Dual-Doppler Lidar Wind Profiling in LUMEX

(The Lidar Uncertainty Measurement Experiment)

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CoRP 2015

Outline

- Doppler Lidar
    - Single and Dual Techniques
- The Lidar Uncertainty Measurement Experiment (LUMEX)
- Dual Doppler Analysis and Results
- Future Work

Heterodyne Doppler Lidar Systems

- “Light Detection And Ranging”
- Low-energy laser, typically infrared
- Measure wind speed along the line of sight by observing the Doppler effect frequency-shifted backscattered photons

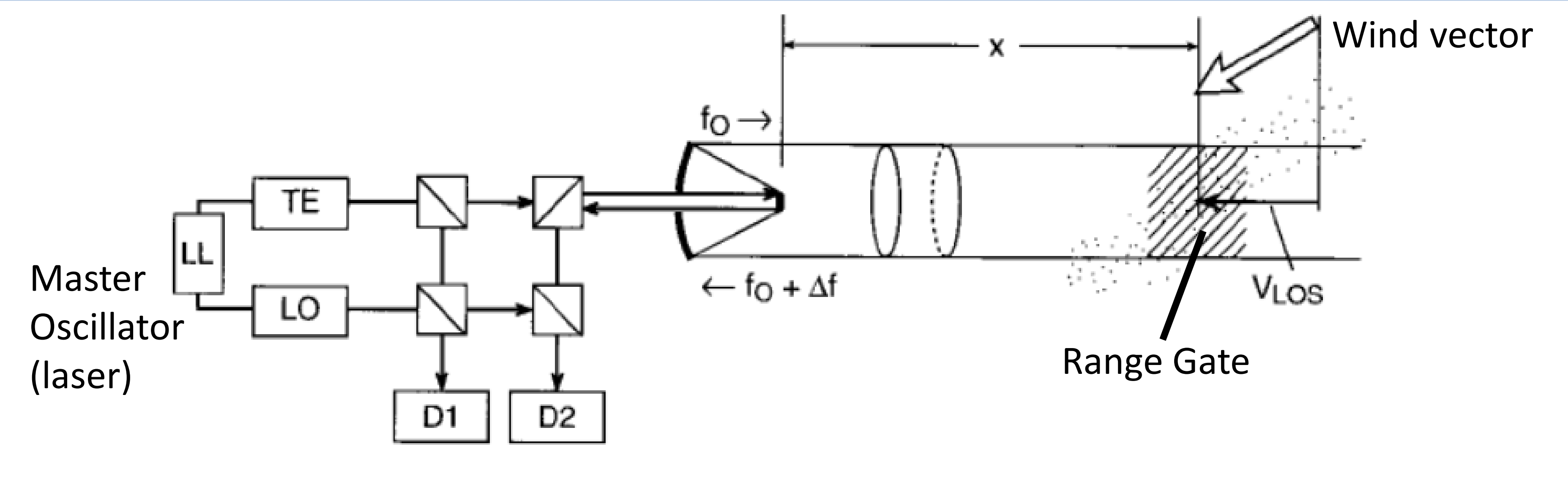
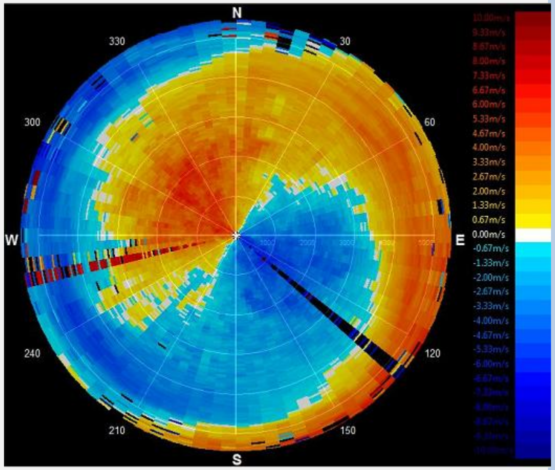


Image adapted from Prof. Xinzhao Chu’s Lidar Remote Sensing Lecture Notes, CU-Boulder 2012

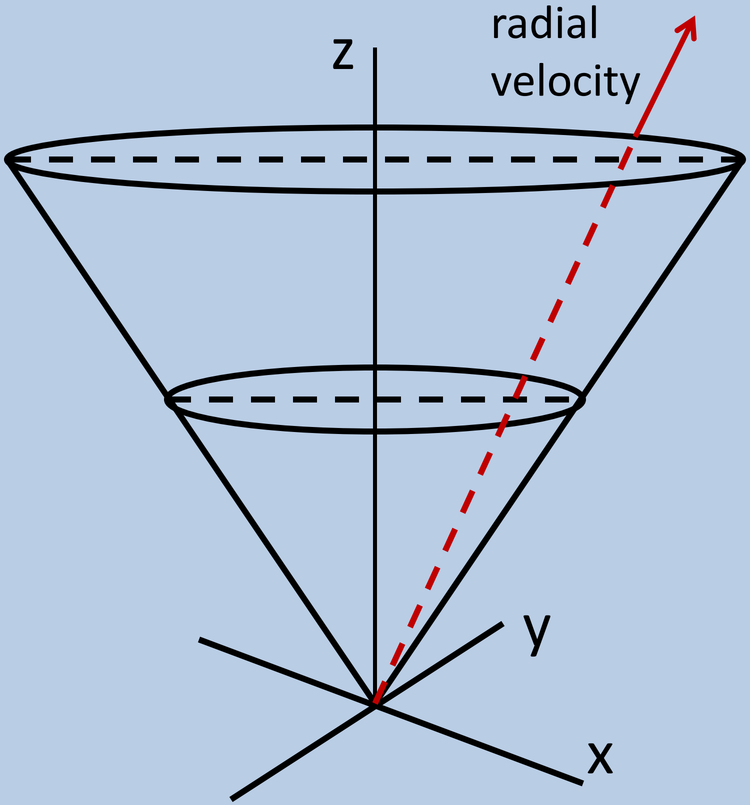
Single Doppler Lidar Wind Retrieval

- Thorough scanning is necessary to build a multi-dimensional wind profile with only one lidar.

- Vary azimuth with constant elevation



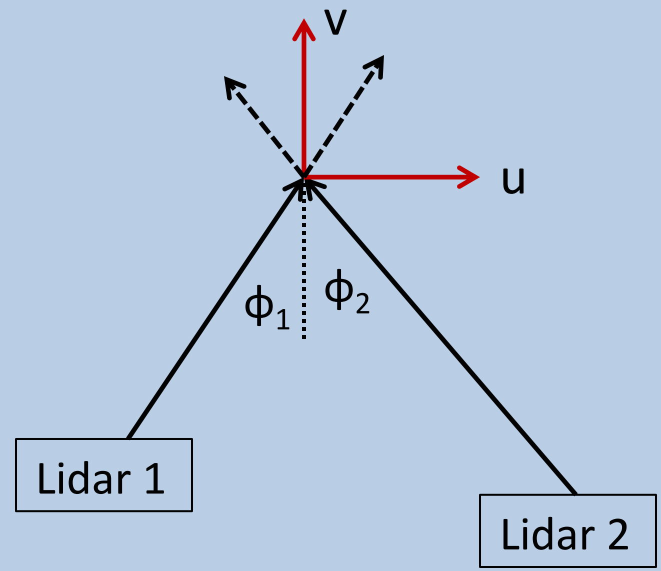
- Vary elevation with constant azimuth



Dual-Doppler Scanning

- Principle is well established with radar

- Two Doppler lidars, not co-located, simultaneously observing the same point in space



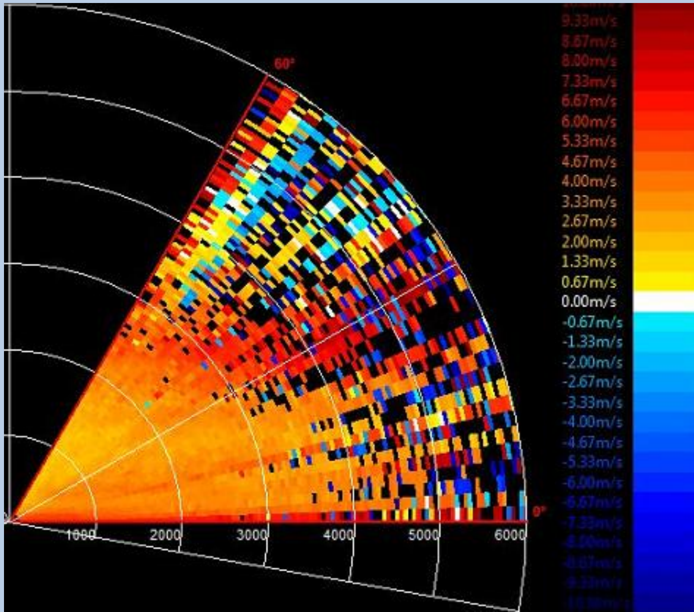
$$\begin{pmatrix} v_{r\,1} \\ v_{r\,2} \end{pmatrix} = \begin{pmatrix} \cos(\theta_1)\sin(\phi_1) & \cos(\theta_1)\cos(\phi_1) & \sin(\theta_1) \\ \cos(\theta_2)\sin(\phi_2) & \cos(\theta_2)\cos(\phi_2) & \sin(\theta_2) \end{pmatrix} \begin{pmatrix} u \\ v \\ w \end{pmatrix}$$

- v_r is radial velocity, ϕ azimuth, θ elevation

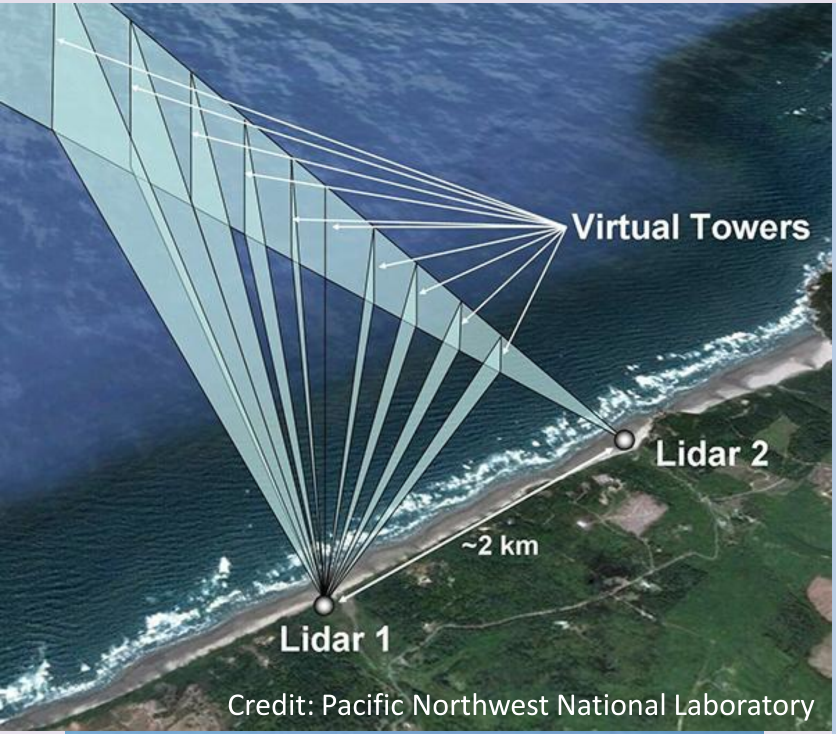
- Assume w is negligible

$$u = \frac{1}{\sin(\phi_1 - \phi_2)} \left(\frac{v_{r\,1}\cos(\phi_2)}{\cos(\theta_1)} - \frac{v_{r\,2}\cos(\phi_1)}{\cos(\theta_2)} \right)$$

$$v = \frac{1}{\sin(\phi_1 - \phi_2)} \left(\frac{v_{r\,2}\cos(\phi_1)}{\cos(\theta_2)} - \frac{v_{r\,1}\cos(\phi_2)}{\cos(\theta_1)} \right)$$



Advantages



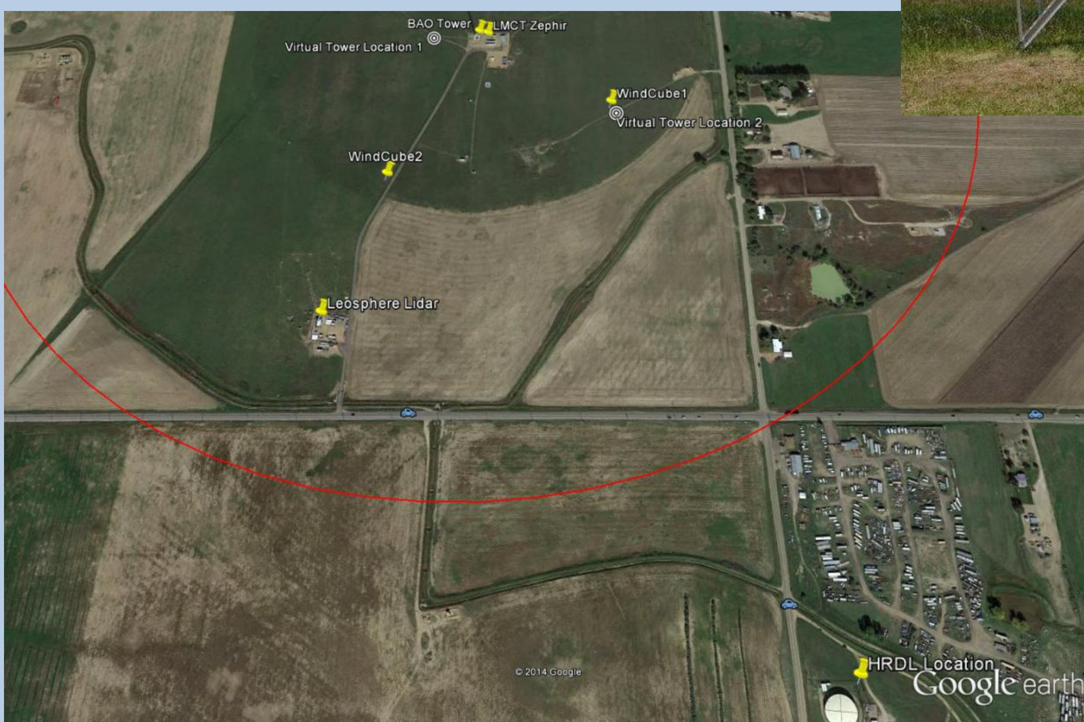
Credit: Pacific Northwest National Laboratory


Credit: Vattenfall

- Small spatial footprint
    - Variable bin sizes
- Small temporal footprint
    - Variable scan rate
- “Virtual towers”
    - Can take measurements centered over hard-to-reach places
    - Wind turbine applications

LUMEX

- Dual-Doppler phase
  July 1 – 13, 2014
- Boulder Atmospheric Observatory (BAO)



Lower Right Image Credit: Cooperative Institute for Research in Environmental Sciences

LUMEX

Major Goals of LUMEX:

- Characterize sampling error of vertical velocity statistics
- Analyze sensitivities of different Doppler lidar systems
- Validation and comparison of turbulence analysis techniques with Doppler lidar
- Characterize error of spatial representativeness for separation distances up to 3 km
- Validate and improve various methods of single and dual Doppler wind profile retrieval

Dual-Doppler in LUMEX

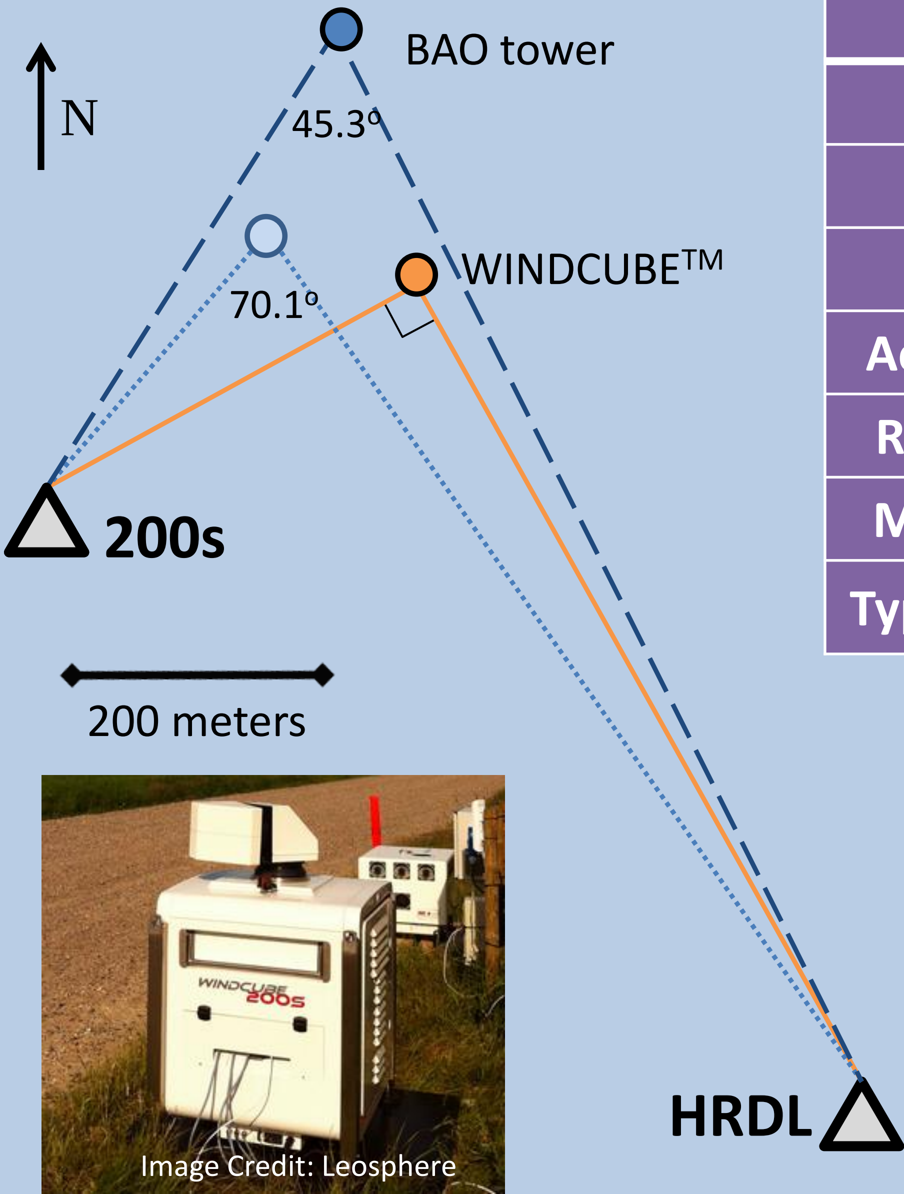
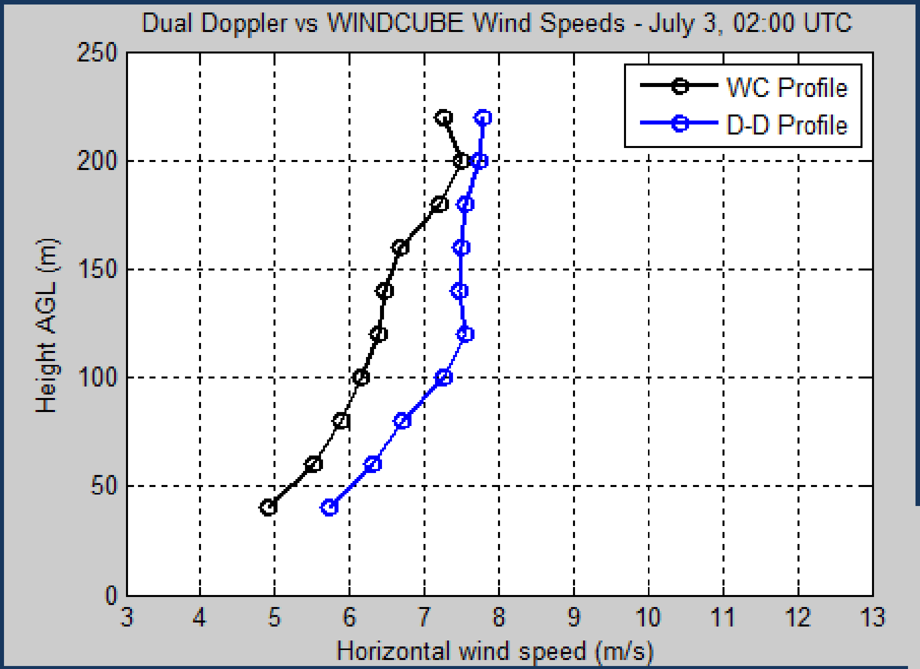


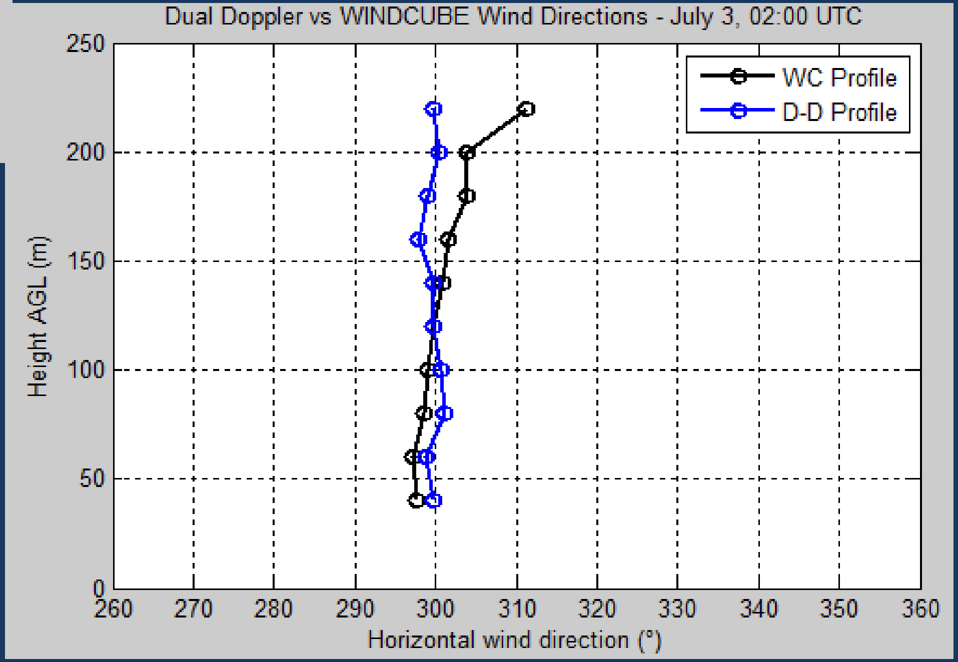
Image Credit: Leosphere

Lidar Parameters	HRDL	200s
Wavelength (µm)	2.02	1.54
Pulse Energy (mJ)	1.5	0.1
Pulse Rate (Hz)	200	10 000
Accumulation Time (s)	0.5	1
Range Resolution (m)	30	50
Minimum Range (km)	0.2	0.1
Typical Max Range (km)	3	3

- Multiple virtual tower sites and scan styles employed to observe dependence on **intersection angle** and **dwell time**

Dual-Doppler and Reference Data





Error Characterizations

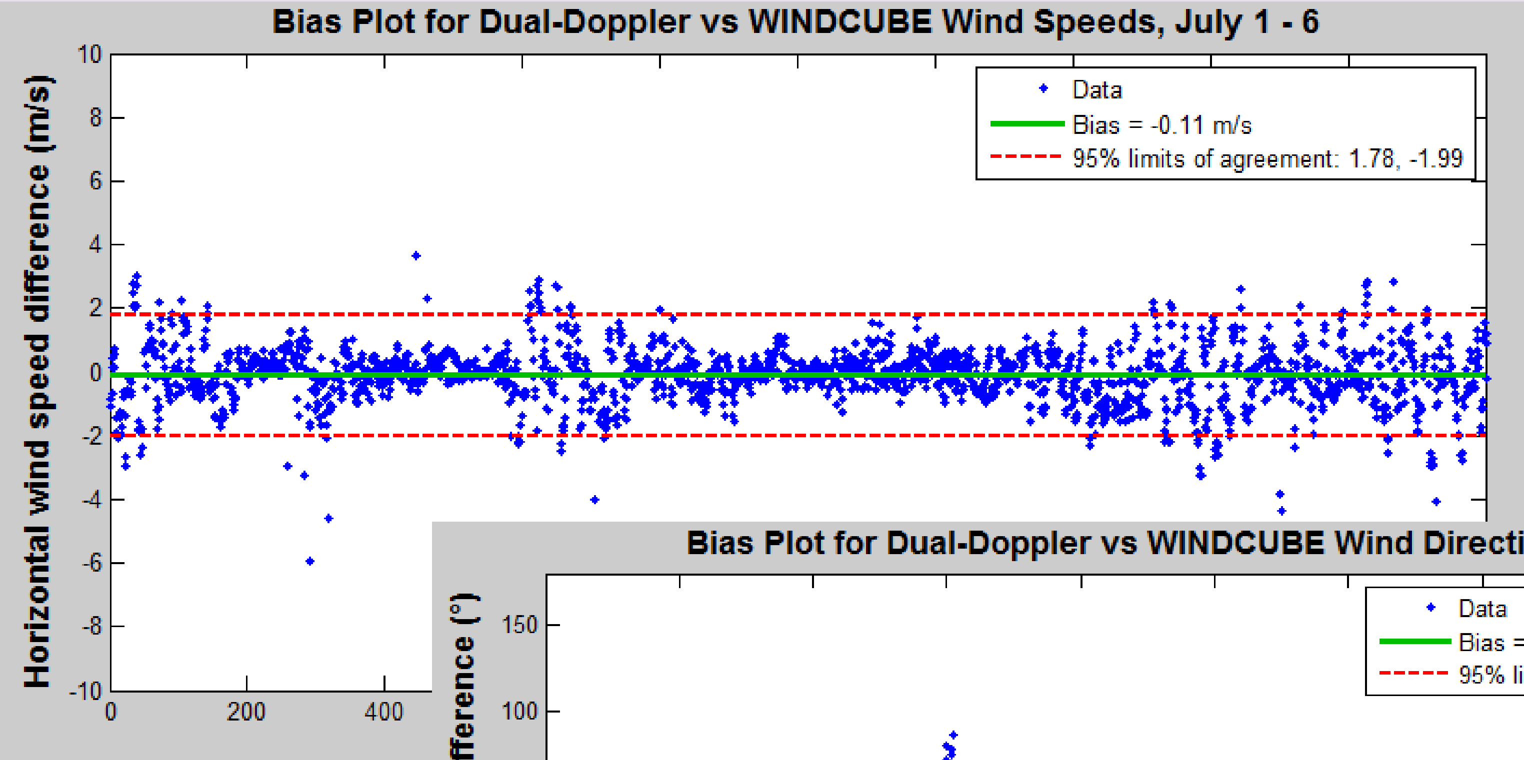
- Biases
- Medians and Standard Deviations of the absolute difference over each data pair

$$\bar{y} = \frac{\sum_1^N \left| x_{\mathrm{dd}} - x_{\mathrm{ref}} \right|}{N}$$

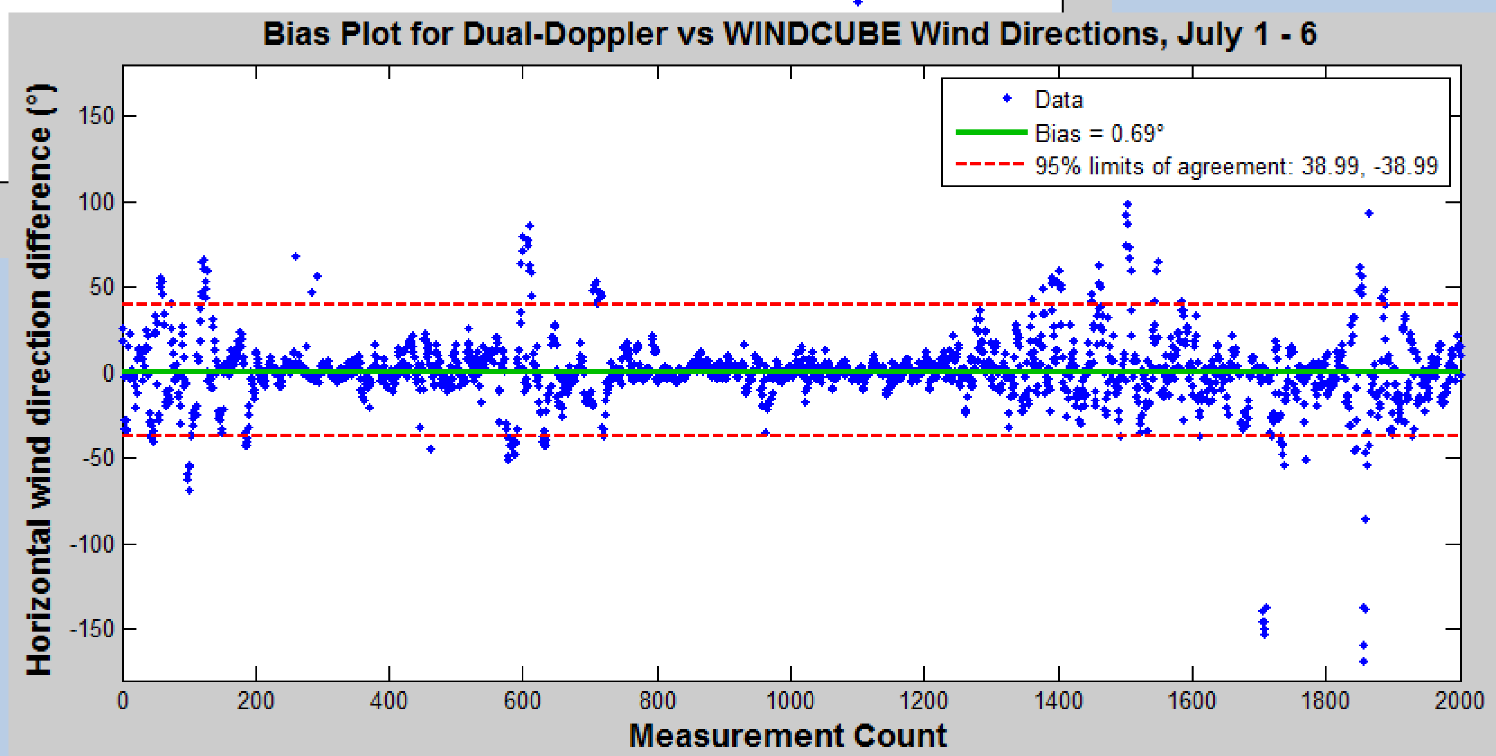
$$\sigma = \sqrt{\frac{\sum_1^N (y_i - \bar{y})^2}{N}}$$

- No dependence of accuracy on altitude was found. This validates the assumption of *w = 0* for the experiment in general.

Bias plots, July 1 - 6



Bias:
-0.11 m/s



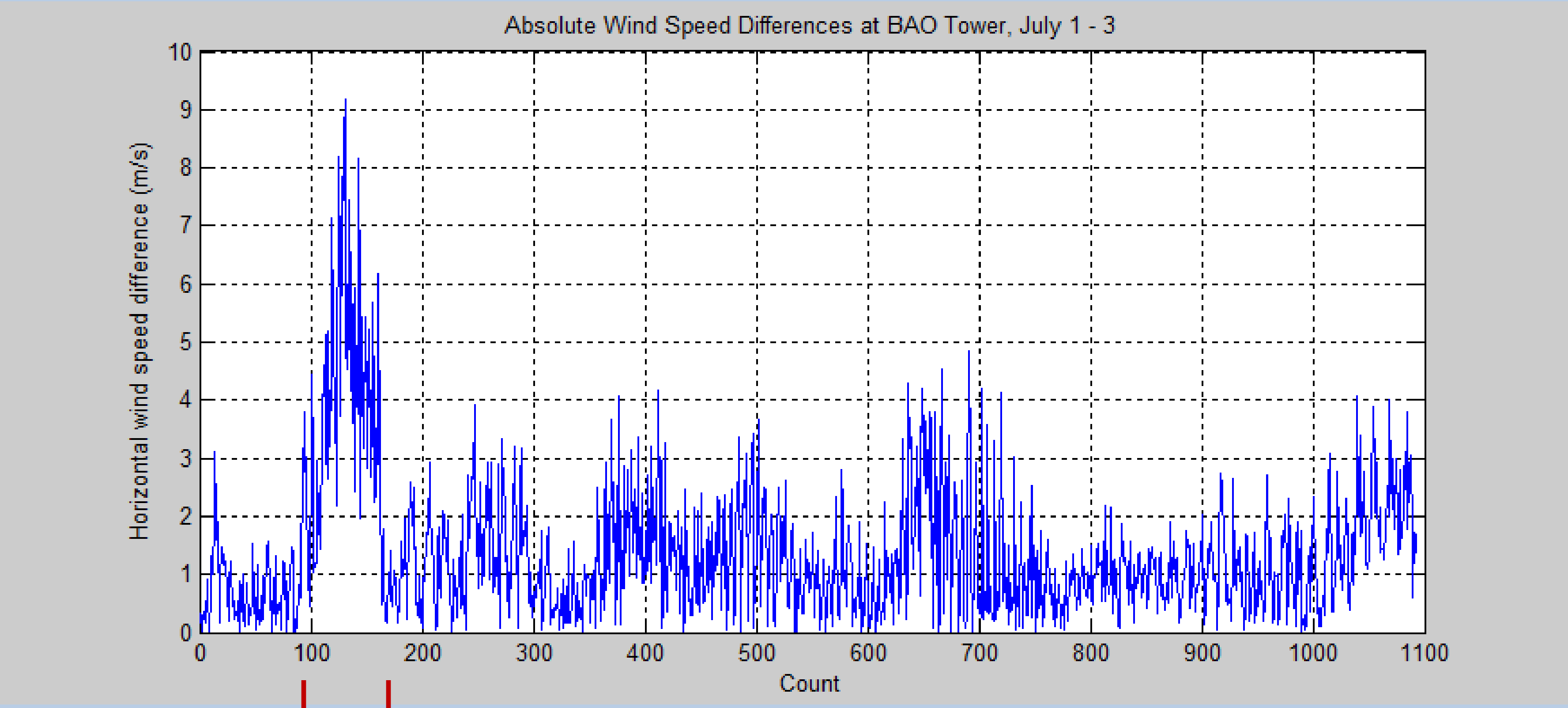
Bias:
0.69°

July 1 - 6

Dual-Doppler Comparison	Median Absolute Difference (m/s)	Standard Deviation (m/s)
BAO u	**1.31**	1.77
BAO v	**0.73**	0.90
BAO horizontal wind	1.01	1.25
BAO horizontal direction	12.3°	19.2°
WINDCUBE u	**0.46**	0.97
WINDCUBE v	**0.47**	0.92
WINDCUBE wind speed	0.47	0.70
WINDCUBE wind direction	6.4°	17.1°

After filters were applied, these statistics were calculated from 1025 BAO comparisons and 2058 WINDCUBE comparisons.

Favorable Conditions - BAO Wind Speed



High horizontal and vertical winds

High horizontal winds and vertical shear

Future Work

- Improve the understanding of intersection angle dependence by analyzing the third virtual tower results.

- Quantify the benefits of longer dwell time at a single virtual tower

- Increased effectiveness and accuracy of our future dual-Doppler experiments

- Completing the other goals of LUMEX
    - Characterizing the uncertainty of a wide variety of Doppler lidar retrievals

Image Credit: Leosphere

Questions?

Photo Credits: Scott Sandberg, Raymond Hoff

Acknowledgements

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