Simulation of Particle Dispersion in a Trellised Agricultural Canopy using the QUIC Dispersion Model

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Abstract

The QUIC (Quick Urban and Industrial Complex) Dispersion Modeling System is a high-resolution numerical tool that was originally developed to rapidly compute the transport of contaminants in urban areas. QUIC includes an empirically based mass consistent building-resolving wind model for determining time-averaged three-dimensional velocity fields in cities as well as an urbanized Lagrangian dispersion model with turbulence parameterizations for computing particle concentrations and deposition. More recently, the capacity to compute dispersion through vegetative canopies and windbreaks has been added to the system. In this work, we evaluate QUIC's ability to compute the dispersion of particles in trellised agricultural canopies such as vineyards. The simulations are based on field experiments conducted by our team in a commercial vineyard near Monmouth, Oregon during the fall of 2011 and 2013. During these experiments, microspheres with a similar size and mass to multiple natural particles of interest in vineyards including the spores of *Erysiphe necator* and of *Botrytis cineria*, were released for different wind directions with respect to the structured canopy (δ). Comparisons between QUIC and the experimental results for mean winds and concentrations are presented. A discussion of QUIC's performance with respect to different meteorological conditions is presented along with recommendations for potential model improvements.

Field Experiments

- Field study performed in a vineyard near Monmouth, Oregon [1,2,3]
  - 44° 49′ 28′′ N, 123° 14′ 15′′ W
- Sept 2011: LAI = 1.4
  - Canopy height, h = 1.93 m
- Aug 2013: LAI = 1.0
  - Canopy height, h = 2.15 m
- North to South oriented rows spaced at 2.45 meters apart on center
- Meteorological tower centered in aisle
  - Collected temperature, H_2O flux, CO_2 flux, and wind data at 20 Hz
  - 2011: 4 anemometers, 28 days
  - 2013: 6 anemometers, 19 days

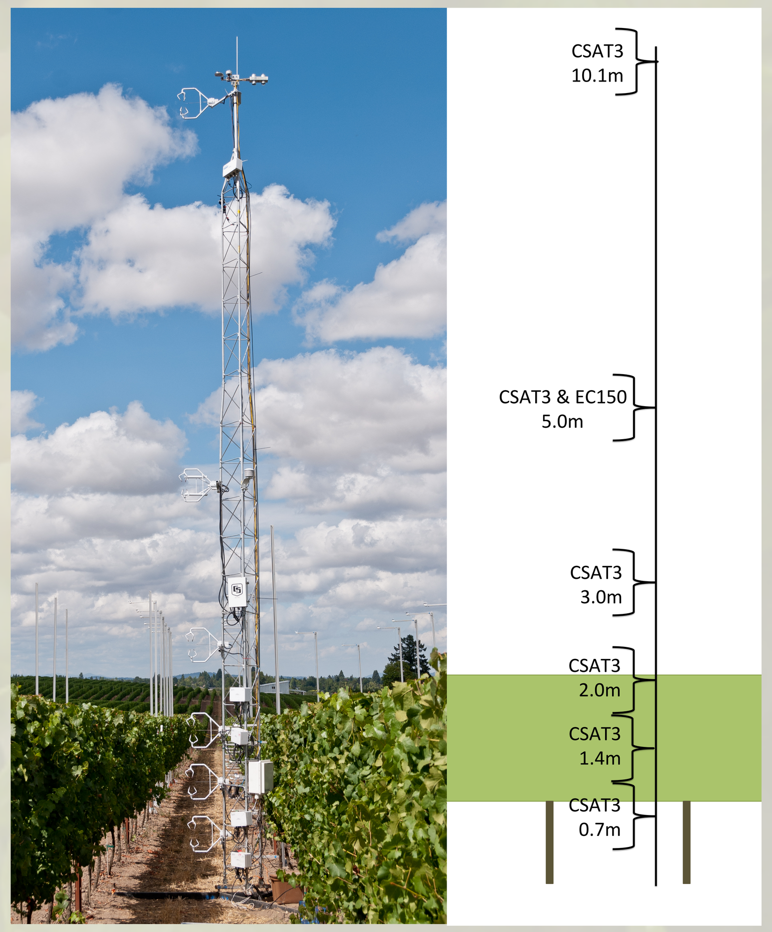


Figure 1. Meteorological tower in the vineyard.

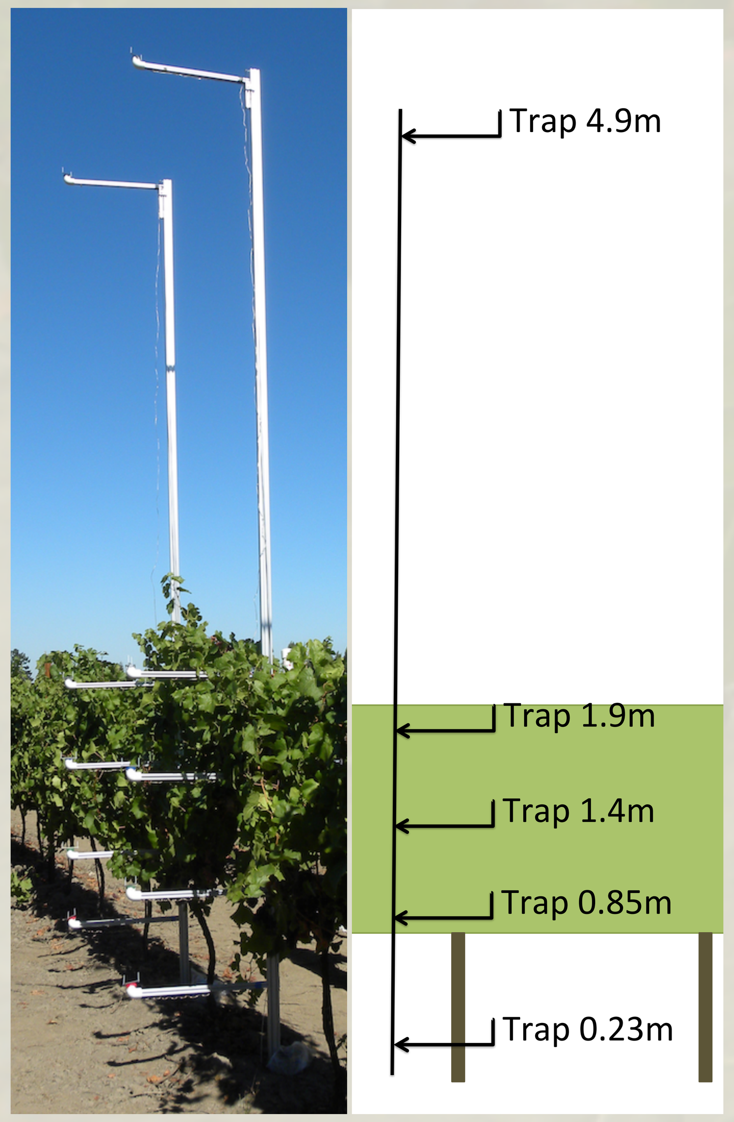


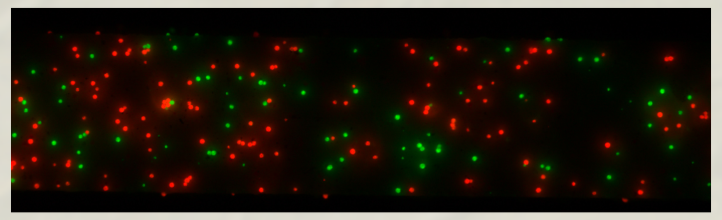
Figure 2. Trap towers in the vineyard.

Particle Dispersion Events

- Particle dispersion events conducted
  - Inert fluorescing polyethylene microspheres released from a point
  - 3 release heights within the canopy
  - Released multiple colors of particles simultaneously
- Events performed during all wind conditions
- Array of towers with rotating arm impaction traps placed downwind of the release point
  - Spheres collected on rods
- Concentrations calculated from mass collected and volume swept by trap:

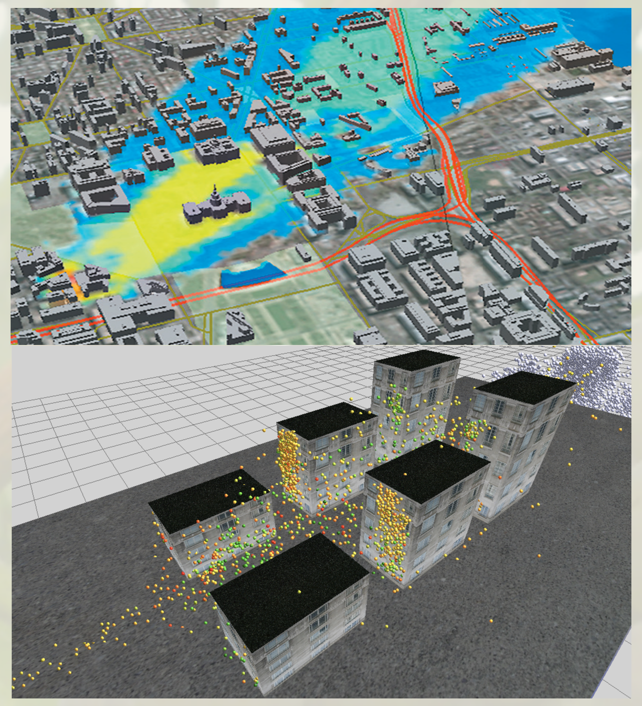
$$c = m_{particles} / V_{swept}$$

Figure 3. Impaction rod with microspheres. →

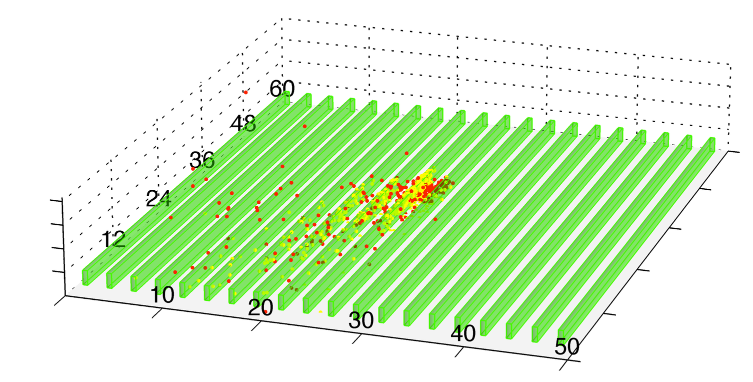


Quick Urban Industrial Complex

- QUIC-URB [4]
  - Produces 3D wind field in urban areas
  - Uses empirical parameterizations & mass conservation
  - Developed using wind-tunnel datasets for simple building configurations
  - Vegetation models recently added
- QUIC-PLUME [5]
  - Multi-thread random-walk dispersion model with more terms than is typical



↑ *Figure 4. Examples from QUIC*



← *Figure 5. Heterogeneous canopy in QUIC with airborne (red) and deposited (yellow) particles*

Table 1. Simulation meteorological settings

δ	Mass	Duration	U(5m)	1/L
[°]	[mg]	[s]	[m/s]	[1/m]
-13.6	370	300	2.19	0.047
10.7	340	420	2.93	-0.017
21.2	830	420	2.73	-0.042
54.7	500	1200	2.94	-0.016
89.1	500	1200	1.75	-0.040

Canopies:

- Heterogeneous Vegetation (H.V.)
  - A = 1.95 in plants (from LES [6])
  - A = 1.1 in aisles (from met tower)
- Porous structures (P.S.)
  - 50% Solidity
  - A = 1.1 in aisles

Simulation Parameters:

- 50 m x 60 m x 30 m domain
- z_0 = 0.01 on all surfaces
- `Vines' 2 m tall (H) with 0.5 m gap at ground, 0.5 m wide at 2.5 m spacing
- Parabolic-Z spacing starting at Δz = 0.1 m. 0.25 m x 0.25 m spacing for grid in X and Y directions
- Cionco [7] velocity profile used for z<H, log law above

$$U(z \le H) = U(H)\exp\left(A\left(\frac{z}{H}-1\right)\right)$$

$$U(z \ge H) = \frac{U\left(z_{ref}\right)\left(\ln\left(\frac{z-d}{z_0}\right)+\Psi\left(\frac{z-d}{L}\right)\right)}{\ln\left(z_{ref}/z_0\right)}$$

- 0.5 m x 0.5 m x 0.2 m cells used for concentration integration
- Plume source was spherical with r = 0.1 m located at [25.5,40,0.7] m

Mean Wind Comparisons

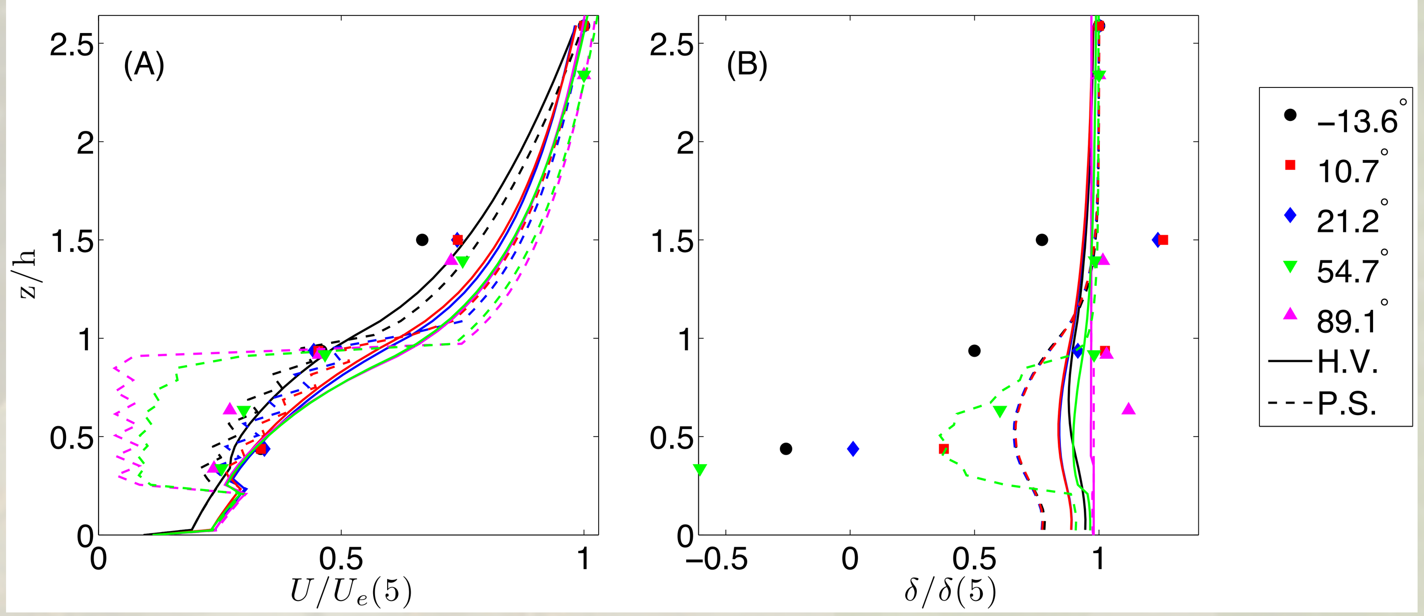


Figure 6. Profiles of wind speed (A) and wind profile rotation (B) in and above the canopy during the particle dispersion events.

- Field data shows attenuation and channeling effects of canopy
- QUIC profiles attenuate nearly correctly
- QUIC does not sufficiently rotate the velocity profile
- Conservation of Momentum not accounted for in QUIC

Dispersion Concentration Comparisons

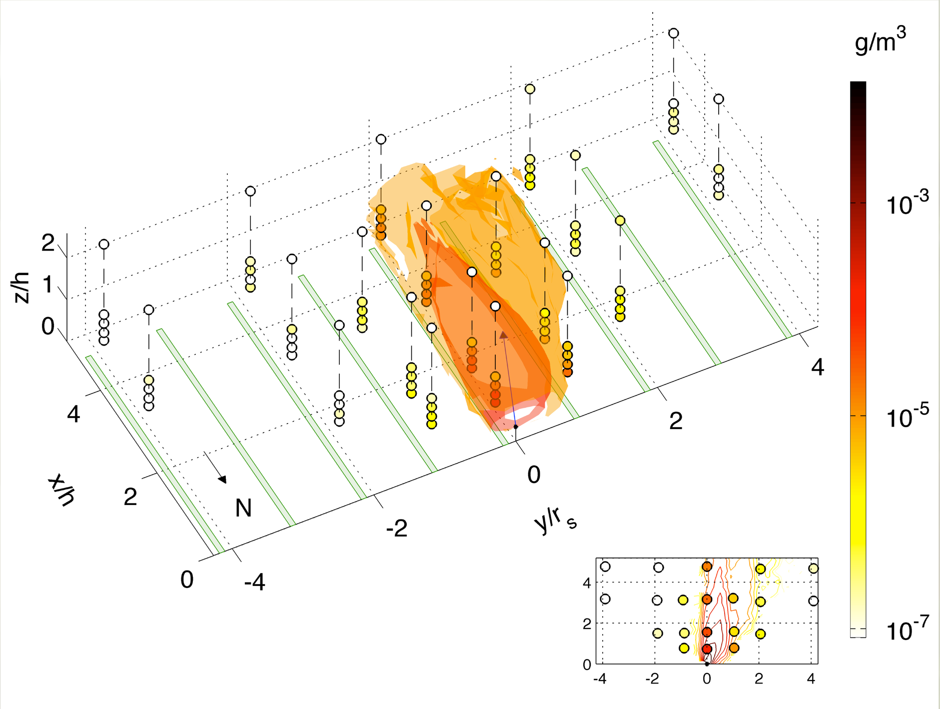


Figure 7. Concentrations from 21.2° release

- QUIC's high resolution snapshot of the plume shown as isosurfaces
- Field concentrations shown as circles in correct 3-D locations
- Effects of channeling seen in field data data, i.e. the plume propagates parallel to rows while in the canopy
  - QUIC recreates this behavior
- QUIC overpredicts in the release point aisle, underpredicts elsewhere
- Paired-in-space comparisons made using suite of quality metrics:

$FAC2,10 =$ Percent of QUIC predictions within multiples of 2 and 10 of the field concentrations

$$GME = \exp\left(\overline{\log\left(\left(C_e - C_{QUIC}\right)^2\right)}\right)$$

$$r^2 = 1 - \frac{\sum_i \left(C_e - C_{QUIC}\right)^2}{\sum_i \left(C_{QUIC} - \overline{C_e}\right)^2}$$

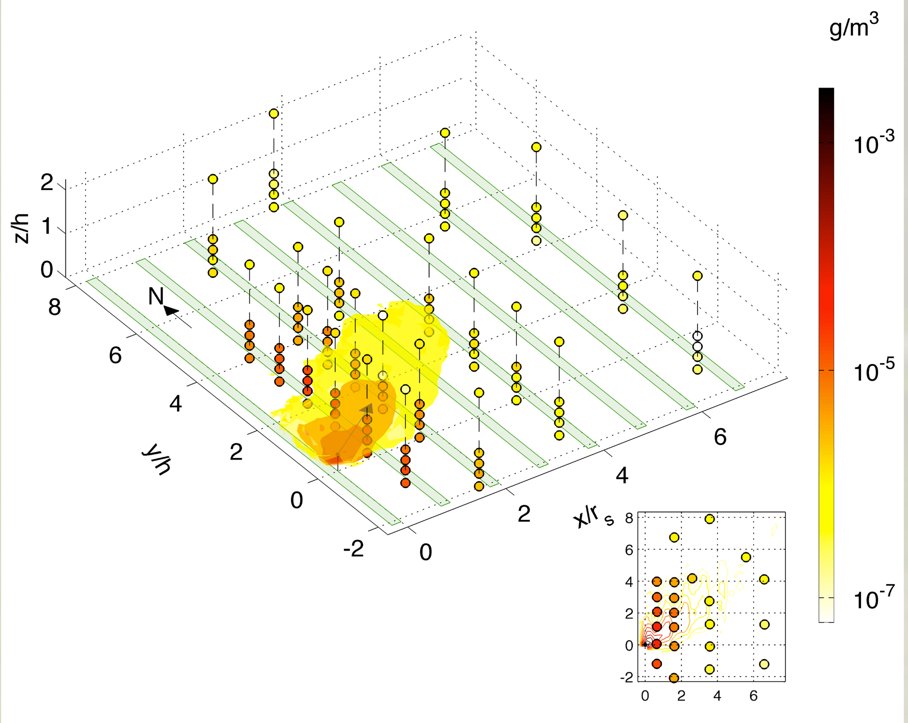


Figure 8. Concentrations from 54.7° release

Table 2. Quality metrics for the 5 simulated plumes compared to the field data from the same.

δ	Heterogeneous Vegetation			Porous Structures			Gaussian Plume Model [1]		
[°]	FAC2/10	GME	r^2	FAC2/10	GME	r^2	FAC2/10	GME	r^2
-13.6	0.12/0.42	1.37e-6	0.25	0.03/0.27	2.32e-6	0.19	0.10/0.52	3.24e-6	0.60
10.7	0.05/0.41	1.96e-6	0.25	0.02/0.30	2.41e-6	0.22	0.23/0.61	3.19e-6	0.69
21.2	0.13/0.34	1.15e-6	0.21	0.05/0.16	1.75e-6	0.16	0.05/0.45	5.43e-6	0.49
54.7	0.05/0.20	1.91e-6	0.00	0.10/0.35	1.95e-6	0.04	0.38/1.00	1.33e-6	0.59
89.1	0.12/0.25	1.61e-6	0.14	0.05/0.24	1.97e-6	0.13	0.24/0.98	1.86e-6	0.30

Conclusions:

- Attenuation is not correct, could use an assigned profile using field data
- Cross-vegetation fluxes are lower than desired, either from turbulence or deposition
- Wake regions of vegetation need further parameterization development
  - Versions based on windbreaks [7] and street canyons could be used [8]

References

1. Miller NE, Stoll R, Mahaffee W, Neill TM, Pardyjak, E. R. (2014) An Experimental Study of Momentum and Heavy Particle Transport in a Trellised Agricultural Canopy. *Ag. and For. Met.* Submitted
2. Miller NE, Gould A, Stoll R, Mahaffee W, Pardyjak ER. (2012) An Experimental Study of Momentum and Heavy Particle Transport in a Row-Oriented Agricultural Canopy. *30th Conference on Agricultural and Forest Meteorology.* Boston, MA. **3.6**
3. Miller NE, Stoll R, Mahaffee W, Neill TM, Pardyjak, E. R. (2014) The Effect of Wind Direction on Particle Transport in a Trellised Agricultural Canopy. *31st Conference on Agricultural and Forest Meteorology. Portland, OR.* **11.3**
4. Pardyjak ER, Brown MJ. Evaluation of a Fast-Response Urban Wind Model – Comparison to Single-Building Wind Tunnel Data. International Society of Environmental Hydraulics Conf. Tempe, AZ, December 2001
5. Williams MD, Brown MJ, Singh B, Boswell D. (2004) QUIC-PLUME Theory Guide. Los Alamos National Laboratory. LAUR-04-0561
6. Bailey BN, Stoll R. (2013) Turbulence in Sparse, Organized Vegetative Canopies: A Large-Eddy Simulation Study. Boundary-Layer Meteo. 147:369—400
7. Speckart SO, Pardyjak ER. (2013) A method for rapidly computing windbreak flow field variables. *J. of Wind Eng. and Ind. Aerod.* Submitted
8. Singh B, Hansen BS, Brown MJ, Pardyjak ER. (2008) Evaluation of the QUIC-URB fast response urban wind model for a cubical building array and wide building street canyon. *Environ. Fluid Mech.* **8**:281–312

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