Long-Term Vertical Velocity Statistics Derived from Doppler Lidar in the Continental Convective Boundary Layer

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Distributions of vertical velocity (w) are needed to understand both PBL turbulence and boundary-layer clouds.

Most studies of w statistics are derived from short-term aircraft observations or tower based studies:
- BAO (300 m)
- Cabaw (213 m)

Long-term measurements of w statistics are lacking, but are needed for evaluating model results and developing new parameterizations:
- ARM LASSO (LES ARM Symbiotic Simulation and Observation) project

Data collected by Department of Energy’s Atmospheric Radiation Measurement (ARM) Climate Research Facility provide a unique opportunity to address this need.

Outline:
- Data description
- Composites of w stats
- Sorting the results
- Conclusions
ARM Doppler Lidars and Analysis Criteria

- Halo-Photonics DL Deployed at ARM fixed sites and AMF
  - Near-IR (1.5 µm)
  - Range is typically less than 2 km for clear-air retrievals
- Value Added Product (VAP) has been developed that includes wind profiles and key statistics: variance, skewness, and kurtosis
- Utilize ARM meteorological and flux data, wind profiles from 915 MHz radar wind profilers
- Data selection criteria
  - Require SNR to be ≥ 0.03 (more stringent criteria used for higher order stats)
  - Define $z_i$ using a threshold of variance (0.04—based on Tucker et al. 2009)
  - $z_i > 0$, $w_* > 0$ (implies positive surface heat flux)
  - Cloud Fraction < 0.001
Representative Case: 18 July 2015

ECOR = Eddy Covariance System
Composite Statistics

Peak value smeared by averaging

Daytimes values positively skewed

Kurtosis of Gaussian Distribution = 3

More peaked

Less peaked
The $w$ statistics can be sorted by many different ways—think of factors that could influence the PBL turbulence:

- Time of day
- Wind direction
- Season
- Surface shear stress/friction velocity ($u^*$)
- Wind Shear at PBL top
- Static stability

Use Kolomogorov-Smirnov test to determine if differences are statistically significant:

- Look to see if values could be from the same parent distribution
Change in Variance Profile with Time

- All values of $\sigma_w^2$ have been normalized by $w^*$.
  - Values tend to be smaller than short-term results presented by Lenschow et al. (2012):
    
    $$\frac{\sigma_w^2}{w^*_2} = 1.8 \left( \frac{z}{z_i} \right)^{2/3} \left( 1 - 0.8 \frac{z}{z_i} \right)^2 \frac{z}{z_i}$$

- Normalization works best in late-morning and afternoon.
  - PBL approximately steady state

Limit analysis to 17 to 23 UTC
Differences in land use and surface roughness associated with wind direction could lead to differences in velocity statistics.

Limit analysis to periods with southerly winds.

Error bars: 75th and 25th percentiles.
Dependence on Season

$\sigma_w^2/w_*^2$ changes with season, differences in surface heterogeneity?
Skewness larger in PLB top during warm seasons
Dependence on $u^*$

Values of $u^*$ from surface flux measurements were sorted to determine critical values.

- $u^*$ in Lenschow et al. (2012) ranged from 0.16 to 0.52 ms$^{-1}$

Large: 0.59 ms$^{-1}$
Small: 0.27 ms$^{-1}$

Large values of $u^*$ lead to small values of $\frac{\sigma_w^2}{w^*_2}$ and kurtosis.
Dependence on Stability

Stability defined using $-\frac{z_i}{L}$

- Values greater than 30 are unstable, less than 30 moderately unstable

Unstable cases have smaller values of $\frac{\sigma_w^2}{w^*}$ and kurtosis
Dependence on Wind Shear Across the Boundary-Layer Top

- Wind shear determined from radar wind profiler
  - Based on wind speed differences between $z/z_i$ of 1.1 and 0.9

Cases with large amounts of shear are less skewed over much of the BL

Large: 1.4 ms$^{-1}$
Small: -0.6 ms$^{-1}$
Conclusions

- Data from ARM Doppler lidars provide a unique opportunity to look at long-term vertical velocity statistics.
- Scaling with $w^*$ works best for cases when BL is quasi-stationary.
- There are systematic differences in the $\sigma_w^2/w^*^2$, skewness, and kurtosis associated with differences is:
  - **Season**: Variance largest in spring; Skewness larger in warmer seasons.
  - **Surface stress**: smaller values of $u^*$ lead to large values of $\sigma_w^2/w^*^2$.
  - **Stability**: Moderately unstable conditions lead to larger values of $\sigma_w^2/w^*^2$ and kurtosis.
  - **Wind Shear across the BL top**: small values of shear lead to larger values of skewness.
  - **Future efforts will extend work to stable conditions**

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