Evaluation of a simple CFD model in a complex vegetated urban area during the 2015 Engineering-quad experiment at the University of Utah

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Abstract

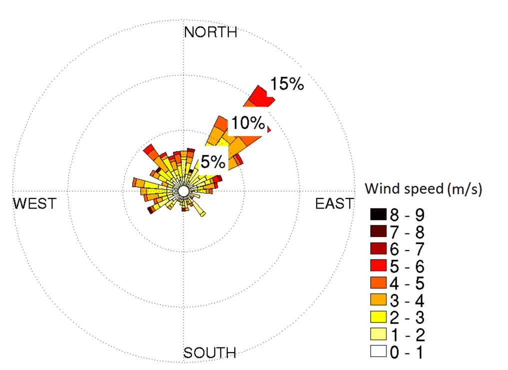
In urban areas, vegetation cover has an important effect in modulating the urban heat island (UHI). For example, during the day, trees typically cool the air via evapotranspiration and shading thereby reducing energy consumption. Nonetheless, their effects are often neglected in microclimate wind modeling studies due to the lack of appropriately-resolved models that include complex flow modifications resulting from vegetation. This study explores the effects of vegetation canopies on the alteration of urban microclimate in highly-vegetated areas. Here, we use a fast-response simple CFD model called Quick Urban Industrial Complex wind field modeling system (QUIC-URB), which uses empirical parameterization along with mass conservation to produce averaged three-dimensional wind fields. This model is used to assess and compare the diurnal cycle of the mean wind field around buildings and vegetation elements using experimental data from near-surface time-averaged wind measurements obtained during the 2015 engineering-quad experiment at the University of Utah. During this experiment, low-cost local energy-budget measurement stations (LEMS) were used to measure wind speed and direction. Three different test cases are investigated including: the no-vegetation canopy model, the default vegetation canopy model in QUIC-URB (that accounts for momentum damping with appropriate attenuation coefficients for different trees species), and a grouped trees with averaged attenuation coefficient. Statistical comparisons during high wind and low wind timeframe has been done. Wind speed mean error is 30% and wind direction mean absolute difference is less than 90.

Objectives

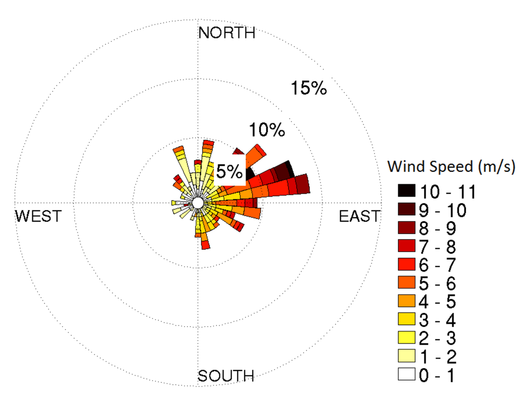
- Develop a physically robust fast-response energy transport simulation tool
- Determine the large-scale impacts of vegetation on urban environment
- Evaluation of current wind model in QUIC-URB
- Improve parameterizations for highly vegetated urban area

Experiment Setup

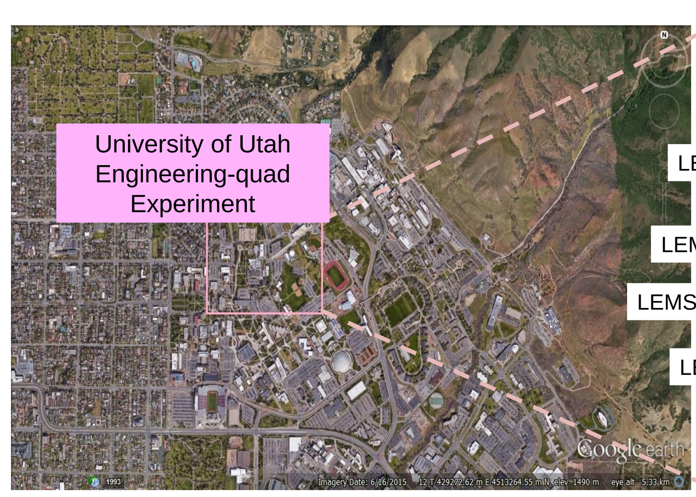
- **Location**: Latitude: 40°45'52.9" Longitude:111°50'56.9" Engineering–quad at the University of Utah
- **Timeframe:** May 2015 to present (2016)
- **Focus:** Measuring energy budget
- **Equipment:**
  - ❖ low-cost local energy budget measurement
  - ❖ station (LEMS)
  - ❖ 13 different locations
  - ❖ Sampling frequency of 0.1 Hz
  - ❖ Sensors :
    - Wind speed and direction (Davis Anemometer)
    - Humidity and air temperature (SHT 15)
    - Infrared ground temperature (TN9)
    - Solar radiation (Licor LI200)
    - Soil moisture and temperature (Decagon 5TM)
  - ❖ Weather station data University of Utah William Browning Building (WBB) at 36m above ground level [1]



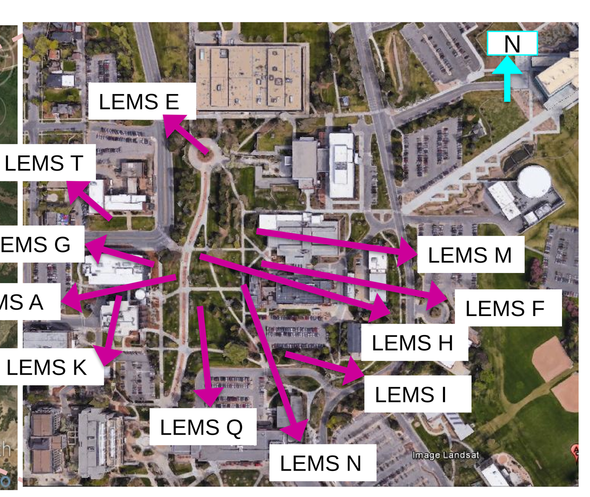
Wind rose representation during June 29-July 7,2015



WBB wind rose representation during June 15 ,2015



Engineering-quad experiment location



LEMS location

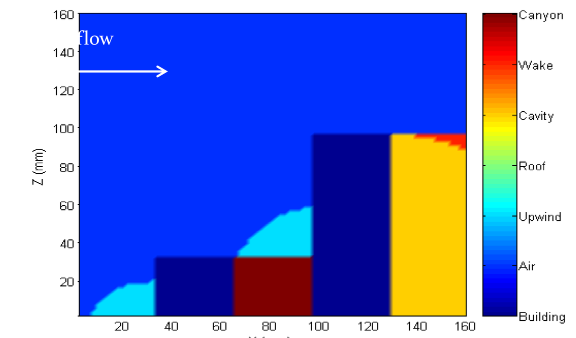
LEMS configuration

Simulation Setup

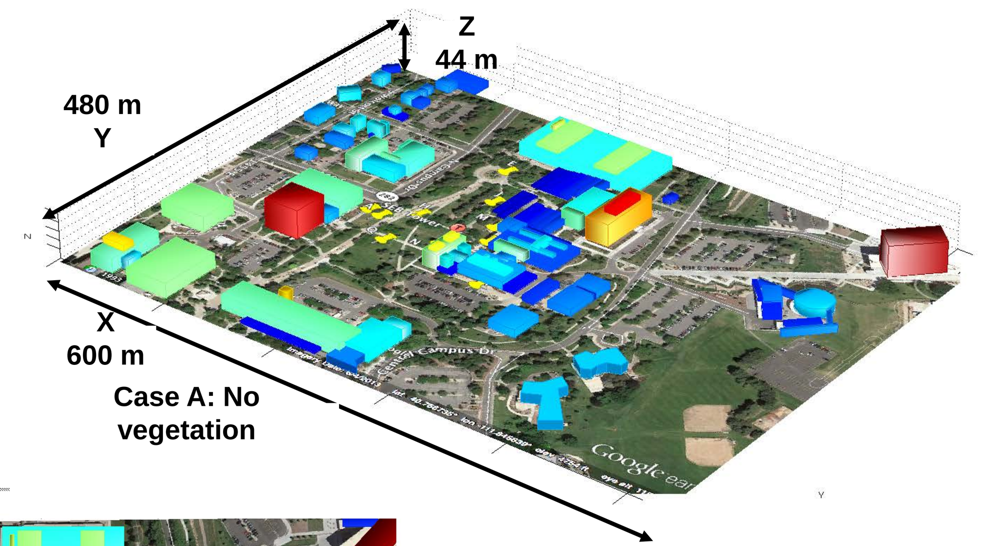
- **Simple CFD model:** Quick Urban Industrial Complex wind field modeling system (QUIC-URB)
  - ❖ Determine mean wind field in urban areas
  - ❖ Uses mass-conserved empirical parameterizations From wind tunnel database for building configuration [2]
- **Domain:** size (600 m × 480 m × 44 m), with 103 buildings and 150 trees, Grid Resolution (4 m × 4 m × 1.1 m)
- **Test cases:** A) No vegetation B) Individual trees C) Grouped trees with averaged attenuation coefficient
- **Simulation day**: 1) June 15,2015(one day) 2) June 29-July 07,2015 (week)
- **Input**: Logarithmic wind profile with WBB as a reference

$$U(z) = \frac{U_{ref}(\ln(\frac{z+z_0}{z_0})+\psi_M(z/L)}{\ln(\frac{z_{ref}+z_0}{z_0})}$$, z_0=0.1m, Neutrally stable

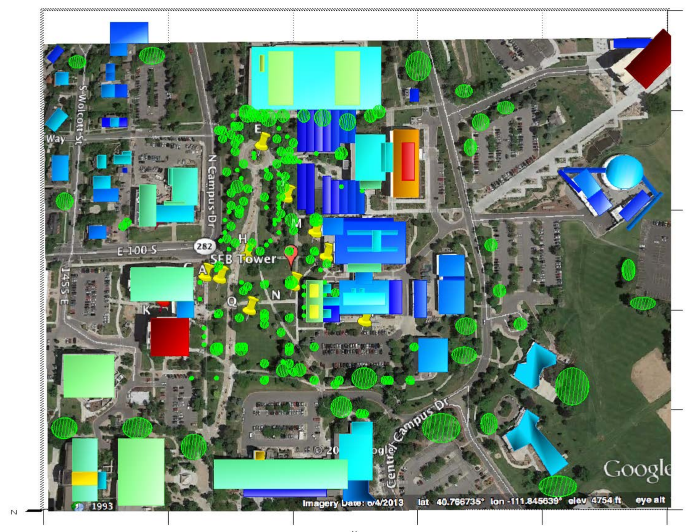
- **Computational time: ~**20 minutes (2.6 GHz Intel Core i5 – MacBook Pro using 2 processors)



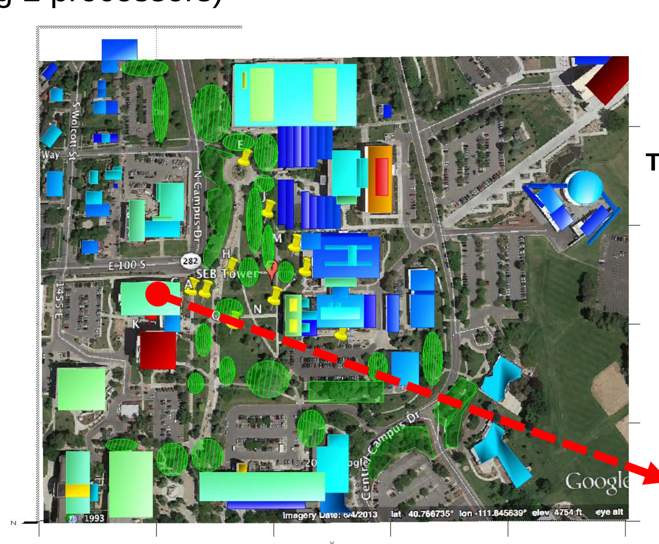
QUIC-URB applied algorithms in simulation



Case A: No vegetation



Case B: Individual trees



Case C: Grouped trees

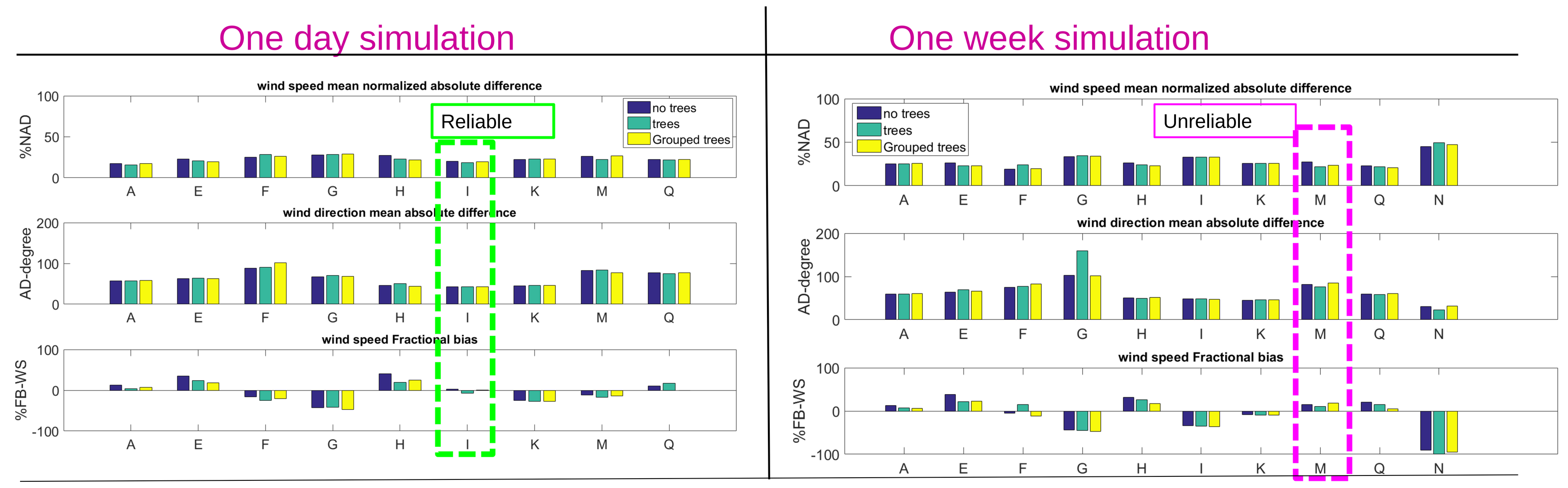
WBB weather station

Type of trees in the domain

Type of trees in domain	**Conifer**	**Deciduous**
Attenuation coefficient	1.06	4.03
Trunk/Height	1	0.25

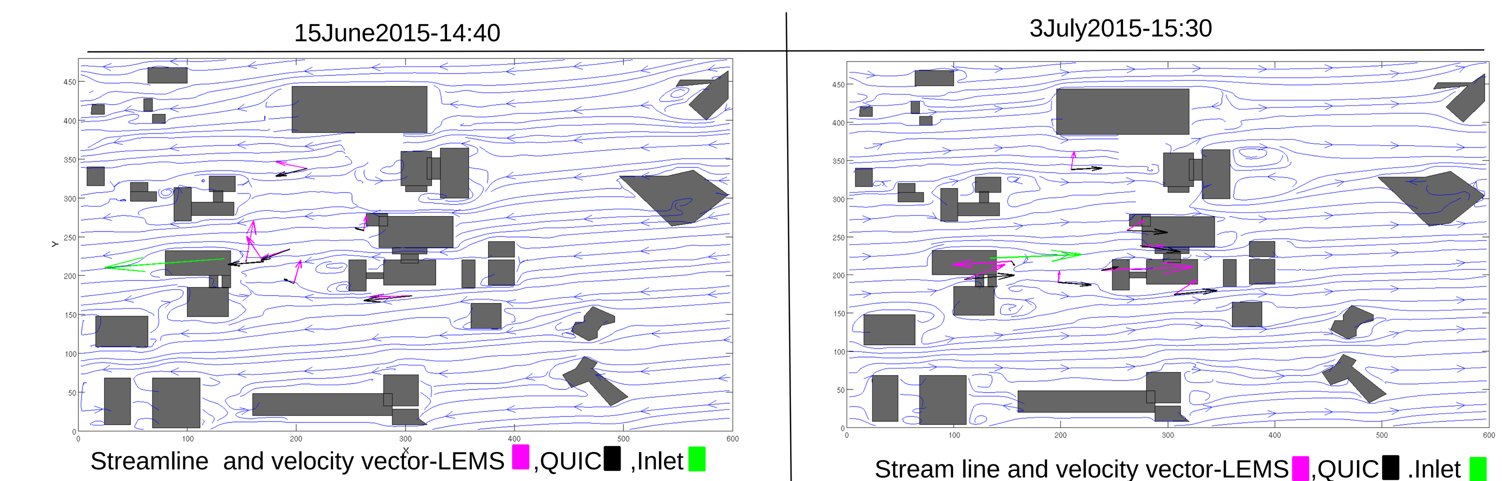
Results

- **Quantitative comparison:** Quality metrics used to compare simulation and experiment include
  - ❖ Normalized Absolute Difference
    $NAD = \frac{\sum|Observation-Simulation|}{\sum(Observation+Simulation)}$
  - ❖ Absolute Difference
    $AD = |\overline{Observation - Simulation}|$
  - ❖ Fractional bias
    $FB = \frac{\overline{Observation} - \overline{Simulation}}{0.5(\overline{Observation} + \overline{Simulation})}$



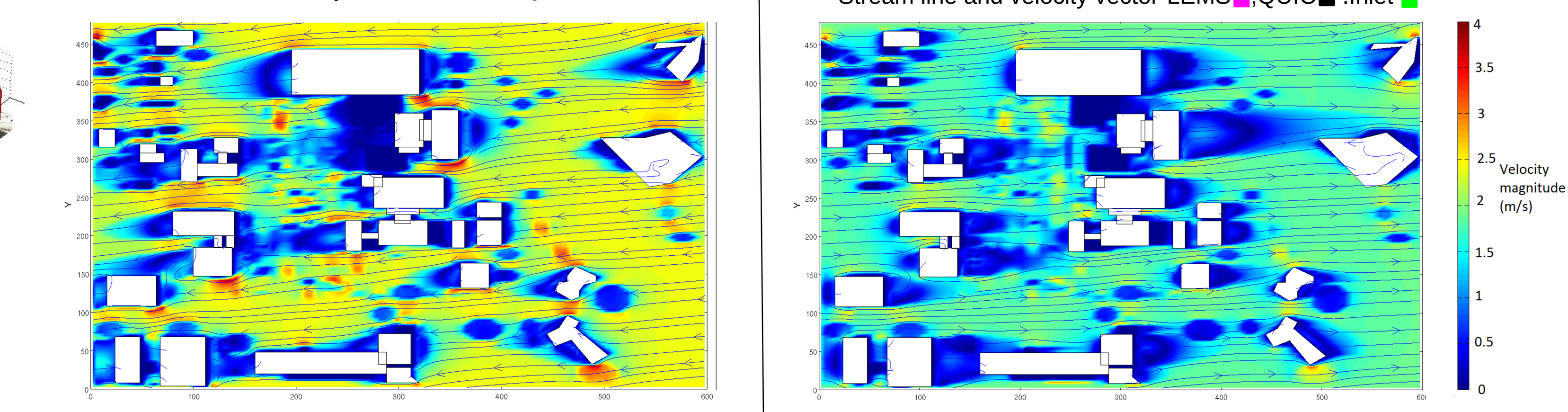
NAD, AD, and FB for wind speed and direction in all cases- week and one day simulation

•**Qualitative comparison**



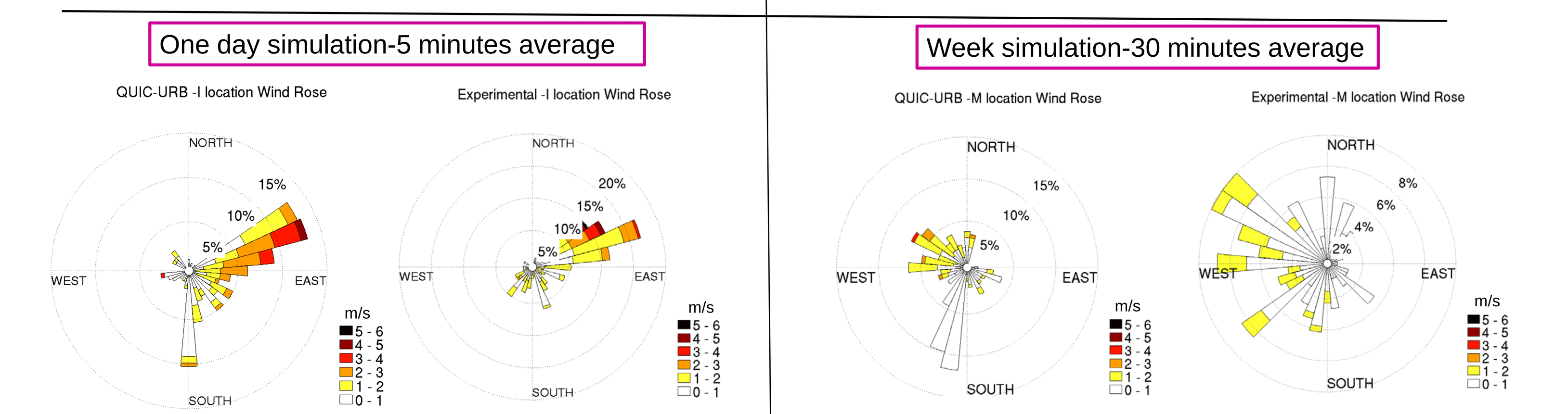
Streamline and velocity vector-LEMS , QUIC , Inlet

Stream line and velocity vector-LEMS , QUIC , Inlet



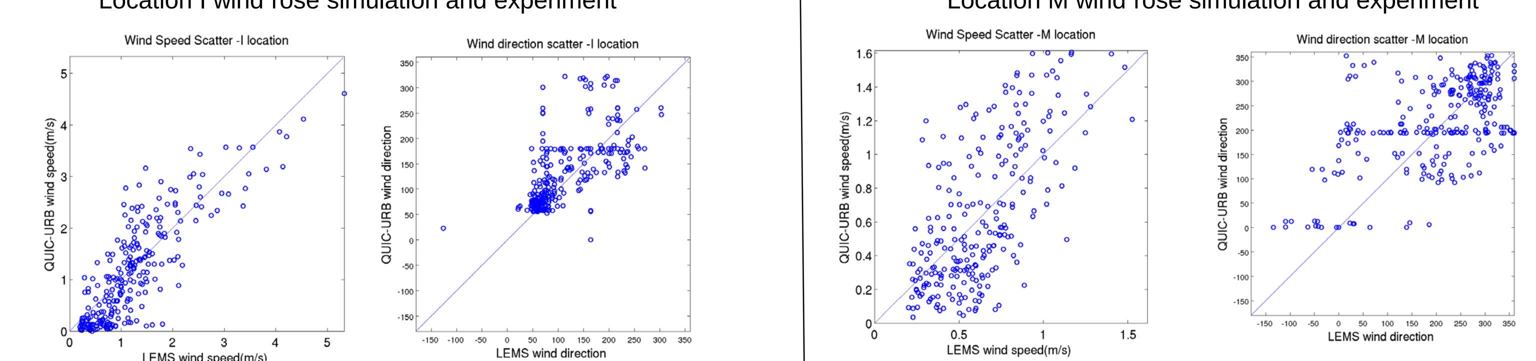
Velocity magnitude contour

Velocity magnitude contour



Location I wind rose simulation and experiment

Location M wind rose simulation and experiment



Wind speed simulation and experiment scatter plot-Location I

Wind speed simulation and experiment scatter plot-Location M

Summary

- To evaluate the current version of QUIC-URB, 3 test cases have been compared against University of Utah Engineering-quad Experiment.
- Wind speed error has been quantified and compares reasonably well compared to Engineering-quad data, specifically NAD is about 30%.
- Wind direction comparison indicates the mean absolute difference for all cases is less 90 degree
- Result suggests longer time period comparison to understand physical aspects of domain

Future work

- Develop new model that account for dynamic effect of vegetation
- Improved urban profile based on plan area fraction, wind direction, surface roughness, and leaf index area

References

[1] MesoWest;2015, http://mesowest.utah.edu, Retrieved on November 10, 2015.
[2] Singh, B., Hansen, B., Brown, M.J. and Pardyjak, E.R., Evaluation of the QUIC-URB Fast Response Urban Wind Model for a Cubical Building Array and Wide Building Street Canyon, Environmental Fluid Mechanics, 8(4), 281-312, 2008

Acknowledgements

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