Water Vapor Turbulence Profiles in Stationary Continental Convective Boundary Layers

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(1) Background

- Lidars are able to provide measurements of turbulence in boundary layer
- Will concentrate analysis on convective boundary layers (CBLs) that are quasi-stationary
- Typically need lidar time-series observations over ~120 minutes to get good statistics in CBL
- Raman lidar provides measurements of water vapor mixing ratio (tracer of motion)
- Doppler lidar provides direct measurements of vertical velocity
- Need to account for instrument noise and outliers when computing variance and skewness

The Math, Simplified

Lenschow et al. JTECH, 2000

Components of a time series: $q(z,t)=\overline{q(z)}+q'(z,t)+\varepsilon(z)$

Definition of a lag: $q'_\tau = q'(t+\tau)$

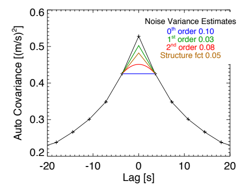
First order autocorrelation: $M_{11}(\tau)=\frac{1}{T}\int_0^T\left[q'(t)+\varepsilon(t)\right]\left[q'(t+\tau)+\varepsilon(t+\tau)\right]dt$

Which in the mean simplifies to: $M_{11}(\tau)=\overline{(q'+\varepsilon)(q'_\tau+\varepsilon_\tau)}=\overline{q'q'_\tau}+\overline{q'\varepsilon_\tau}+\overline{q'_\tau\varepsilon}+\overline{\varepsilon\varepsilon_\tau}$

And at zero (no) lag we get: $M_{11}(0)=\overline{q'^2}+2\overline{q'\varepsilon}+\overline{\varepsilon^2}$

Assume no correlation between q′ and ε: $M_{11}(\tau)=\overline{q'q'_\tau}$ and $M_{11}(0)=\overline{q'^2}+\overline{\varepsilon^2}$

Thus, as we approach $\tau=0$ we get: $\overline{q'^2}=M_{11}(\rightarrow 0)$ and $\overline{\varepsilon^2}=M_{11}(0)-M_{11}(\rightarrow 0)$



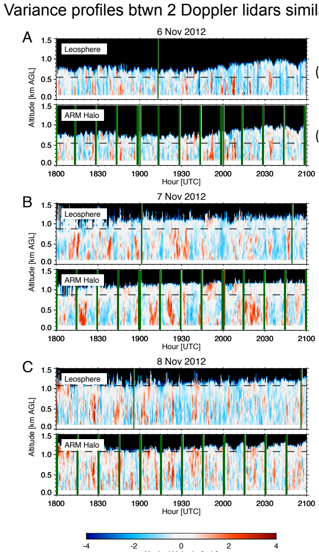
"Structure" function: $M_{11}(\tau)=\overline{q'^2}-C\tau^{2/3}$

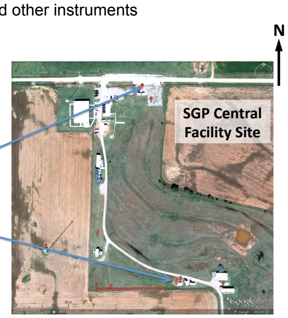
Thus we can estimate the contribution of the instrument noise to the total variance!

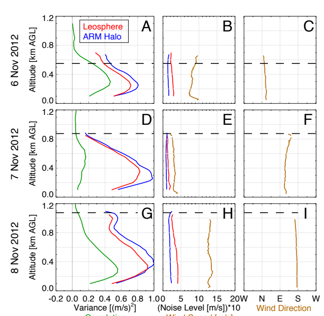
(3) Vertical Velocity Variance from LABLE

- LABLE: Lower Atmosphere Boundary Layer Experiment, Sep-Nov 2012 at SGP site
- Primary goal: to investigate horizontal differences in vertical motion and turbulence
- Deployed 2 additional Doppler lidars (a,b), a sodar (c), and a scintillometer (d) to SGP CF site
- Complements the ARM Doppler lidar (1), Raman lidar (3), and other instruments

- Data from 3 consecutive CBL periods analyzed
- Wind direction/speed different on each day (N, SE, S)
- Variance profiles btwn 2 Doppler lidars similar but different







(2) Instruments

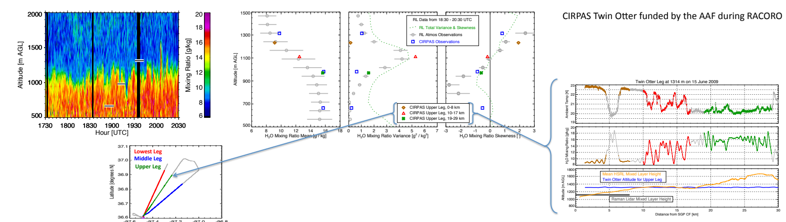
- Raman lidar water vapor mixing ratio
  - 10-s, typically 75-m resolution (to get good S/N)
  - System upgrade in September 2004 enabled investigation of turbulent processes
- Doppler lidar vertical wind speed
  - 1-s resolution, 30-m resolution
  - Deployed at SGP in 2010

ARM Doppler lidar is from Halo Photonics and is deployed near 915 MHz Wind Profiler

(This system was deployed during LABLE)

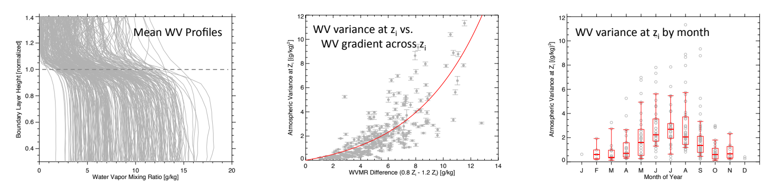
(4) Validation of Water Vapor Turbulence Profiles

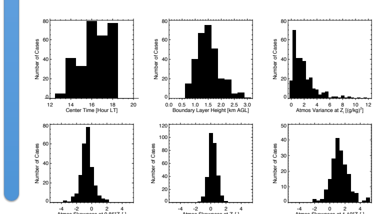
- Used tunable laser hygrometer data from Twin Otter during RACORO to validate the method
- HSRL data on NASA King Air critical for determining where Twin Otter was relative to CBL top
- This example is from 15 June 2009:

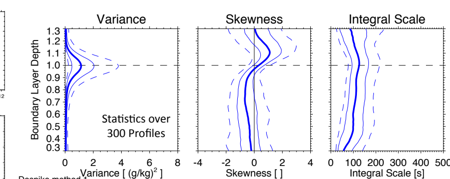


(5) Water Vapor Turbulence Statistics

- Data from 300 separate quasi-stationary CBL cases from 2005-2007 over range of seasons
- Cases chosen so there are no synoptic changes (e.g., fronts, drylines) passing during period
- Primarily clear sky or CBL topped with Cu. The top of the CBL is denoted with z_i







Lines denote the 10th, 25th, 50th, 75th, and 90th percentiles