Boundary layer observations using Doppler lidar during INFLUX

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NOAA Global Monitoring Laboratory

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INFLUX: Goals

- Develop and assess methods of quantifying GHG emissions at the urban scale.
- Determine whole-city emissions of CO_2 and CH_4
- Measure emissions of CO_2 and CH_4 at 1 km^2 spatial and weekly temporal resolution
- Distinguish biogenic vs. anthropogenic sources of CO_2
- Quantify and reduce uncertainty in urban emissions estimates

PennState PURDUE UNIVERSITY NOAA AMES RESEARCH CENTER NASA Earth Networks GNS SCIENCE NIST National Institute of Standards and Technology U.S. Department of Commerce

Davis et al. (2017)

INFLUX: Measurements

In-situ tower-based CO_2, CO and CH_4
Flask sampling of $^{14}CO_2$
Aircraft sampling of GHG
Eddy covariance and radiative flux measurements

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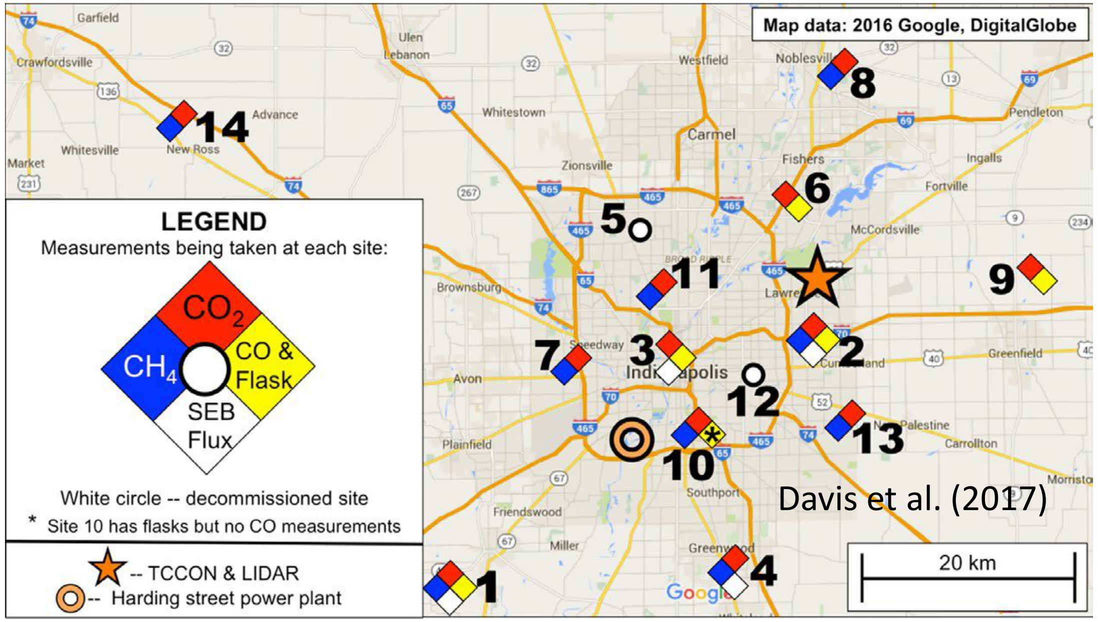
<u>Scanning Doppler lidar </u>to provide information on the depth and dynamics of the atmospheric boundary layer (BL):

- wind and turbulence profiles and
- the height of the boundary layer

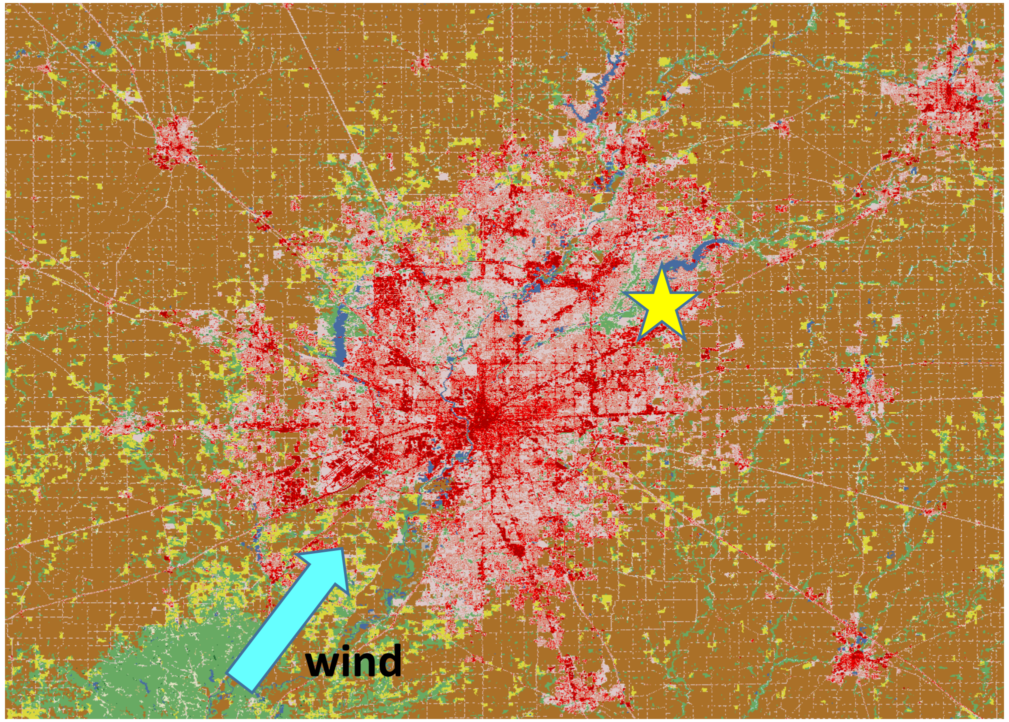


Davis et al. (2017)

Doppler lidar measurements during INFLUX study

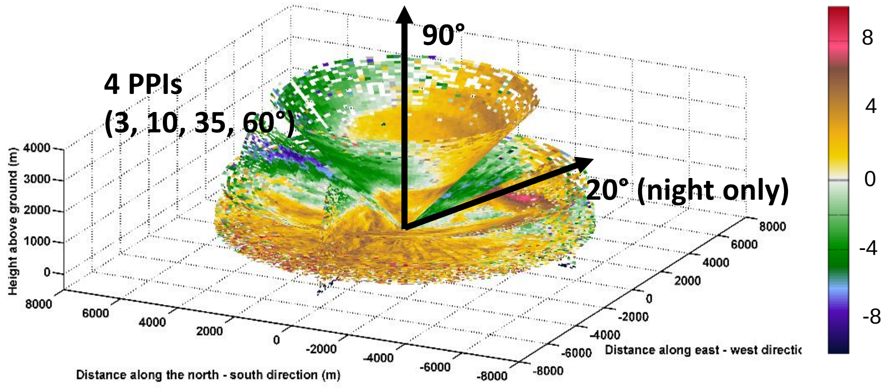
1. Halo Photonics Streamline Lidar

April 2013 - June 2015 ; January 2016 – April 2019 (upgraded)



Continuous 20-min sequence

- Azimuthal (plan position indicator, PPI) scans
- Elevation (range-height indicator, RHI) scans
- Stare the lidar beam at the fixed elevation angle



Variables derived from lidar measurements

Scan	Duration (min)	Key variables
PPI at ϕ = 3°	2	u, v, $\overline{v_r'^2}$
PPI at ϕ = 10°	2	u, v, $\overline{v_r'^2}$
PPI at ϕ = 35.3°	2	u, v, $\overline{v_r'^2}$, TKE
PPI at ϕ = 60°	2	u, v, $\overline{v_r'^2}$
RHI to the south	1	v, $\overline{v'^2}$
RHI to the east	1	u, $\overline{u'^2}$
South stare at ϕ = 20°	3 (night only)	v, $\overline{v'^2}$, RCI, $\overline{\mathrm{SNR}'^2}$
East stare at ϕ = 20°	3 (night only)	u, $\overline{u'^2}$, RCI, $\overline{\mathrm{SNR}'^2}$
Zenith (vertical) stare	10 (day) / 4 (night)	$\overline{w'^2}$, RCI, $\overline{\mathrm{SNR}'^2}$

Bonin et al. (2018)

Doppler lidar measurements during INFLUX study

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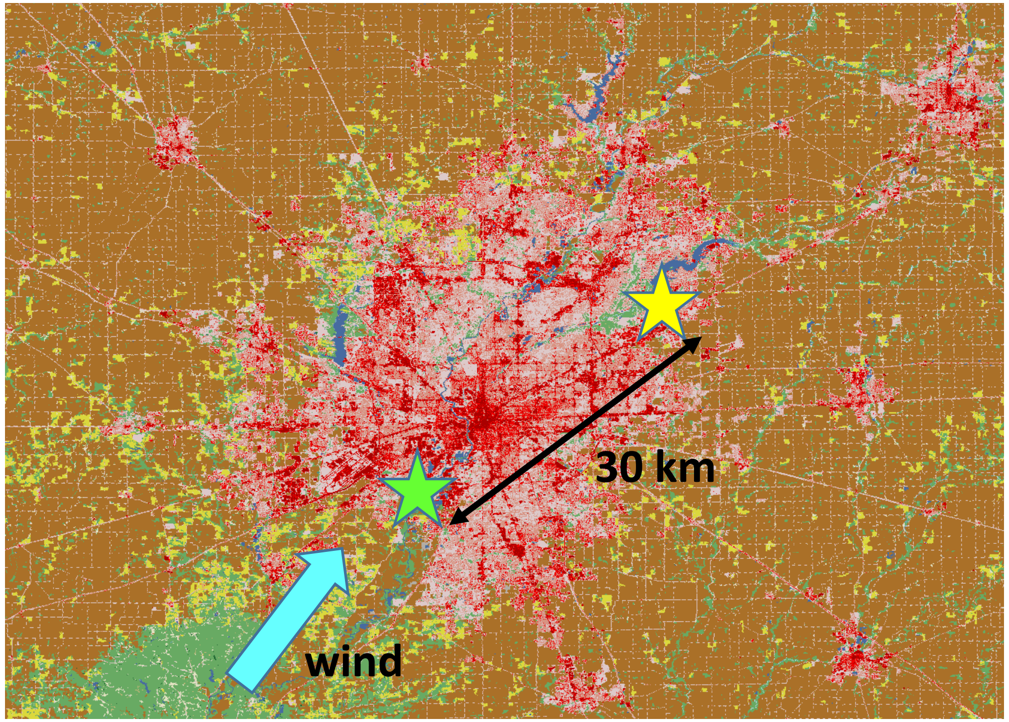

2. Second Doppler lidar

May-June 2014

September – November 2017

Continuous 20-min sequence

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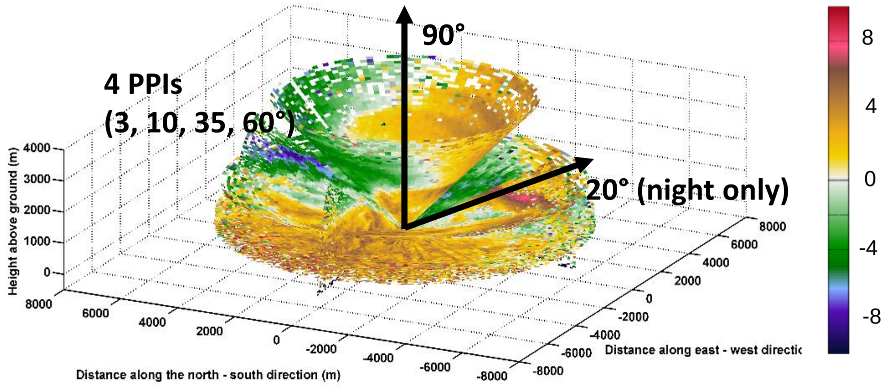

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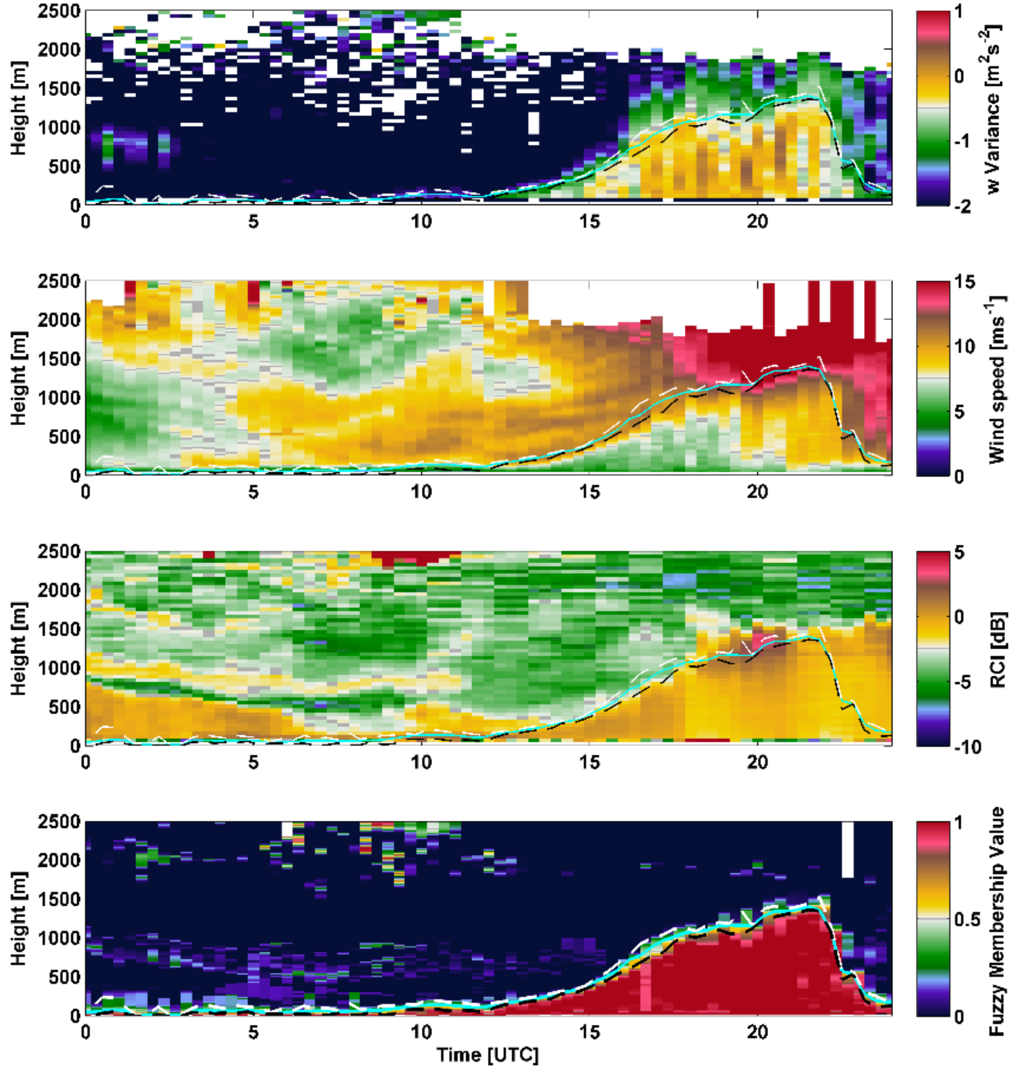
Bonin et al. (2017)

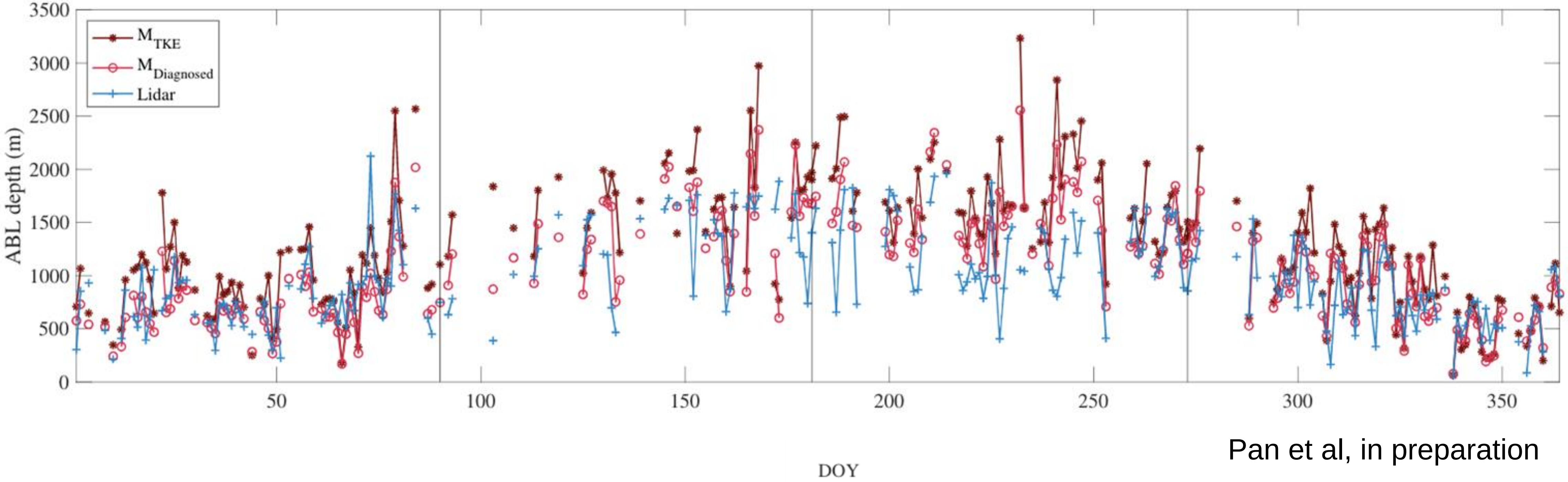
Mixing Layer Height Retrieval

- Combine several indicators of turbulent mixing to create a fuzzy aggregate
  - Vertical velocity variance, horizontal wind variance, aerosol backscatter and wind profiles
- First estimate based on wind variance.
- Refine using gradients in aerosols and winds
- MLH is determined for every 20 minutes scan cycle



Bonin et al. (2017)

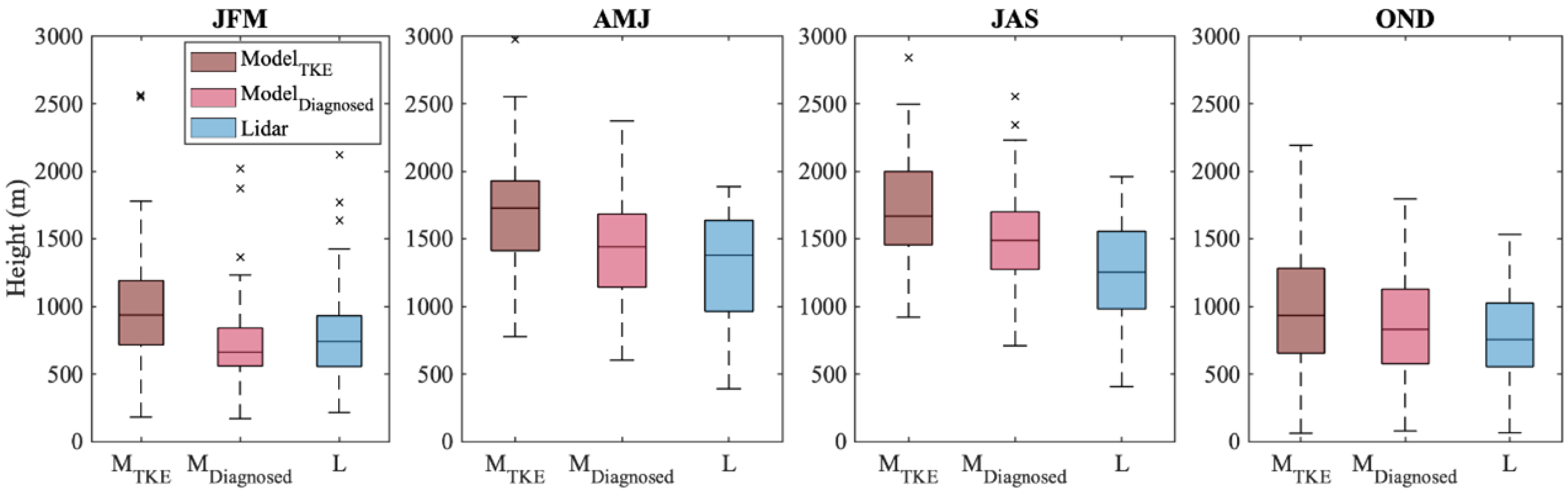
Mid day ABL depth



Pan et al, in preparation

- WRF configuration: MYNN-NOAH
- Time : 2-5 PM
- Model diagnosed ABL: hybrid method (virtual potential temp and TKE)
- Model TKE ABL: same TKE as lidar assuming isotropic turbulence

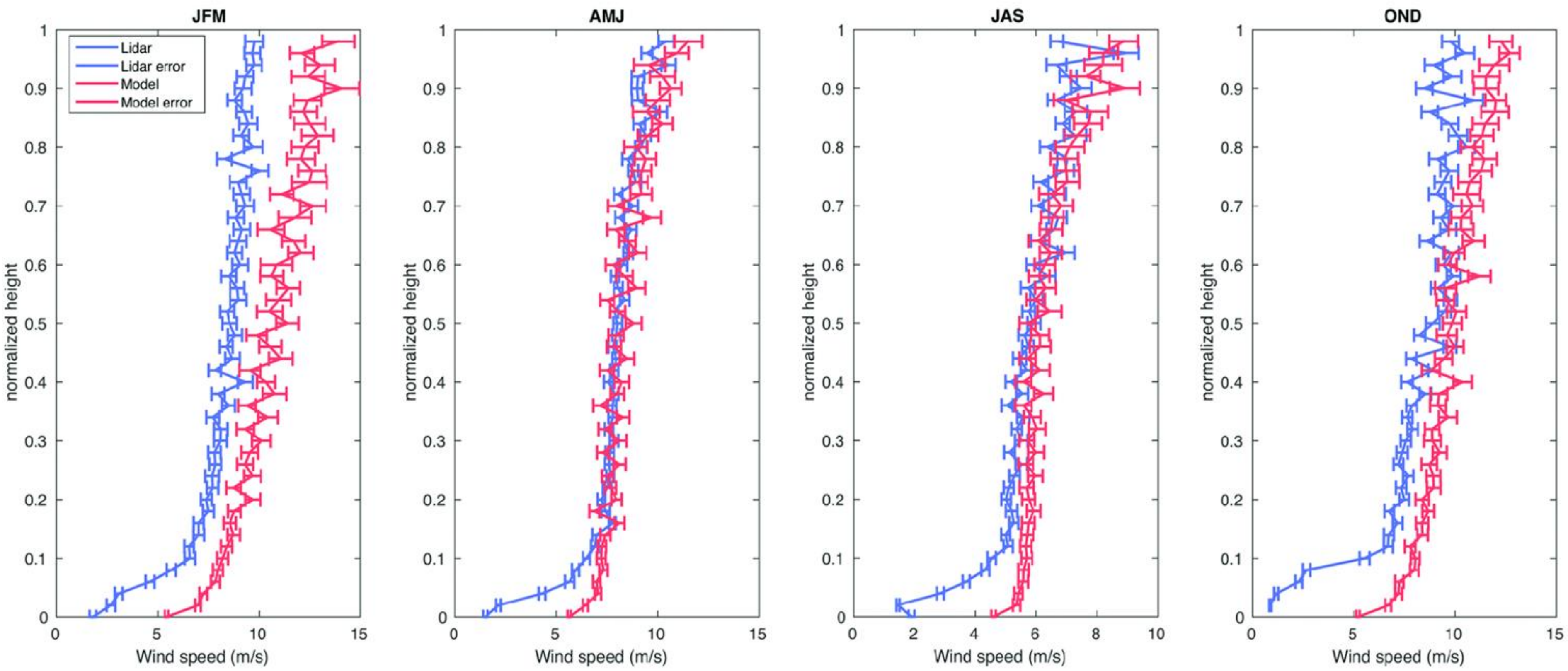
Seasonal biases in mid day ABL depth



Pan et al, in preparation

- Model ABL depth is higher than observations.
- Winter is less biased than summer.
- TKE-depth is greater than model-diagnosed ABL depth.

Seasonal biases in mid day Winds



Pan et al, in preparation

- Model is always too windy near the ground.
- Winter ABL winds are too high. Summer ABL winds are about right.

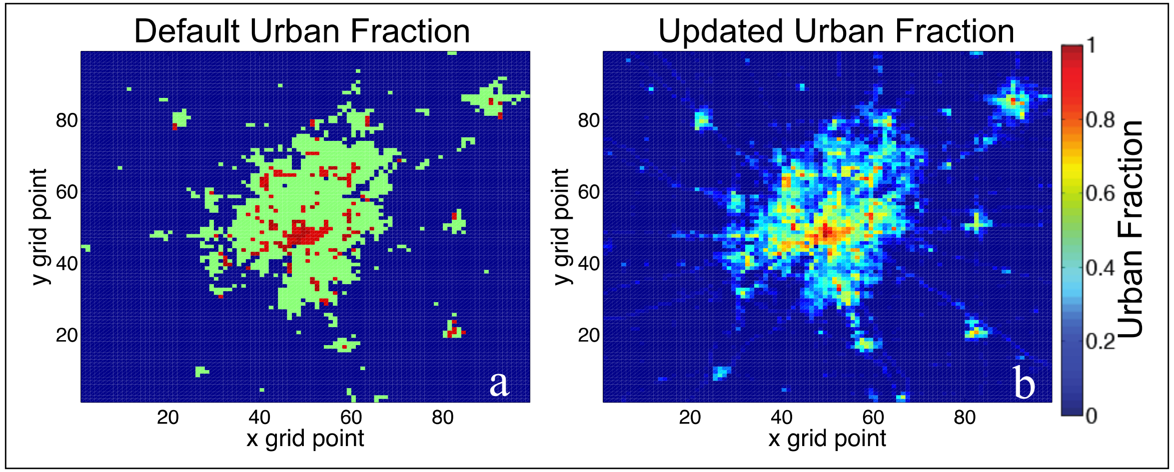
Seasonal biases in mid day Winds

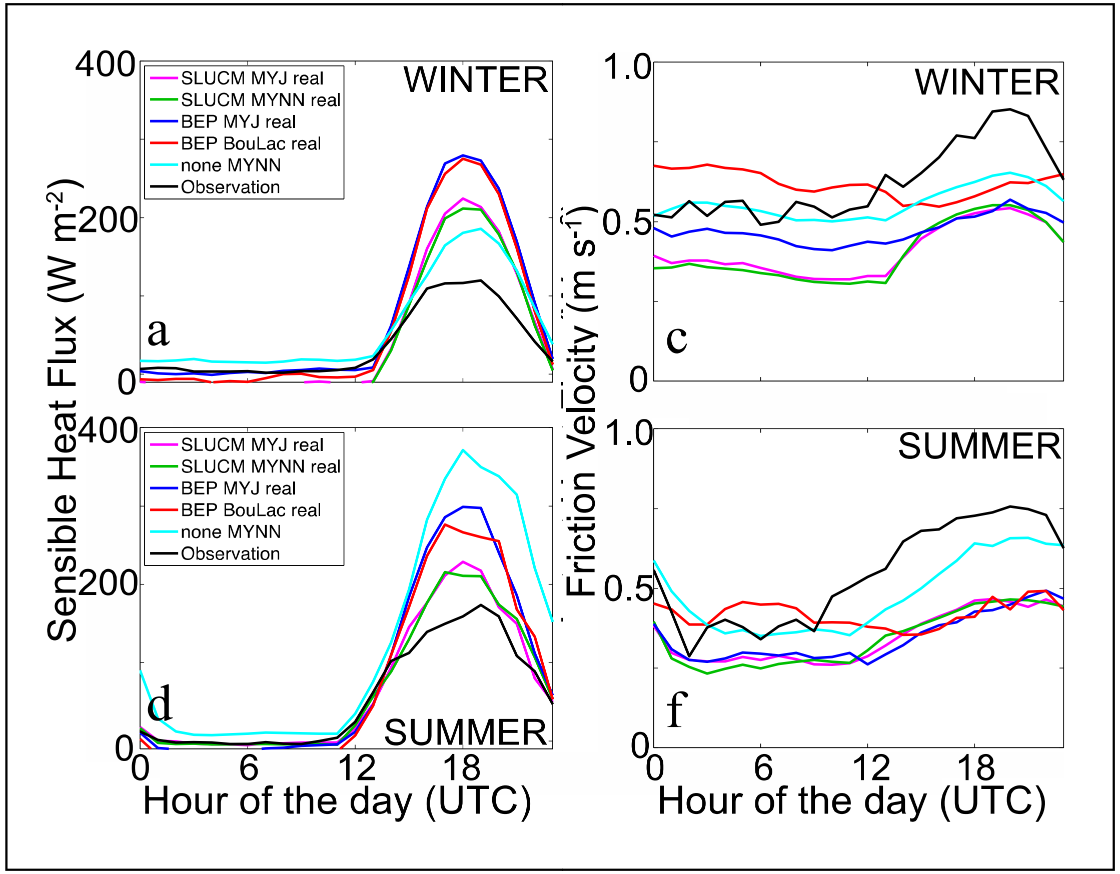
- ME of wind speed and direction between lidar and model

	Count		Wind speed(m/s)			Wind direction(degree)		
	Model	**Lidar**	**Model**	**Lidar**	**Difference**	**Model**	**Lidar**	**Difference**
JFM	7656	10367	10.5±0.07	8.0±0.04	2.5±0.11	231±1	222±1	9±2
AMJ	6260	9604	8.4±0.05	7.9±0.04	0.5±0.09	212±1	202±1	10±2
JAS	9709	14439	6.4±0.04	5.7±0.03	0.7±0.07	218±1	210±1	8±2
OND	7973	10691	9.7±0.06	8.1±0.05	1.7±0.11	241±1	230±1	11±2

Pan et al, in preparation

Identify causes of errors



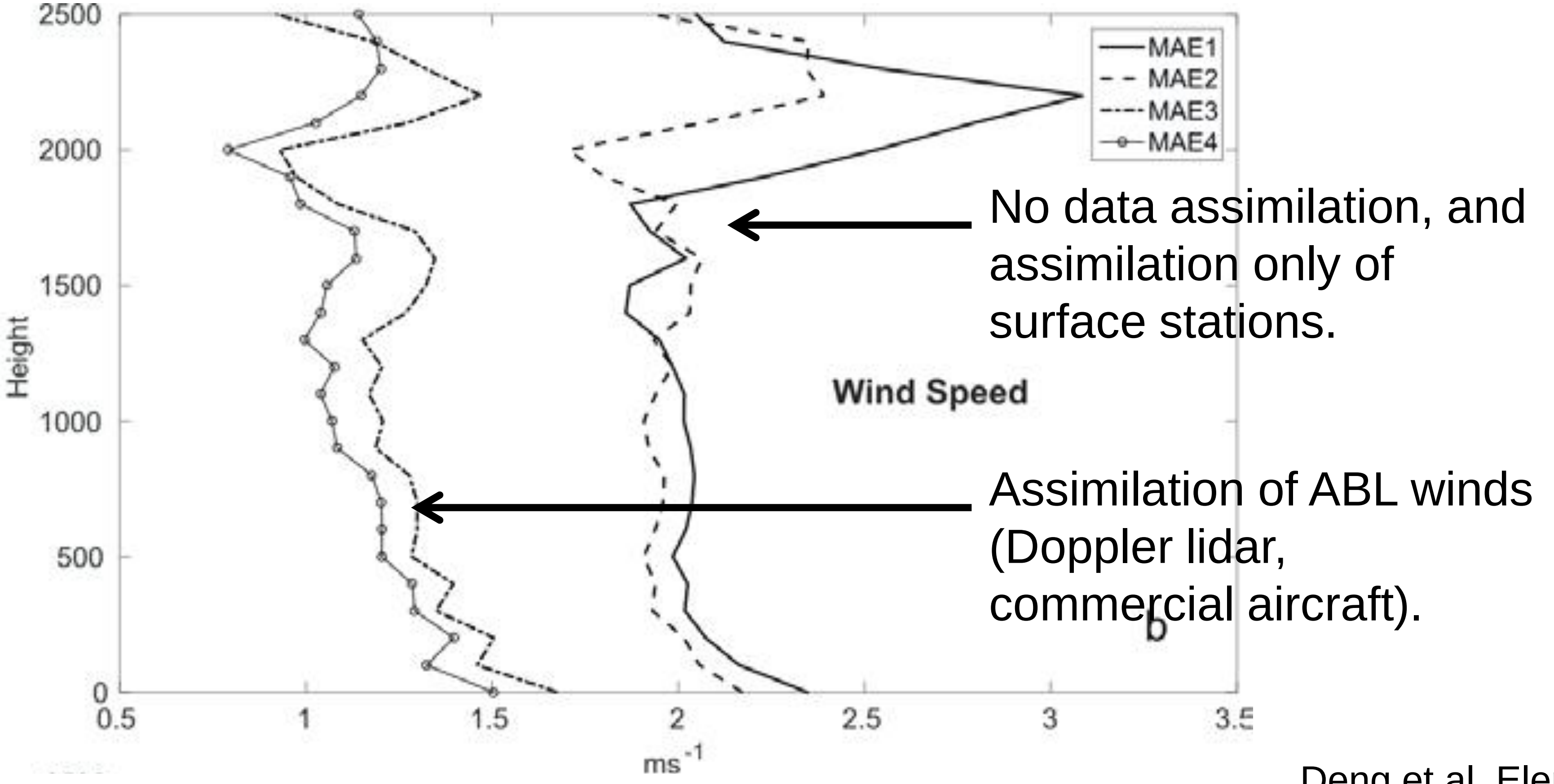


Sarmiento et al, Elementa, 2017

- WRF makes Indy a (bumpy) parking lot by default.
- Urban sensible heat fluxes are greatly overestimated.
- May help explain overestimate in ABL depth.

- Improving the urban land cover improves sensible and latent heat fluxes, but results in friction velocity being underestimated. And incoming solar is underestimated. Surface forcing is complex.

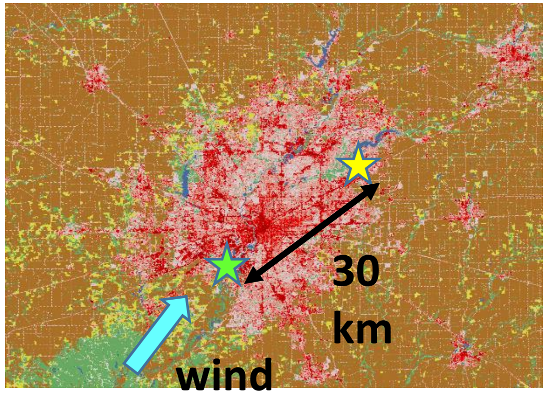
Assimilate data

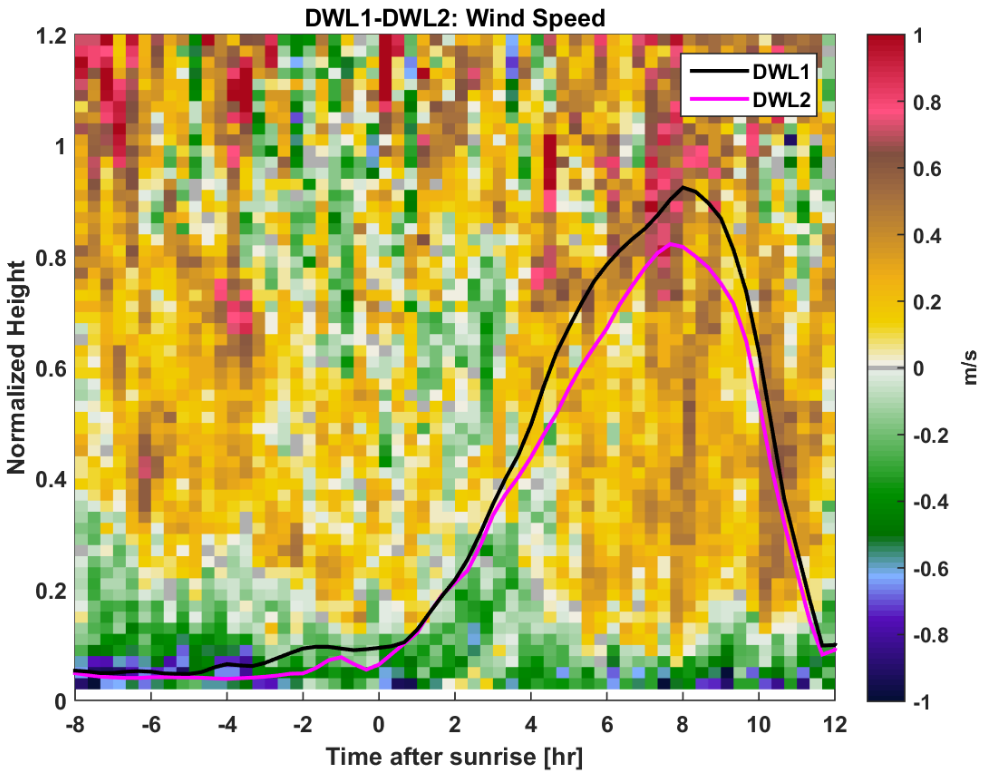


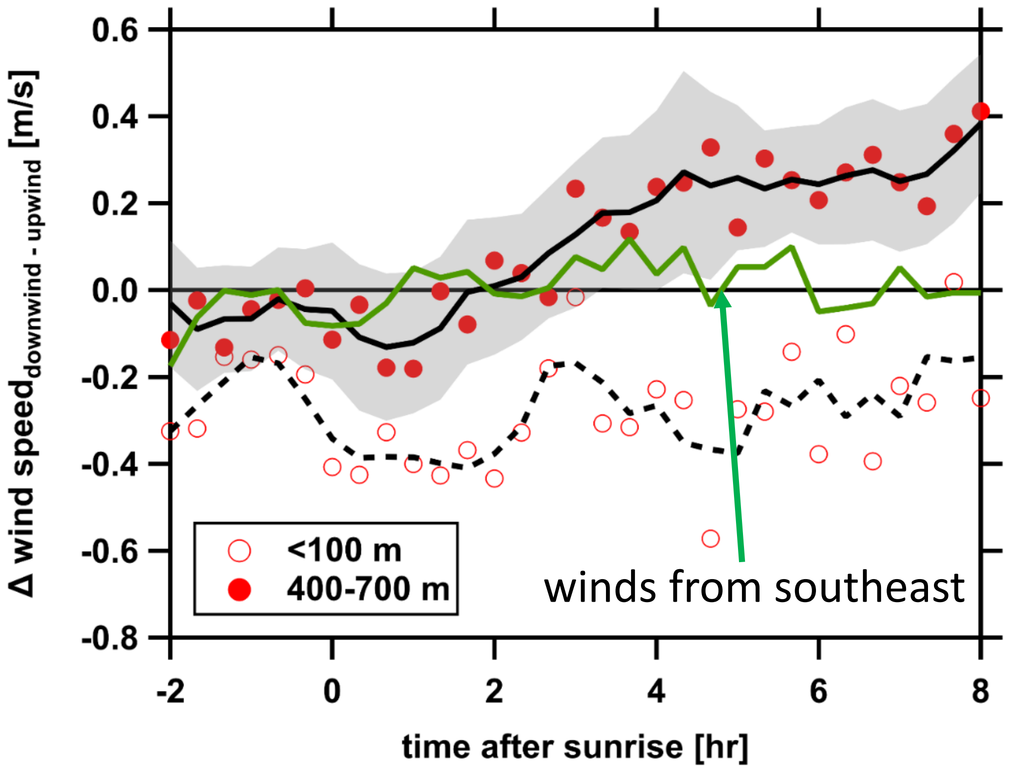
Deng et al, Elementa, 2017

- Doppler lidar wind data assimilation greatly reduces random errors

Urban Wind Island Effect

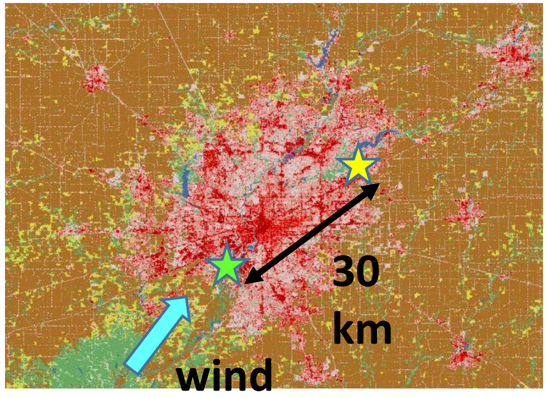


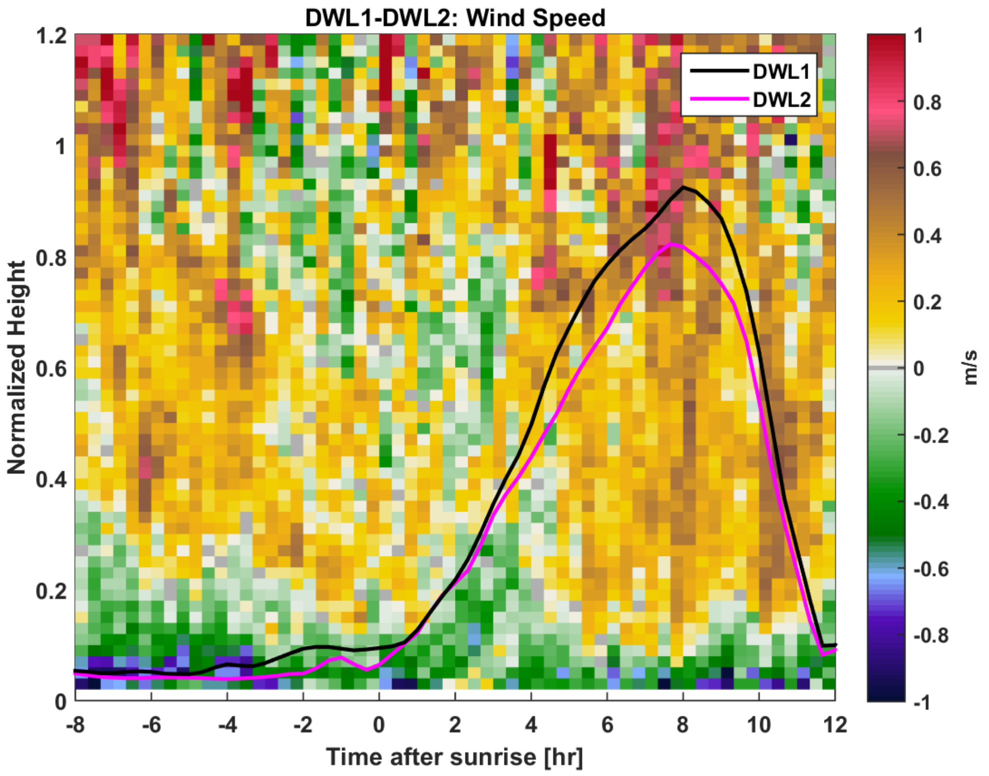


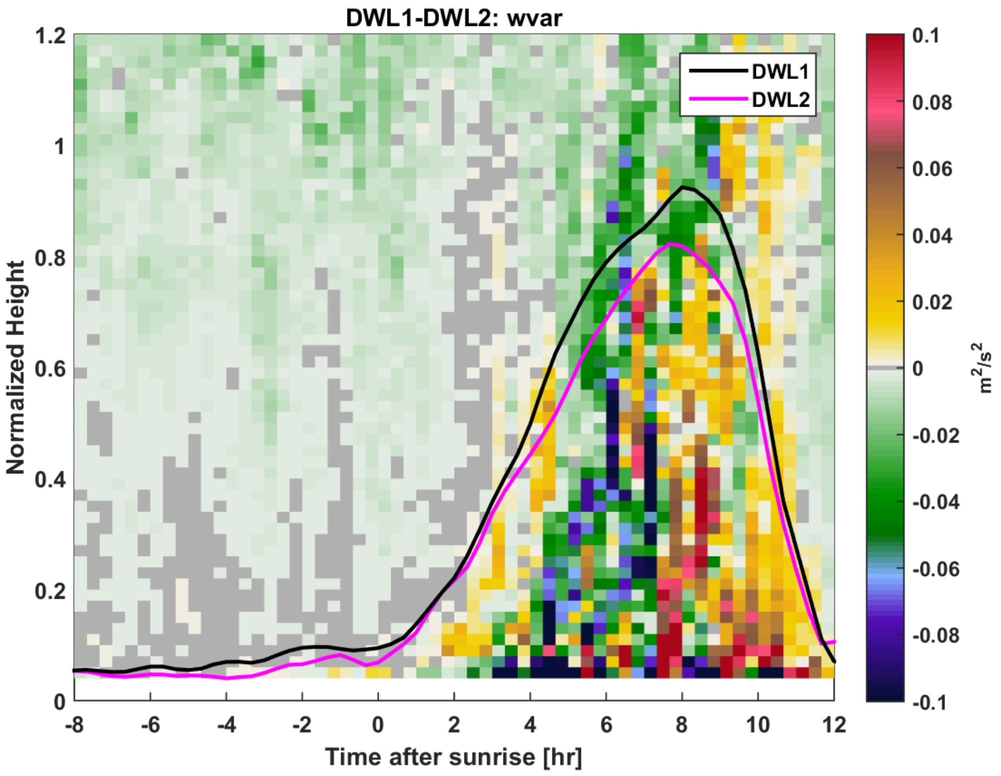


- Higher wind speed in the city than the rural area
- Higher wind speeds are observed at the downwind site throughout the urban boundary layer.

Urban Wind Island Effect



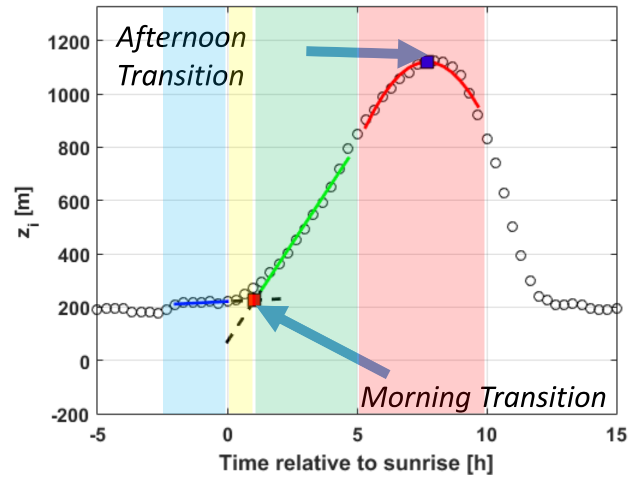




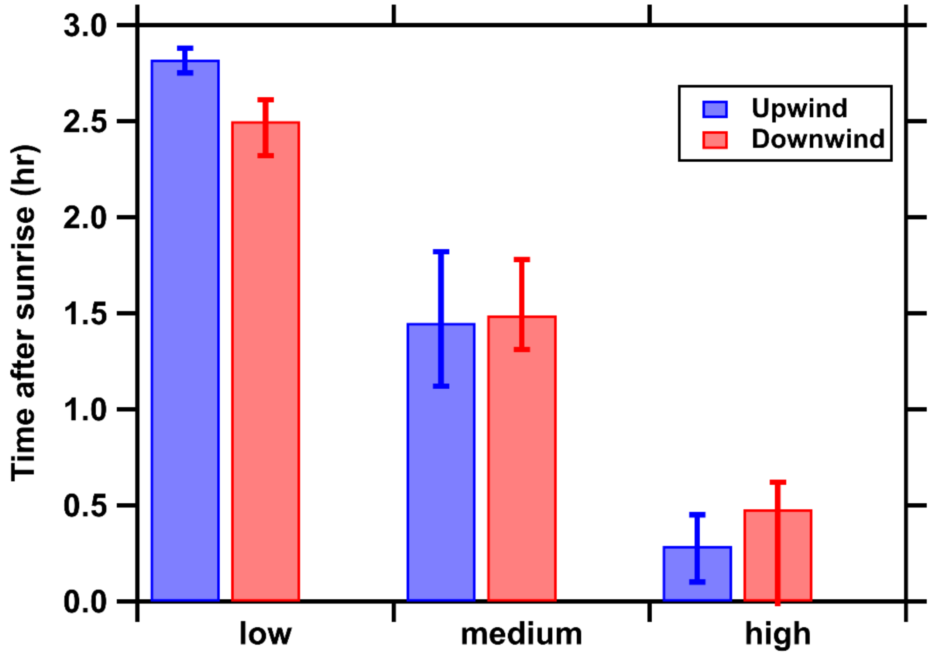
- Higher wind speeds are observed at the downwind site throughout the urban boundary layer.
- Higher turbulence at the downwind site during the MLH growth phase mixes in high momentum air from aloft.

Mixed Layer Evolution

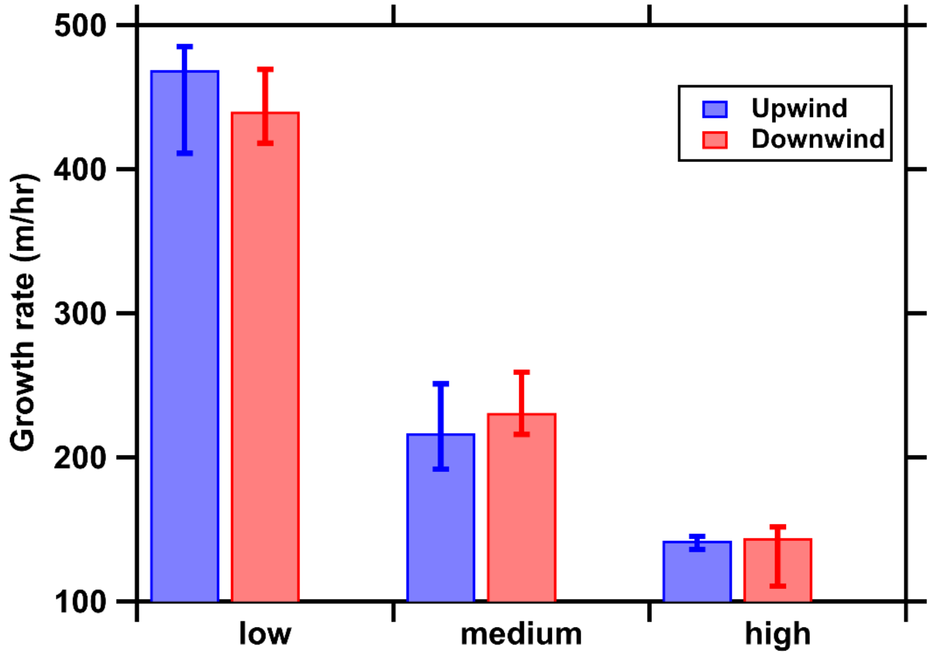
- Wind direction: 180 - 270°
- Wind Speed:
  low (< 5 m/s), medium (5-10 m/s) high (>10 m/s)



Morning Transition



Rapid Growth Rate



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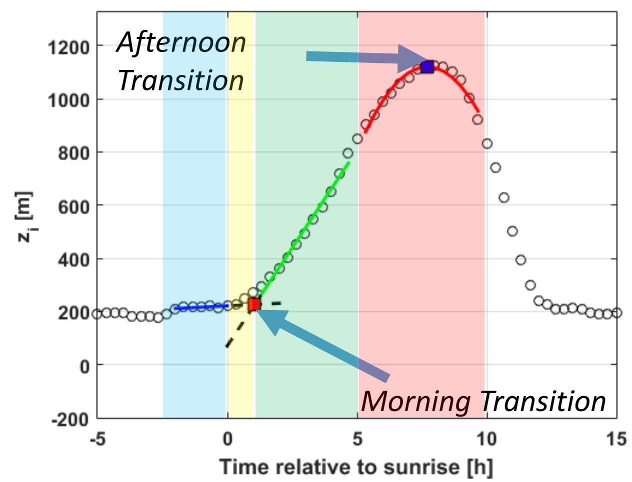
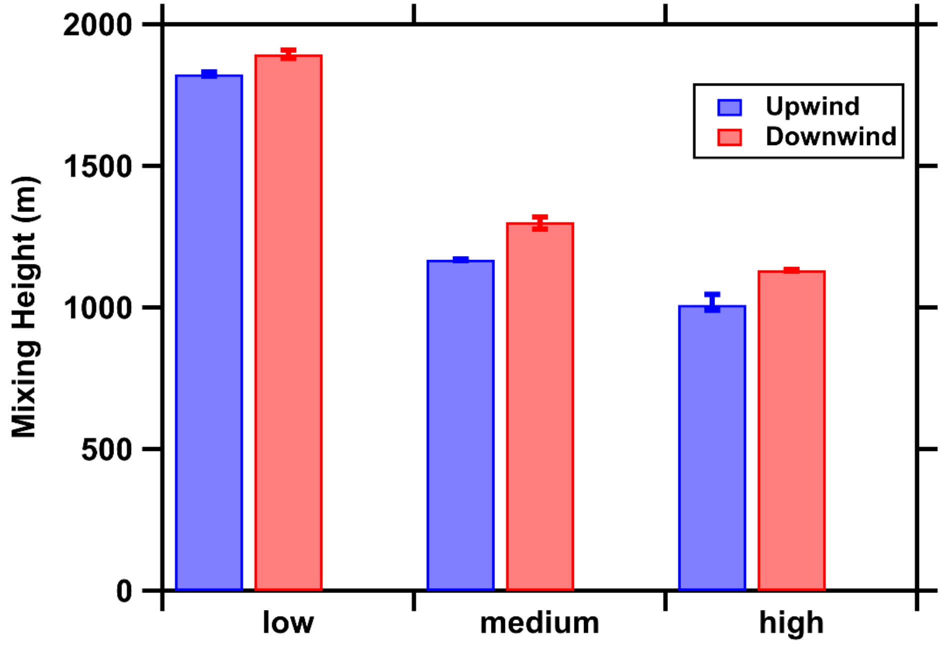
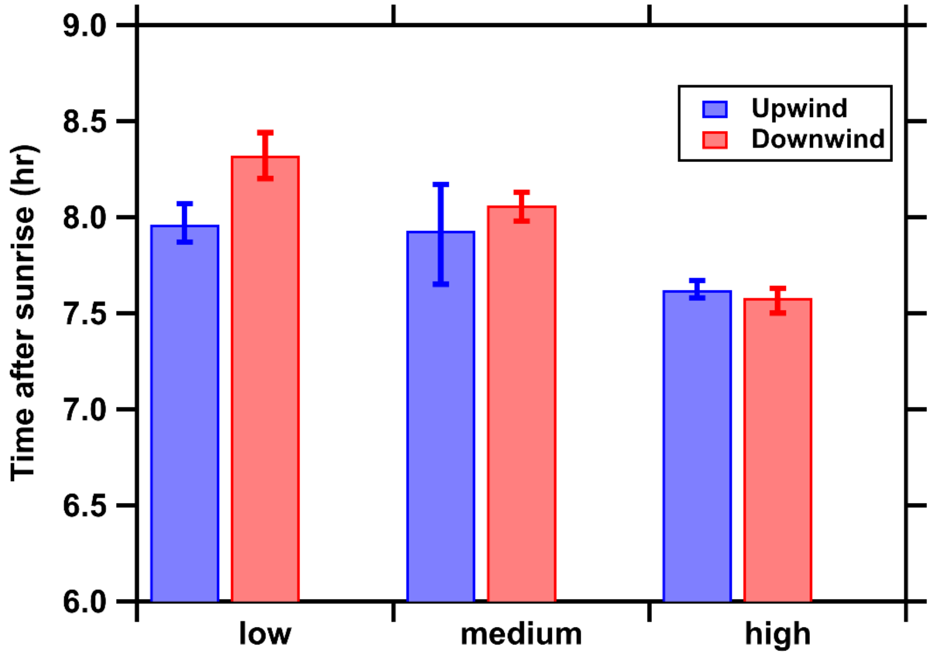


Maximum MLH

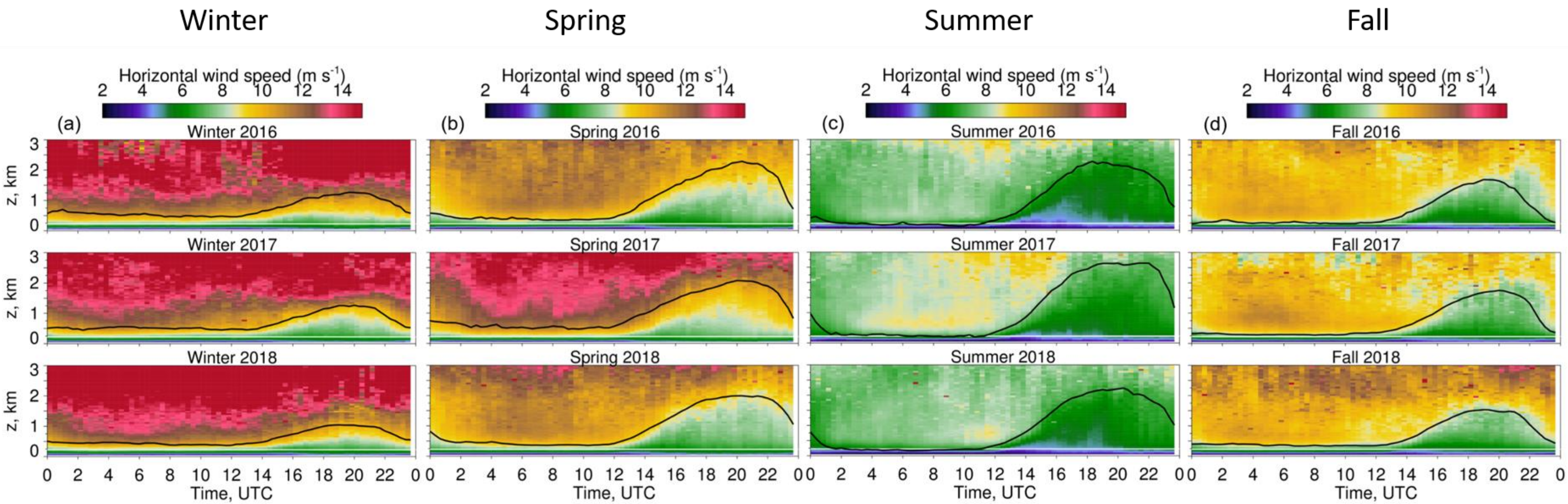


Afternoon Transition



Diurnal variability of wind speed and BLH

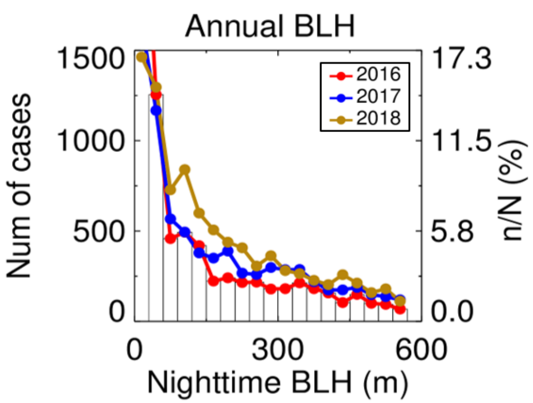
Seasons of 2016-2018

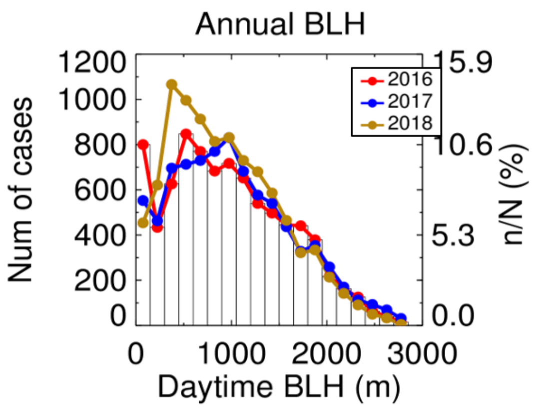


- Stronger winter winds compare to summer
- Higher daytime BLH for spring and summer
- Weaker winds below BLH for all seasons

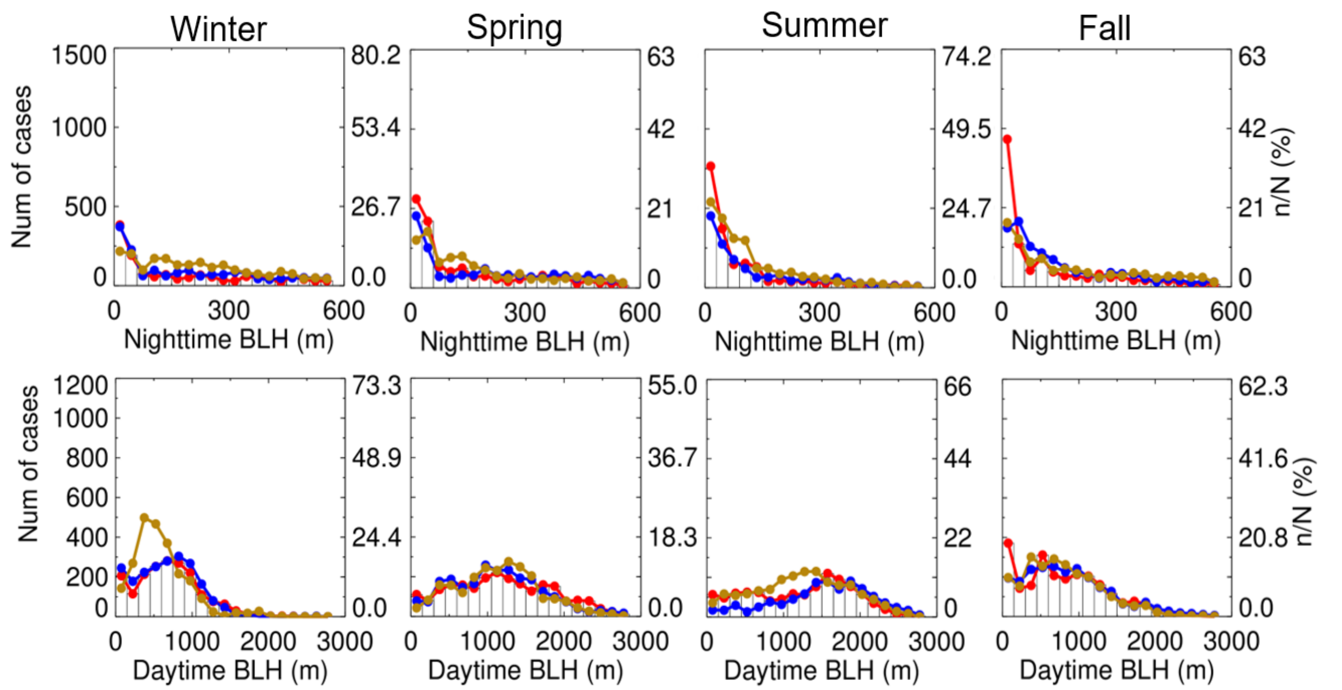
Pichugina et al, in preparation

Annual and Seasonal distributions of BLH



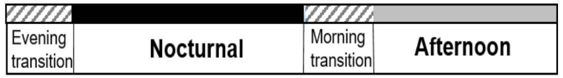


Year	Mean	STD	Num
	Nighttime		
2016	223	296	8691
2017	270	307	8804
2018	230	246	9765
	Daytime		
2016	986	632	8479
2017	1026	636	8452
2018	943	575	9362



Afternoon (daytime) BLH is calculated from 2.5 to 3 h before sunset for each day

Nocturnal (nighttime) mean is calculated from 1 h after sunset to sunrise



Pichugina et al, in preparation

Summary

- Doppler lidar observations of the boundary layer have proven to be very valuable in assessing model performance at Indianapolis.
    - Land surface forcing is an important element of urban ABL development and also deserve careful study.
    - Rural meteorological boundary conditions play an important role in simulations of the urban boundary layer, and also deserve careful study.
- Assimilation of Doppler lidar winds reduced boundary layer wind random errors by ~50% in Indianapolis.
- Doppler lidar observations of winds and mixing height can be used to study the effect of urban areas on boundary layer processes.
- Long-term measurements of wind and mixing height in Indianapolis provides an excellent dataset to test urban model developments.
    - This should be complemented with studies of the surface fluxes, and evaluation of the upwind meteorological simulation.