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PERFORMANCE OF A 2 μm COHERENT DOPPLER LIDAR

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INTRODUCTION

The coherent Doppler lidar produces estimates of the radial velocity $v\,[m/s]$ from the Doppler frequency or mean-frequency $f_m\,[Hz]$ of the backscattered laser field using $v=\lambda f_m/2$ where $\lambda[m]$ is the laser wavelength. The performance of a 2μm coherent Doppler lidar developed by Coherent Technologies, Inc. (Henderson et al., 1993) is described by the systematic and random errors of velocity estimates. The systematic error is determined from the estimated velocity of a non-moving hard target as 3.6 cm/s. The estimation error due to the additive detector noise is 6.2 cm/s.

VELOCITY ESTIMATION AND DATA ANALYSIS

The performance of velocity or mean-frequency estimators is described by the probability density function of the estimates, which can be approximated by a Gaussian distribution of "good estimates" with standard deviation $g\,[m/s]$ centered on the true velocity and a fraction b of uniformly distributed "bad" estimates (Frehlich and Yadlowsky, 1994). Improved velocity estimates can be obtained by accumulating the signal from K pulses. For measurements of winds using a Doppler lidar, the estimates of the radial velocity $v_k(R)[m/s]$ at range R can be modeled as $v_k(R)=u_k(R)+e_k(R)$ where $u_k(R)[m/s]$ is the wind field component at time kT_P and $T_P\,[s]$ is the time interval between estimates and $e_k(R)[m/s]$ is the estimation error. If the two components $u_k(R)$ and $e_k(R)$ are statistically independent, then $\sigma_v^2(R)=\sigma_u^2(R)+\sigma_e^2(R)$ where σ_x^2 is the variance of x. The spectrum of the data is the sum of the spectrum of the wind field and the estimation error. The spectrum of the estimation error component is a constant equal to $T_P\sigma_e^2$ which produces an accurate estimate of the estimation error when the high-frequency component separates from the low-frequency wind component (see Figs. 1,2).

Horizontal-path 2.09μm Coherent Doppler lidar data was collected at Denver, Colorado. The sampling interval for the complex data was $20nsec$. The Maximum Likelihood (ML) estimate of velocity was computed with $M=16$ data points and a search velocity of $26m/s$ (Frehlich and Yadlowsky, 1994). During the observation time for one estimate, the pulse travels $\Delta p=48m$ and the width of the range weighting function $\Delta r=30m$. The effective range resolution is $\Delta R=\Delta r+\Delta p=78m$. The ML velocity estimates and the spectrum for 6000 shots (20.4 minutes of data) and a range gate centered at 5 km are shown in Fig. 1. The velocity fluctuations are described by two components: a slowly varying component at low frequencies due to the random wind field $u_k(R)$ and a statistically independent estimation error component $e_k(R)$.

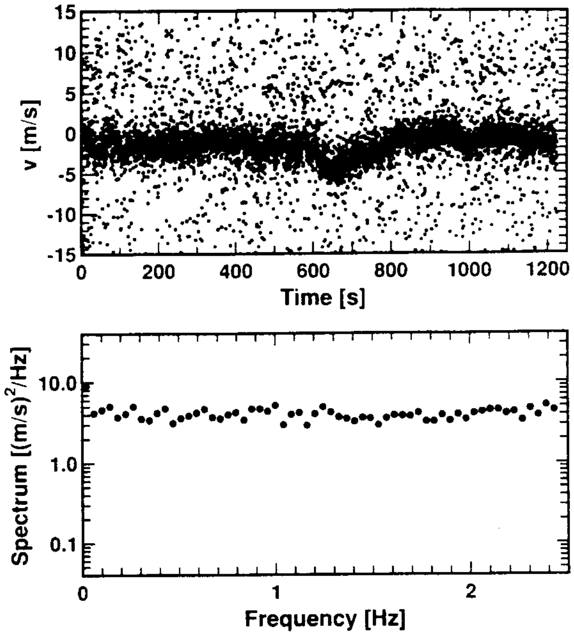

Fig. 1. The ML estimates of the velocity at a range bin centered at 5 km. The estimate of the spectrum is also shown.

This same data was processed with a ML estimator using $K=10$ adjacent pulses per estimate and the results are displayed in Fig. 2. The pulse accumulation removes the "bad" estimates. This permits accurate estimation of both b and g. The performance for the single and multiple shot estimates are shown in Fig. 3. Accumulation of multiple pulses reduces estimation error and the fraction of bad estimates.

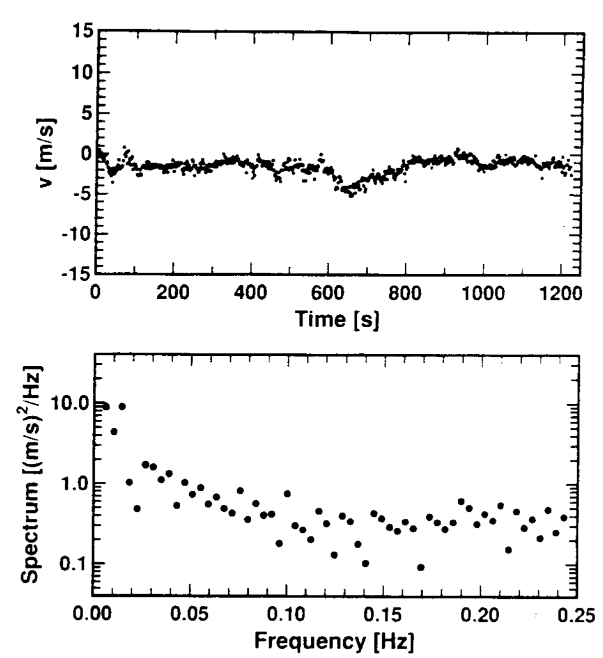

Fig. 2. Same as Fig. 1 except that 10 accumulated pulses of data are used for each estimate.

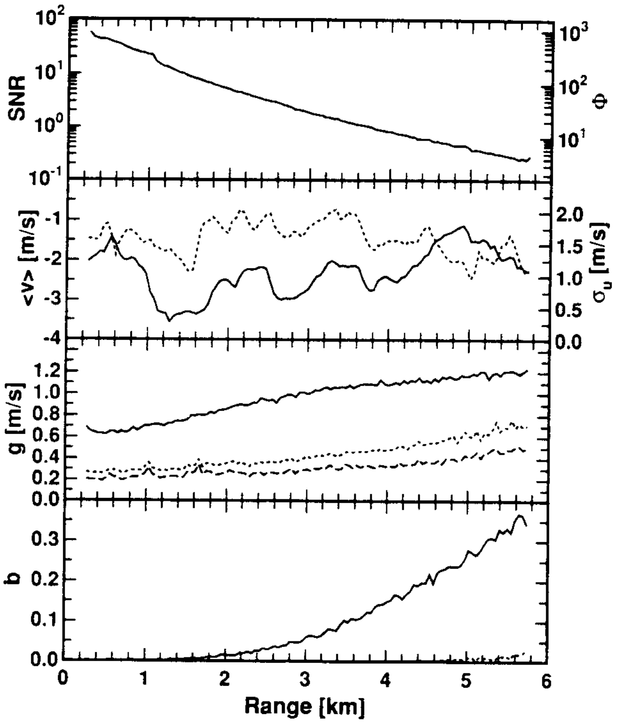

Fig. 3. Doppler lidar parameters as a function of range R, SNR is the signal-to-noise ratio, Φ=$SNR\ M$ is the number of coherent photoelectrons per estimate, $<v>$ is the average velocity (———), σ_u is the standard deviation of the the velocity u (· · ·), g is the standard deviation of the good estimates using 1 (———), 5 (· · ·), and 10 (- - -) shots per estimate, and b is the corresponding fraction of bad estimates.

Spatial Statistics of Velocity

The performance of Doppler lidar estimates of velocity is sufficient to estimate the spatial statistics of the atmospheric wind field, defined by the structure function

$$D_v(r)=<[v(r_0)-v(r_0+r)]^2> \qquad (1)$$

For locally stationary Kolmogorov turbulence

$$D_v(r)=C_v\varepsilon^{2/3}r^{2/3} \qquad (2)$$

where $C_v \approx 2$ is the Kolmogorov constant and $\varepsilon[m^2/s^3]$ is the energy dissipation rate. The average of this estimate over two intervals (1-2 km and 3-4 km) are shown in Fig. 4, as well as the theoretical prediction Eq. (2) with ε determined by the measured structure function at r=240m. The estimated structure function is below the Kolmogorov theory for small separation, which indicates the effects of the spatial averaging of the velocity field by the laser pulse. For large separation the structure function becomes a constant. There is a small region between these two regimes where the Kolmogorov model Eq. (2) is reasonably correct which is consistent with measurements along a horizontal path.

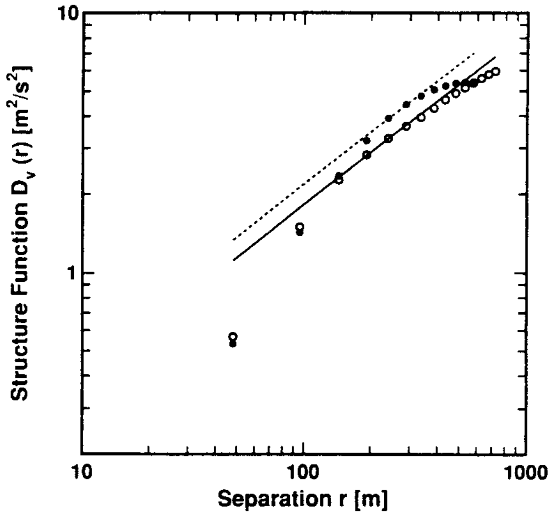

Fig. 4. Estimates of the velocity structure function Eq. (1) averaged over the range interval 1-2 km (o) and 4-5 km (●) using the ML estimator with 10 accumulated pulses (see Fig. 2). The predictions of Eq. (2) using the structure function estimate at a separation of 240 m is indicated by (———) for ε=0.00869m^2/s^3 and (· · ·) for ε=0.0114m^2/s^3.

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