Mean and Turbulent Flow Statistics in a Trellised Agricultural Canopy

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Motivation

- Desire to understand dispersion of particles in perennial crop canopies: primarily vineyards
  - Need to know mean field and turbulent fluxes
- Previous work in 'homogeneous' plant canopies
  [e.g. Aylor & Ferrandino 1989; Finnigan 2000]
- Urban canopies
  [e.g. Klein *et. al.* 2007; Hanna & Baja 2009]
- Trellised canopy
  [e.g. Bailey *et. al.* 2013, 2014]

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What impact does the relationship between canopy architecture and the above-canopy wind direction have on turbulent transport in a trellised canopy?

Studied in a vineyard in Oregon:

- 2011 & 2013 [Miller *et. al.* 2012, 2014a, 2014c]
  Particle release events using inert fluorescing microspheres

- $\delta =$ the angle between vine row direction and above-canopy wind direction
  $\delta = 0$ for parallel, $\delta = \pm 90$ for perpendicular

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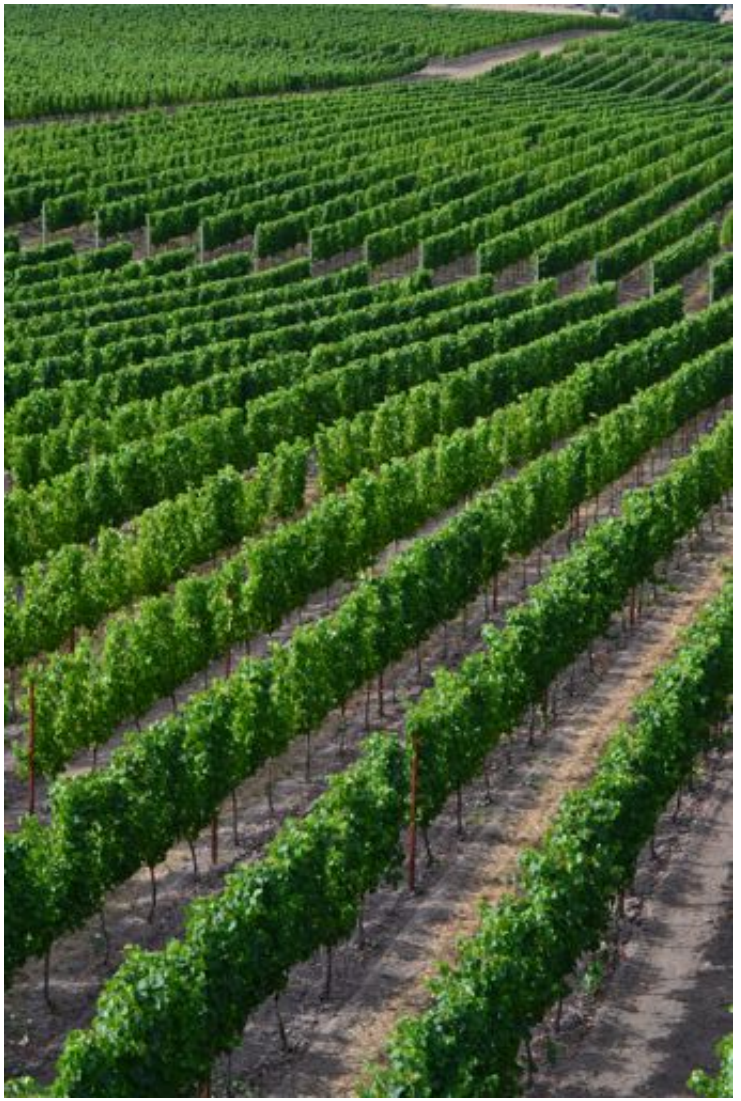
The Field Site

- Grape Vineyard
  - Relatively flat
  - N-S oriented rows
- Monmouth, Oregon
- 44° 49' 28" N
  123° 14' 16" W

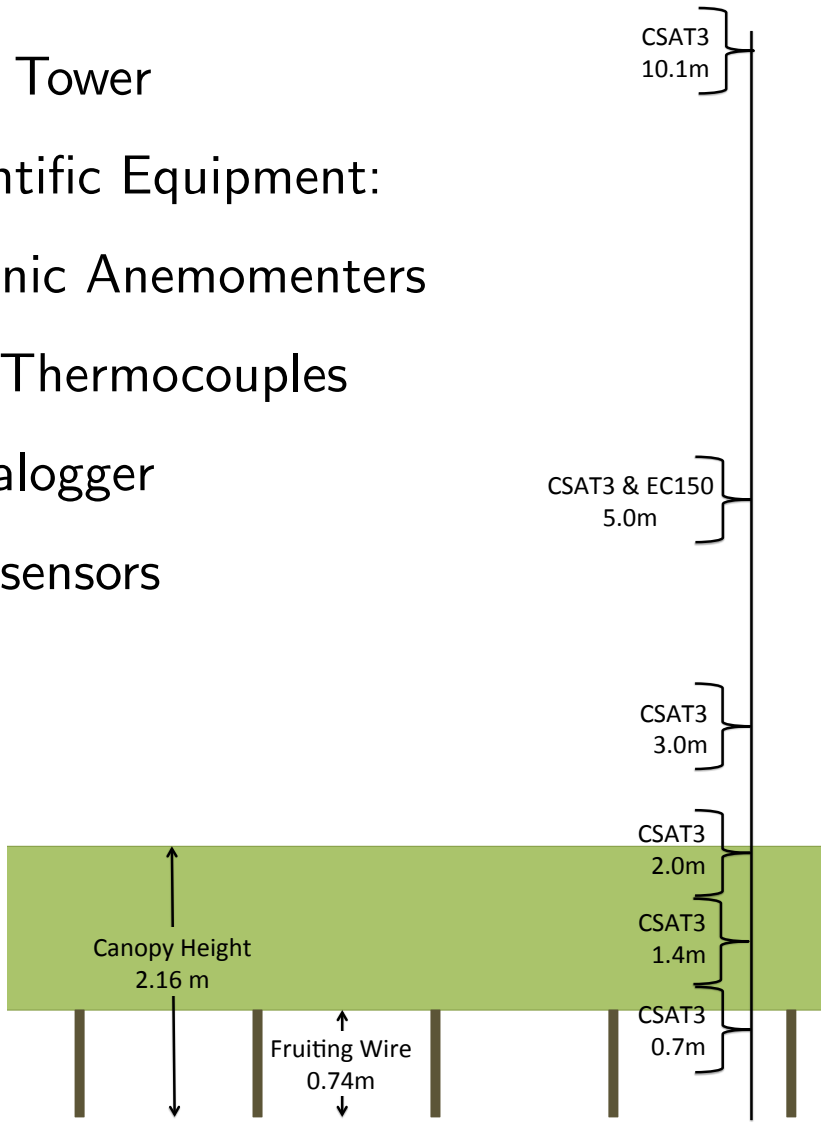
- 2 Separate Campaigns
  - Sept-Oct 2011
    5 weeks
    - LAI = 1.4
  - Aug 2013
    4 weeks
    - LAI = 1.0



Experimental Setup

- Meteorological Tower
- Campbell Scientific Equipment:
  - 6 CSAT3 Sonic Anemomenters
    - Fine-wire Thermocouples
  - CR3000 datalogger
  - Many other sensors

- Rows spaced at 2.5 m o/c



Flow Field Results: Roses

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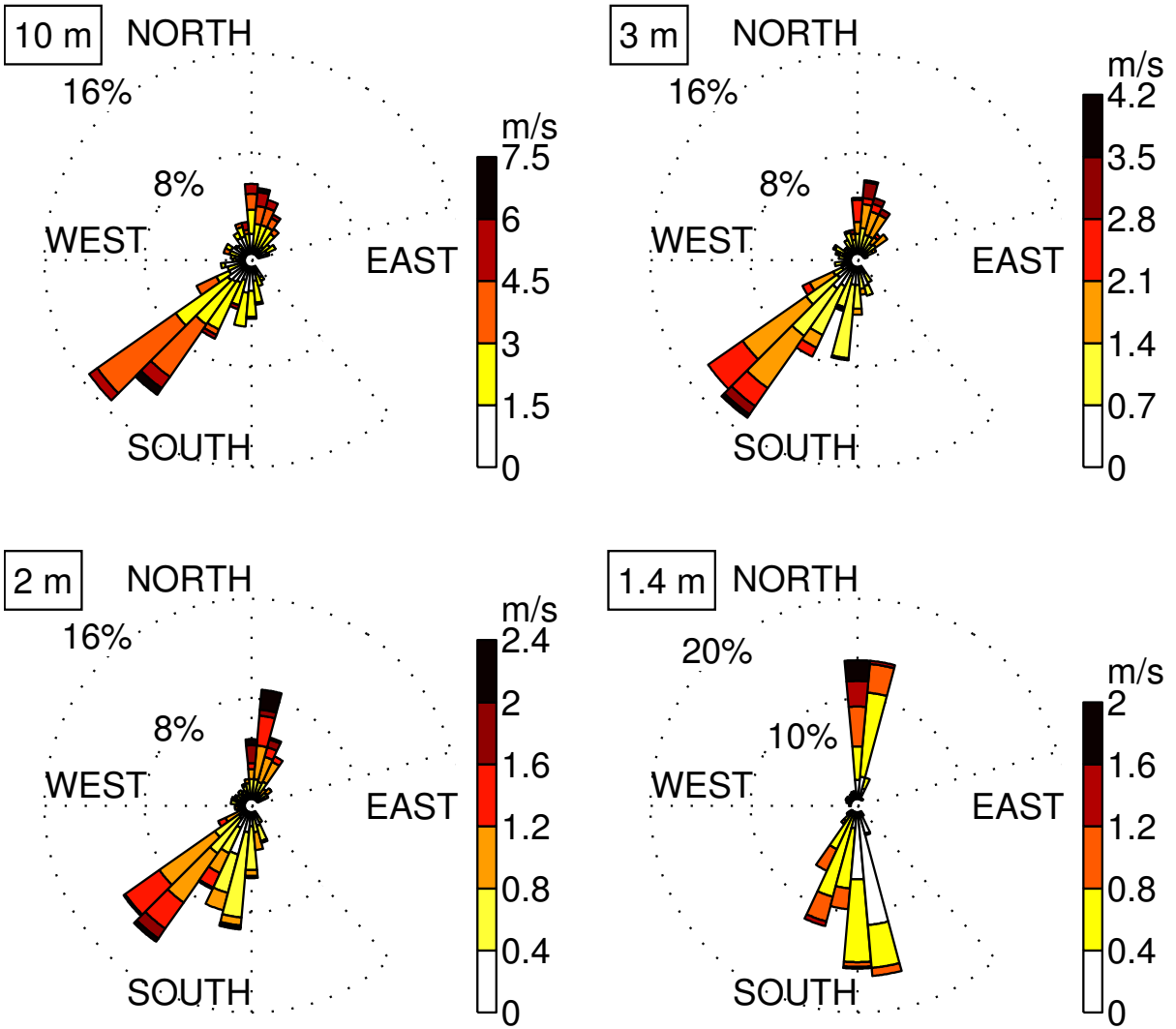
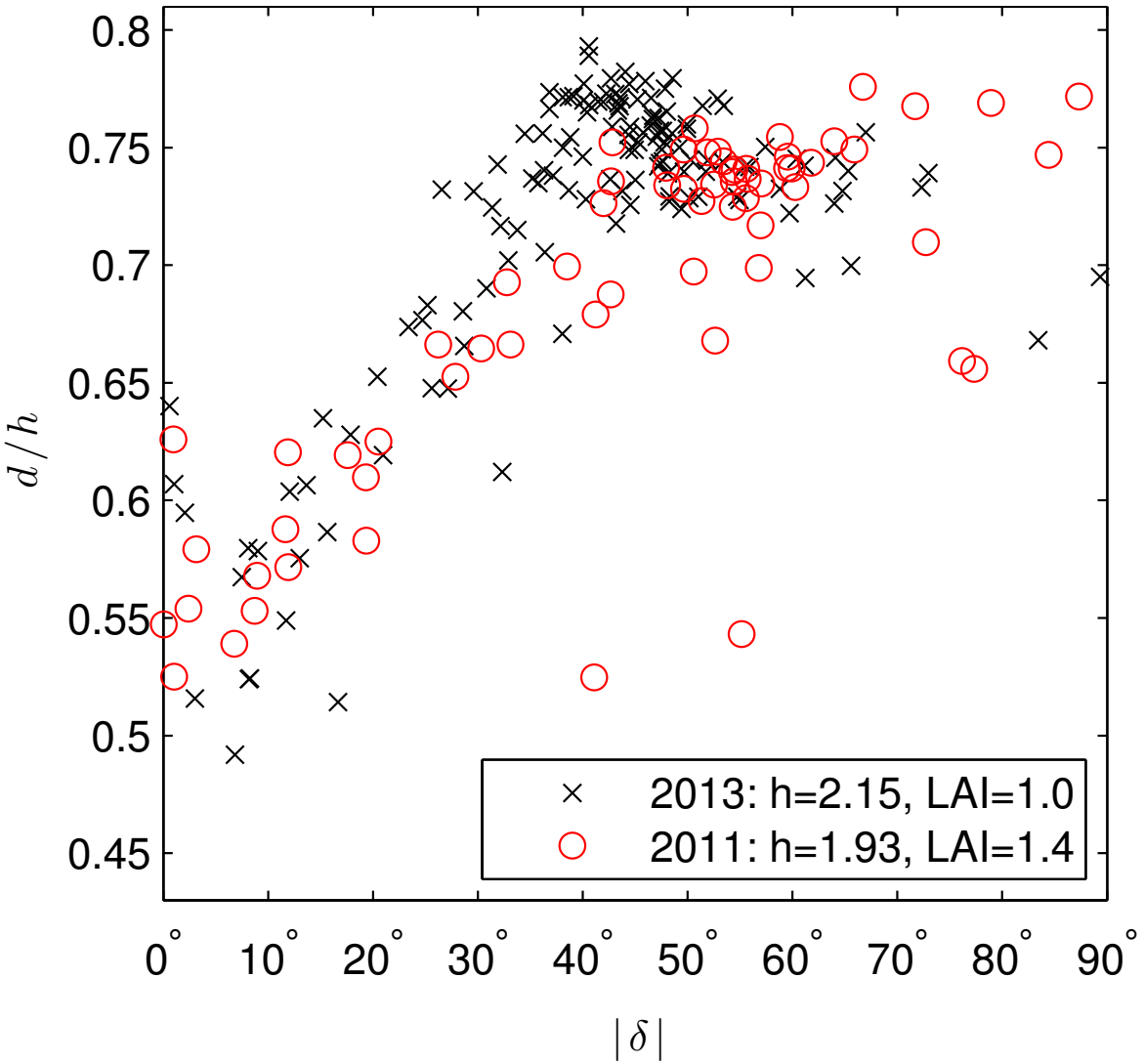


Flow Field Results: Displacement Height



$$d = \frac{\int_0^h z\overline{u'w'}dz}{\int_0^h \overline{u'w'}dz}$$

[Judd *et. al.* 1996]

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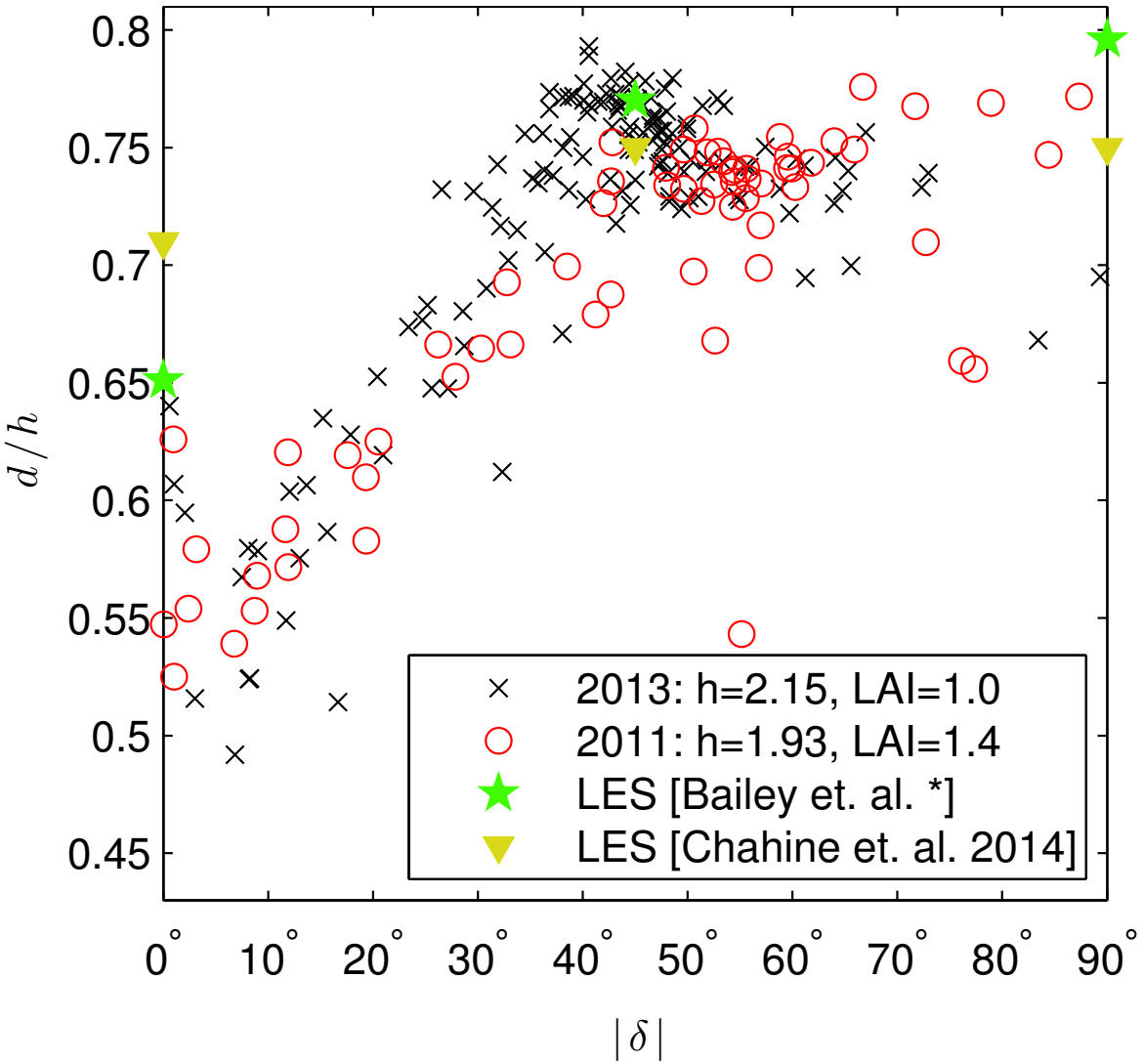

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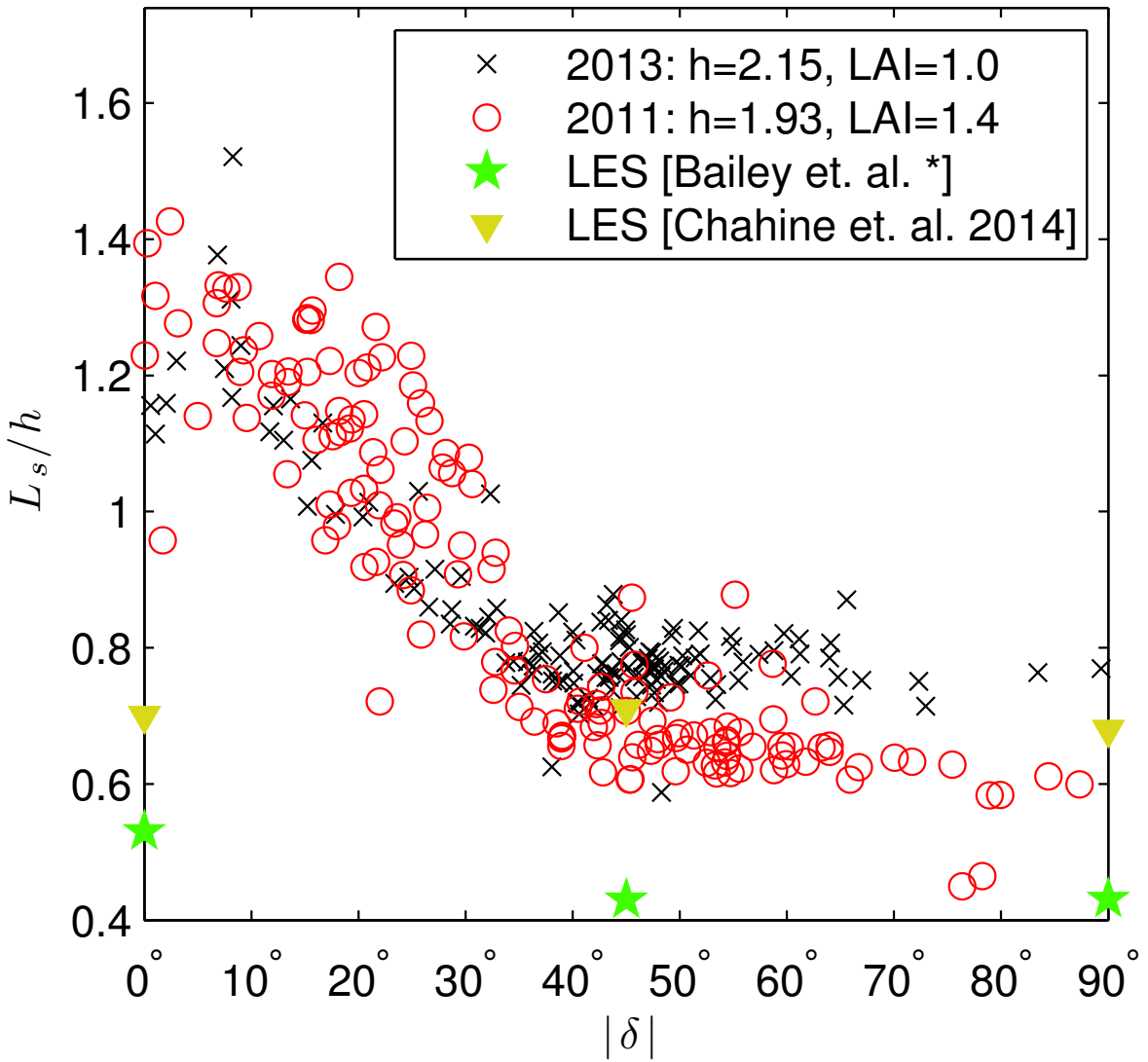
* Code & setup in [2013]
$\delta = 90$ case in [2014]
Other cases run for this talk

Flow Field Results: Shear Length



$$L_s = \frac{U_h}{\frac{dU}{dz}|_h}$$

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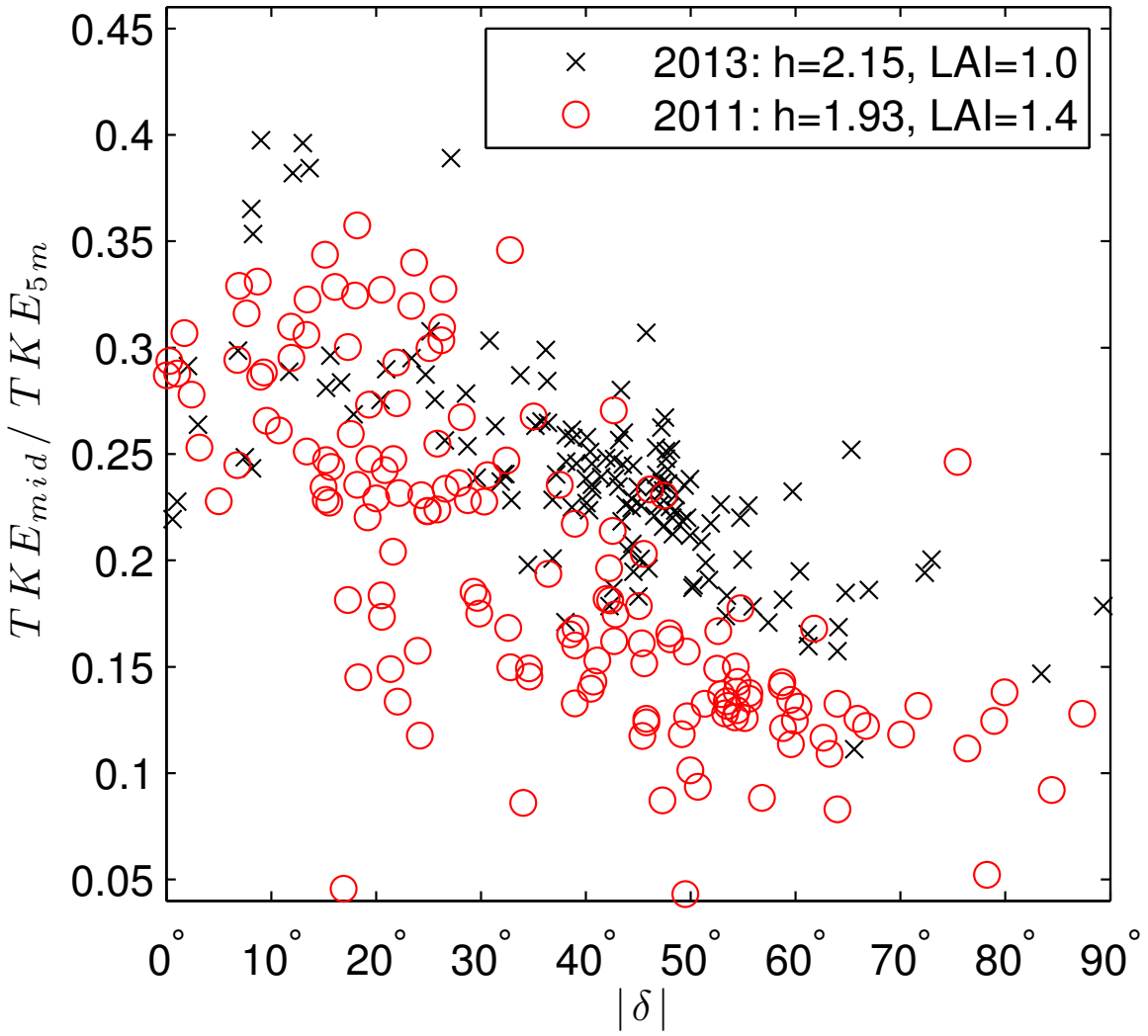
Flow Field Results: TKE

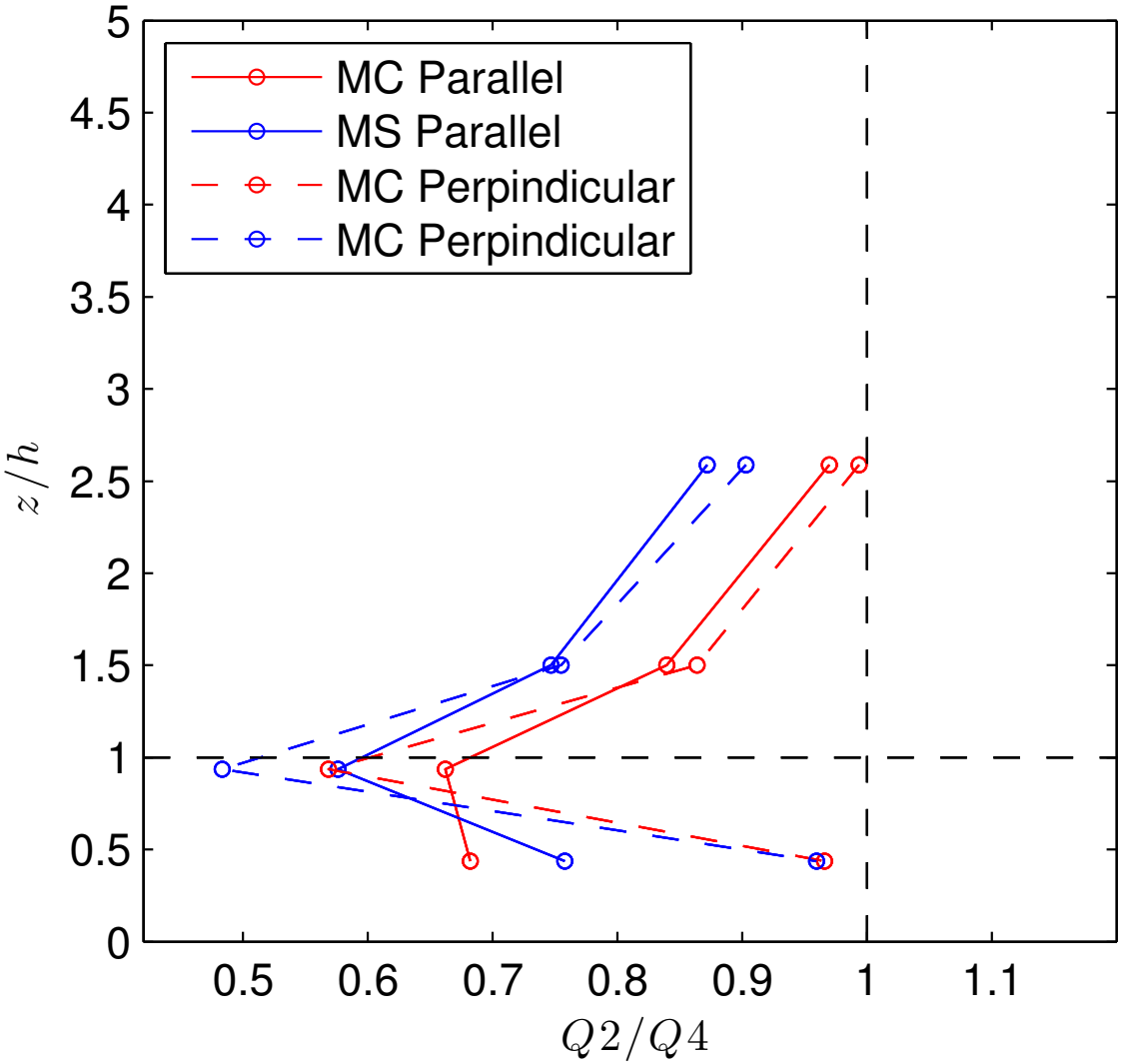


$$TKE = 0.5\left(u'^2 + v'^2 + w'^2\right)$$

2013: $\frac{h_{mid}}{h_{5m}} = \frac{0.34h}{2.34h}$

2011: $\frac{h_{mid}}{h_{5m}} = \frac{0.44h}{2.59h}$

Flow Field Results: Ejections and Sweeps



Ejections = $u' < 0,\ w' > 0$

Sweeps = $u' > 0,\ w' < 0$

Compare to:
Finnigan 2009,
Bailey *et. al.* 2013

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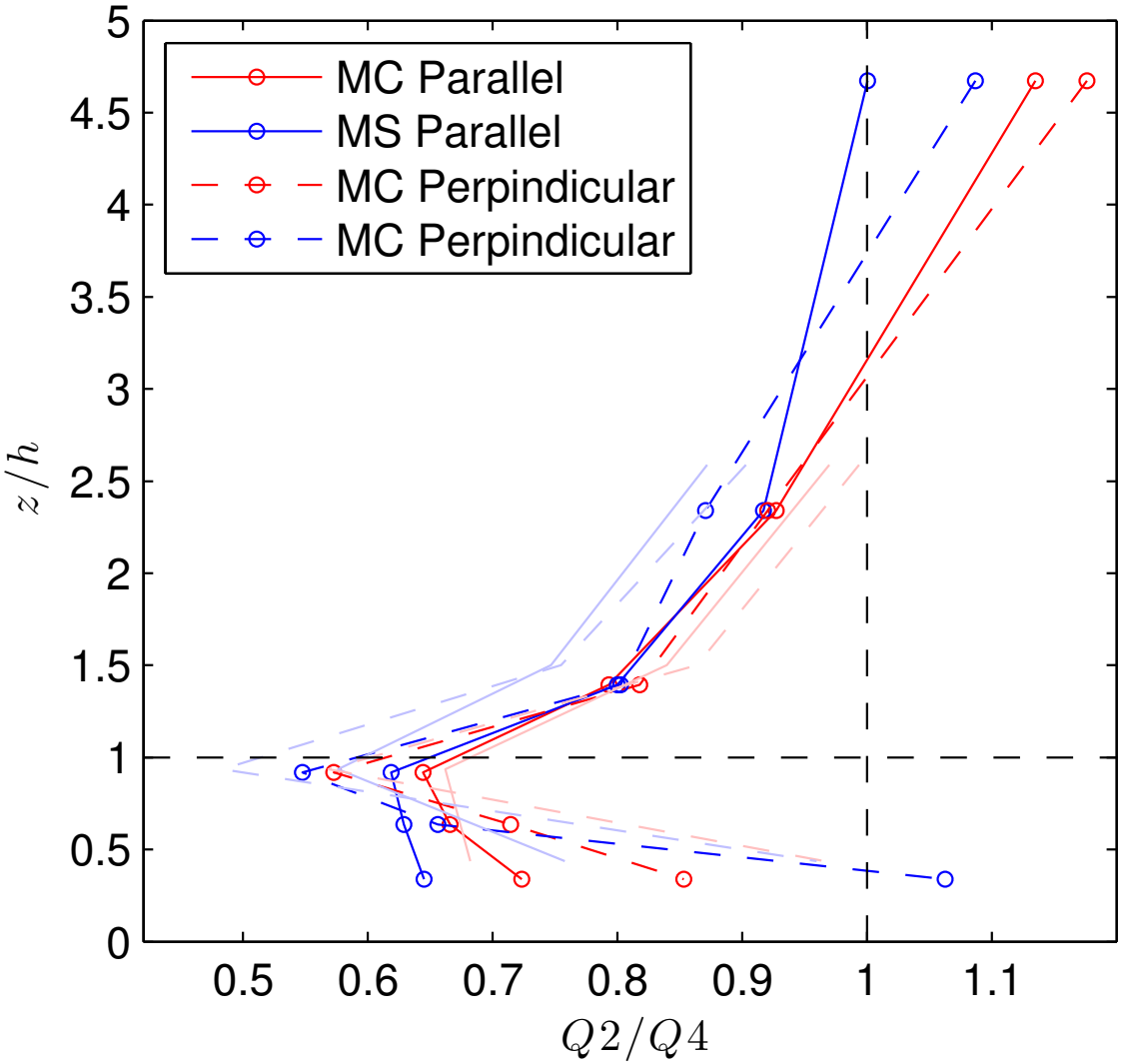

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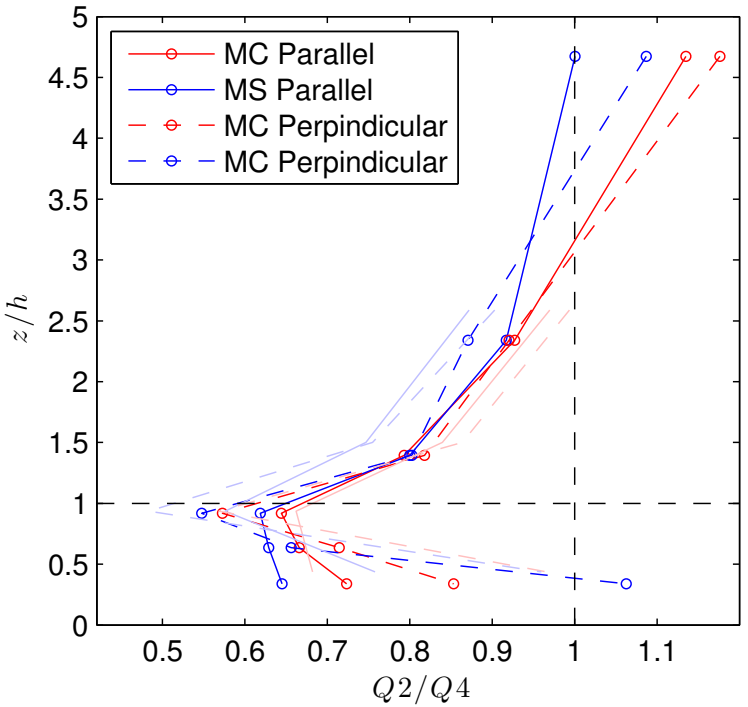
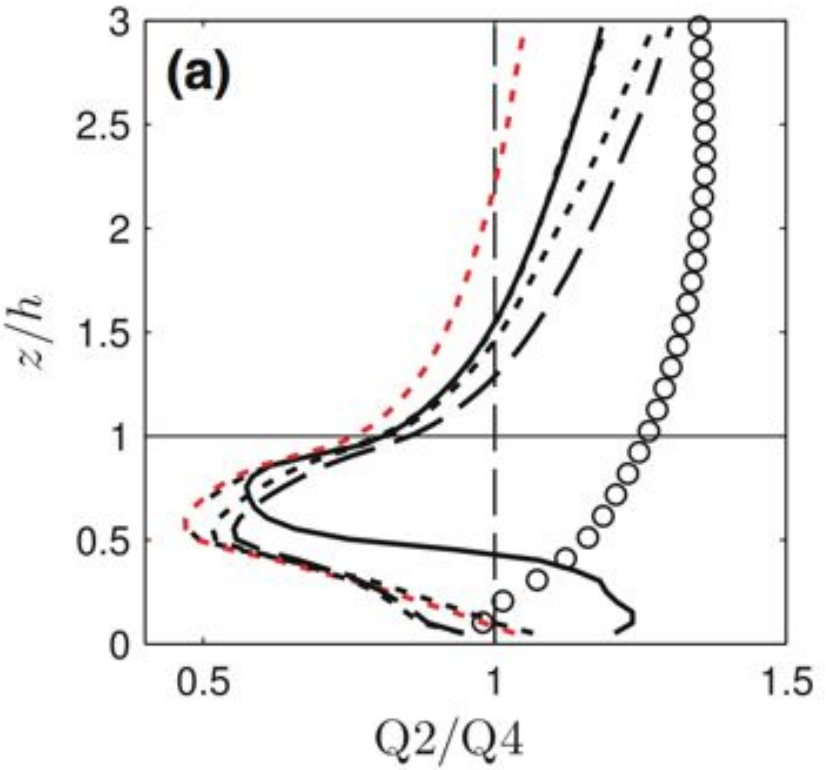


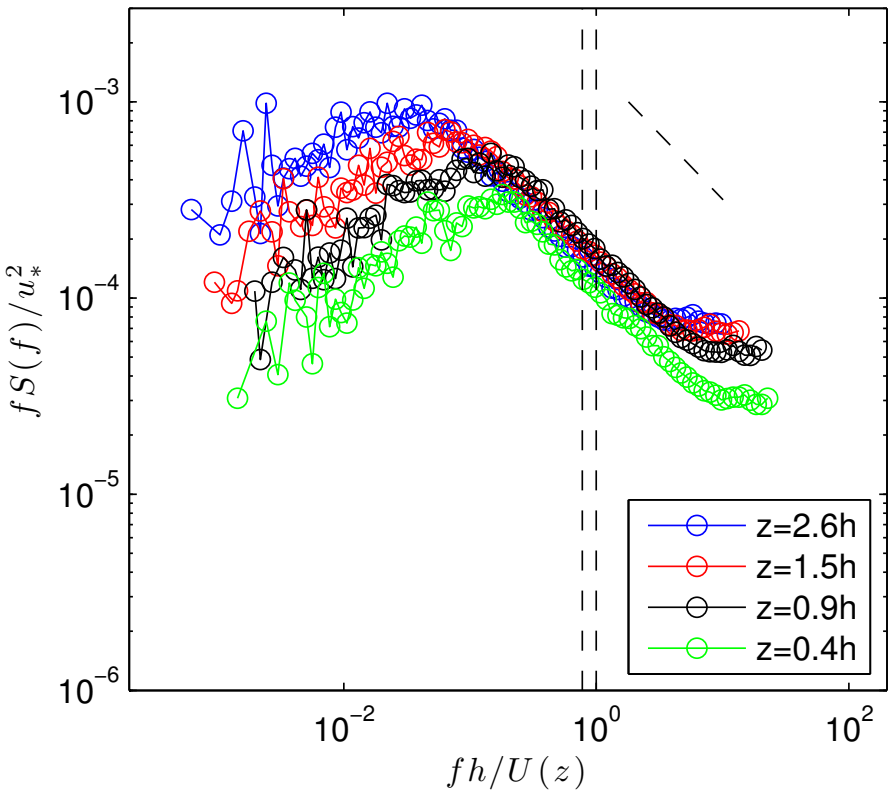


[Bailey *et. al.* 2013]

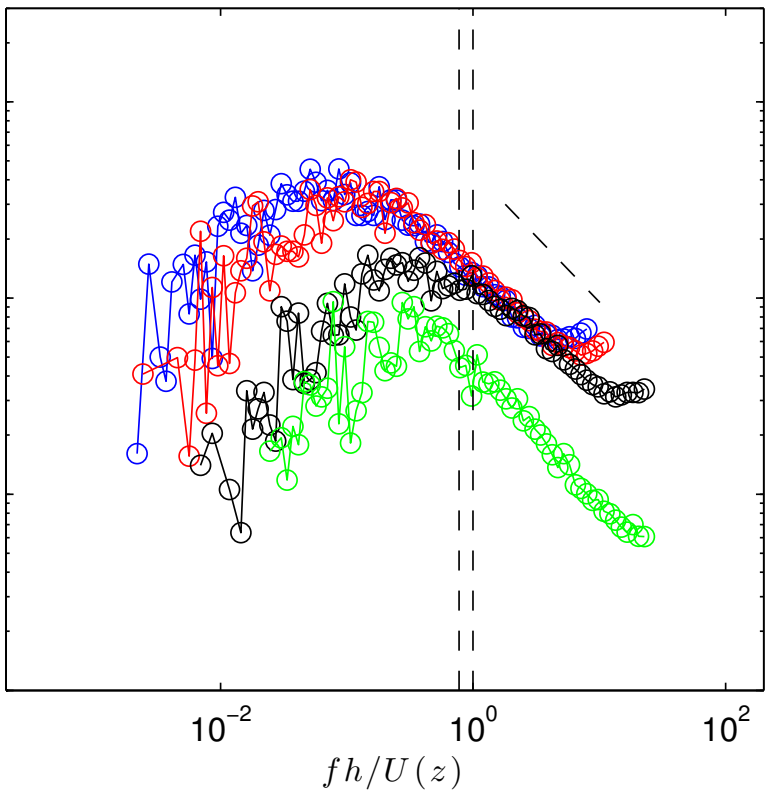
Flow Field Results: Energy Spectra

Row-parallel component

Parallel winds



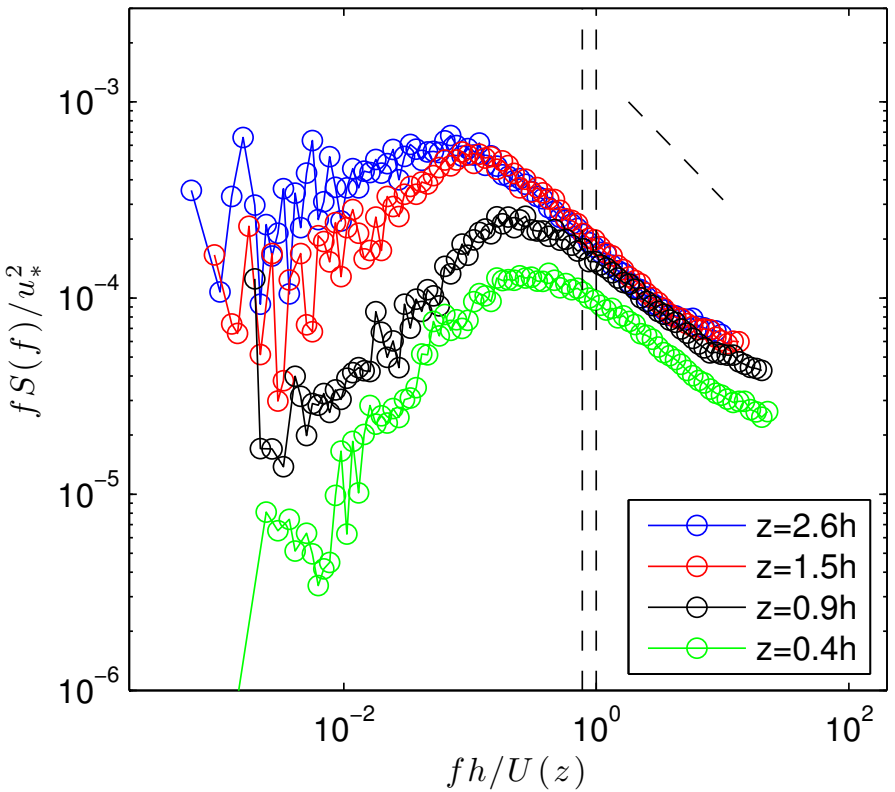
Perpendicular winds



Flow Field Results: Energy Spectra

Row-perpendicular component

Parallel winds



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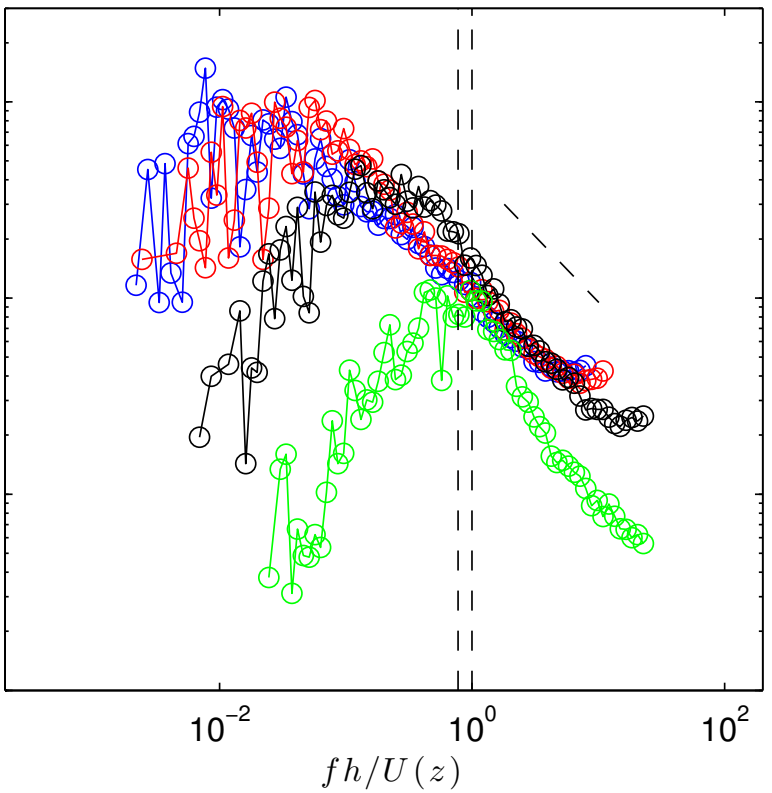

Flow Field Results: Energy Spectra

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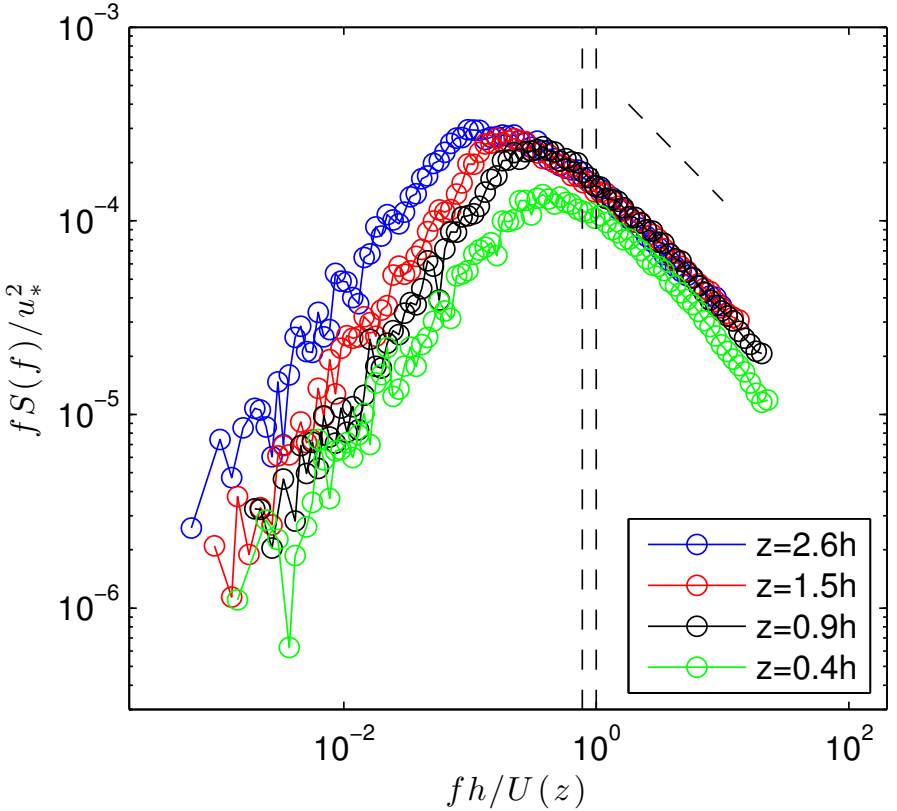
Vertical component

Parallel winds



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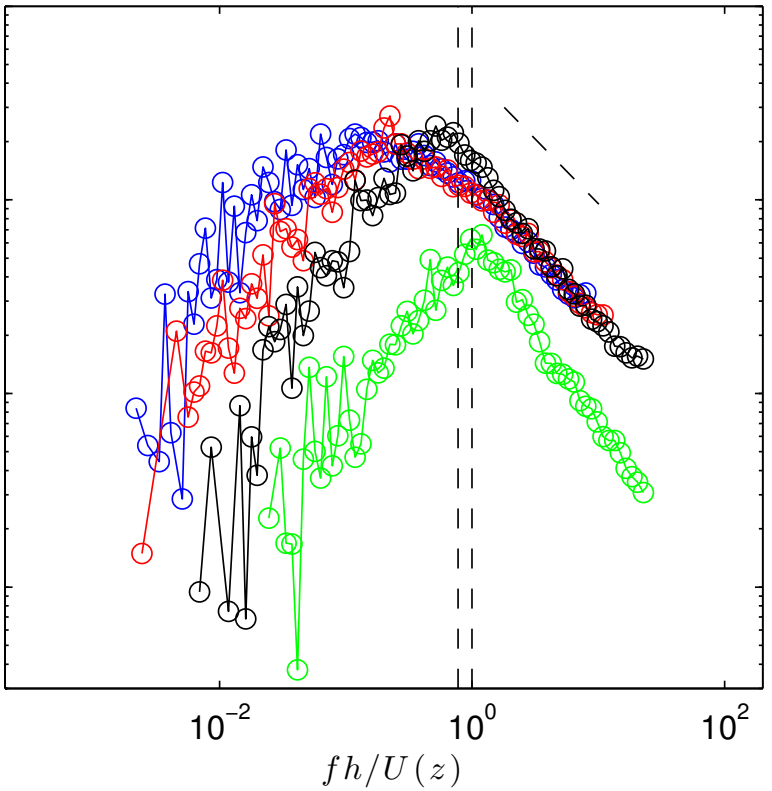
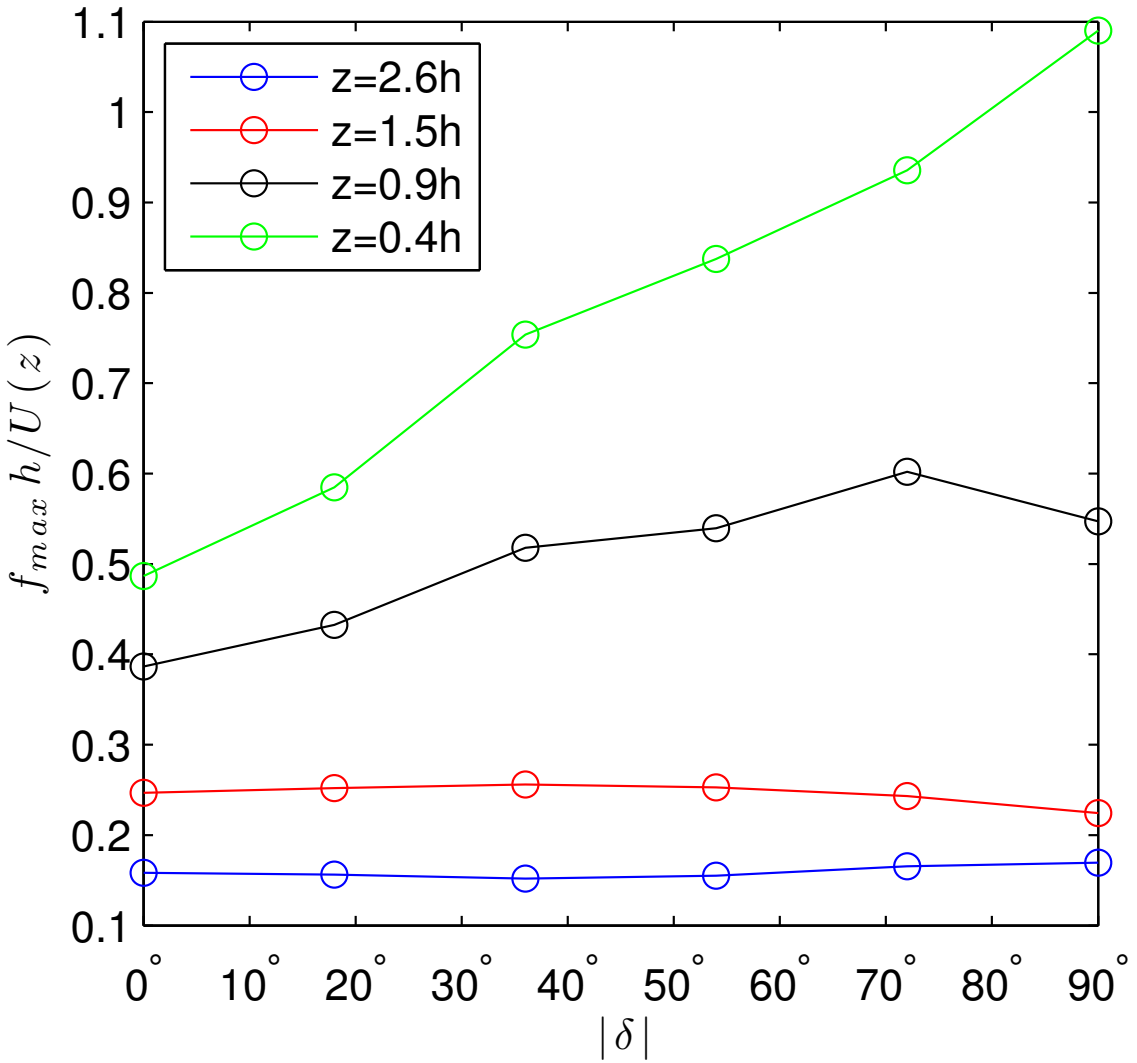
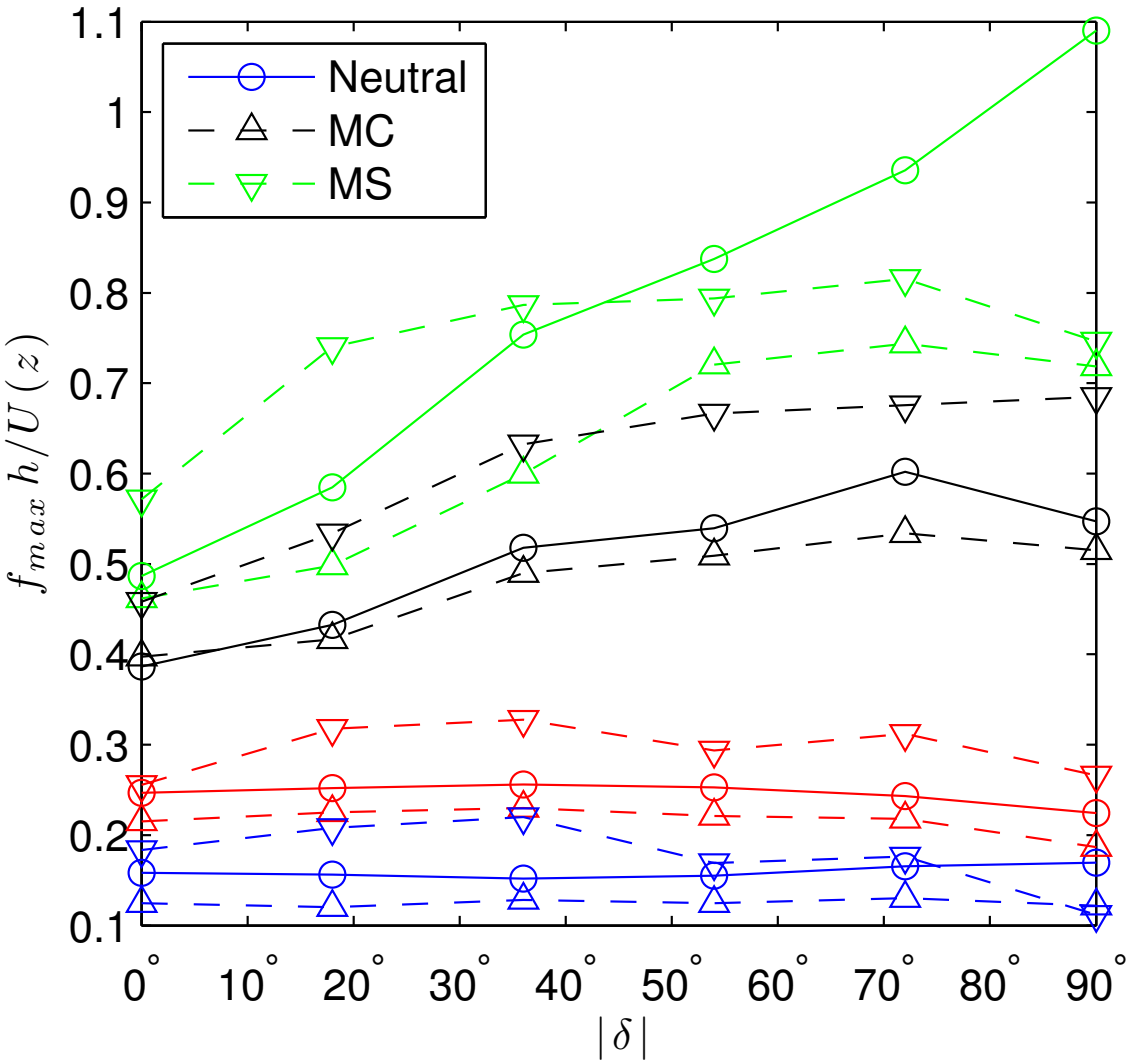


Flow Field Results: Spectra peak scale



- f of max energy not affected by δ when $z > h$
- f_{max} increases with δ in the canopy
- Canopy more efficient at breaking up larger scales at larger δ?

Flow Field Results: Spectra peak scale



- f_{max} increases with stability [Kaimal & Finnigan 1994]
- Not true at $z = 0.4h$
- Canopy has less influence on MC or MS flows?

Summary

- Conducted experiments in an Oregon vineyard
- The canopy architecture results in wind channeling within the aisles
- d/h increased with δ
- L_s/h and TKE decreased with δ
- Ejection-to-sweep ratio showed dependence on δ
- f_{max} increased with δ in the canopy

Ongoing and Future Work

- Examine similar statistics for vineyards on slopes
  - Coming this August
- Compare to fast response parameterized models like QUIC [Nelson 2009]

  [Miller *et. al.* 2014b]
- Compare to Price's wind-tunnel results [Price *et. al.* 2014]
- Compare to Bailey's LES results [Bailey *et. al.* 2013, 2014]
- Study particle dispersion within the vineyard under variety of conditions

  [Miller *et. al.* 2012, 2014a, 2014c]

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References

- Aylor DE, Ferrandino FJ. (1989) Dispersion of spores released from an elevated line source within a wheat canopy. *Bound.-Layer Meteor* **46**: 251-273
- Bailey BN, Stoll R, Pardyjak ER, Mahaffee WF. (2013) Turbulence in Sparse, Organized Vegetative Canopies: A Large-Eddy Simulation Study. *Boundary-Layer Meteo.* **147**: 369-400
- Bailey BN, Stoll R, Pardyjak ER, Mahaffee WF. (2014) The effect of canopy architecture and the structure of turbulence on particle dispersion. *Atmos. Env.* Submitted
- Chahine A, Dupont S, Sinfort C, Brunet Y. (2014) Wind-Flow Dynamics Over a Vineyard. *Boundary-Layer Meteo.* **151**: 557-577
- Chamecki M, Default N, Isard S. (2012) Atmospheric dispersion of wheat rust spores: A new theoretical framework to interpret field data and estimate downwind dispersion. *J. Appl. Meteorol. Climatol.* **51**: 672-685.
- Dupont S, Patton EG. (2012) Influence of stability and seasonal canopy changes on micrometeorology within and above an orchard canopy: The CHATS experiment. *Ag. and For. Met.* **157**:11-29
- Finnigan JJ, (2000) Turbulence in Plant Canopies. *Ann Rev. Fluid Mech.* **32**: 519-571
- Hanna S, Baja E. (2009) A simple urban dispersion model tested with tracer data from Oklahoma City and Manhattan. *Atmospheric Environment* **43**: 778-786
- Kaimal JC, Finnigan JJ. (1994) *Atmospheric Boundary Layer Flows : Their Structure and Measurement*. Oxford University Press. London, England. pp 304.
- Nelson MA, Williams MD, Zajic D, Pardyjak ER, Brown MJ. (2009) Evaluation of an Urban Vegetative Canopy Scheme and Impact on Plume Dispersion. 8th AMS Urb. Env. Symp., Phoenix, AZ. Paper **JP6.4**
- 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 Conf. on Ag. and For. Met.* Boston, MA. **3.6**
- Miller NE, Stoll R, Mahaffee W, Neill T, Pardyjak ER. (2014a) The Effect of Wind Direction on Particle Transport in a Trellised Agricultural Canopy. *31st Conf. on Ag. and For. Met.* Portland, OR. **11.3**
- Miller NE, Pardyjak ER, Stoll R, Mahaffee W. (2014b) Simulation of Particle Dispersion in a Trellised Agricultural Canopy using the QUIC Dispersion Model. *31st Conf. on Ag. and For. Met.* Portland, OR. Poster **13**
- Miller NE, Stoll R, Mahaffee W, Neill TM, Pardyjak ER. (2014c) An Experimental Study of Momentum and Heavy Particle Transport in a Trellised Agricultural Canopy. *Ag. and For. Met.* Submitted.
- Price T, Stoll R, Stegmeir M, Bailey BN, Pardyjak ER, Johnson J. (2014) A wind tunnel study of momentum transport in sparse perennial agricultural canopies. *31st Conf. on Ag. and For. Met.* Portland, OR. **2.1**