Comparison of Wind Retrievals from a Scanning LIDAR and a Vertically Profiling LIDAR for Wind Energy Remote Sensing Applications

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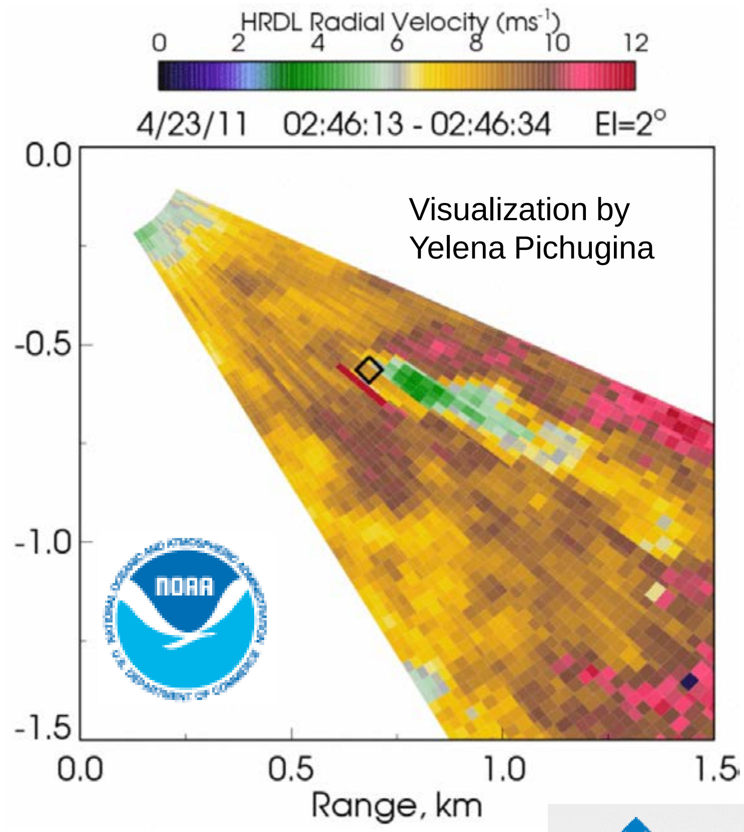
Scanning LIDAR presents unique opportunity for "simultaneous" wind measurements over large regions

- ✓ Horizontally inhomogeneous flows can be probed with single instrument
- ✗ Line-of-sight (LOS) velocities do not provide a complete description of the horizontal wind field
- → This study: Compare two LIDARs for additional wind field description.



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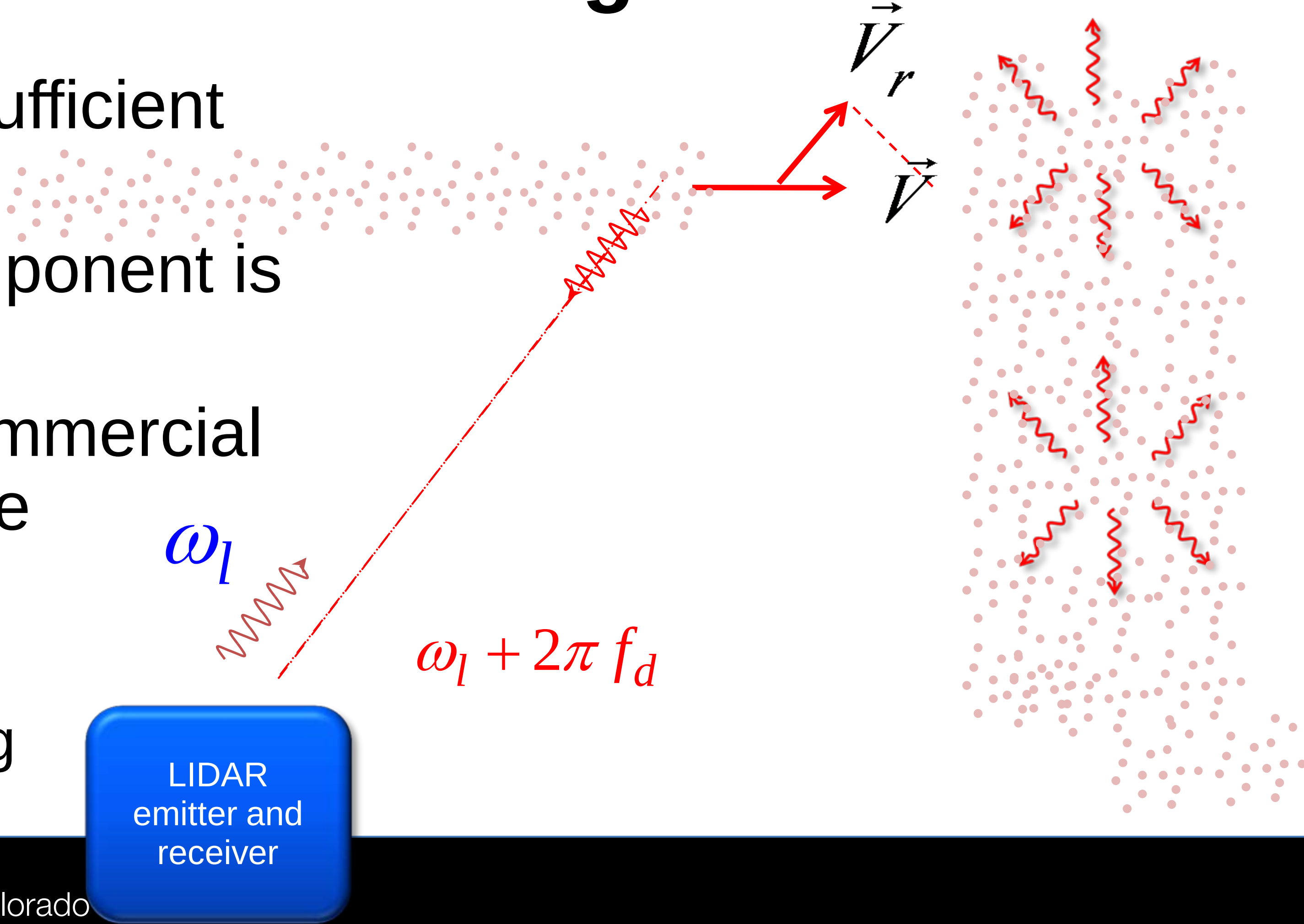
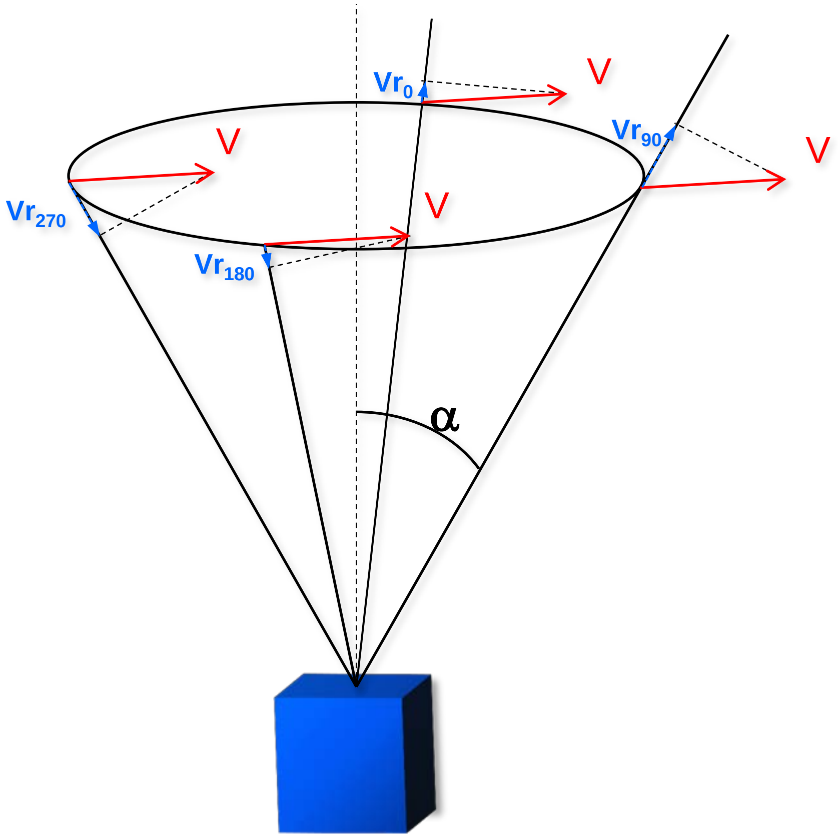
Smalikho et al., 2013, *J. Atmos. Ocean. Technology*
Aitken, Lundquist et al., 2013, *J. Atmos. Ocean. Technol.* (in review)

LIDAR operates by measuring the Doppler shift of a signal scattered off of particles moving with the flow

- Requires sufficient particles
- Radial component is measured
- Several commercial systems are available:
    1) Profiling
    2) Scanning



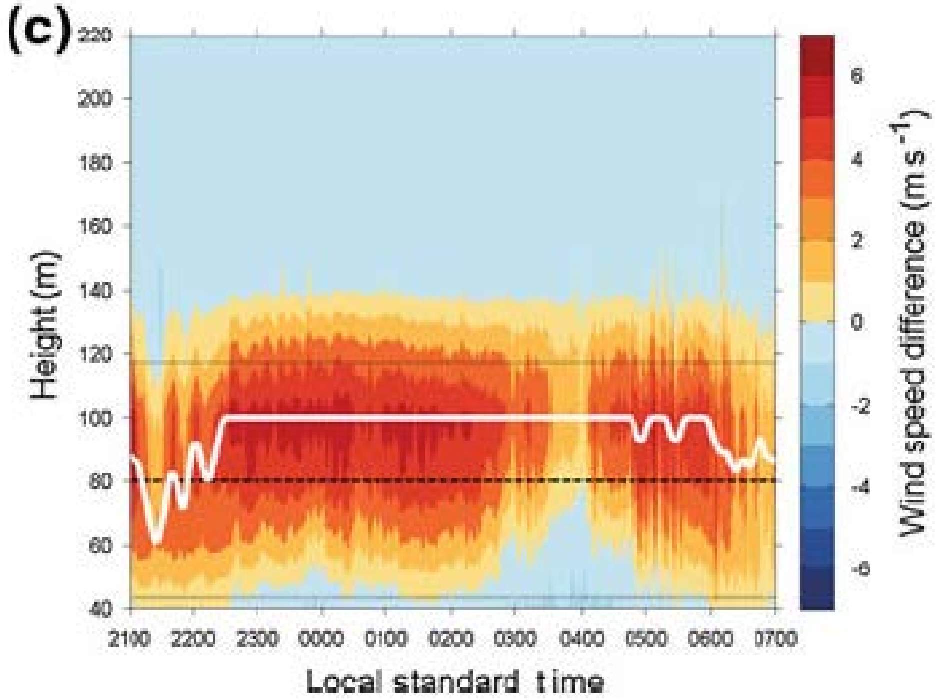
Profiling LIDAR, Windcube (WC68) invokes homogeneity over a measured volume to quantify components of wind



- Assume flow constant over time to measure in four radial directions (~ 4 seconds)

Profiling Windcube data during CWEX provides turbine wake insight

Difference of wind speeds upwind (two rotor D) and down wind (three rotor D)



- Climatology and case studies of wake behavior
- → CWEX-13 includes a scanning lidar to quantify wake variability

Rhodes and Lundquist, 2013, The Effect of Wind Turbine Wakes on Summertime Midwest Atmospheric Wind Profiles. *Boundary-Layer Meteorology*

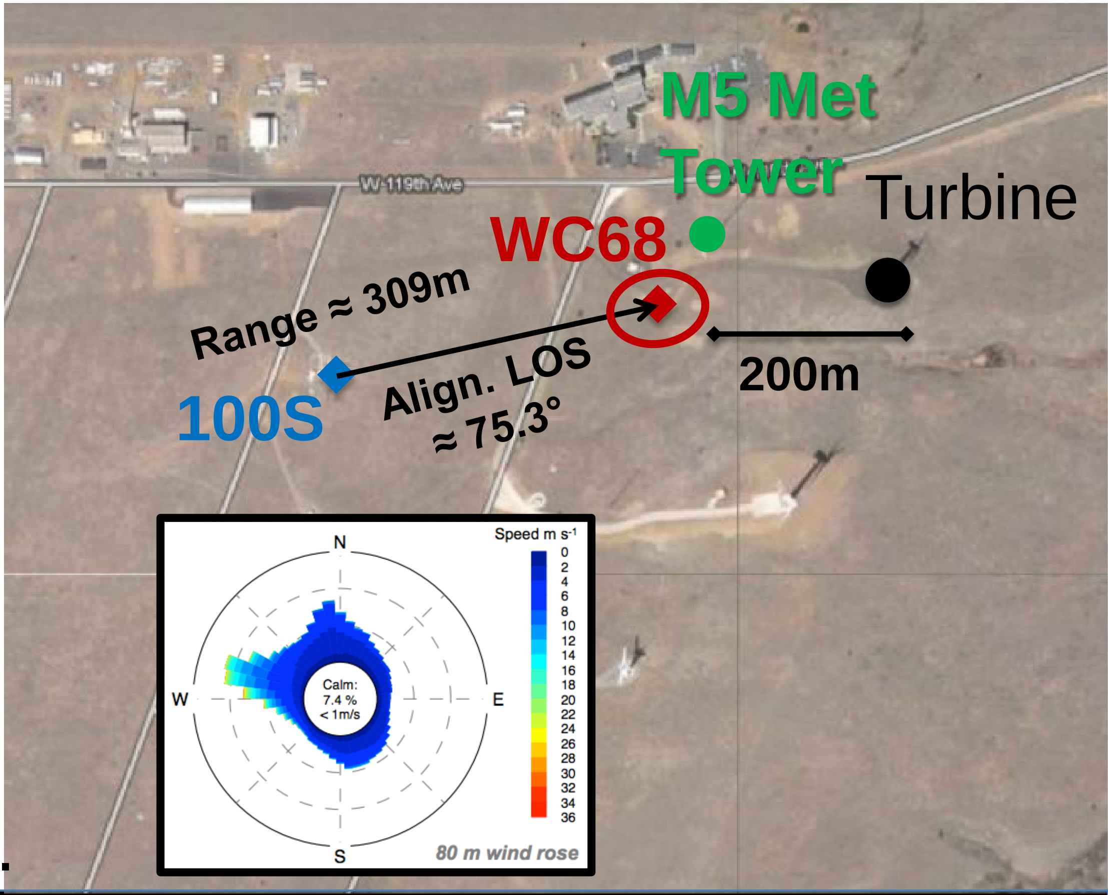
Scanning LIDAR (100S) measures Line-of-Sight (LOS) velocities

- User determines scan type, e.g.
  - VAD, similar to profiling LIDAR
  - horizontal slices
  - vertical slices (RHI)
- Carrier to Noise Ratio (CNR) filtering is crucial for sufficient backscatter return.*
- Dual-scanning LIDAR approach can reconstruct wind field, e.g.
  - Newsom et al. (2005, 2008)
  - Calhoun et al. (2006)

*See Aitken et al. *J. Atmos. Ocean. Tech.* 2012

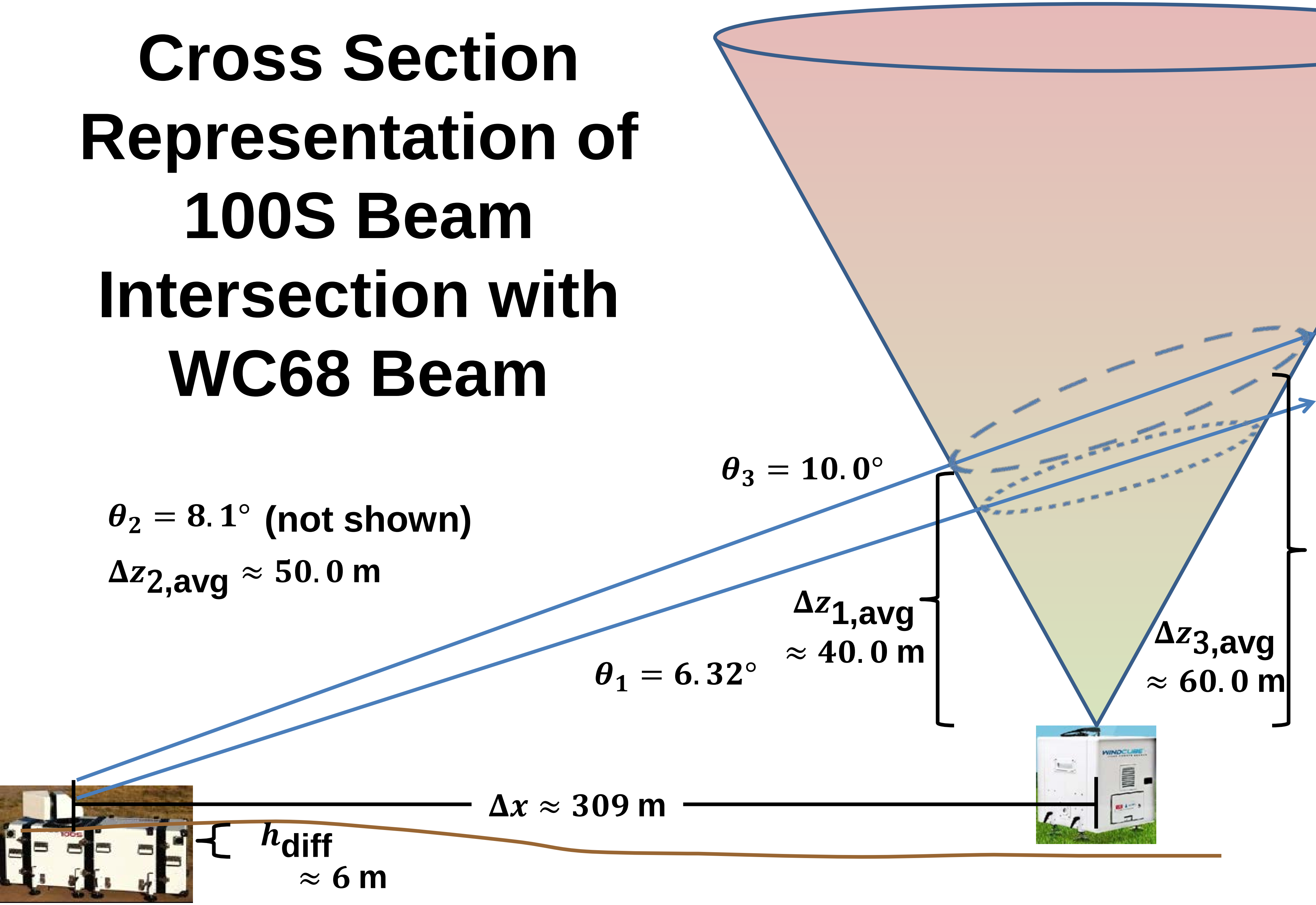
Sampling occurred for 45 days during Fall 2012 at NREL's National Wind Technology Center

- 100S provided horizontal scans at 6.32°, 8.10°, & 10.0° elev. matching WC68 profile measurements at ~40m, 50m, & 60m
  - Δr ~ 25m
  - Δa ~ 0.5 deg
  - WS Accuracy ~ 0.2 ms^{-1} to 0.5 ms^{-1} (past 2 km)
  - CNR < -24.5 dB filtered
- ~ $^1/_4$ of 2.76M data pts.



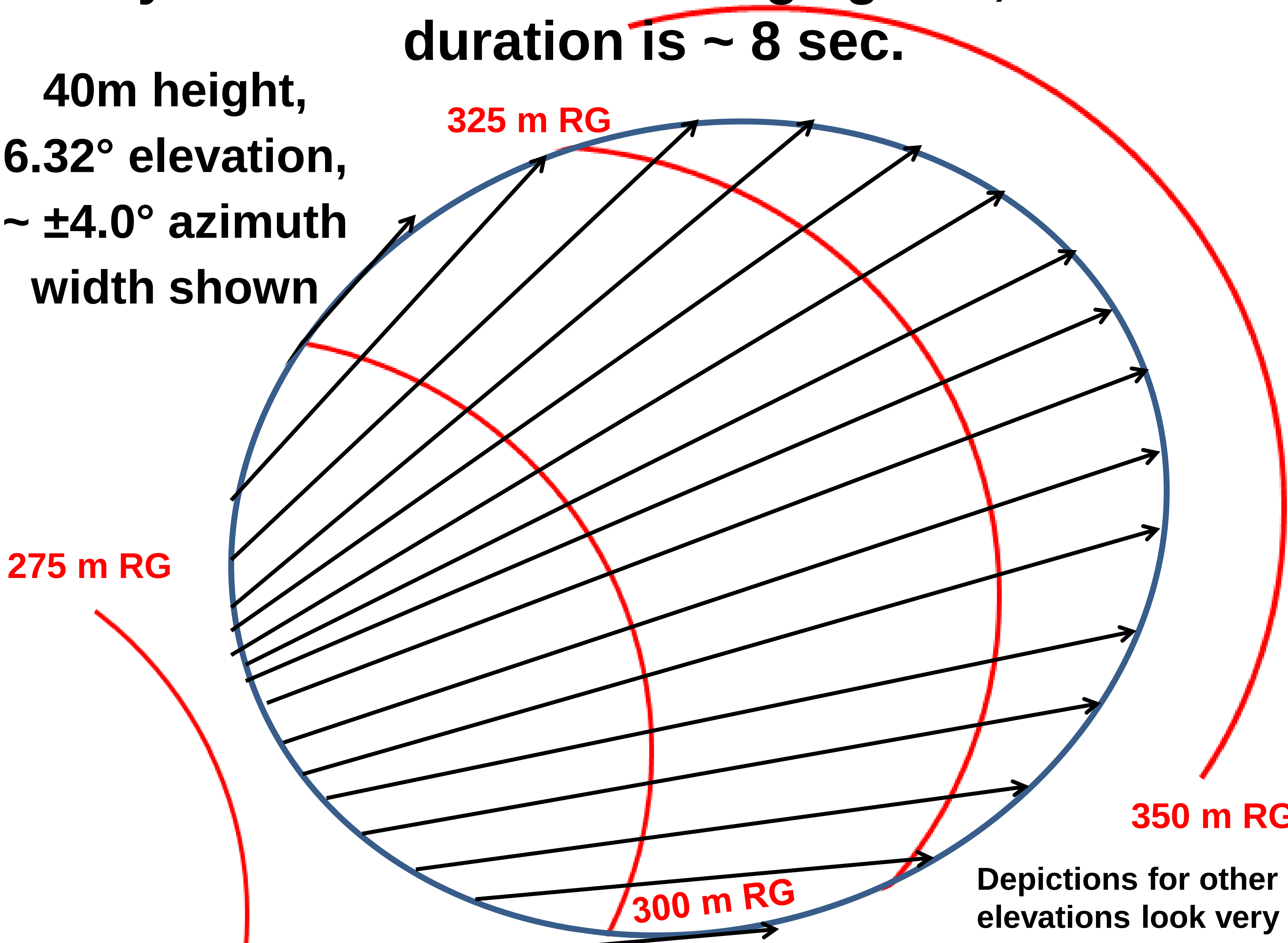
http://www.leosphere.com/products2.php?rubrique=164&cat=wl&item=100sts

Cross Section Representation of 100S Beam Intersection with WC68 Beam



Comparison between 100S and WC68 utilizes many azimuths and four range gates; collection duration is ~ 8 sec.

40m height,
6.32° elevation,
~ ±4.0° azimuth width shown

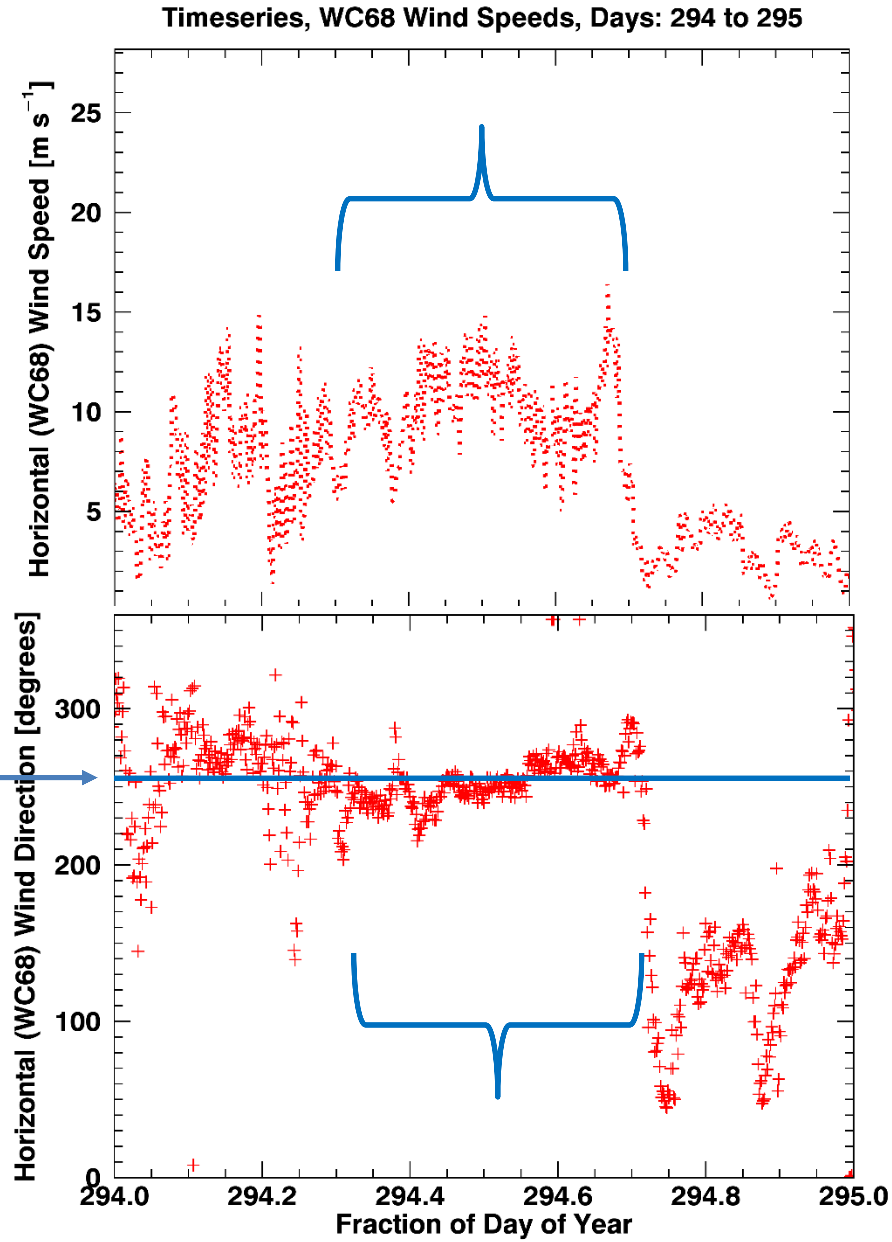


Depictions for other elevations look very similar.

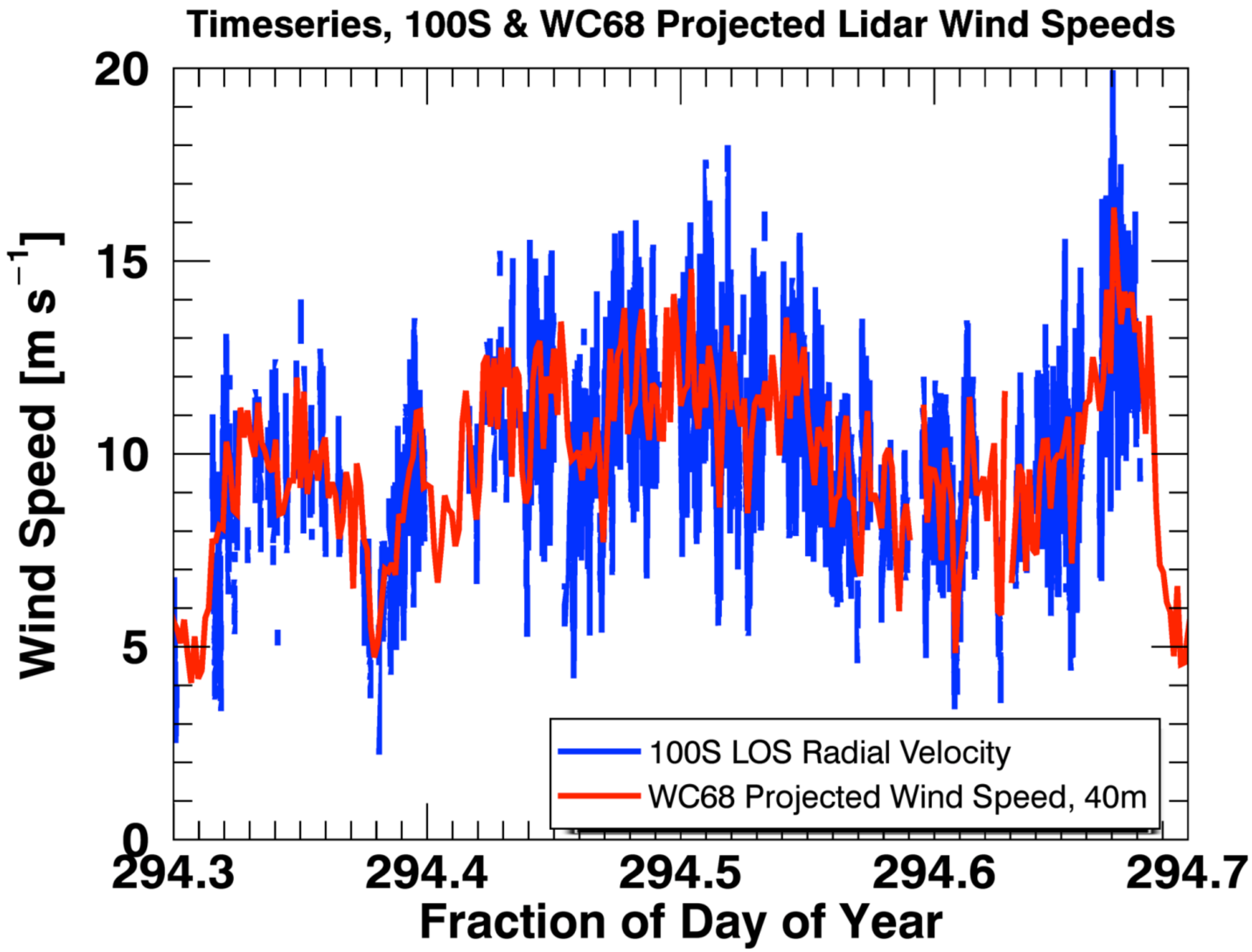
This presentation focuses on time period of aligned LOS wind direction

- 24,700 data points available
- This is ~ 1% of the entire dataset.

100S Aligned LOS Wind Direction ~255.3°



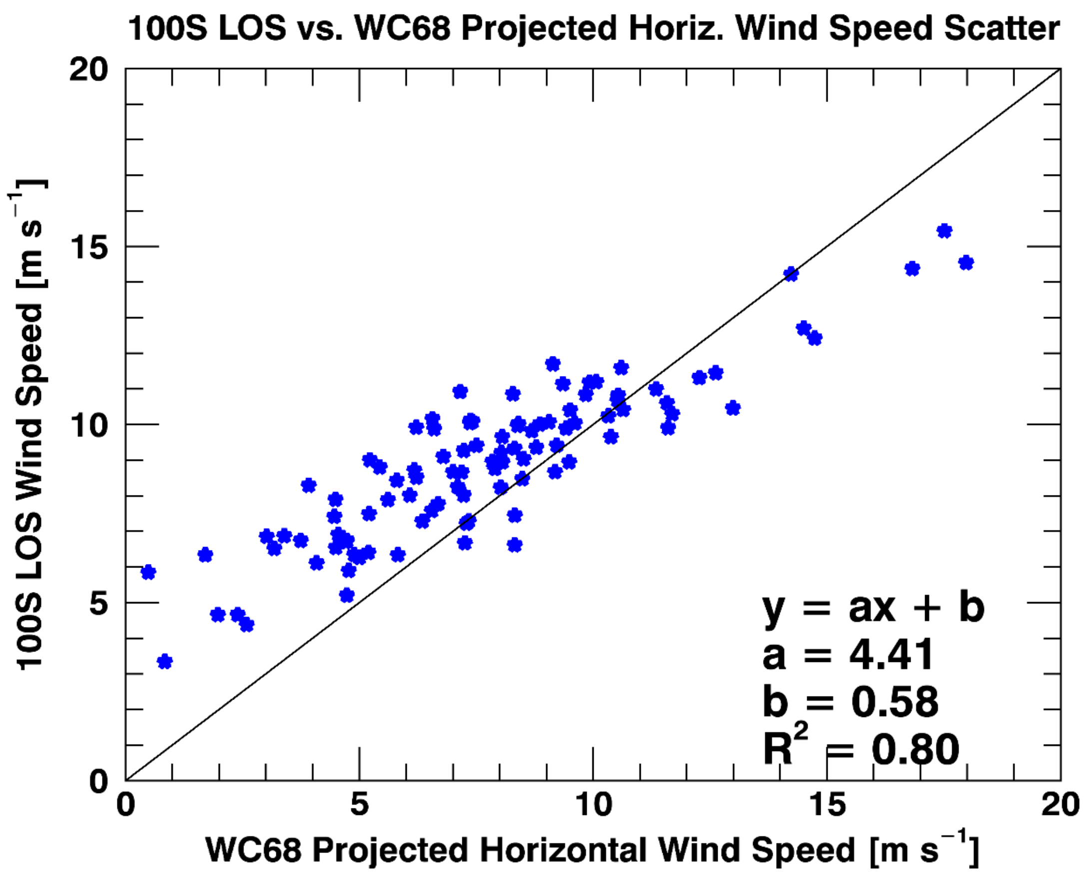
Time series of WC68 Projected Velocities and 100S LOS Velocities show similar magnitudes and trends



WC68 velocities, 2-min averages

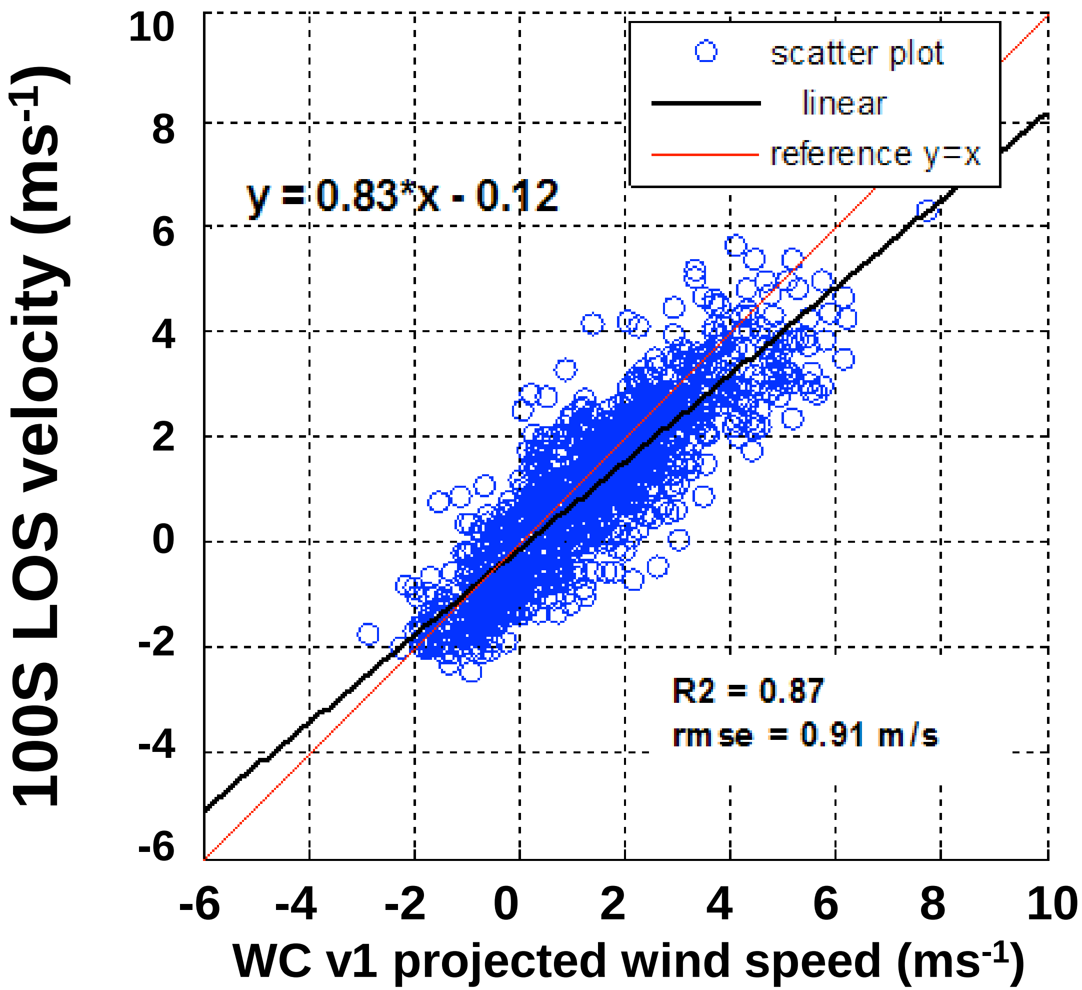
100S velocities, 1-sec measurements

Scatterplot also shows general agreement between WC68 Projection and 100S LOS Velocities



The slope is not 1:1, suggesting that the differences in time-averaging here are important.

Comparisons between 1 Hz WC68 data & 100S data demonstrate time averaging importance



We have learned the necessity to carefully match time periods for this analysis.

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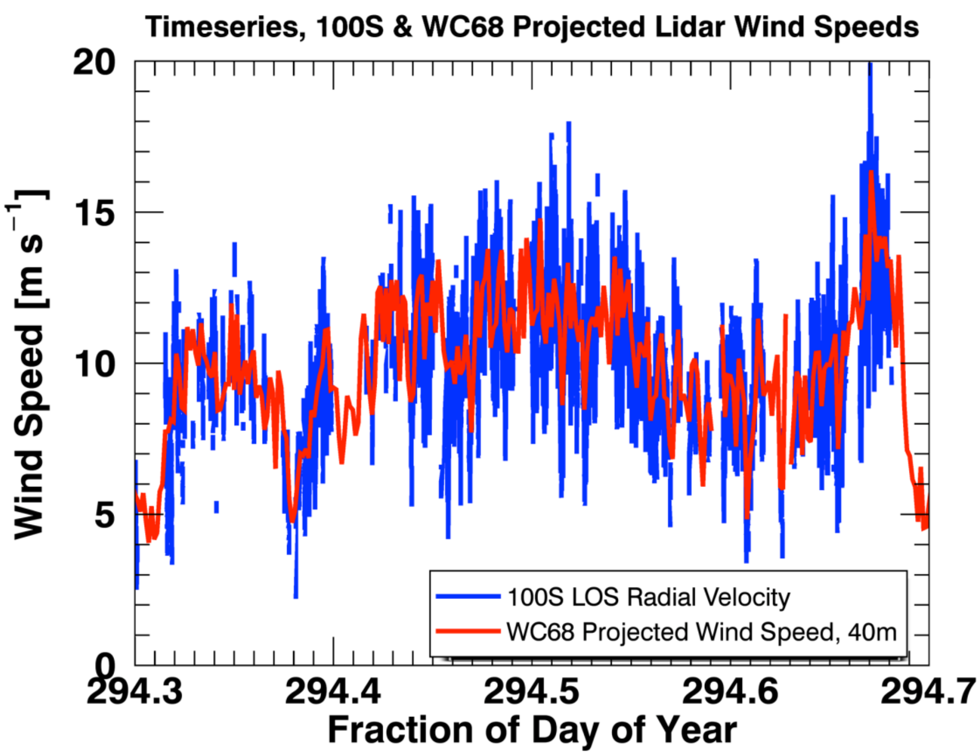
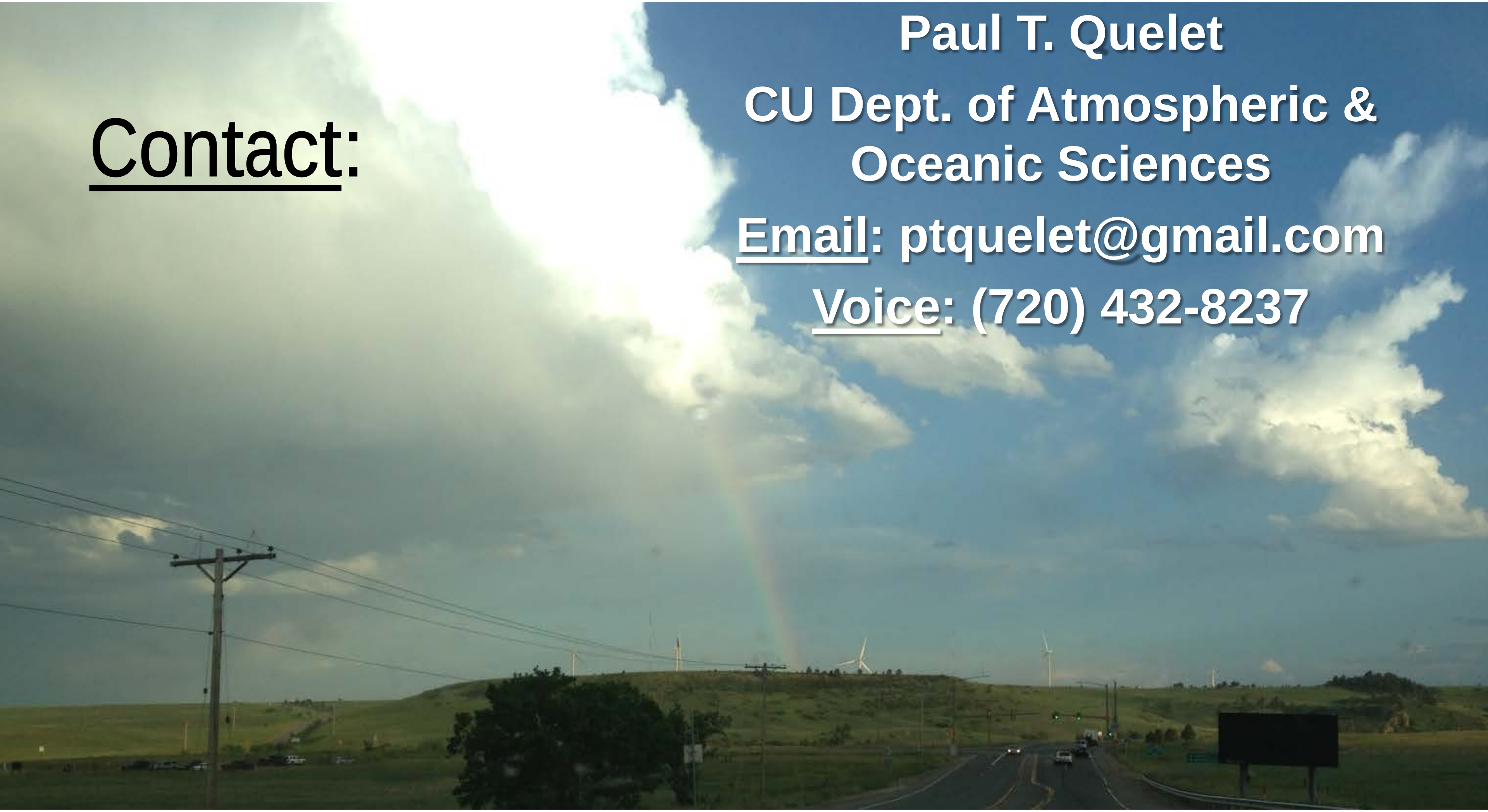
Image courtesy Mehdi Machta, Leosphere

Initial comparison to WC68 shows promise for 100S scanning lidar

- Agreement over ten hour time period was present in data set
- Next steps include:
  - assessing 50m and 60m agreement
  - exploring 45 day time series
  - filtering by vertical velocity and strength of turbulence





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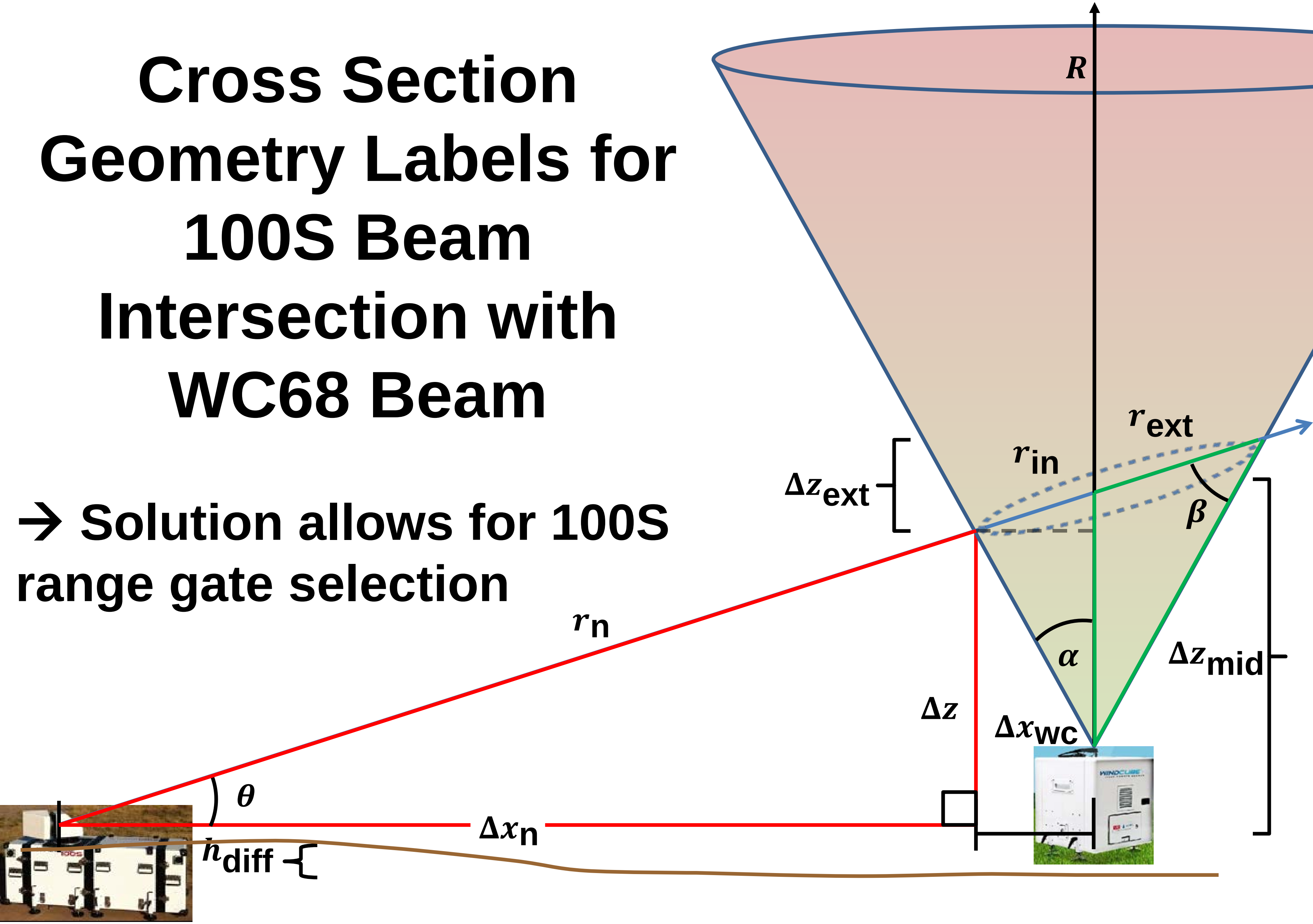
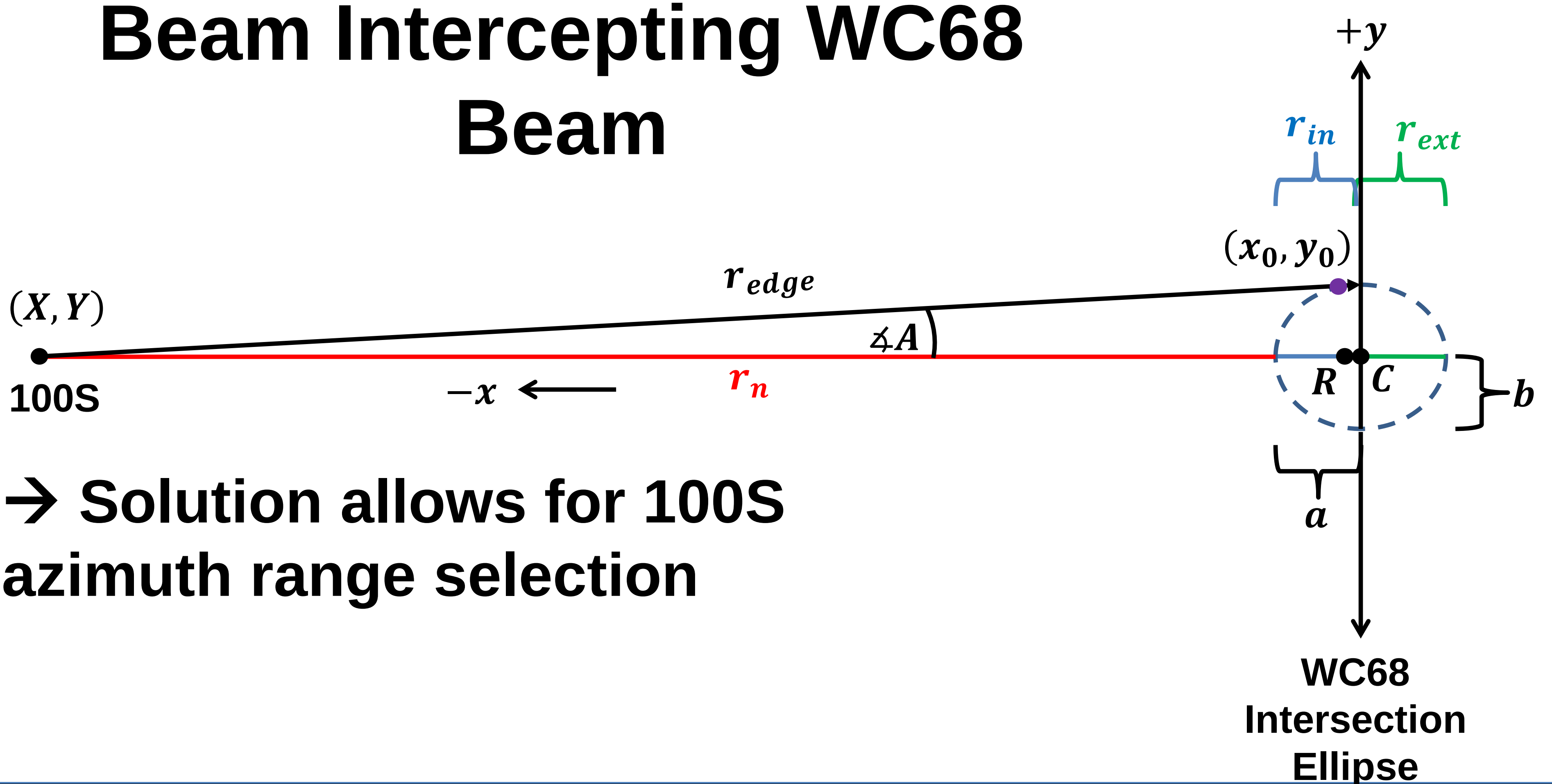
Extra Slides

Cross Section Geometry Labels for 100S Beam Intersection with WC68 Beam

→ Solution allows for 100S range gate selection



Intersection Plane View Geometry Labels for 100S Beam Intercepting WC68 Beam



→ Solution allows for 100S azimuth range selection

Table Summary of Geometric Selections for Intersection

Elevation Angle	Azimuthal Range	Range Gates Used
	71.3° - 79.3° (~±4.0°)	275 m, 300 m, 325 m, 350 m
	70.3° - 80.3° (~±5.0°)	275 m, 300 m, 325 m, 350 m
	69.3° - 81.3° (~±6.0°)	275 m, 300 m, 325 m, 350 m, ~~375m (outside threshold)~~

Data Flow Process for Instruments

A. WC68

A1) Read in Raw Data → 2 minute averages

A2) Replace Missing Data Periods with NaN

A3) Extract Date Information using Day of Year Frac. → Convert to UTC

B. 100S

B1) Read in Raw Data → 1 Hz Resolution

B2) Replace Missing Data Periods with NaN

B3) Extract Day of Year Information using Day of Year Fraction

B4) Filter for CNR Threshold (-24.5 dB)

B5) Filter for data with geometry inside WC68 cone

Data Flow Process for Instruments

A. WC68 (cont.)

- A4) Time Match to 100S Cone Geometry Data
- A5.1) Project WC68 into 100S Line of Sight (LOS) direction
- A5.2) Nonlinear Regression fit to Cosine Function

B. 100S (cont.)

- B6) Time Match to WC68 Cone Geometry Data
- B7) Smoothing, Discrete Averaging, & Interpolation → same Time Axis
- B8) Radial Range Gate Averaging

E.g. Leosphere Comparison Figure

Horizontal Winds WC68 (Projected in LOS dir.) **100S LOS Velocities**

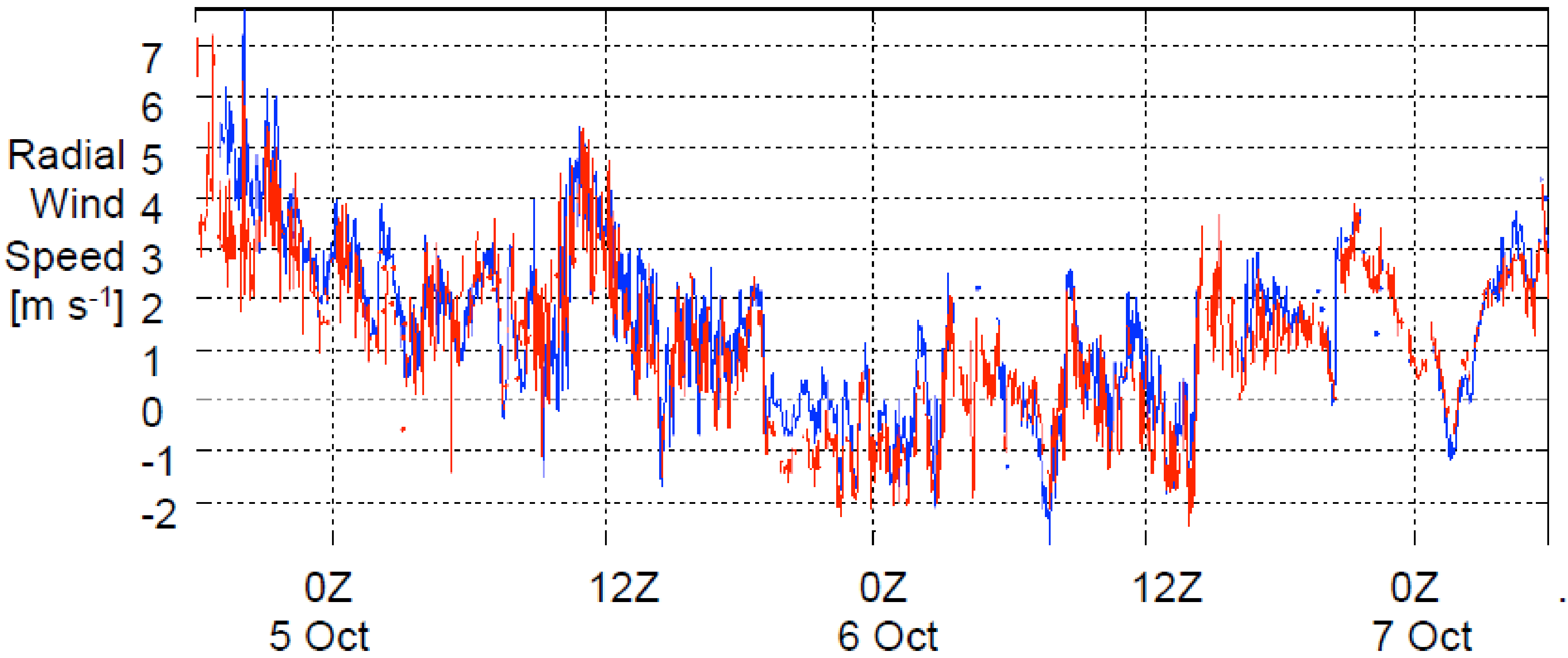


Image courtesy Mehdi Machta, Leosphere