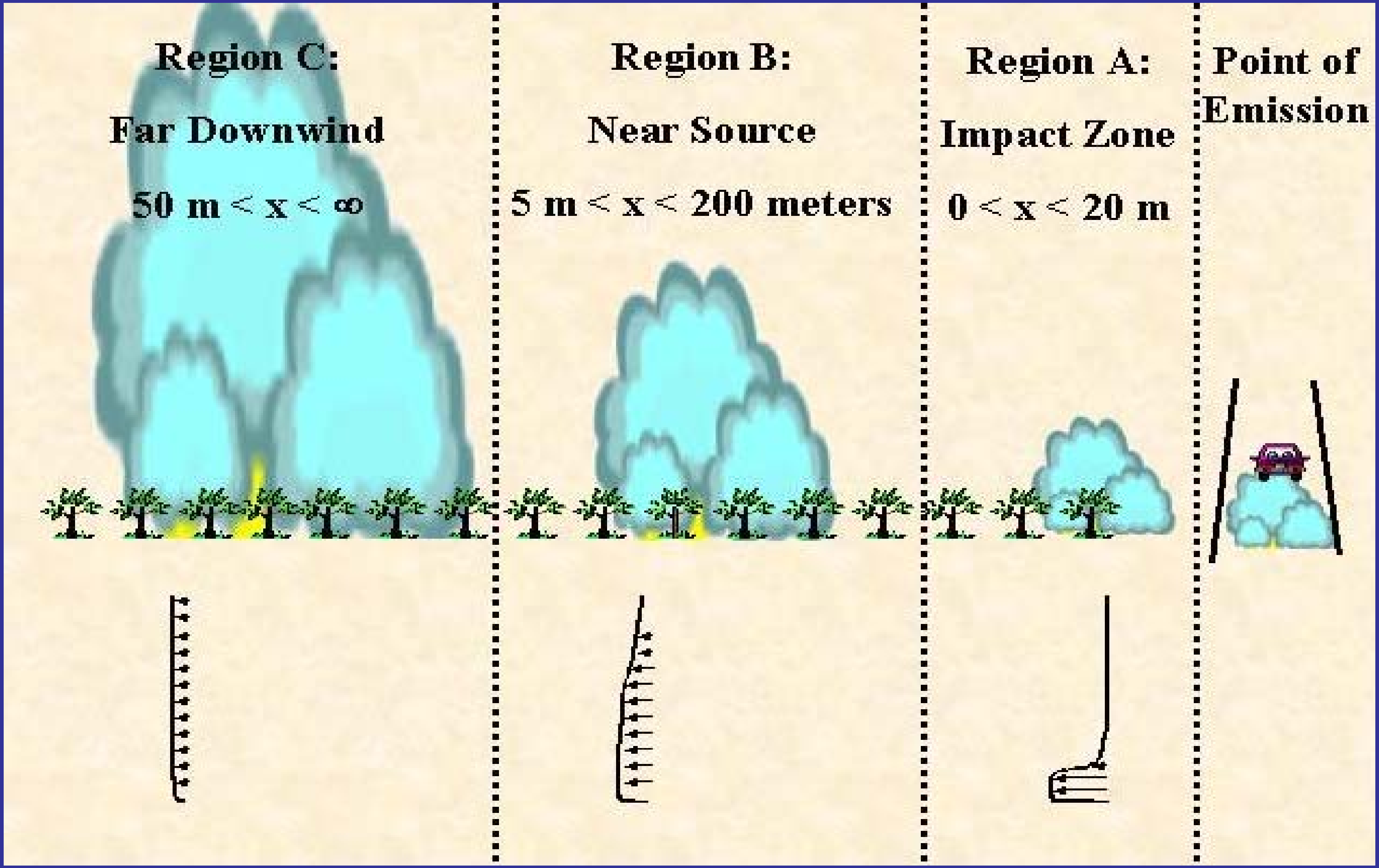
Downwind of Dust Source



Downwind Regimes

Removal of PM_{10} dust by vegetation/land cover

- Region "A":
  - Plume height ~ vegetation height
  - Work in progress
- Region "B":
  - Mixed height > Plume height > vegetation height
  - Addressed in this study
- Region "C":
  - PM_{10} ~ constant with height
  - Addressed in regional scale models

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Gaussian Plume Approach

- **Use Gaussian plume model to simulate dispersion**
- **Assumptions:**
    - o **Gaussian profile is reasonable**
    - o **Deposition is "slow" compared to dispersion. I.e. can distribute removal over entire plume**
    - o **Can use bulk deposition models even though concentration gradients high very near the source**

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Gaussian Approach Cont.

- Basic equation similar to ISC3:

$$C = \left(1 \times 10^{-6}\right) \frac{QVD}{2\pi u_s \sigma_y \sigma_z} \exp\left[-0.5\left(\frac{y}{\sigma_y}\right)^2\right]$$

Q = pollutant emission rate (g/s)

V = a vertical term that includes reflection, deposition, and mixing

D = chemical decay term (equal to 1 since dust non-reactive)

σ_y, σ_z = standard deviation of vertical and lateral concentration

u_s = mean wind speed at release height.

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Gaussian Approach Cont.

Assume line source ⇒ Integrate crosswind:

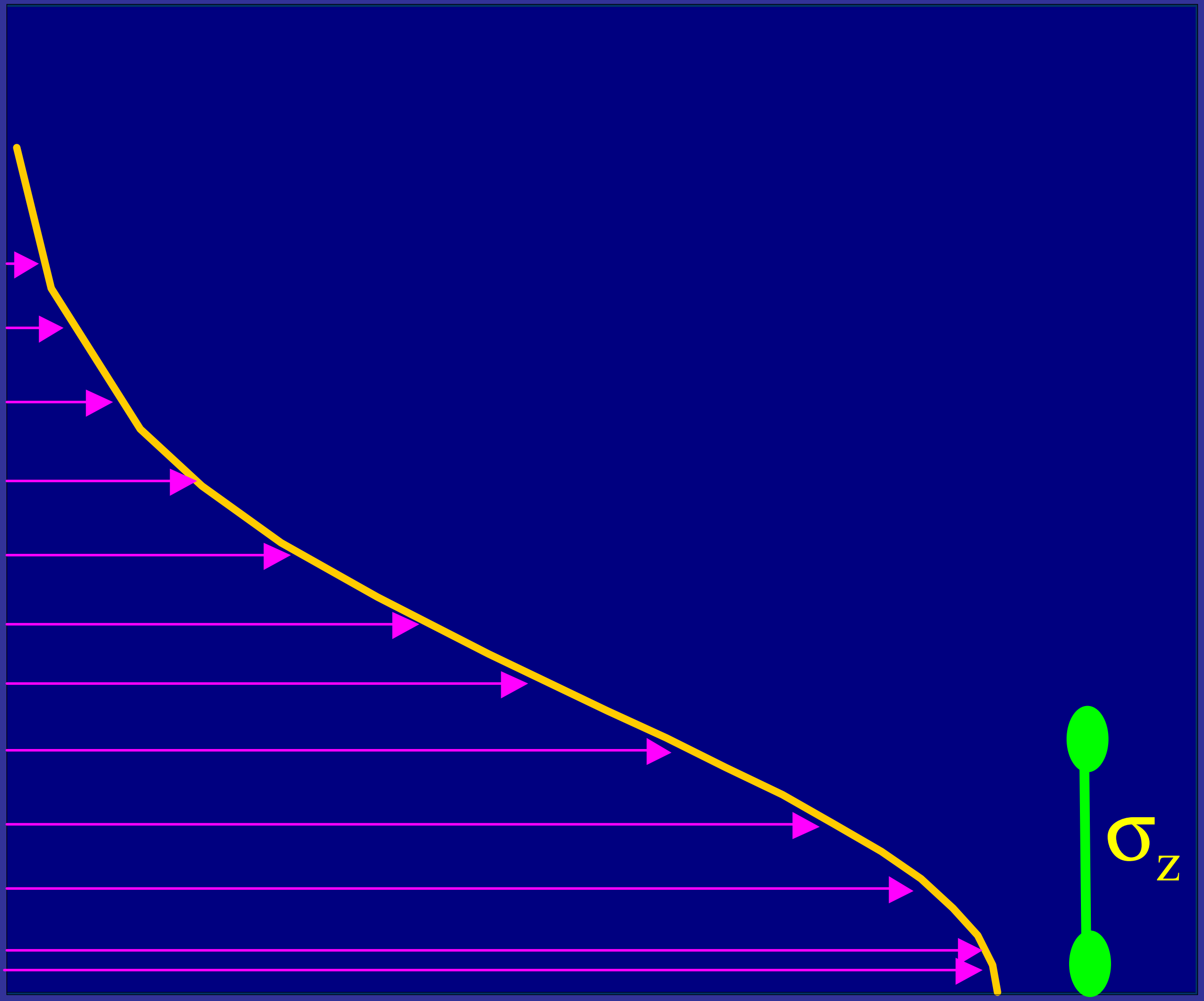
$$C = \left(1 \times 10^{-6}\right) \frac{\dot{Q} V}{\sqrt{2\pi}\, u_s \sigma_z}$$

Vertical term:

$$V = \exp\left[-0.5\left(\frac{z_r - h}{\sigma_z}\right)^2\right] + \exp\left[-0.5\left(\frac{z_r + h}{\sigma_z}\right)^2\right] + [.....]$$

If h = 0, z = 0, V=2

Gaussian Approach Cont.



Gaussian Approach Cont.

Vertical Standard Deviation:

$$\sigma_z = ax^b$$

Constants a, b from Turner (1970) dependent on atmospheric stability and distance downwind

Guassian Approach Cont.

Additional Considerations:

- Initial height ⇒ + x' to downwind distance

$$\sigma_z = a\left(x + x'\right)^b = IH \approx H_{vehicle}$$

- Assume WS uniform with height. I.e. WS×Time=Distance
- Limited accuracy near ground and near source

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Box Model Approach

- Proposed by Gillette (2002)
- Mass balance on long box downwind of unpaved road. Particle flux only at entrance, top, and bottom
- Dispersion through top ∝ Concentration

$$\left.\frac{dm}{dt}\right|_{top} = K * C \qquad K = Au_*$$

- Deposition at ground ∝ Concentration

$$\left.\frac{dm}{dt}\right|_{depos} = V_d * C$$

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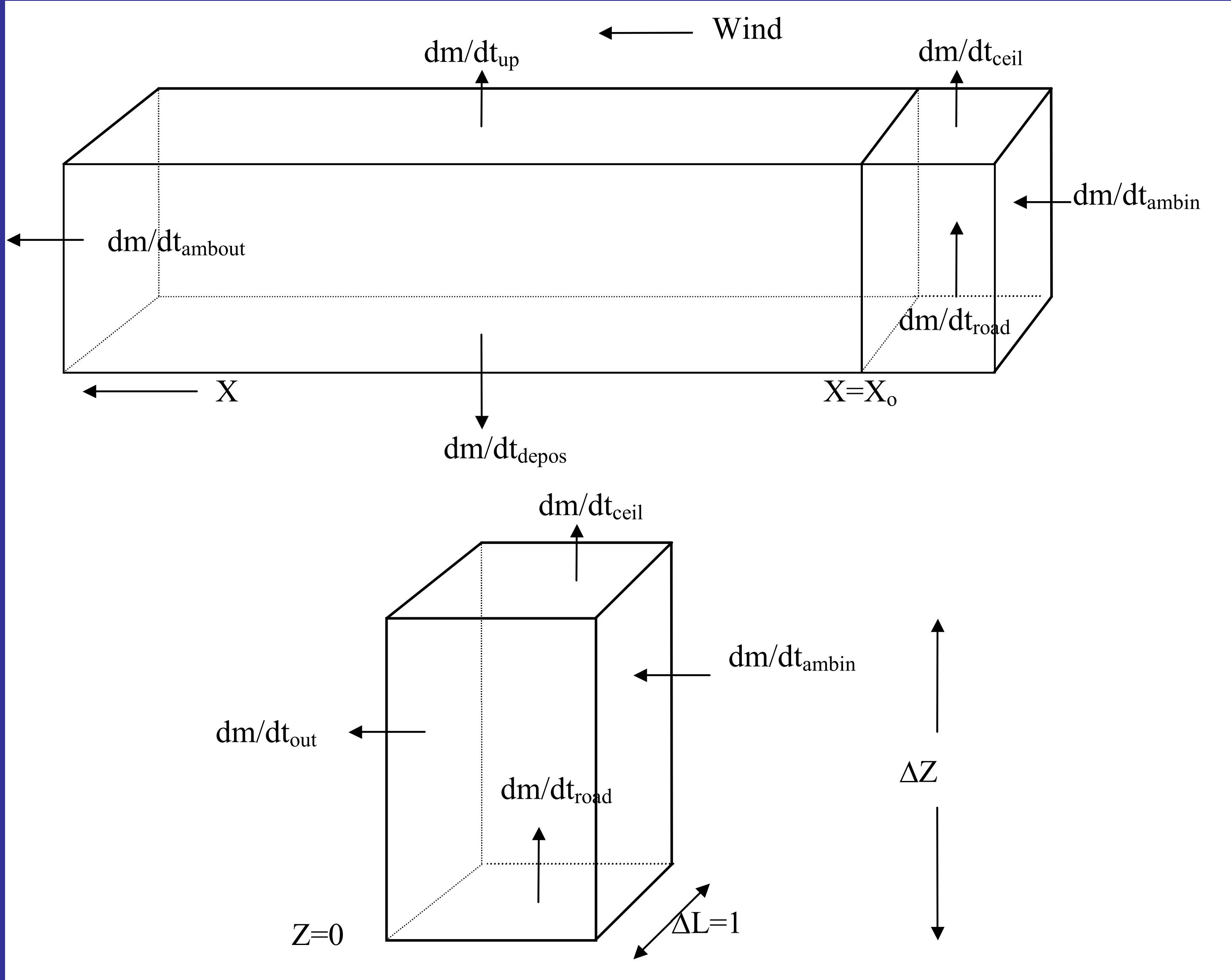

Wind
dm/dt_up
dm/dt_ceil
dm/dt_ambin
dm/dt_ambout
dm/dt_road
X
X=X_o
dm/dt_depos
dm/dt_ceil
dm/dt_ambin
dm/dt_out
dm/dt_road
ΔZ
Z=0
ΔL=1

Box Model Cont

- Resultant Equation for Transportable Fraction

$$\Phi = \frac{\frac{dm_{up}}{dt}}{\frac{dm_{road}}{dt}} = \left[1 - \frac{V_d}{(V_d + K)}\right] = \frac{K}{(V_d + K)}$$

where V_d and K (= 0.06 u^*) are constant

Dry Deposition

- Flux to Ground ∝ Concentration

  $F_{dep} = V_d * C$ $V_d \equiv$ Deposition velocity
- Framed for removal from uniform concentration in bulk medium (e.g. Slinn, 1982)
  - Ground release is opposite situation
  - Roughness elements < concentration profile
  - Assumptions may apply ~10's m downwind
- Assume removal due to impaction mostly

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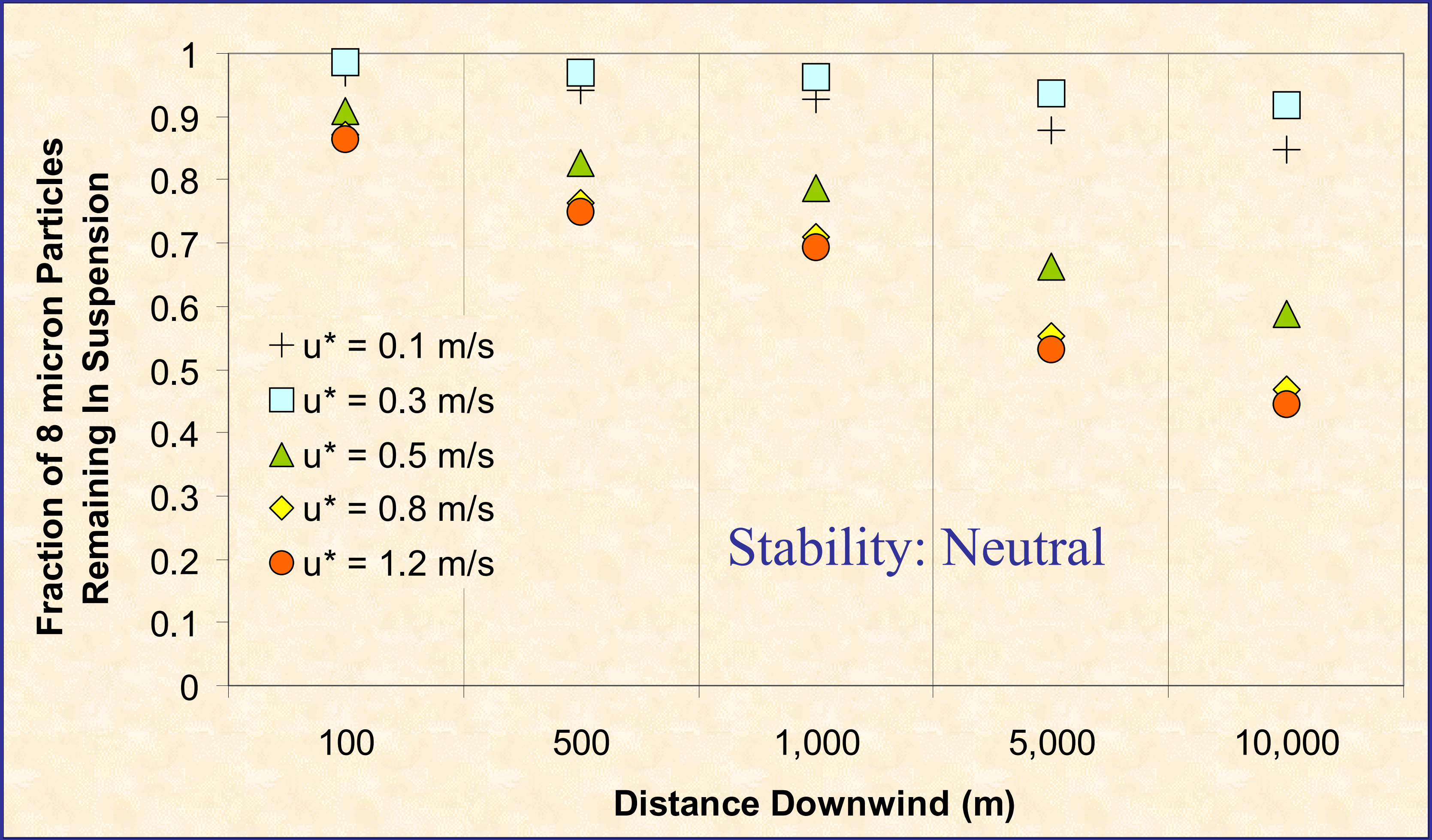
Results: ISC Fraction in Suspension vs. distance



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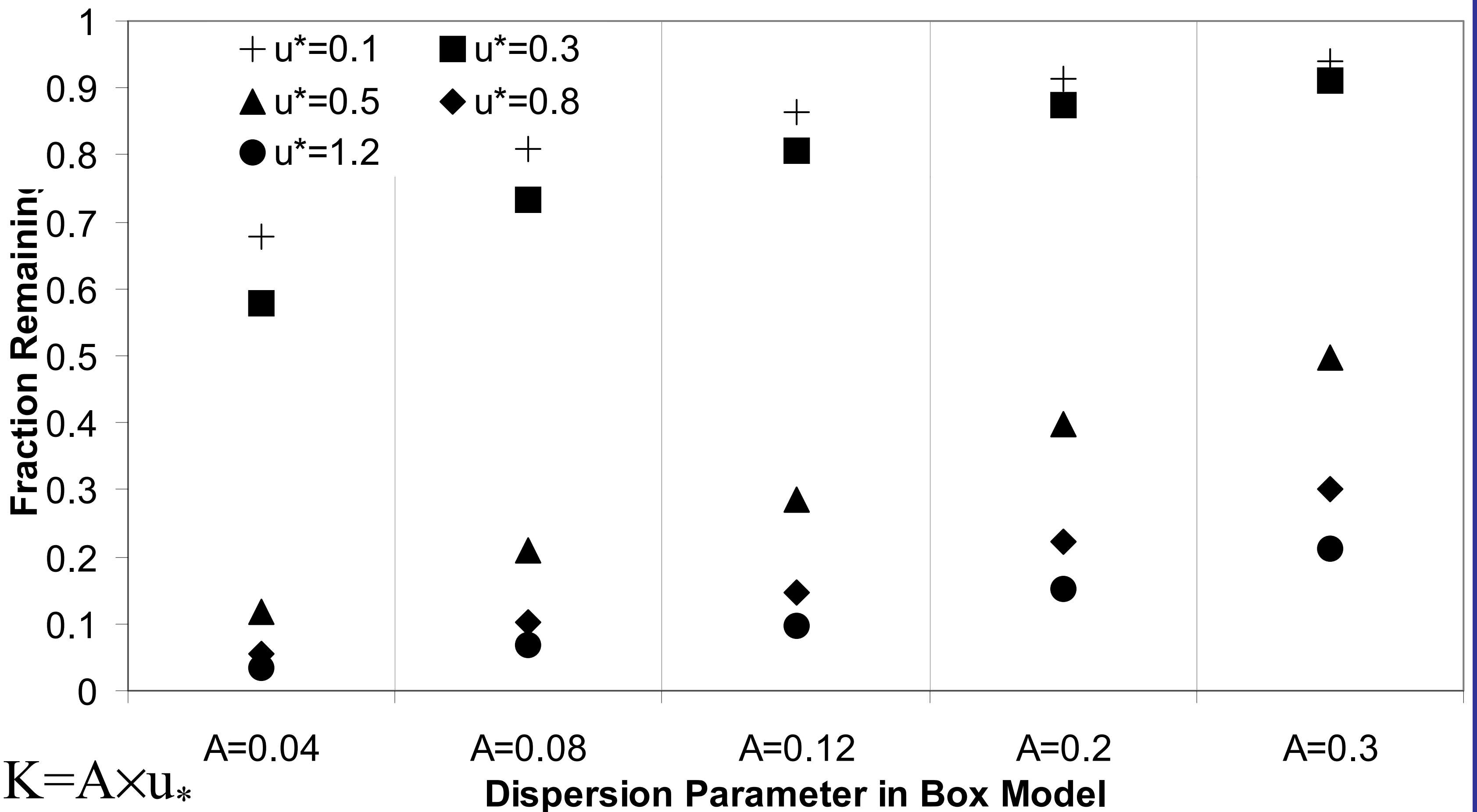
Results: Box Model Prediction



$K = A \times u_*$

Results: Box Model Difficulties

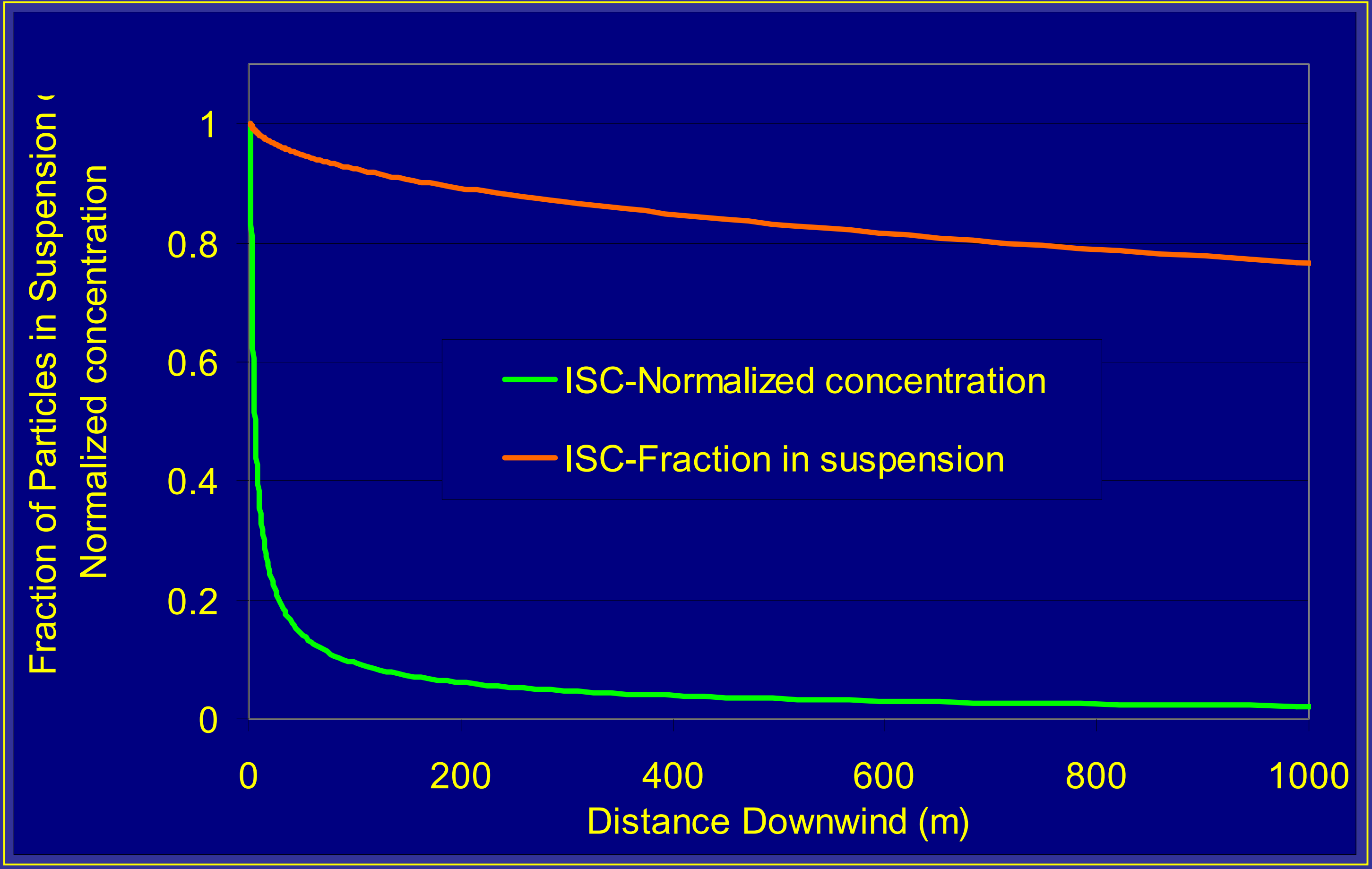
- Deposition O.K.
- For first order dispersion, I.e. $\left.\frac{dm}{dt}\right|_{top} = K * C$ Limited applicability
- To specify K correctly, require specification of distance downwind

Results: Stability and Transportable Fraction

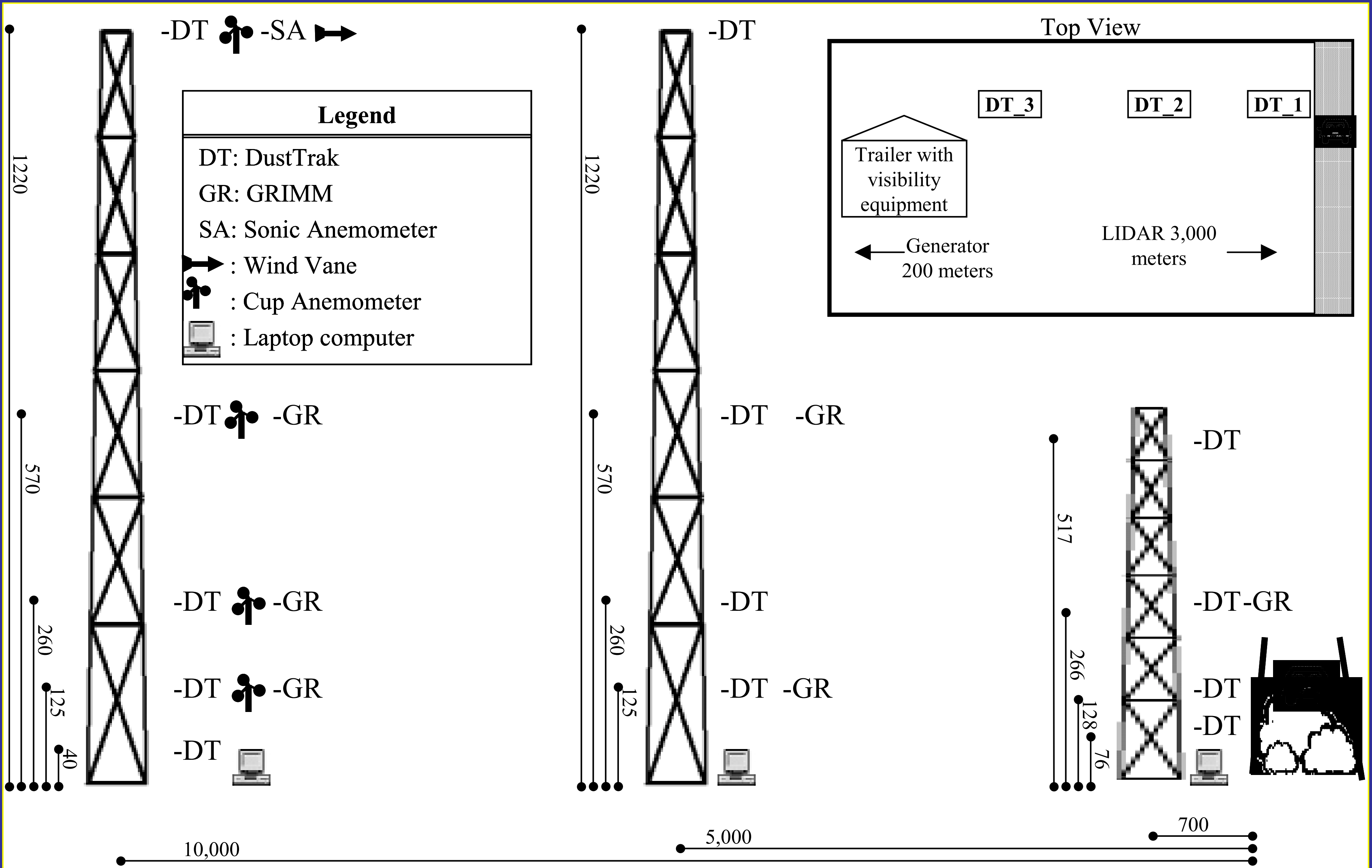
Stability	**u* = 0.3 m/s**		**u*=0.5 m/s**	
	500 m	*5,000 m*	*500 m*	*5,000* m
Very Stable	0.95	0.87	0.72	0.43
Stable	0.96	0.91	0.79	0.57
Neutral	0.97	0.94	0.83	0.66
Moderately Unstable	0.98	0.98	0.91	0.86
Very Unstable	0.99	0.99	0.93	0.92

Note: Particle size differences similar to u* differences

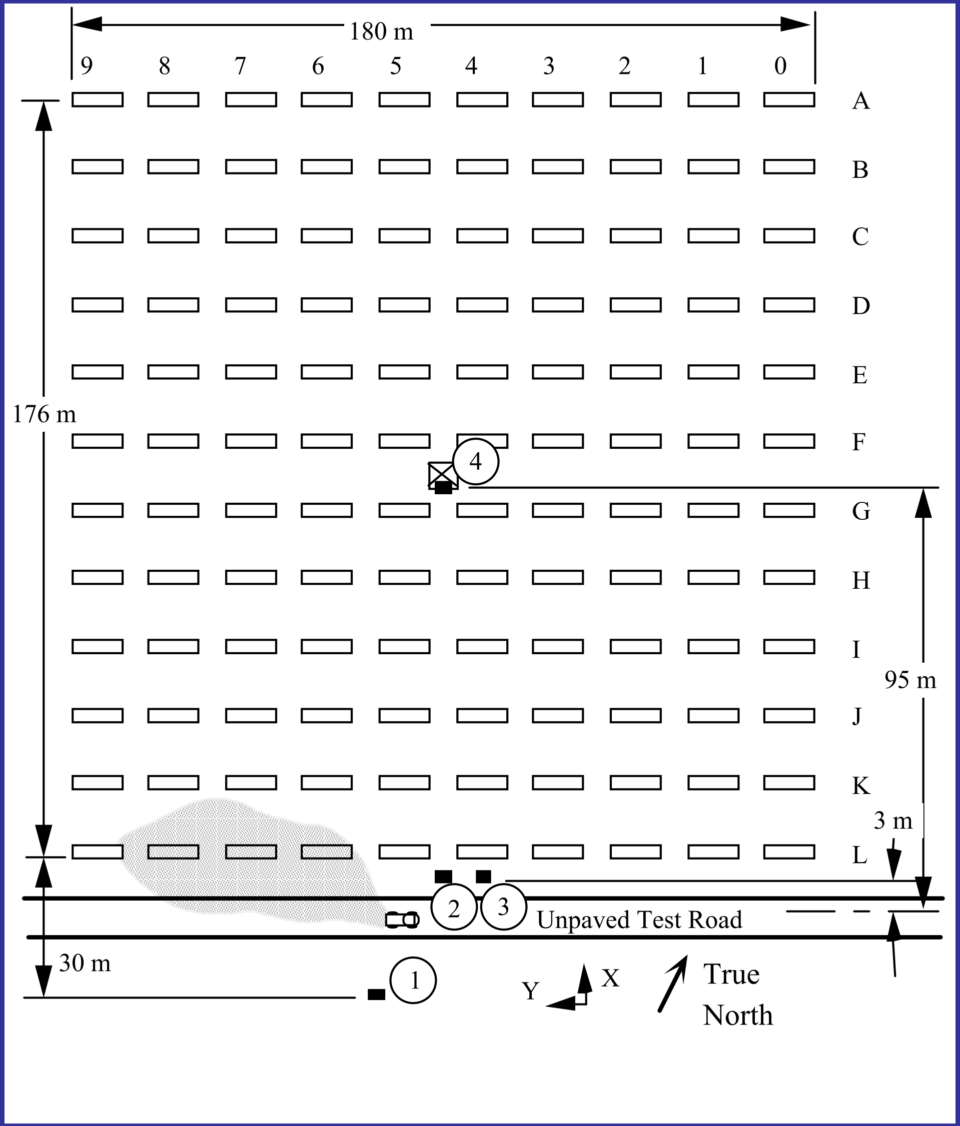
Results: Concentration not indicator of removal



Measurements: Daytime desert



Measurements: Nighttime urban?



Array of cargo containers.

Dimensions (m): $2.5 \times 2.4 \times 12.2$

Effective z_0: 0.1 m

Effective u_*: 0.4 m/s

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Results: Measurement vs. model

- Daytime Desert fraction PM_{10} removed:
  - Measured: 0%
  - Modeled: 3%
- Nighttime urban fraction PM_{10} removed:
  - Measured: 85%
  - Modeled: 30%

Conclusions

- Fraction of PM_{10} removed near source
  - Decreases with WS initially, increases at higher WS
  - Minimum for unstable conditions
  - Minimum for small roughness height
  - Not proportional to concentration
- Box model has limitation in dispersion

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Future Work

- Gaussian model simple and holds promise
- Essential to have field data
  - Multiple atmospheric conditions
  - Multiple roughness (vegetative/land cover type and density)
- Examine “Region A” removal

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