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
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: ~10° 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
Lidar was set up to stare with its beam passing close to the sonic anemometer.

\[ \Delta r = 30 \text{ m}, \Delta t = 1 \text{ s} \]

Sonic velocity vector was projected along the lidar beam, i.e.

\[ u_{sonic}^r = \frac{\mathbf{r} \cdot \mathbf{u}_{sonic}}{||\mathbf{r}||} \]

Correlation = 0.991
RMS Difference = 44 cm s\(^{-1}\) difference
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 **121 m**
    - Nominal temporal resolution of about 6 seconds.
  - To compensate, the radar vertical velocities were reprocessed by averaging over **60-second** time intervals.

- **Lidar**
  - \( \Delta r = 30 \text{ m}, \Delta t = 1 \text{ s} \)
  - Vertical velocities were averaged and resampled to match height and time resolution of the Radar, i.e. **121 m** and **60 s**.
Sample Comparison

Doppler lidar vs 915 MHz vertical velocities for 20110618

60–sec, 121–m 915 MHz Vertical Velocity

60–sec, 121–m Doppler Lidar Vertical Velocity

Vertical Velocity (ms⁻¹)

Proudly Operated by Battelle Since 1965
Radar-Lidar Comparison Results

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

\[
R = \frac{\langle w'_{915} \rangle \langle w'_{lidar} \rangle}{\sqrt{\langle w'_{915}^2 \rangle} \sqrt{\langle w'_{lidar}^2 \rangle}}
\]
Radar-Lidar Comparison Results: Positive Surface Heat Flux

No precipitation

\[ \left( T'w' \right)_\text{surface} > 0 \]

\begin{align*}
\text{Median} &= -19.44 \text{ cm s}^{-1} \\
\text{Mean} &= -19.83 \text{ cm s}^{-1} \\
\text{Std. Dev} &= 1.14 \text{ m s}^{-1} \\
\text{Skewness} &= 0.15 \\
\end{align*}

\begin{align*}
\text{Median} &= -5.82 \text{ cm s}^{-1} \\
\text{Mean} &= -0.92 \text{ cm s}^{-1} \\
\text{Std. Dev} &= 0.71 \text{ m s}^{-1} \\
\text{Skewness} &= 1.05 \\
\end{align*}

\begin{align*}
R &= 0.66 \\
\text{Correlation} &= 0.560 \\
w_{915} &= -0.189 + 1.055w_{\text{lidar}} \\
\end{align*}
Radar-Lidar Comparison Results: Negative Surface Heat Flux

No precipitation

$z < 2 \text{ km}$

$\left( T'w' \right)_{\text{surface}} < 0$
## Results Sorted by Surface Stability

<table>
<thead>
<tr>
<th>Surface Stability Regime</th>
<th>( \overline{w'_{915}} ) (cm s(^{-1}))</th>
<th>( \overline{w'_{lidar}} ) (cm s(^{-1}))</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>( (T'w')_{surface} &gt; 0 )</td>
<td>u*&lt;0.38ms(^{-1})</td>
<td>-21.63</td>
<td>-1.83</td>
</tr>
<tr>
<td></td>
<td>u*&gt;0.38ms(^{-1})</td>
<td>-19.01</td>
<td>-0.49</td>
</tr>
<tr>
<td>((T'w')_{surface} &lt; 0 )</td>
<td>u*&gt;0.38ms(^{-1})</td>
<td>-6.19</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>u*&lt;0.38ms(^{-1})</td>
<td>0.37</td>
<td>-0.25</td>
</tr>
</tbody>
</table>

- For z<2 km
- Heat flux and friction velocity from 4-m sonic on tower
- Median u* over 3 month period = 0.38 ms\(^{-1}\)
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 (~10°)
Zenith Misalignment Check

Wind Speed = 10.0 to 15.0 ms\(^{-1}\)
Height Layer = 0.3 to 1.0 km
\(\phi = 100.0^\circ, \theta = 0.7^\circ\)

\((T'w')_{\text{surface}} < 0\)

No precipitation
Mean winds from lidar VAD scans

Predominately Southerly flow
From lidar VAD scans

hypothetical observation
given wind speed, \(\phi\), and \(\theta\)
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