Field-scale particle transport in a trellised agricultural canopy during periods of row-aligned winds

Nathan E. Miller*, Rob Stoll*, Walter Mahaffee**, Tara Neill**, Eric R. Pardyjak*
*University of Utah, SLC, UT **USDA-ARS, Corvallis, OR

Abstract

The transport of particulate plays an important role in trellised agricultural canopy ecosystem processes. This includes the transport of pests, pollutants, and biological propagules. The concentrations of these particulates are typically highest very near their sources, but it is well documented that they also have the potential to be transported over large length-scales and from field to field. In fact, in natural ecosystems the movement of pollen is needed for plant species survival while the transport of pathogens and pests can result in economic and ecological damage. In recent years we have performed considerable research on the dispersion patterns of particles in a trellised agricultural canopy but have primarily focused on transport at length-scales between one and seven canopy heights [1,2]. Although this is the space wherein the majority of the particles are dispersed and removed from the flow, field-scale transport is also a common occurrence in agricultural canopies.

In order to better understand the behavior of transport at length-scales approaching the size of the field, multiple particle release experiments were performed during a field campaign in 2013 in a vineyard near Monmouth, Oregon. During these events, inert fluorescent microspheres (10 to 45 μm diameter) were released into the canopy and were sampled at downwind length-scales between seven and 75 canopy heights. These events were performed when the above-canopy winds were blowing nearly parallel to the vine row direction. It was expected that the plume shape patterns from these microsphere plumes would exhibit similarities to those seen for dispersion at equivalent length-scales in other canopy types, e.g., homogeneous vegetation and urban canopies. The specific effects of the vineyard canopy were identified and plume shape parameters were compared to those seen in other canopies and those observed in the same vineyard for plume dispersion at the smaller length-scales.

GOAL: To study field-scale transport patterns of particulate in a trellised canopy and to identify differences from those seen in other canopies.

Field Campaign

- The Vineyard, August 2013 [2,3,4]:
  - Wildwood Vineyard, Monmouth
  - 44° 49′ 28″ N, 123° 14′ 15″ W
  - N-to-S rows spaced at 2.45 m apart o/c
  - $LAI = 1.0$, canopy height, $h = 2.15$ m
- Meteorological tower [4]
  - 10m tower
  - 6 Sonic Anemometers
  - Thermocouples
  - Other sensors (radiation, soil, leaf)
- Particle release events
  - 21 near-source ($x<8.5h$) events over all wind directions [2,3]
  - 2 field-scale ($8h<x<85h$) events during parallel winds

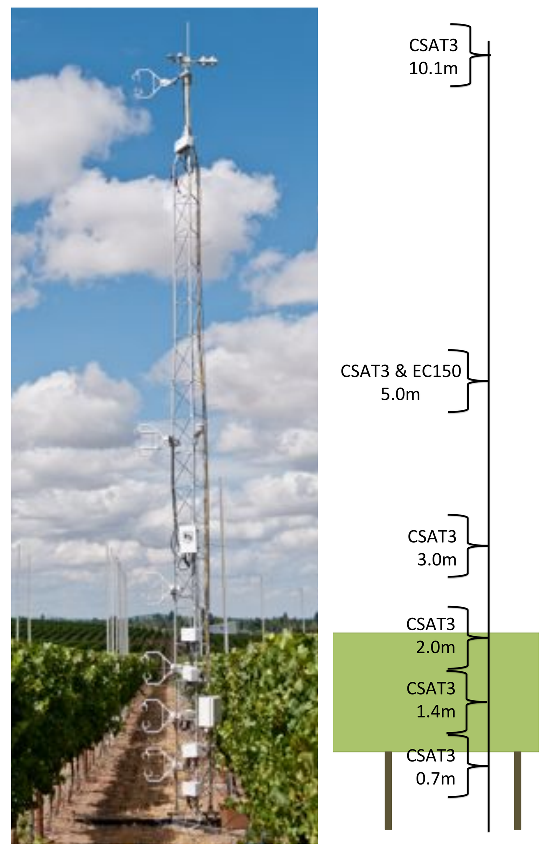

Figure 1: Meteorological tower in the vineyard

Table 1: Meteorological conditions during the field-scales release events. $\delta = \overline{wd} -$ row direction.

Event	time	$U(10\text{ m})$	U_h	$\overline{wd} = \delta$	u_*	h/L
1	16:35	5.80 m/s	2.31 m/s	8.25°	0.56 m/s	-0.021
2	17:53	5.44 m/s	2.21 m/s	6.38°	0.49 m/s	-0.020

Particle Plumes

- Microspheres
  - Inert fluorescing polyethylene microspheres: Cospheric Inc.
  - 10-45 μm diameters mean $= 35.4\ \mu m$
- Release devices
  - 3 collocated ultrasonic Nozzles: Sonaer Inc.
  - Syringe Pump with solution
- Impaction Traps
  - Rotating rod impaction traps
  - 25 towers with 5 traps each
  - 3 arcs at 18, 90, & 180 m downwind

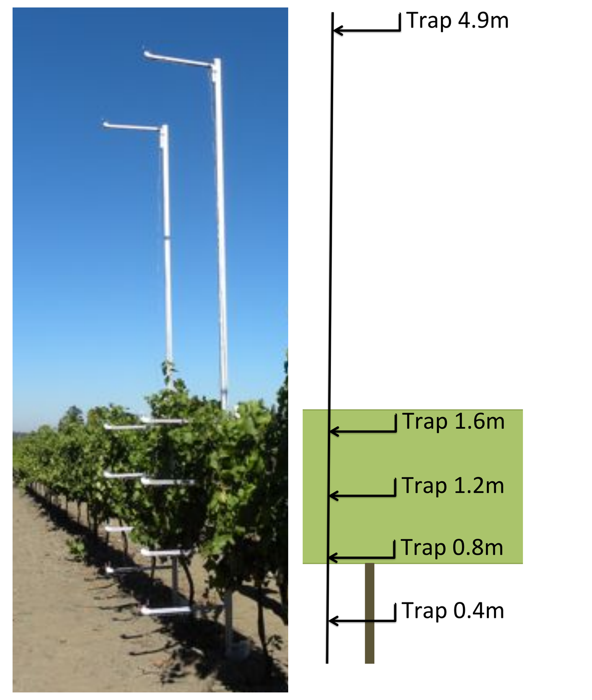

Figure 2: Tower of rotating rod impaction traps in the vineyard

Table 2: Release event parameters.

Event	Duration	Mass	H_r
1	20 min	18.0 g	1.37 m
2	18 min	16.2 g	1.37 m

- Scaled concentration at each trap determined from microsphere count

$$\Pi = \frac{mU_h}{\not{V}\,Q}$$

- m = mass collected
- $\not{V}$ = swept volume
- Q = source strength

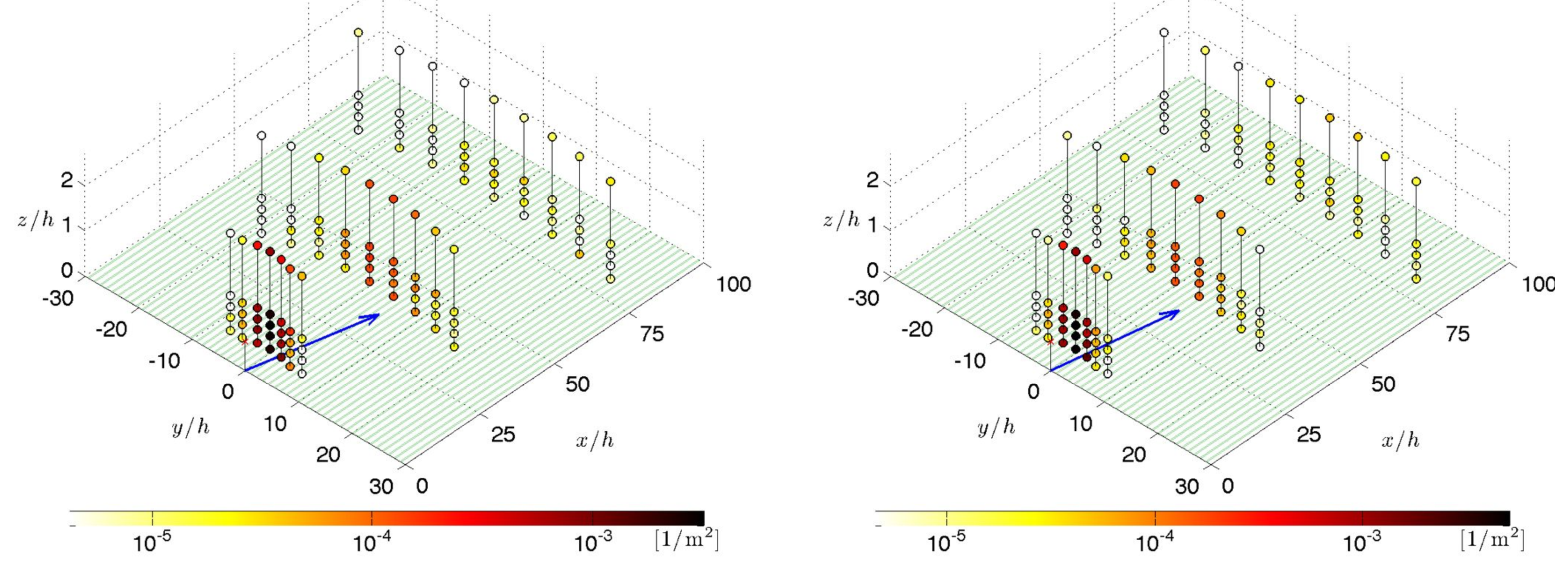

Figure 3: 3D depictions of Π data for Events 1 (left) & 2 (right).

Acknowledgments

- Staff at USDA ARS Labs in Corvallis Oregon
- UofU Global Change and Sustainability Center
- NSF Grant: AGS 1255662
- USDA Project: 5358-22000-039-00D

References

[1] Miller NE, Stoll R, Mahaffee WF, Neill TM, Pardyjak ER. (2015) An experimental study of momentum and heavy particle transport in a trellised agricultural canopy. *Agric. and For. Meteorol.* **211-212**: 100-114

[2] Miller NE, Stoll R, Mahaffee WF, Neill TM, Pardyjak ER. (2016) Heavy particle transport in a trellised agricultural canopy during row-aligned winds. In preparation

[3] Miller NE, Stoll, R, Mahaffee WF, Neill TM. (2016) Heavy particle transport in a trellised agricultural canopy during non-row-aligned winds. In preparation

[4] Miller NE, Stoll R. Mahaffee WF, Pardyjak ER. (2016) The mean and turbulent flow statistics in a trellised agricultural canopy. In preparation

[5] Venkatram A, Isakov V, Pankratz D, Heumann J, Yuan J. (2004) The analysis of data from an urban dispersion experiment. *Atmos. Environ.* **38**: 3647-3659

[6] Franzese P, Huq P. (2011) Urban dispersion modelling and experiments in the daytime and nighttime atmosphere. *Bound.-Layer Meteorol.* **139**: 395-409

[7] Hanna S, Baja E. (2009) A simple urban dispersion model tested with tracer data from Oklahoma City and Manhattan. *Atmos. Environ.* **43**: 778-786

Plume Shape Analysis & Stats

Fit the Skew-Gaussian Equation (SGE) used for near-source plumes [1]:

$$\Pi = \frac{A}{2\pi\omega_y\sigma_z}\exp\left(\frac{-(y-\xi_y)^2}{2\omega_y^2}\right)\left[\exp\left(\frac{-(z-H_r)^2}{2\sigma_z^2}\right)+\exp\left(\frac{-(z+H_r)^2}{2\sigma_z^2}\right)\right]\left[1+\operatorname{erf}\left(\frac{\alpha_y(y-\xi_y)}{\omega_y\sqrt{2}}\right)\right]$$

- A = mass decay
- σ_z = vertical plume spread
- ξ_y = plume centerline offset
- γ_y = skewness = F(α_y)
- μ_y = mean = F($\omega_y, \xi_y, \alpha_y$)
- σ_y = spread = F($\omega_y, \xi_y, \alpha_y$)

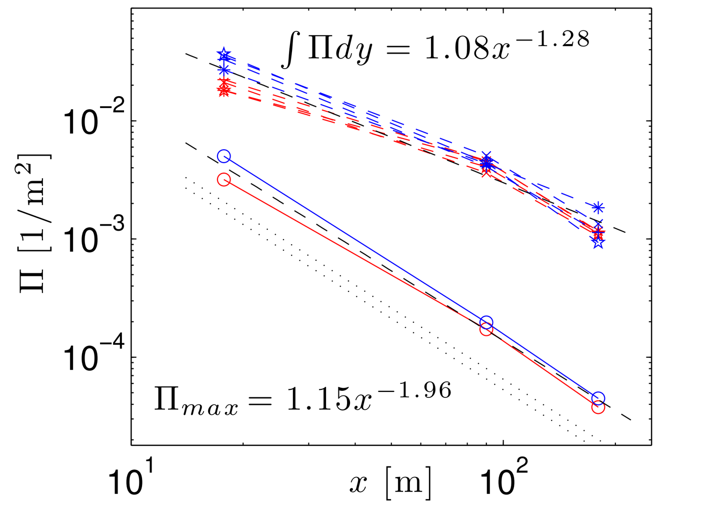

Figure 4: Decay of maximum & spanwise integrated concentrations with x. *Red* = Event 1. *Blue* = Event 2. Dashed lines are best-fit with equations shown. Dotted lines from [5] with exponent of −2.

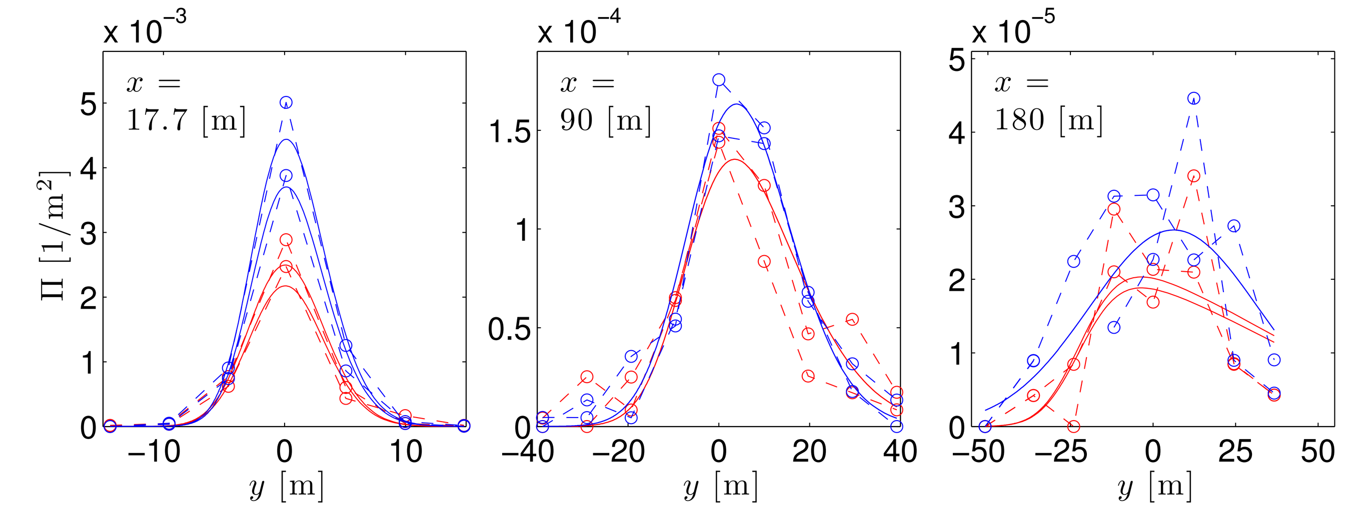

Figure 5: Spanwise profiles of Π with curvefits from SGE for $z = 0.87h$ & $z = 0.40h$ at each downwind distance. *Red* = Event 1. *Blue* = Event 2.

Table 3: Plume shape from fits around $\overline{wd}$. Offset of row direction from $\overline{wd}$ shown with μ_y.

	r^2		σ_y [m]		μ_y [m]		γ_y	
Event	1	2	1	2	1	2	1	2
x = 17.7 m	0.94	0.97	3.10	3.06	-2.43(-2.3)	-1.37(-2.0)	-0.04	0.28
x = 90 m	0.87	0.91	12.9	11.6	-5.60(-11)	-4.53(-10)	0.50	0.26
x = 180 m	-0.27	-0.20	33.4	25.3	-5.41(-23)	-14.3(-20)	0.88	-0.07

- Plume shape parameters were a logical continuation of the near-source plume parameters:

Table 4: Plume shape parameters from a near-source release with $\delta = -7.6°$ [2].

Event	σ_y [m]	μ_y [m]	γ_y
x = 3.0 m	1.16	0.57	-0.01
x = 5.5 m	1.58	0.55	-0.41
x = 8.0 m	2.27	1.04	-0.14
x = 16.0 m	3.45	1.42	-0.19

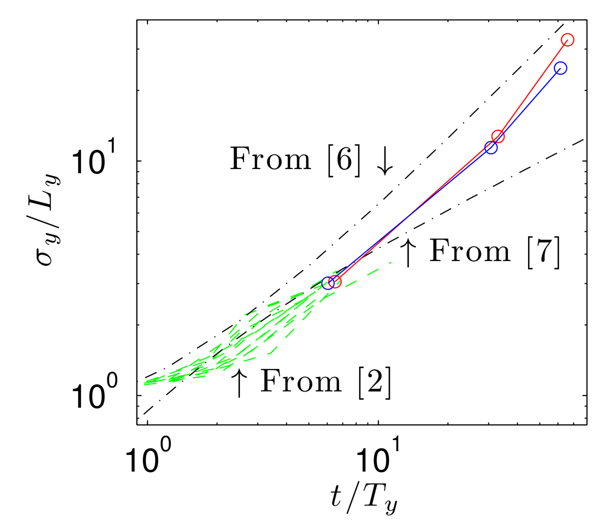

Figure 6: Plume width vs non-dimensional advection time. Comparisons to near-source plumes [2] & from two urban studies [6,7].

Conclusions & Future Work

- μ_y lands between $\overline{wd}$ & row direction = skewness
- σ_y matches near-source plumes and urban studies
- Need more replicants, with higher source strength to improve 180 m plane