Lidar-derived integral length scales and the Monin-Obukhov length

By
Daniel Cooper
Los Alamos National Laboratory

The utility of the scanning Raman lidar to quantitative information is presently dependent upon additional data from point observations from tower-based sensors such as three-dimensional sonic anemometers for critical variables including the Monin-Obukhov Length. The Monin-Obukhov Length (L) is used in a turbulence averaging framework to estimate the flux from high spatial resolution gradients of water vapor mixing ratio as measured by the Raman scanning lidar. However, L values used for the mapped region are derived from a single point as an averaged value over the lidar scanning region. Since the flux is variable over space, L should also be variable; thus for estimating the flux it would be advantageous to have spatially resolved L values along with the spatially resolved water vapor gradients. Furthermore, because Monin-Obukhov similarity theory is commonly used as a framework for characterizing the atmospheric boundary layer, a method to spatially resolve L is useful for a better understanding of the surface-atmosphere exchange processes.

It has been suggested that the L is related to simple statistical properties of the atmosphere, such as the integral time scale. Extrapolating this work, the L can be estimated directly from lidar spatially resolved water vapor concentration data without employing external data sources by computing the Integral Scale Length (ISL). The ISL is the radial distance that energy and mass in the atmosphere can be transported down wind by large coherent eddies, and is the spatial analog to the integral time scale. Large eddies are those that are greater than the ISL, and conversely small eddies are equal to or less than the ISL. The ISL is computed from the lidar using a purely statistical property of the spatial data, the autocorrelation function of space-concentration transects extracted from lidar measured range-height scans. The autocorrelation-lag function is computed and then integrated to estimate the ISL. Once the autocorrelation derived ISL is estimated, it is transformed into a corresponding L value using a power-law similarity function that relates the ISL to the L. Using the spatially resolved L values we will be able to better map the water vapor flux independently of point-sensors.

To compute the integral scale length from lidar data, seventy eight vertical scans acquired over five separate days representing a wide range of unstable conditions were processed using standard lidar analysis techniques. Vertical scans were displayed and prepared for further analysis by extracting horizontal slices at a tower height, 2.7 m above the canopy, creating an approximately 300 m long spatial series. The spatial-series were then processed using standard micrometeorological conditioning methods to estimate the integral spatial scale from the autocorrelation function. Monin-Obukhov lengths were computed from the lidar derived integral scale lengths. Conversely, coincident with the lidar data, tower-based three-axis sonic anemometer data measured at 20 Hz, were used to estimate the L using standard eddy covariance equations, as well as the integral scale length. Thus, the lidar and point-sensor data allows for a inter-comparison of near-simultaneous spatial and temporal techniques.

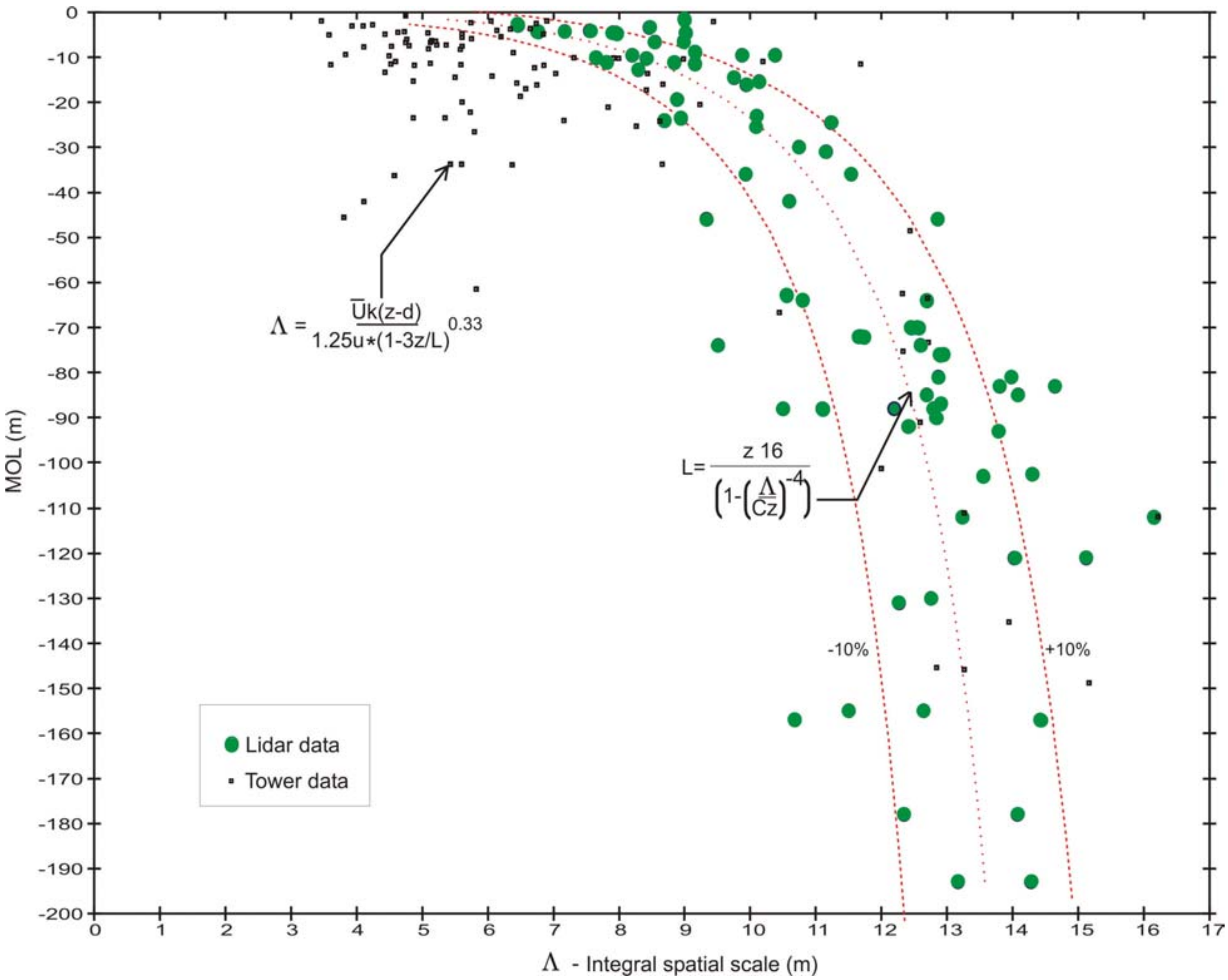

Fig 1. Relationship between lidar and eddy covariance derived Integral spatial scales and the Monin-Obukhov length estimated from two field campaigns. The similarity model based upon a stability function is shown as a dotted line and the ±10% uncertainty functions are shown as dashed lines, the equations used to compute the similarity based estimates based upon z/L and friction velocity are also shown.

In order to characterize the relationship between lidar ISL and tower-based L estimates over a wider range of unstable conditions seventy eight data sets were used, spanning L values between -1 and -200 m. A scatter plot (Figure 1) shows that for the unstable case (when L < 0), the lidar-derived ISL can be related to the L with some confidence. A model for all ISL-L values is also shown in the figure as a dotted line with equation with ±10% limits on either side. The 10% confidence limits where chosen as the expected uncertainty in estimating the L from a sonic anemometer, and linearly propagated into the ISL equation. Most of the lidar and tower based estimates bracket the basic ISL-L model within the expected uncertainty. The lidar derived L scatter plot follows the expected decaying power-law curve, and compares well to the estimates from the sonic anemometer derived ISL-L values. Further, when additional information such as u_* is used in conjunction with the tower-based measured L to estimate the ISL, the variability of the estimates are similar to the variability of the lidar derived L values. The convergence of the two independent data sets suggests that these techniques are characterizing the turbulent time-space fields with reasonable fidelity. The uncertainty in the ISL to L relationship appears relatively constant, except at the smallest L values between 0 and -30. The lidar derived L values drops to approximately zero at an ISL of 6 m while the tower-based estimates drops to zero at an ISL between 3 and 5 m. The discrepancy between the lidar and sonic anemometer results at low ISL values is partially due to the spatial Nyquist frequency of the lidar, as its fundamental resolution is 1.5 m, thus the smallest length scales will be on the order of 3 m without smoothing. With the additional Savitsky-Golay smoothing, the smallest expected resolvable structures are approximately 6 m.

The methodology described above has been studied with data for the unstable case, additional work will be performed for the stable, nocturnal boundary layer observed during VTMX.