Lidar Measurements of Wind and Turbulence for Wind-Energy Applications

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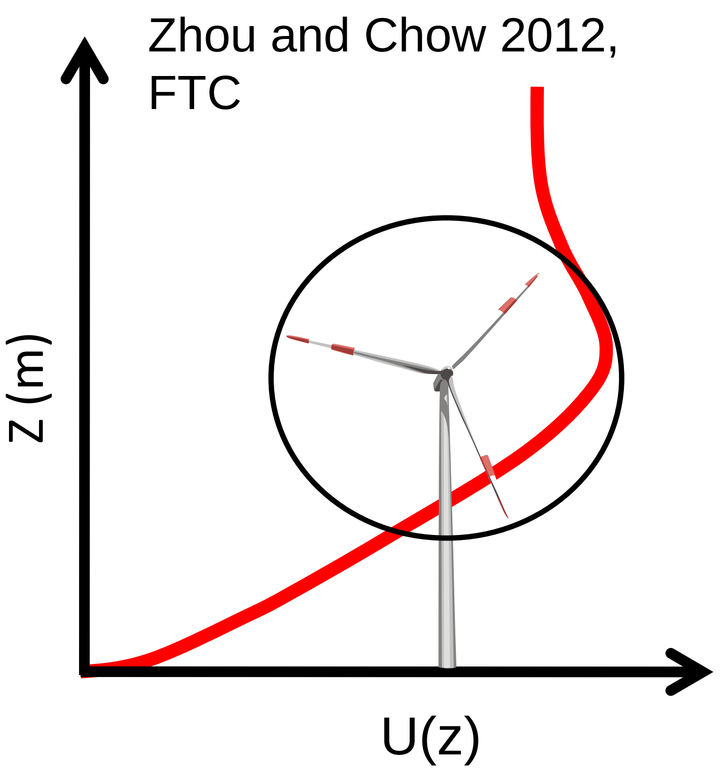
The complexity of the boundary layer currently challenges wind industry – more observations are needed!

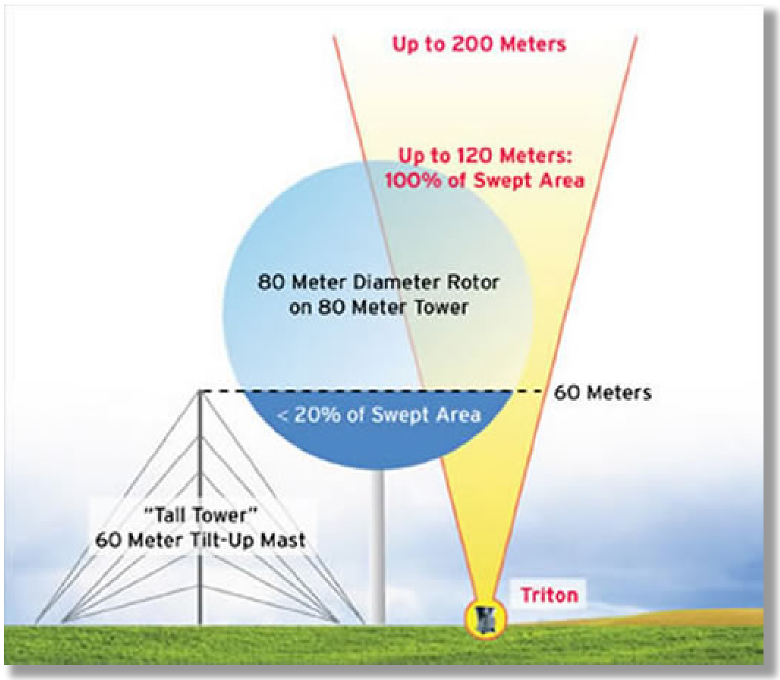
- Turbines are generally in the surface layer but taller turbines may encounter the turbulent mixed layer or nocturnal low-level jets.
- Ideally, we want measurements of temperature, wind speed, wind direction and turbulence across the entire rotor disk plus some heights above.
- Turbulence, wind shear and directional shear impact turbine power performance… hub-height wind speed isn't the only factor!



Meteorological towers only tell half of the story….

1. Hub-height wind speed may not represent the true rotor-disk wind speed

2. High turbulence and high wind shear can lead to high fatigue loads and/or power losses



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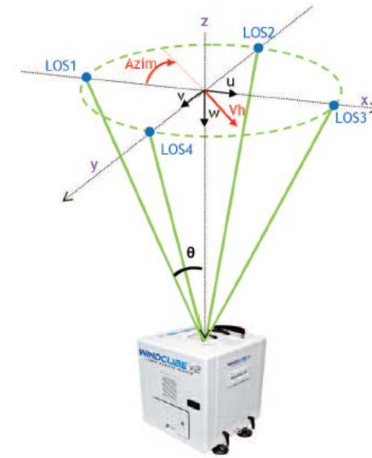
Remote sensing to the rescue!

Recent BAMS article by Banta et al. (2013) discusses how Lidar measurements can provide the needed high resolution wind information.

PBL observations relevant to wind energy: Atmospheric LIDAR remote-sensing platforms

Wind Cube v2 LIDAR from Leosphere/NRG



LIDAR (Laser Detection and Ranging) uses high frequency infrared wavelengths to measure wind speed in 3 directions (*u*,*v*,*w*) and wind direction at a 1 s rate. Turbulence can be calculated from the fluctuations from the mean wind speed.

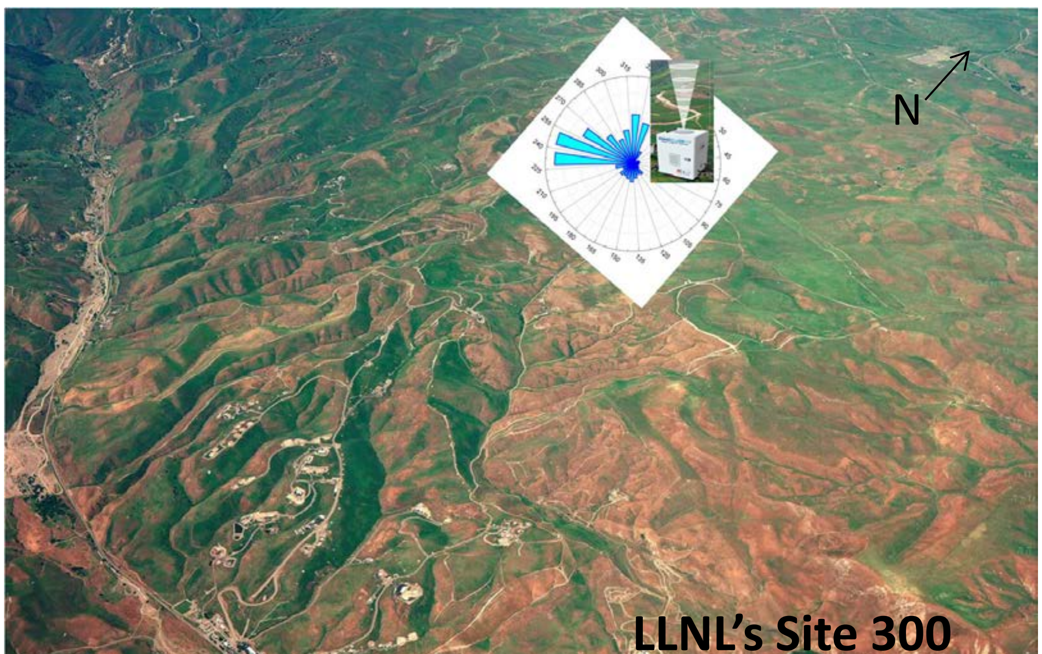
Wind Cube LIDAR range: 10-300 m, 10-12 height gauges.

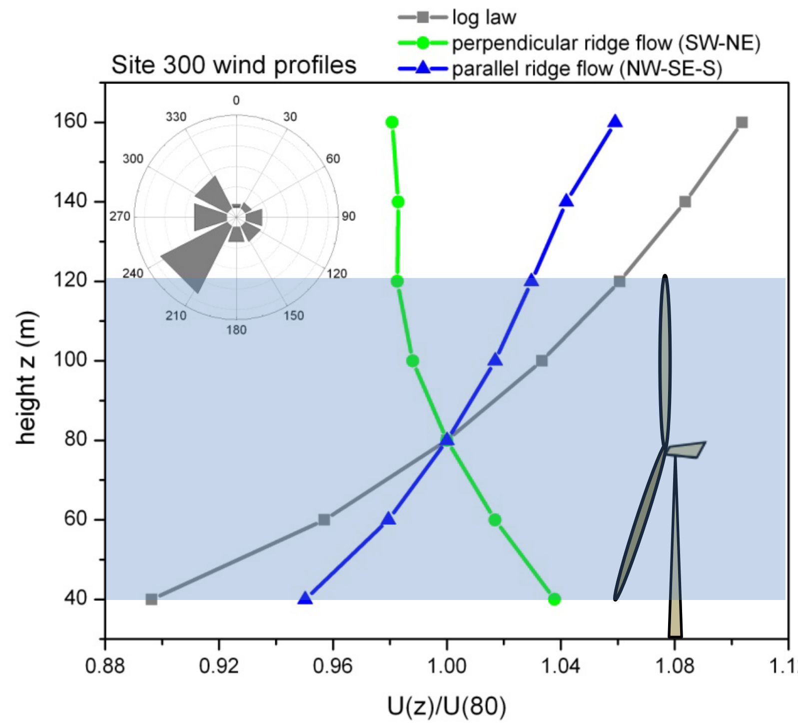
Advantage: A lightweight, mobile system which can run off of solar power.

Disadvantage: No temperature profile for stability, highest frequency turbulence not sampled, limited user-adjustable configurations

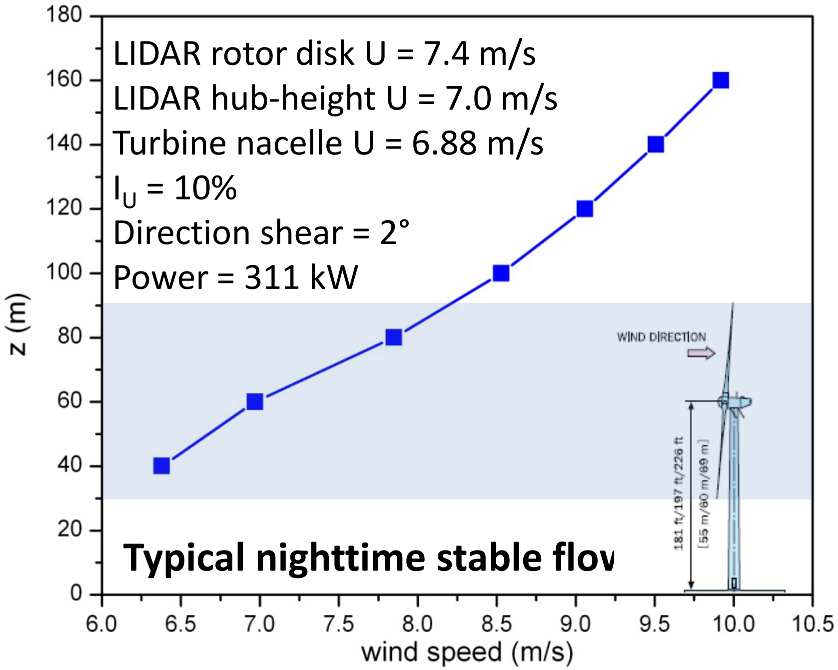
Complex terrain site: Site 300 and Buena Vista wind farm

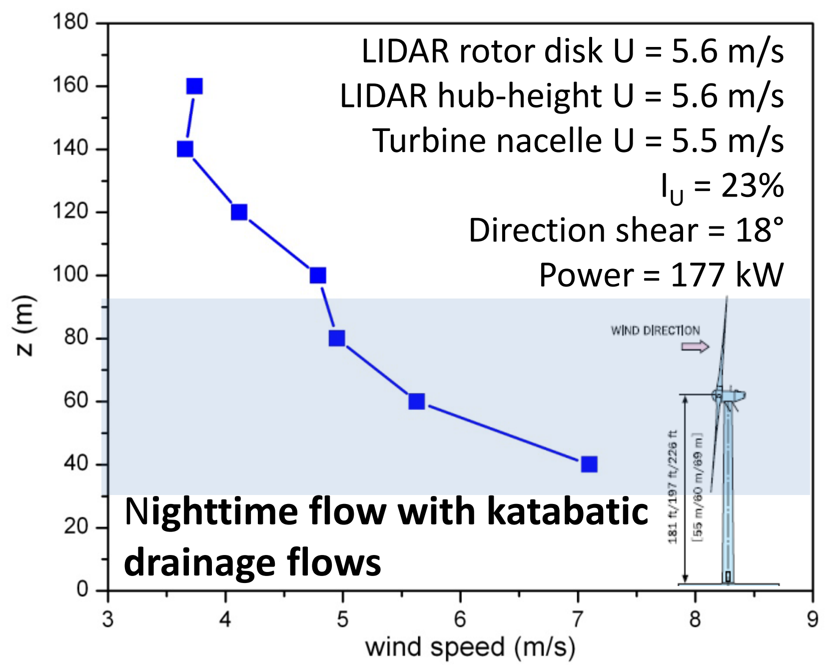
High-resolution measurements from LIDAR show wind flow normal to ridges (e.g., gravity flows) results in higher wind speed nearer to ground than aloft. **This illustrates the need for advanced measurement-modeling studies in complex terrain.**





Flows normal to the ridge line (green) are common at Site 300 and have complex flow features which are not captured by conventional methods.





Observed inflow conditions at the Altamont Pass Wind Farm

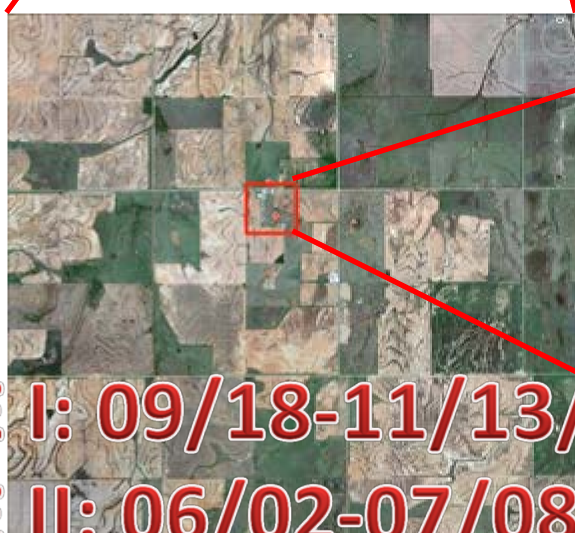
Include times of strong positive and negative wind shear, strong directional shear and high turbulence….all of which affect power generation

These examples show that commercially available Lidars provide useful information about mean wind characteristics.

How well can we measure turbulence characteristics?

LABLE I and II Study Area

A- OU Halo Lidar
B- Leosphere Lidar
C- Metek Sodar
1- ARM Halo Lidar
2- Radar wind profiler
3- Raman lidar
4- 60-m tower (sonics at 4,25,60 m)
5- 2-m Eddy Correlation and flux
6- AERI



LABLE I Setup:

LABLE I: 09/18-11/13/12

LABLE II: 06/02-07/08/13

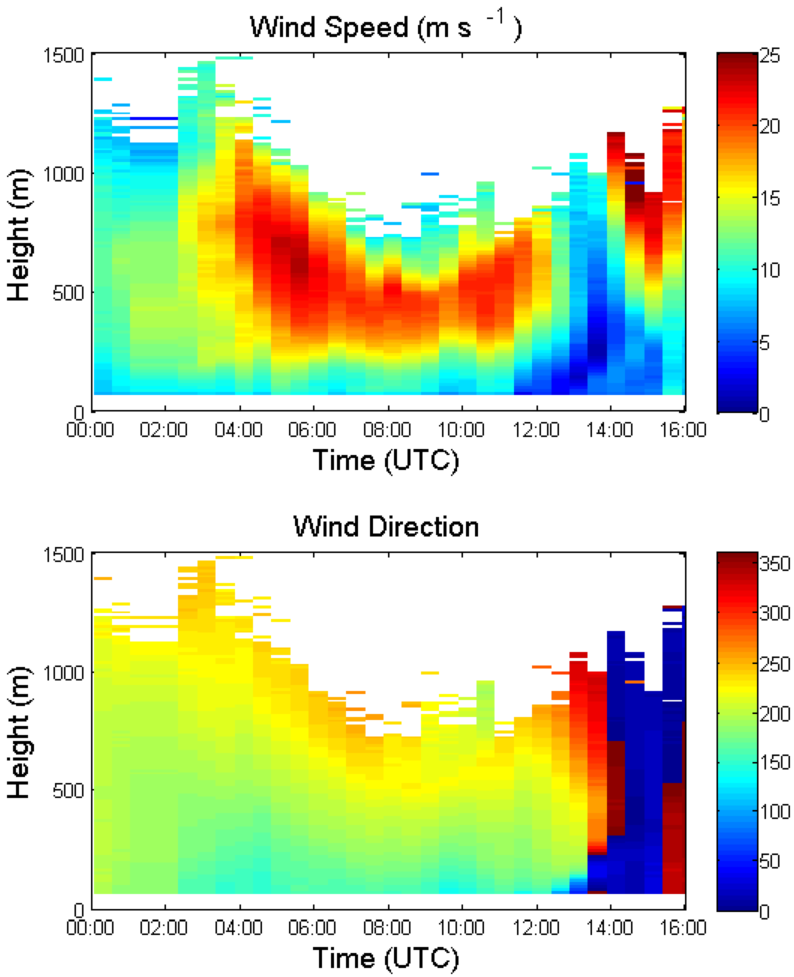
Streamline Halo Doppler Lidar

- Pulsed heterodyne lidar
- Minimum range ≈100 m
- Eye-safe 1.5 µm wavelength
- Capable of VAD, DBS, RHI, stare, and custom scans
- Range resolution: 18 m (OU)
  - 30 m (ARM)
- Maximum unambiguous velocity: 19.4 m s^{-1}
- Maximum rated range: 9.6 km

LLJs Observed During LABLE I

- 20 LLJs with peak winds of 10 m s^{-1}
  - 17 southerly, 3 northerly
- Average LLJ core height ≈500 m AGL
  - Varied between 250-1000 m AGL
- Typical onset around 0-2Z (shortly after sunset)
  - 30% of LLJs began after 6Z

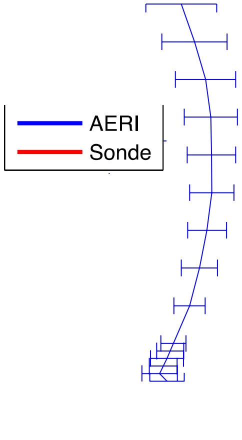
October 17

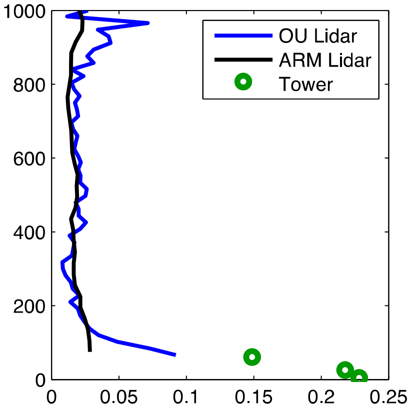


Instrument Comparison LABLE I

10/17/2012

5:30 UTC



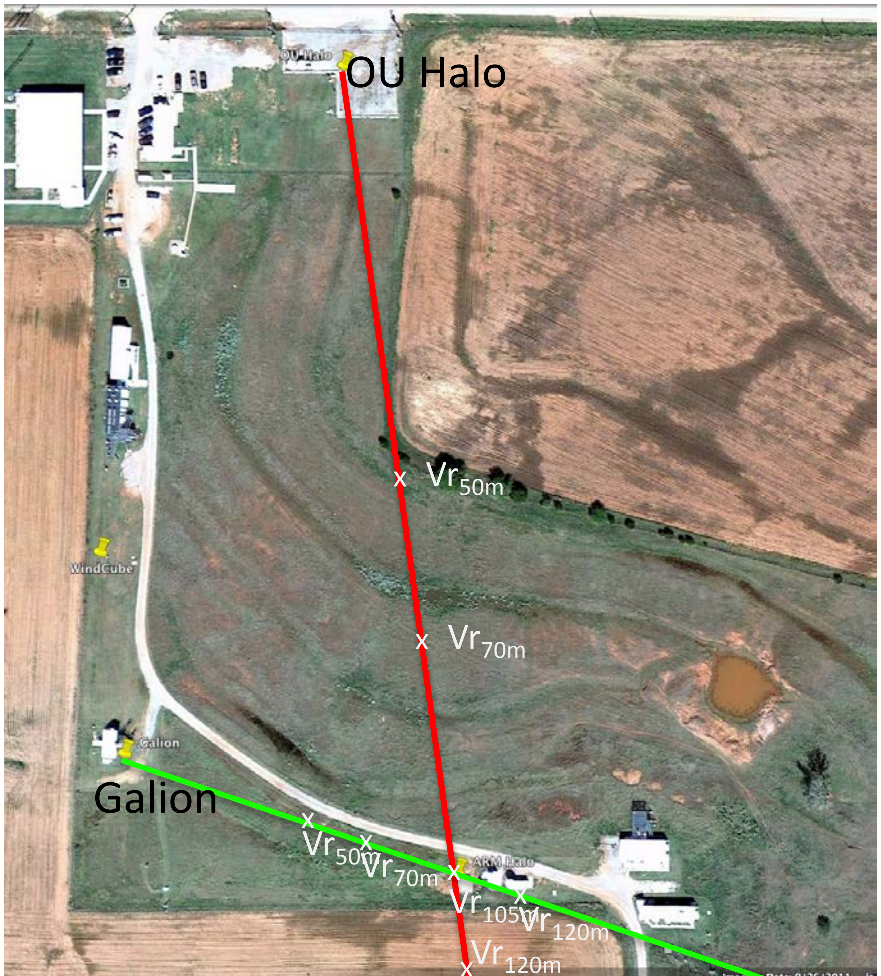


11:30 UTC

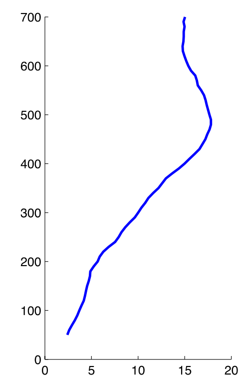
LABLE II

Dates	Scanning Strategy	WindCube Heights	Galion Heights	OU Halo Heights
June 12-19, 2013	ARM Halo: Vertical stare OU Halo, Galion: Horizontal stare 105 m above ARM Halo	40, 50, 60, 70, 80, 90, 105, 116, 124, 135, 165, 195	105 m - 4.6 km (increments of 30 m)	105 m - 4.6 km (increments of 30 m)
June 19-28, 2013	ARM Halo: Vertical stare OU Halo: Six-beam DBS Galion: Five-beam DBS (similar to WindCube)	40, 50, 60, 74, 95, 105, 117, 138, 159, 165, 180, 200	74, 95, 117, 138, 159, 180, 202… Vertical beam: 105, 135, 165, 195…	74, 95, 117, 138, 159, 180, 202… Vertical beam: 105, 135, 165, 195…
June 28-July 3, 2013	ARM Halo, OU Halo, Galion: Virtual tower over WindCube	40, 50, 60, 70, 80, 90, 100, 120, 140, 160, 180, 200	25, 60, 100, 200, 350, 500	25, 60, 100, 200, 350, 500 (ARM Halo: same)
July 3-8, 2013	Various	40, 50, 60, 70, 80, 90, 100, 120, 140, 160, 180, 200		

Dual-Doppler wind profile retrieval

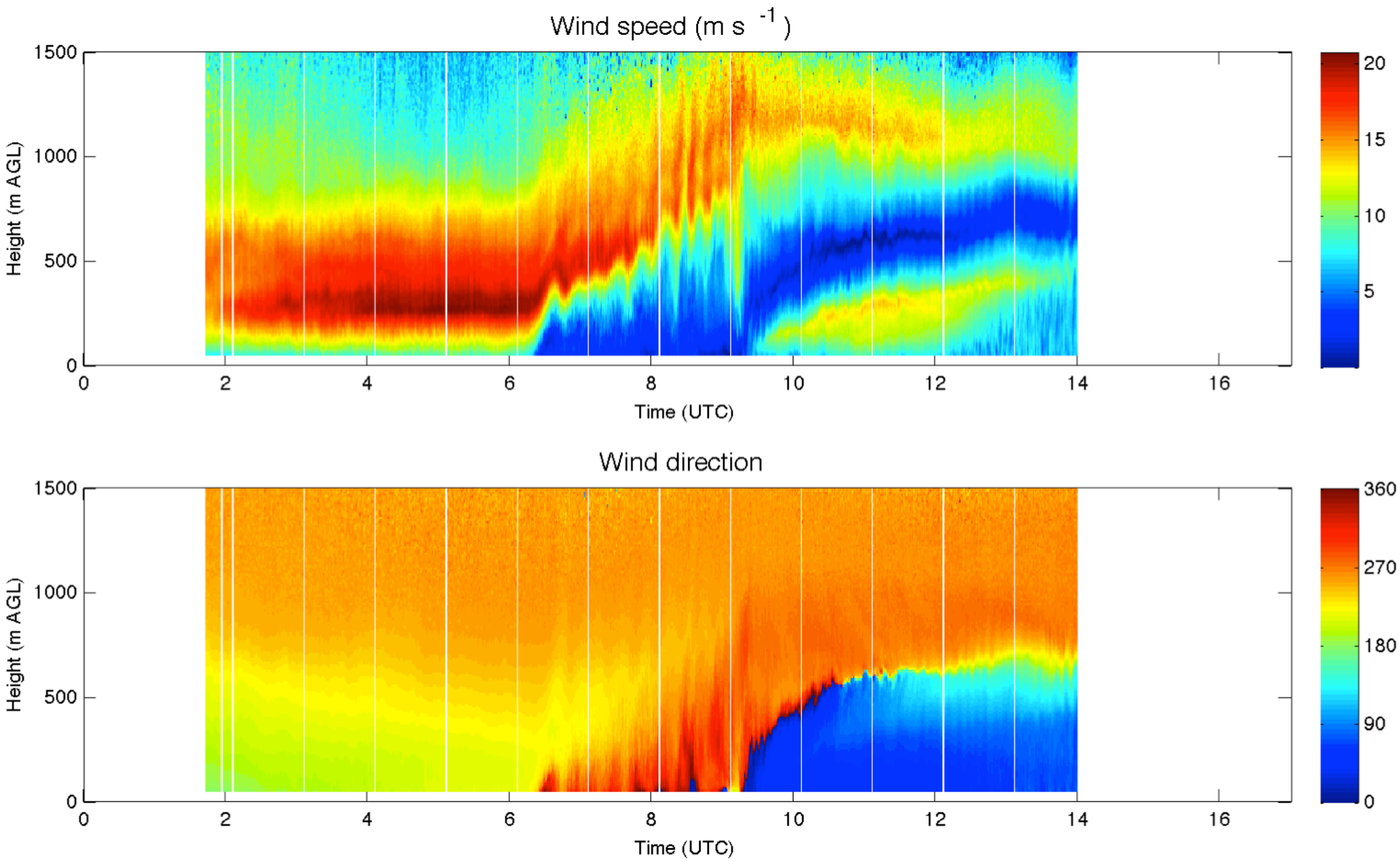


$$L_{OU} \bullet U = Vr_{OU}$$
$$L_{GAL} \bullet U = Vr_{GAL}$$



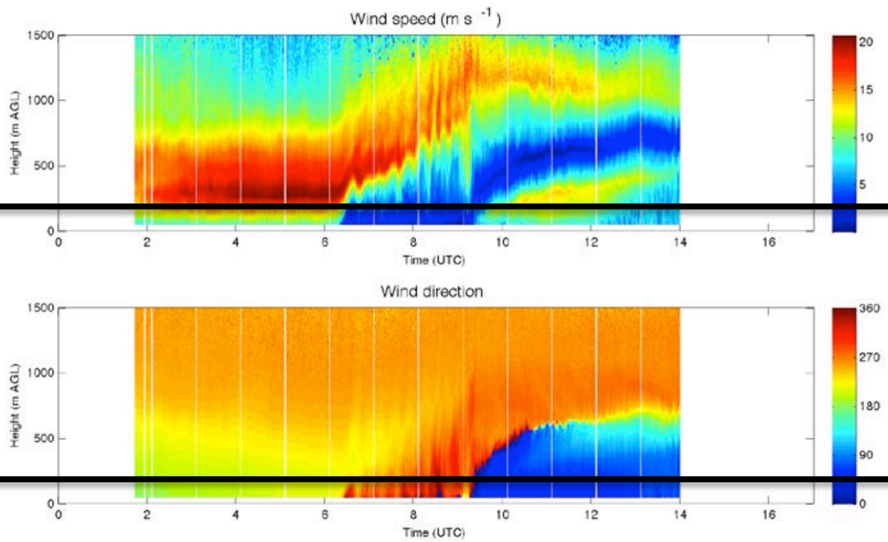
LABLE II Instrument Comparison

Wind Speed and direction from OU Halo and Gallion Dual Doppler analysis

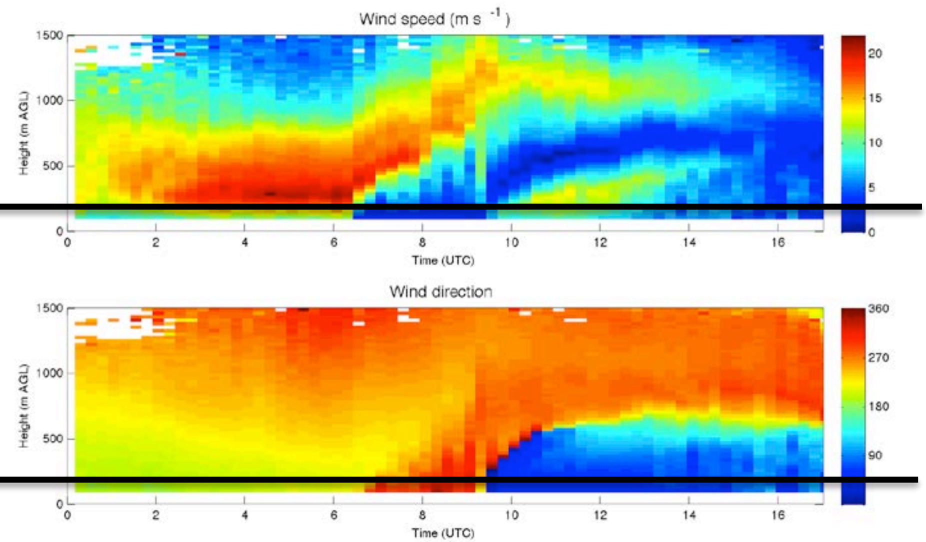


LABLE II Instrument Comparison

Dual Doppler analysis

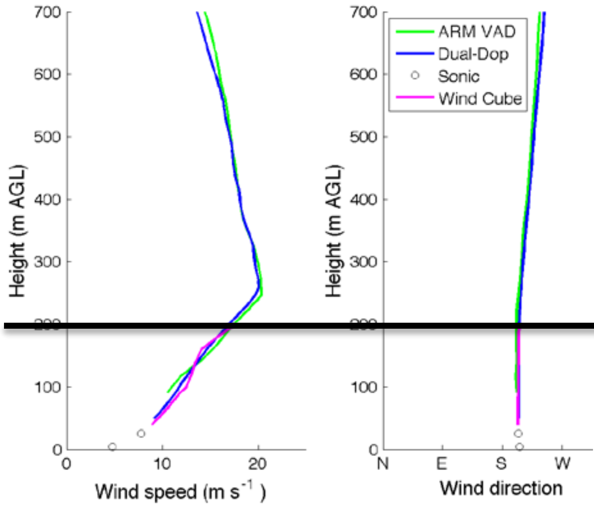


VAD Scans of ARM HALO



LABLE II 06/13/2013

0500 UTC



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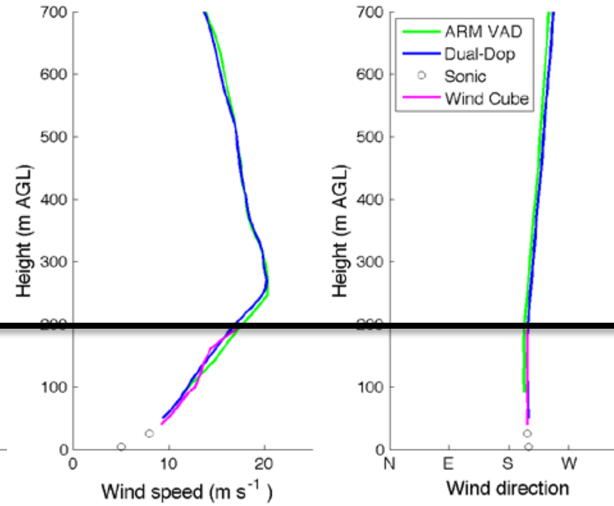

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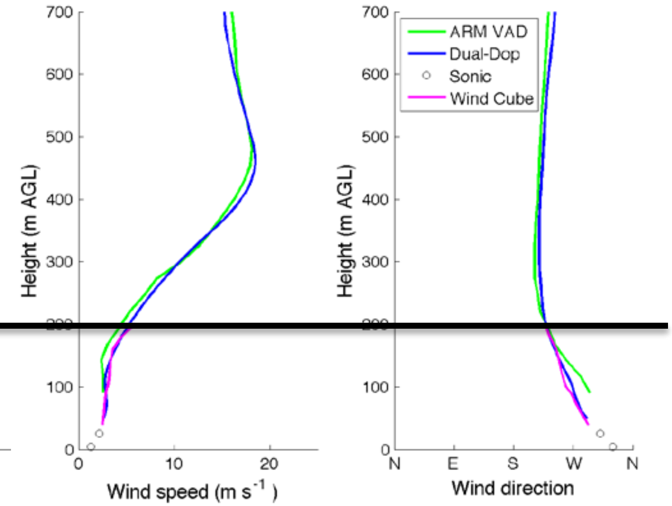

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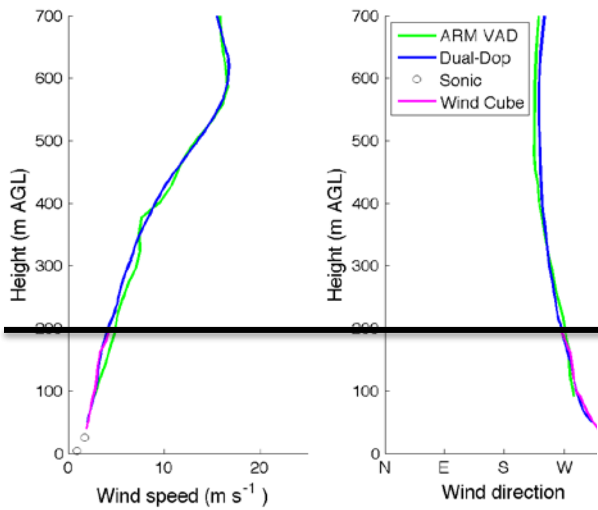

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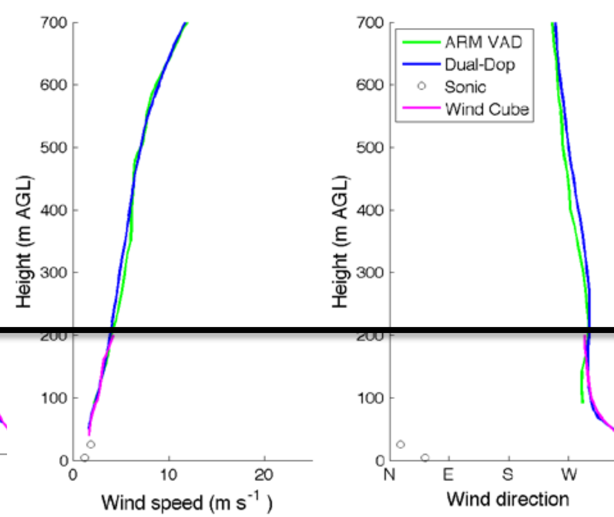

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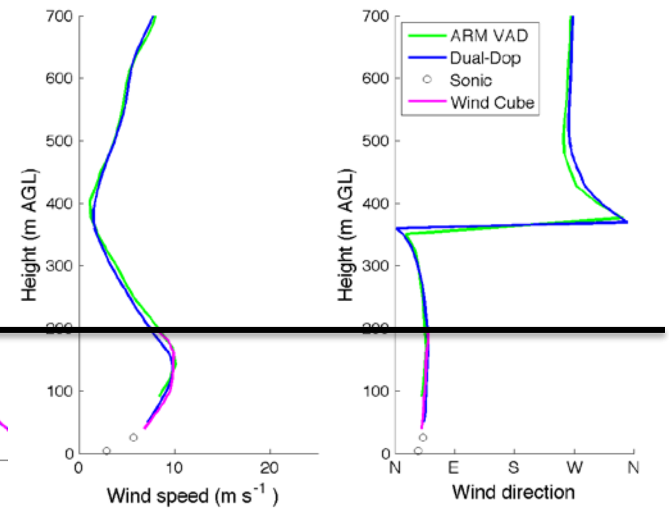
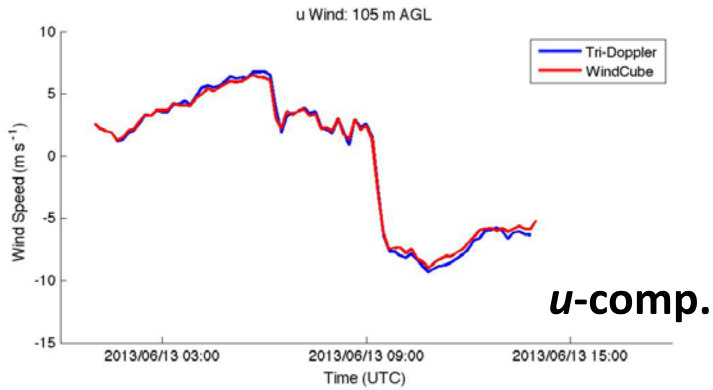
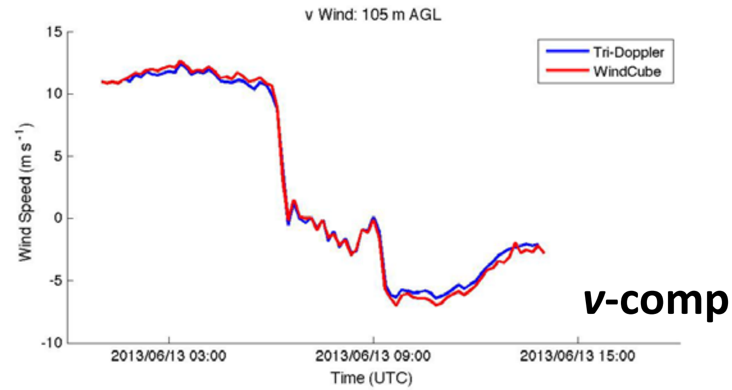
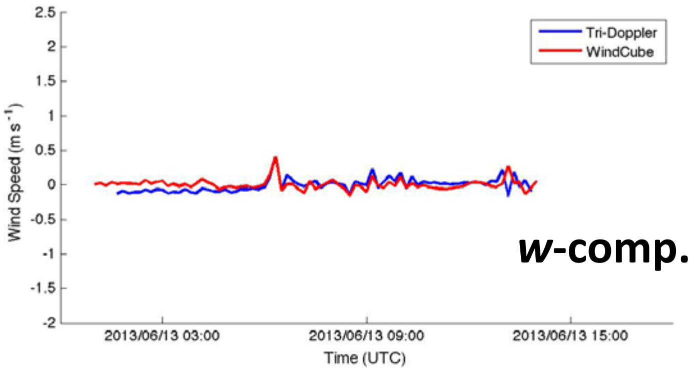
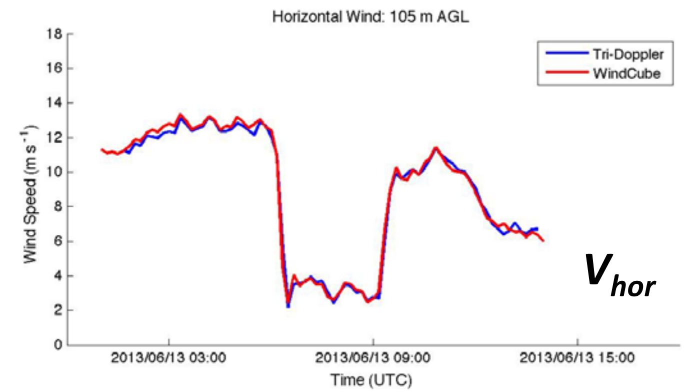
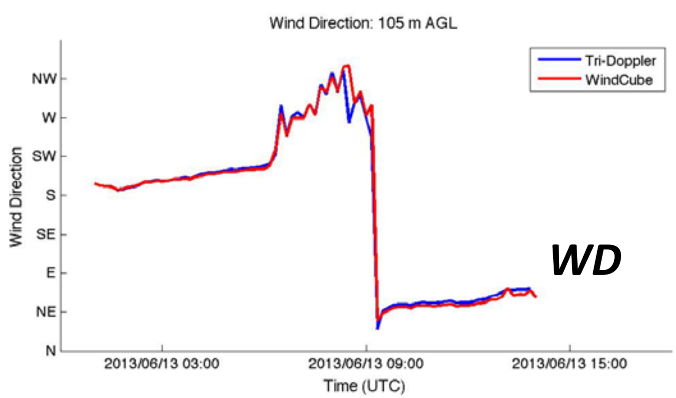




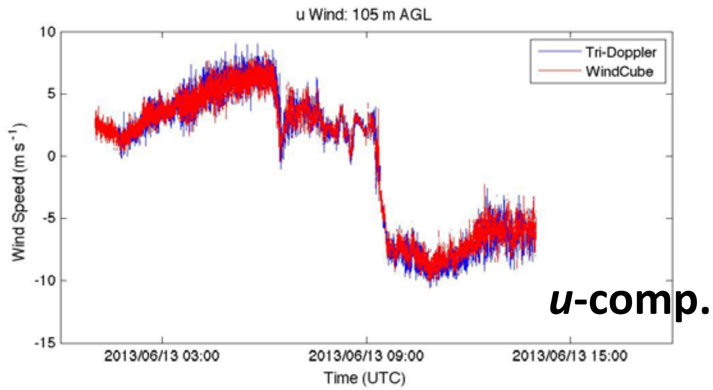


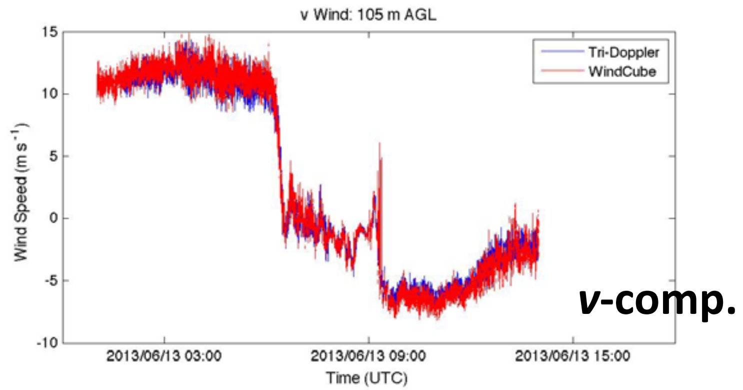


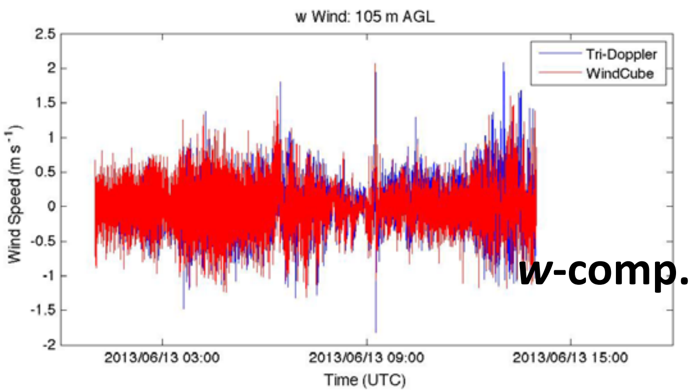


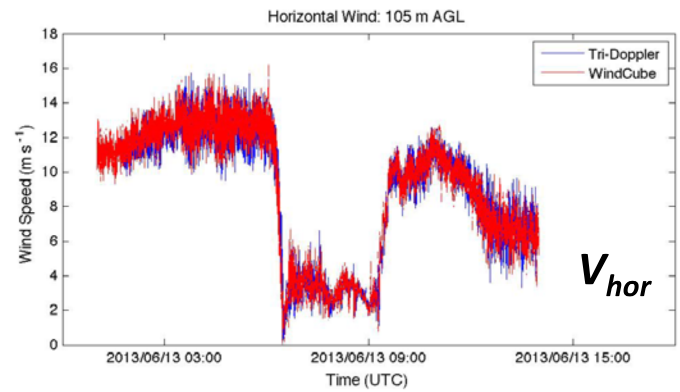


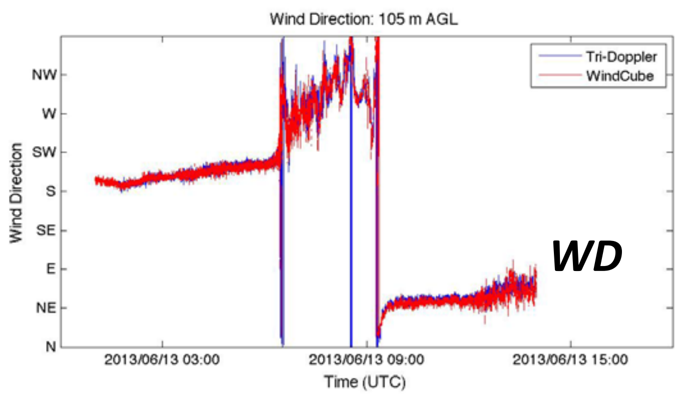
10-min averages of the 3 wind speed components, horizontal wind speed, and wind direction





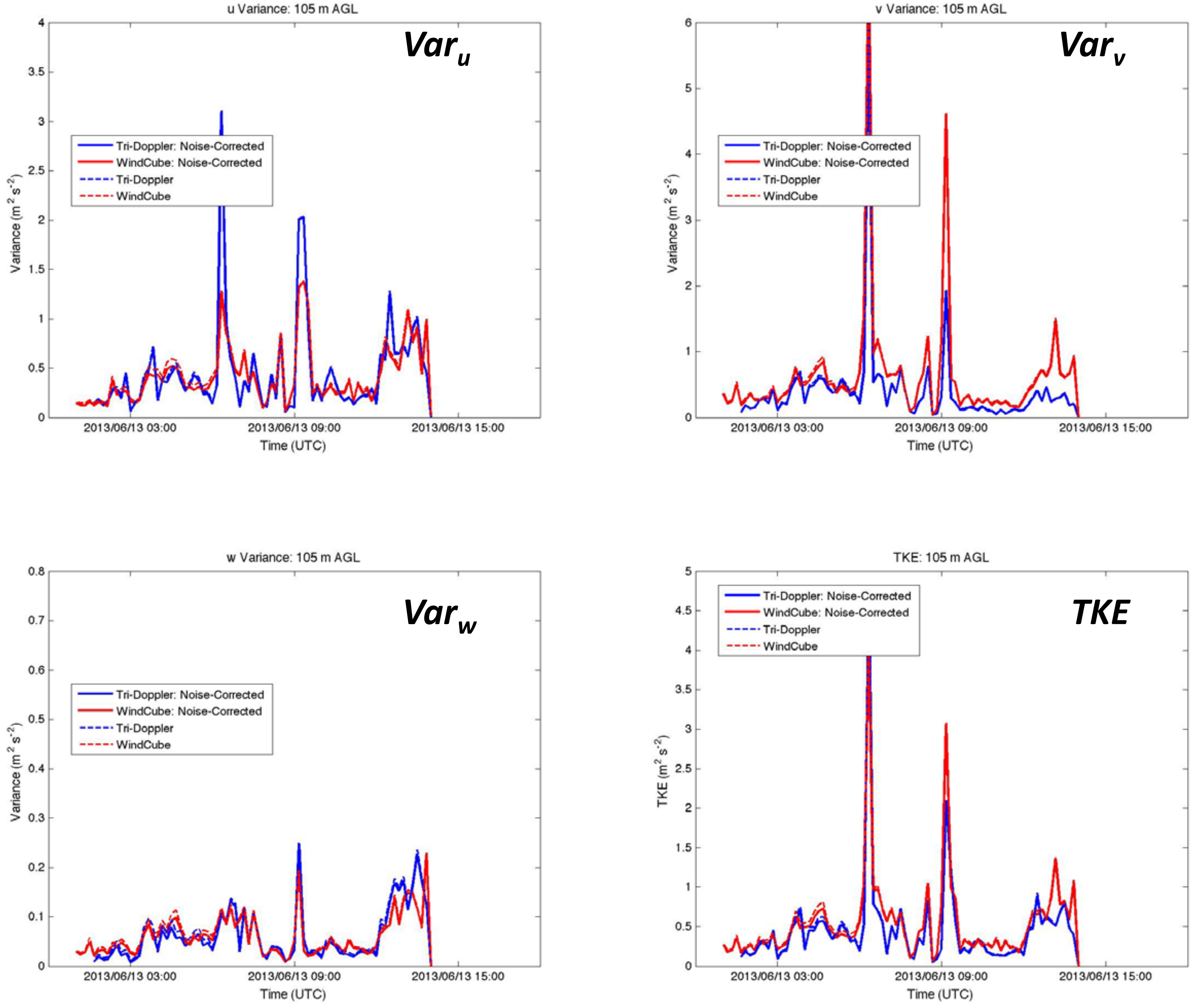




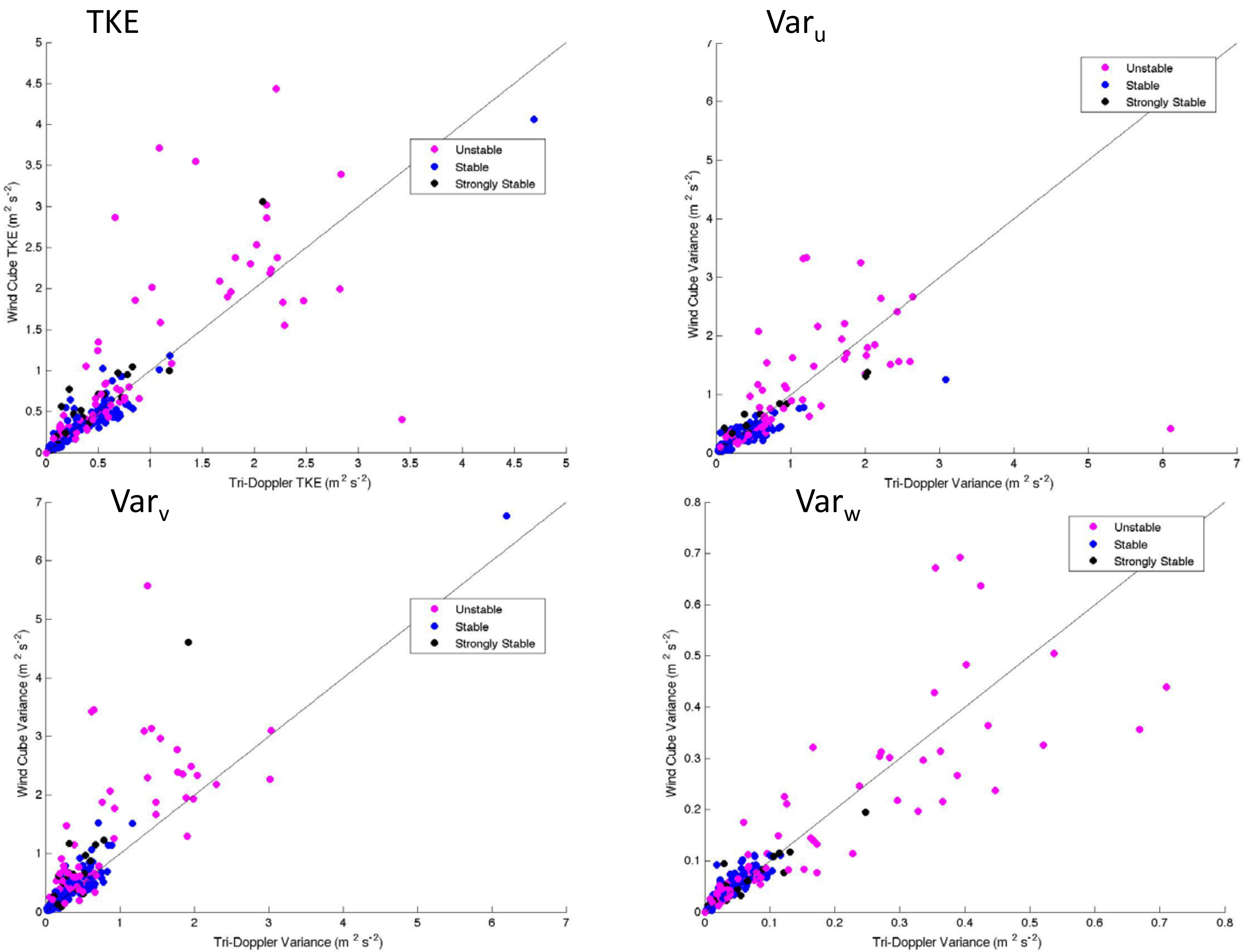


1s measurements of the 3 wind speed components, horizontal wind speed, and wind direction

10-min averages of turbulence parameters



Comparison of Turbulence Parameters



Conclusions

- Lidars measurements provide useful mean wind and turbulence data
  - Not only at hub height but also across the entire rotor disk
- Continuous monitoring with Lidars can provide detailed information about important flow features such as LLJ and drainage flow
- Different scanning strategies are being tested to improve quality of Lidar turbulence measurements