Comparison of Vertical Velocity Observations between the ARM Doppler Lidar and the 915 MHz Radar during MC3E

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Motivation

- Measurements of vertical velocity are crucial for development and evaluation of …
  - boundary layer parameterizations in numerical forecast models
  - turbulence and surface layer parameterizations in large–eddy simulations

- The measurements should be …
  - Height and time resolved through the depth of the boundary layer
  - Sufficient quality and resolution to enable accurate retrieval of higher-order statistical moments, i.e. variance, skewness, kurtosis.

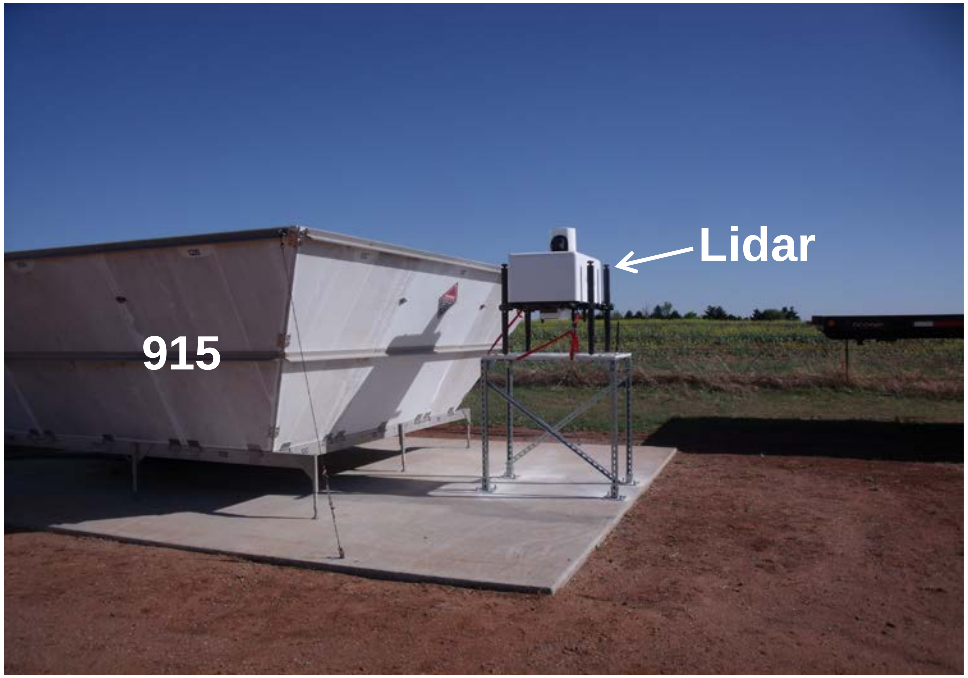
- Instruments capable of providing such measurements include:
  - Radar (clouds and precipitation)
  - Doppler lidar (clear-air)
  - Sodar

Goals

- Compare vertical velocity measurements between
  - 915 MHz radar
  - Coherent Doppler lidar
- Also compare Doppler lidar with sonic anemometer measurements to assess the accuracy of the lidar
- Questions are …
  - How accurate are the lidar measurements as indicated from the comparison to the sonic anemometers
  - How does the 915 compare to the lidar, given the large differences in sampling volumes and scattering mechanisms?
  - How does the 915 compare to the lidar under different atmospheric stability conditions

Experiment Site and Time

- Southern Great Plains (SGP) Site, North Central Oklahoma
- 21 April to 21 July 2011, including MC3E



ARM Doppler Lidars

- Manufacturer: Halo Photonics (UK)
- Specs
  - Wavelength: 1.5 μm
  - Pulse width: 150ns (22.5m)
  - Pulse Energy: ~100 μJ
  - Pulse repetition Frequency: 15 kHz
  - Max Measurement Range: 10 km
  - Typical range: ~2-4 km
  - Velocity precision: ~10cm s^{-1}
- Full upper hemispheric scanning capability
- Sensitive to aerosol backscatter
- Measurements:
  - Radial Velocity
  - Attenuated aerosol backscatter

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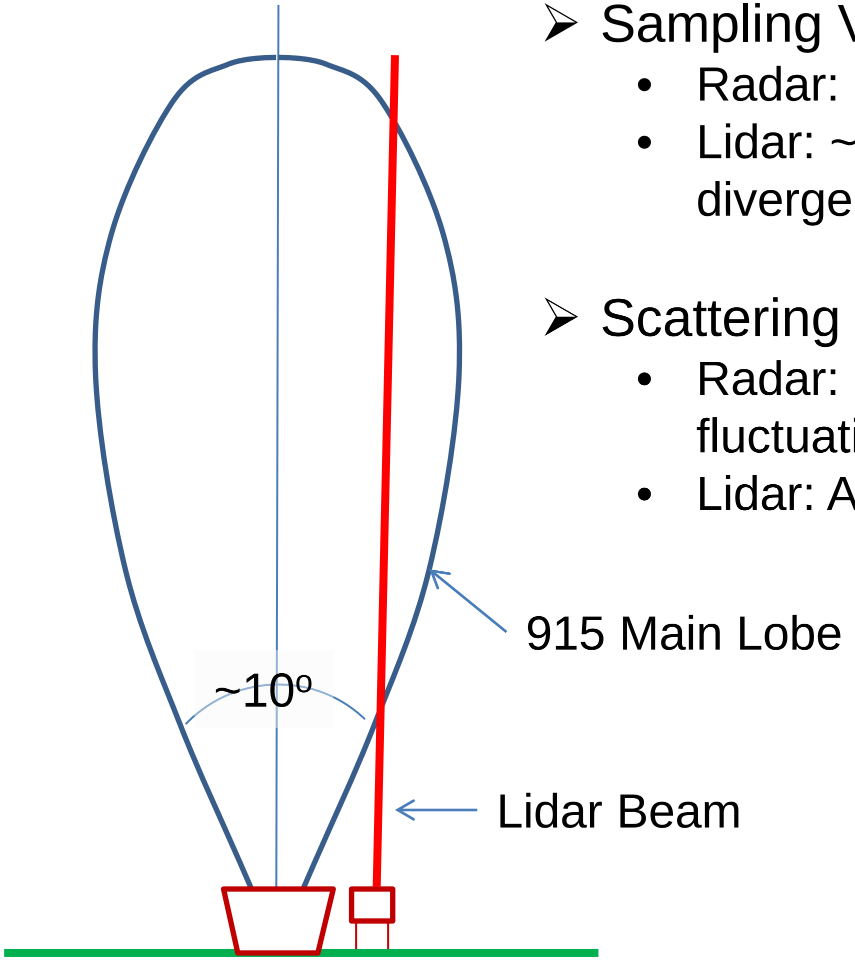
ARM 915 MHz Radar

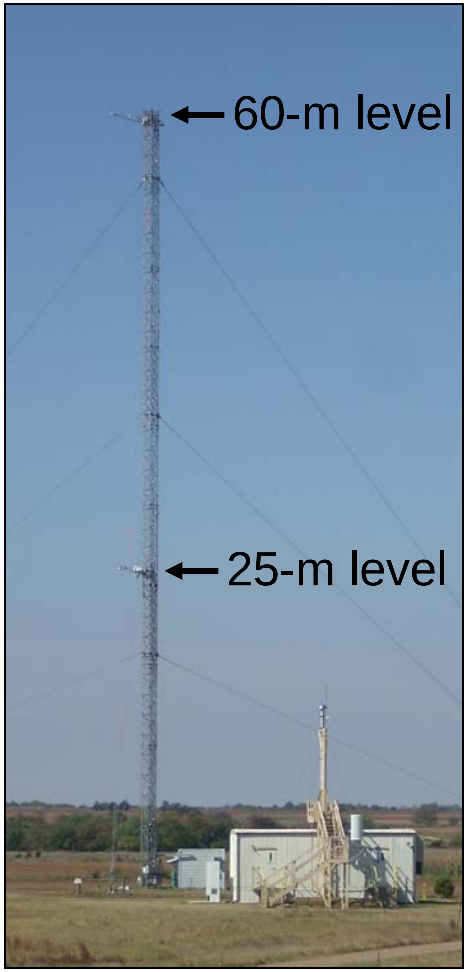
- Manufacturer: Vaisala Corporation
- Single-phased array antenna
- Frequency: 915 MHz
- Max Range: 3-5 km
- Pulse width:
  - low power mode: 60 m
  - high power mode: 400 m
- Measurements:
  - Backscattered signal strength (SNR)
  - Radial velocity
- Sensitive to …
  - Precipitation
  - Bragg scattering in clear-air (refractive index fluctuations)

Radar-Lidar Differences

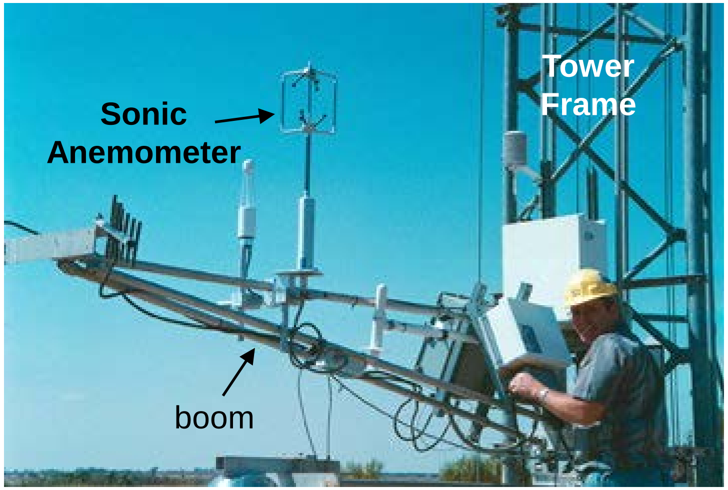


- Sampling Volumes
  - Radar: ~10º main lobe
  - Lidar: ~10 cm diameter beam, ~50 mrad divergence
- Scattering Mechanisms in clear-air
  - Radar: Bragg scattering (i.e. refractive index fluctuations)
  - Lidar: Aerosol scattering (e.g. Mie Scattering)

Doppler Lidar vs Tower Sonic Anemometers



- Sonic anemometers regarded as truth
- Lidar-sonic comparison is used to assess the accuracy of the lidar measurements
- Tower Sonic Anemometers
  - Two levels: 25-m and 60-m
  - Three-component wind measurements (u, v, w)
  - 10Hz sample rate

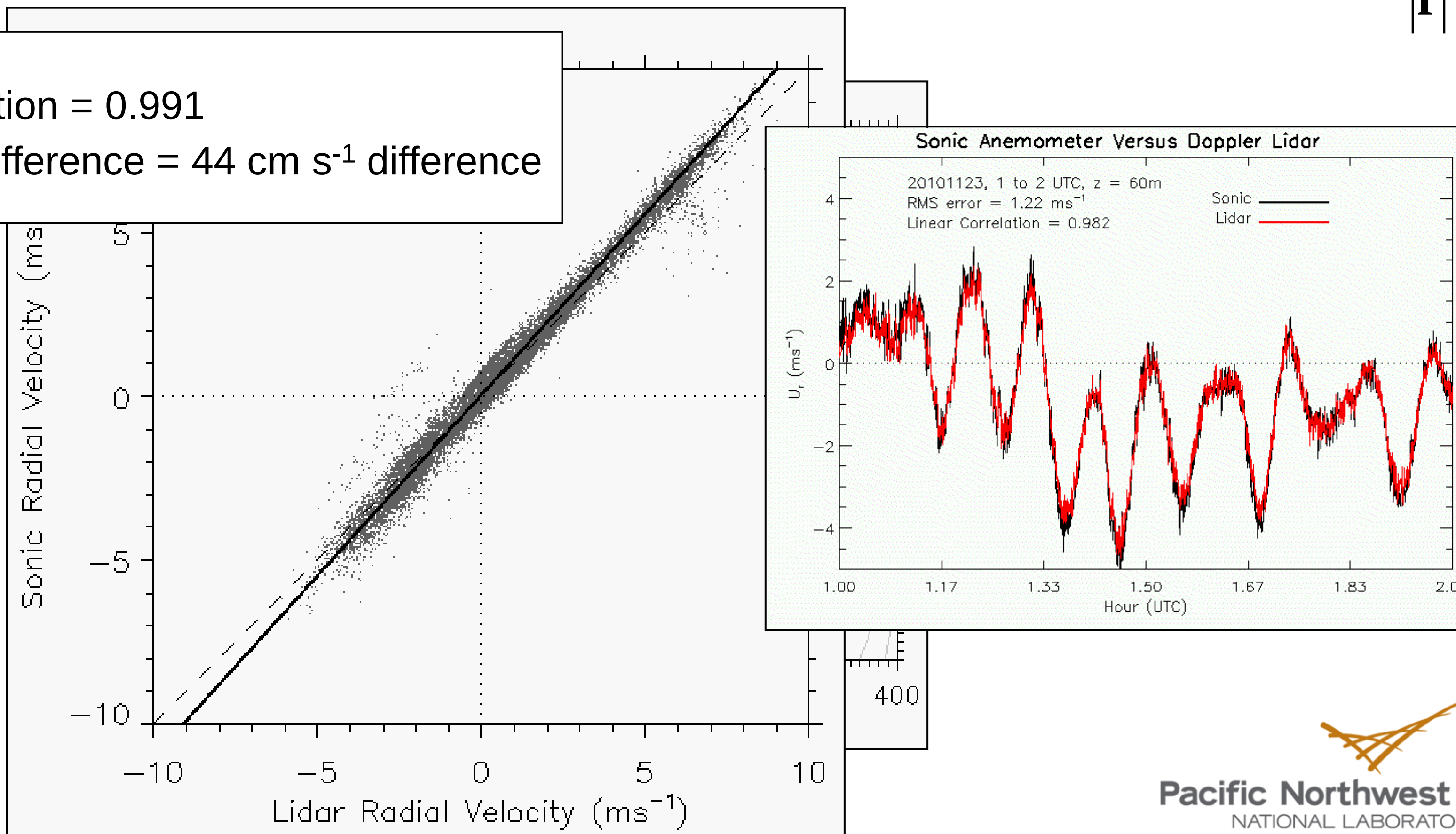


Doppler Lidar vs Tower Sonic Anemometers

- Lidar was set up to stare with it’s beam passing close to the sonic anemometer
- Δr = 30 m, Δt = 1 s
- Sonic velocity vector was projected along the lidar beam, i.e. $u_r^{sonic} = \frac{\mathbf{r} \cdot \mathbf{u}_{sonic}}{|\mathbf{r}|}$

Correlation = 0.991

RMS Difference = 44 cm s^{-1} difference



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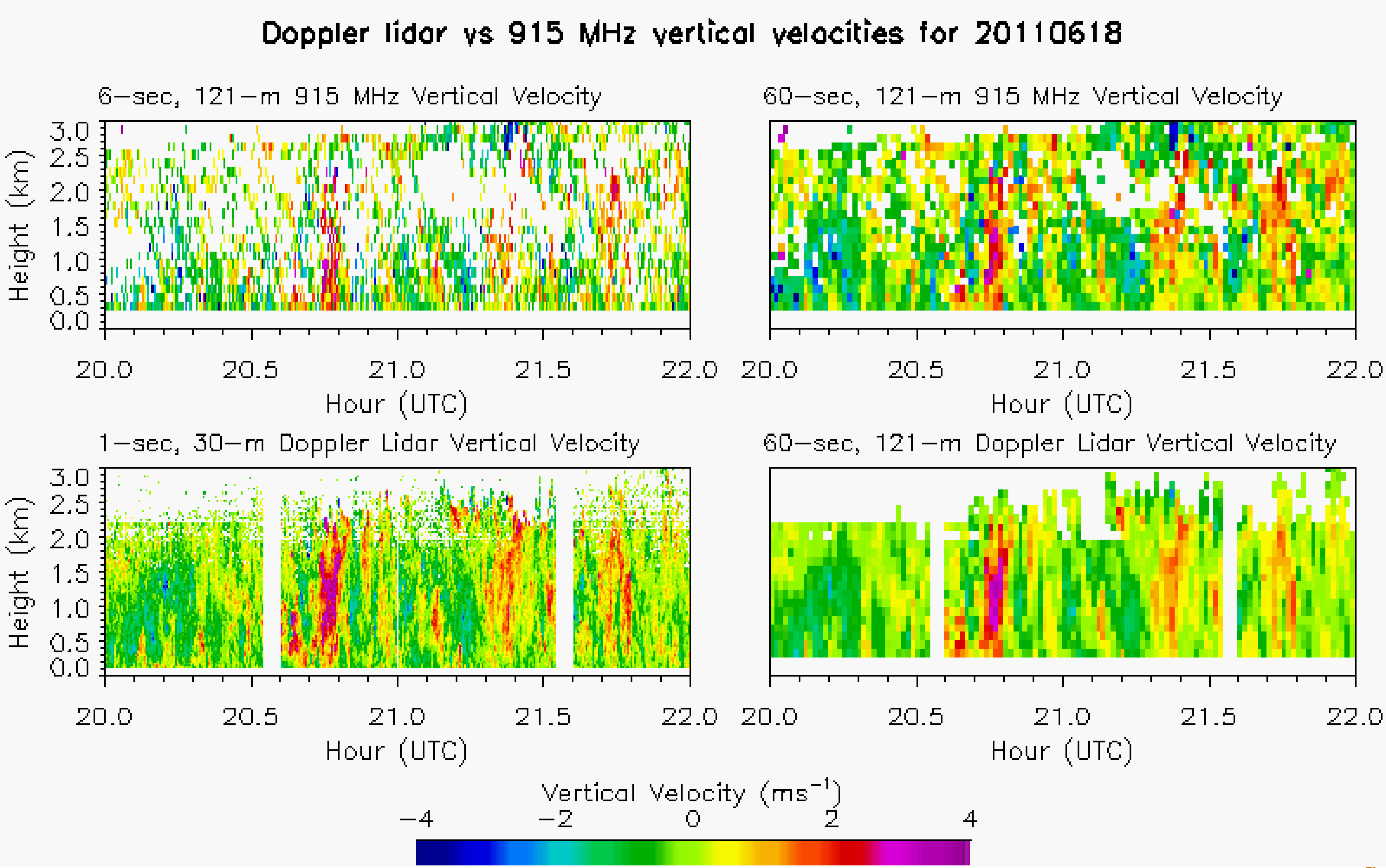
Instrument Configurations and Operating Modes

- Radar
  - Radar was operated exclusively in its low-power, short-pulse mode and sampled only in the vertical direction.
  - The low-power mode provides finer height resolution than the high-power mode, but reduced sensitivity in clear-air.
    - Height resolution of **121m**
    - nominal temporal resolution of about 6 seconds.
  - To compensate, the radar vertical velocities were reprocessed by averaging over **60-second** time intervals.
- Lidar
  - $\Delta r = 30$ m, $\Delta t = 1$ s
  - Vertical velocities were averaged and resampled to match height and time resolution of the Radar, i.e. **121 m** and **60 s**.

Sample Comparison



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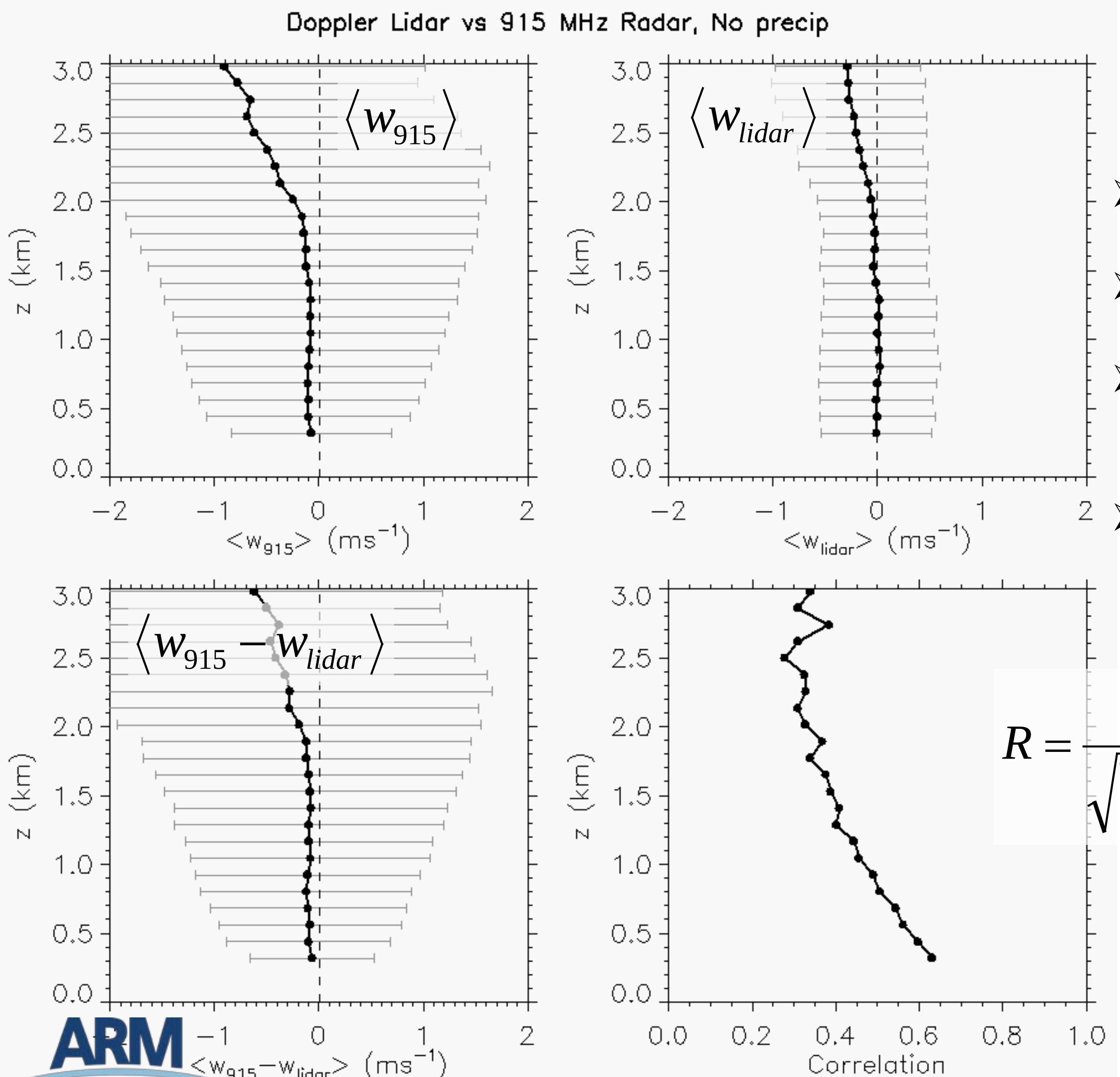
Radar-Lidar Comparison Results



- No precipitation
- All stability regimes
- Mean and Standard Deviation
- Linear Pearson correlation coefficient

$$R = \frac{\overline{w'_{915} w'_{lidar}}}{\sqrt{\overline{w'^2_{915}}}\sqrt{\overline{w'^2_{lidar}}}}$$

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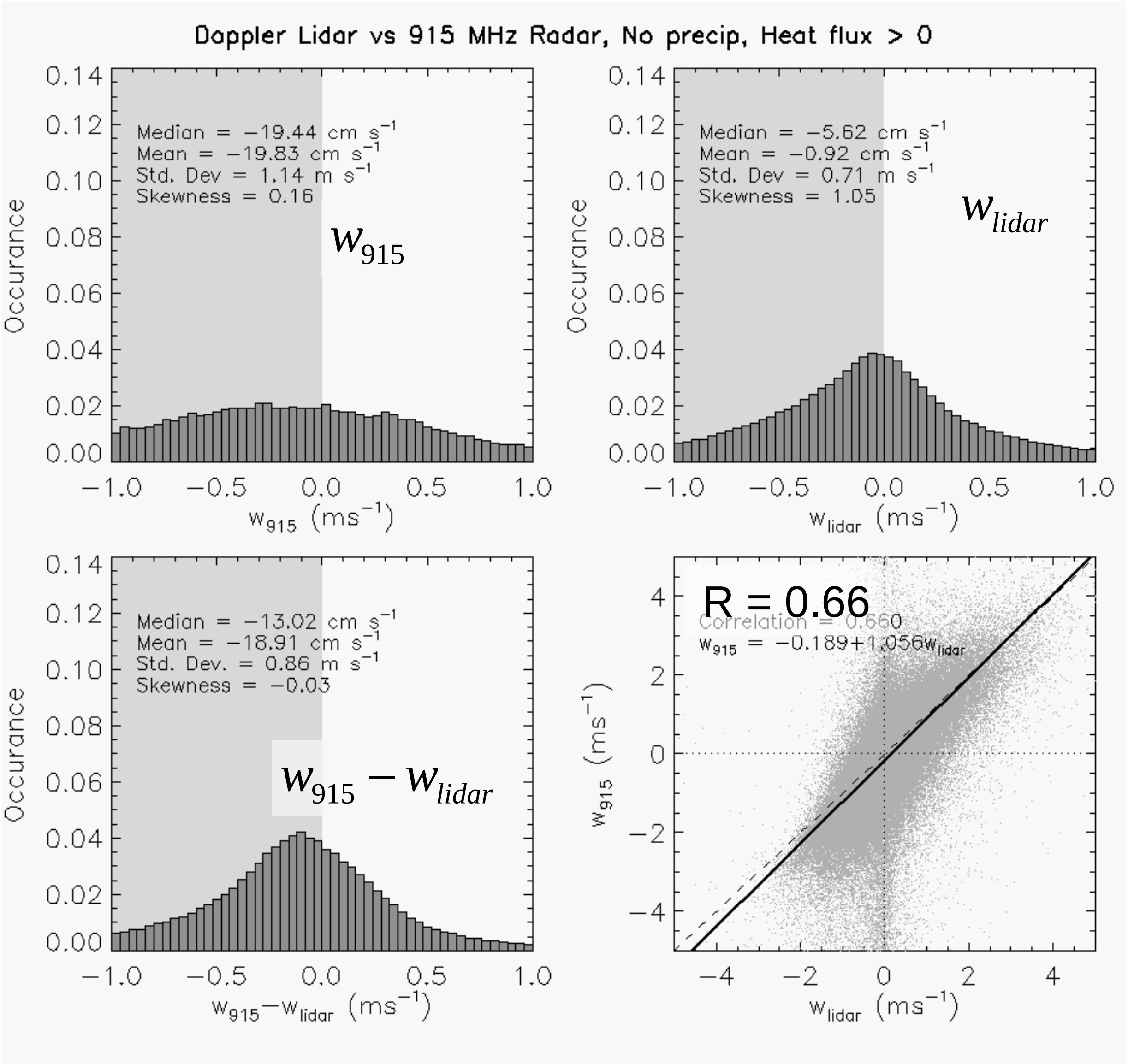
Radar-Lidar Comparison Results: Positive Surface Heat Flux



No precipitation

z < 2 km

$$\left(\overline{T'w'}\right)_{surface} > 0$$

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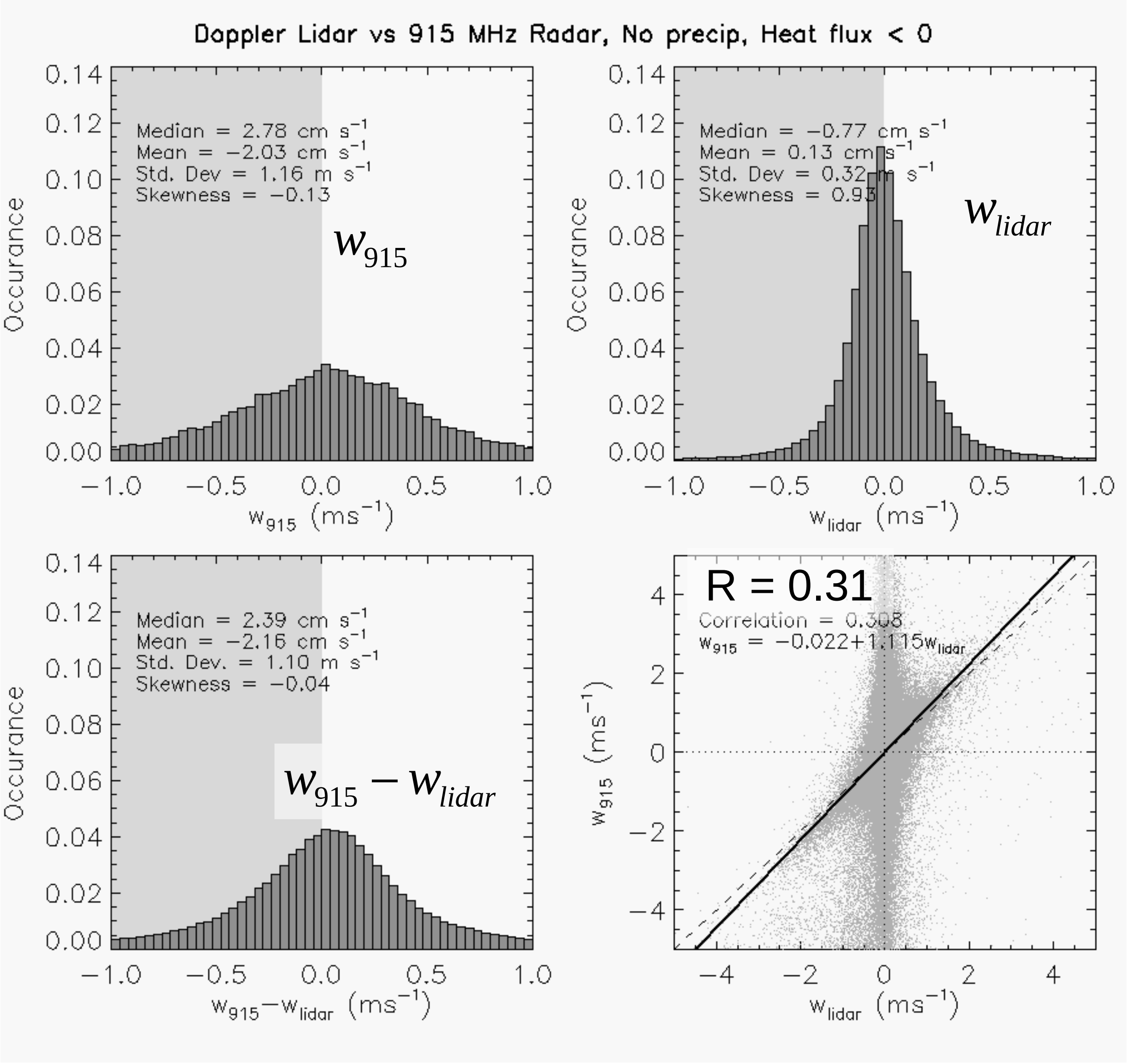
Radar-Lidar Comparison Results: Negative Surface Heat Flux



No precipitation

z < 2 km

$$\left(\overline{T'w'}\right)_{surface} < 0$$

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Results Sorted by Surface Stability

Surface Stability Regime		$\overline{w'_{915}}$ (cm s^{-1})	$\overline{w'_{lidar}}$ (cm s^{-1})	R
$\left(\overline{T'w'}\right)_{surface} > 0$	u*<0.38ms^{-1}	**-21.63**	**-1.83**	**0.670**
	u*>0.38ms^{-1}	**-19.01**	**-0.49**	**0.653**
$\left(\overline{T'w'}\right)_{surface} < 0$	u*>0.38ms^{-1}	**-6.19**	**0.50**	**0.339**
	u*<0.38ms^{-1}	**0.37**	**-0.25**	**0.285**

- For z<2 km
- Heat flux and friction velocity from 4-m sonic on tower
- Median u* over 3 month period = 0.38 ms^{-1}

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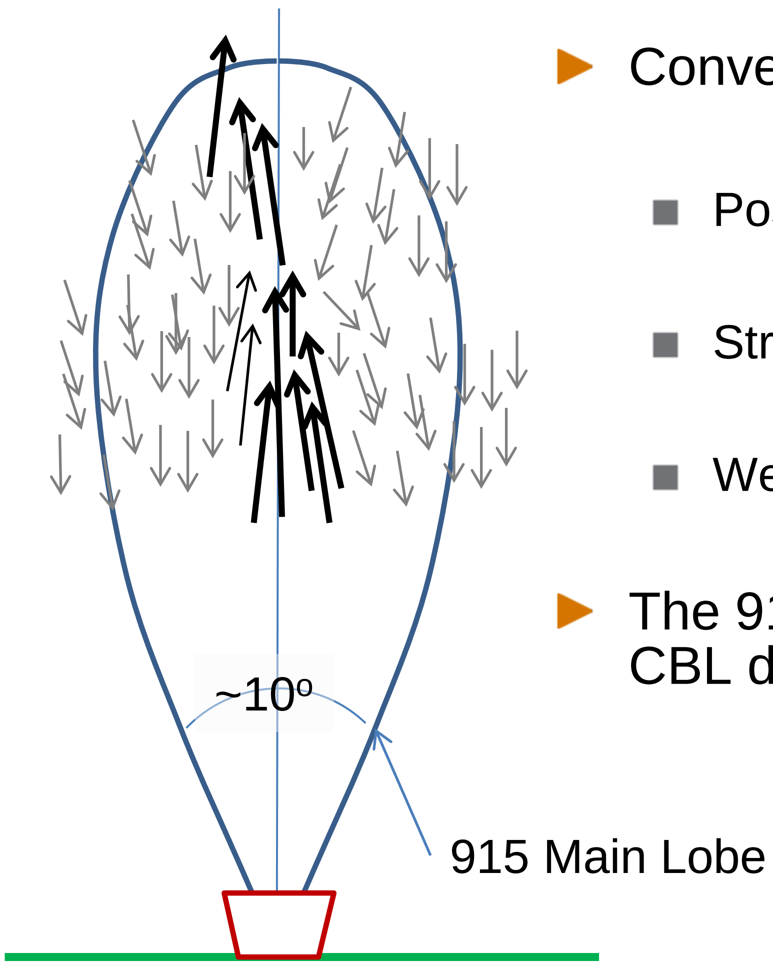
Why is the 915 Negatively Biased in Convective Conditions?



- Convective Boundary Layers (CBL)
  - Positive skewness in vertical velocity
  - Strong concentrated updrafts
  - Weaker broader downdrafts
- The 915 under represents updrafts in the CBL due to wide beam size (~10º)

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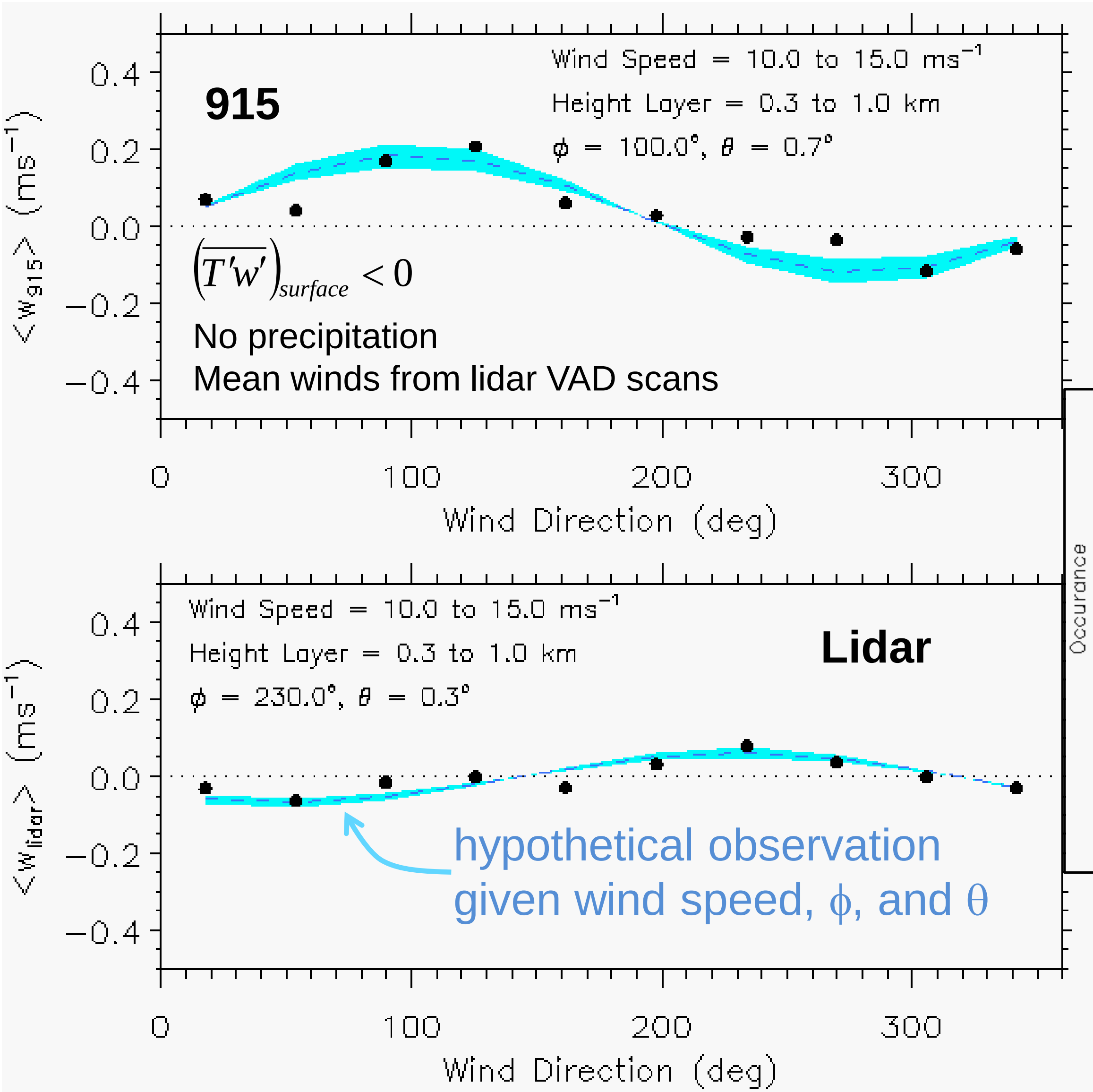
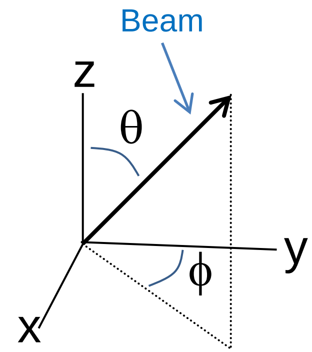
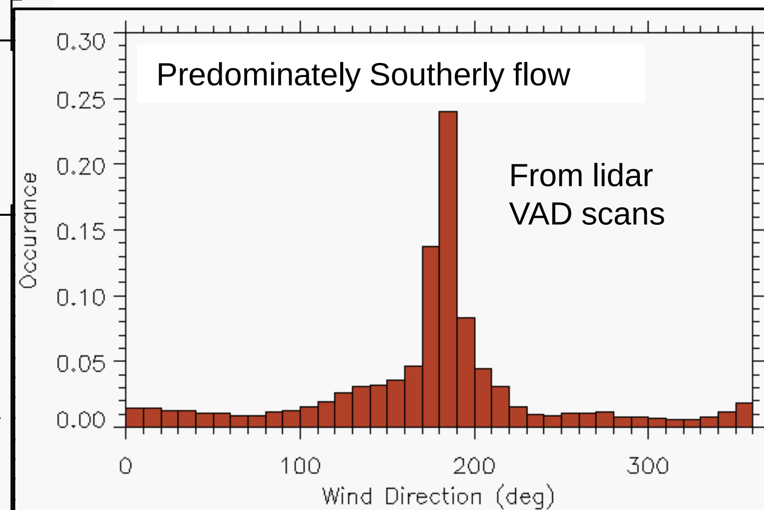
Zenith Misalignment Check







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Summary

- Doppler lidar vs and sonic anemometer showed …
  - Good agreement
  - RMS difference = 44 cm s^{-1}, Correlation = 0.99
- Doppler lidar vs 915 MHz radar showed …
  - Stability dependent bias in the 915
    - -22 cm s^{-1} under convective conditions to ~0 cm s^{-1} under stable conditions
    - Mostly sensitive to heat flux, not as sensitive to u*
    - The 915 under-represents the contribution from updrafts in the CBL due to wide beam
    - Zenith misalignment not an issue
  - Lidar vertical velocities are smaller (in an absolute sense) than the 915 in precipitation
    - 915 measures fall speed
    - Lidar measures "average" of fall speed and air motion