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GROUND-BASED LIDAR WIND MEASUREMENT WITH THE EDGE TECHNIQUE

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The edge technique [1] is a powerful new method that can be used for a wide range of wind measurements. These include high spatial resolution, high accuracy ground and airborne measurements as well as spaceborne wind measurements. Ground and airborne measurements can be made with a spatial resolution as high as 20 m and an accuracy as high as 15 cm/sec. We are developing a ground based wind lidar to demonstrate the capabilities of the edge technique to make these high accuracy, high spatial resolution wind measurements. A scanning lidar with this capability would provide valuable information for studies of turbulent processes in the boundary layer and lower troposphere. It could also be used for high sensitivity detection of wind shear and microbursts in the vicinity of airports. The edge technique can also be applied to the problem of global wind measurement from a spaceborne platform with a vertical resolution of 1 km and accuracies of 1 m/sec. Such a system could make eyesafe wind measurements utilizing well developed diode pumped solid state laser technology at 1.06 μm. Multi-pulse averaging would be used to provide a spatially representative measurement of the wind.

In the edge technique, the laser frequency is located on the steep edge of a high spectral resolution optical filter. Very small frequency shifts cause large changes in measured signal as a result of the steep slope of the edge filter. Figure 1 is a diagram of the ground based wind lidar. The transmitter is an injection seeded Nd:YAG laser with a stretched cavity which yields 15 ns transform limited (35 MHz) pulses of 0.8 J at 10 Hz. The edge filter is a high resolution Fabry Perot etalon which has a

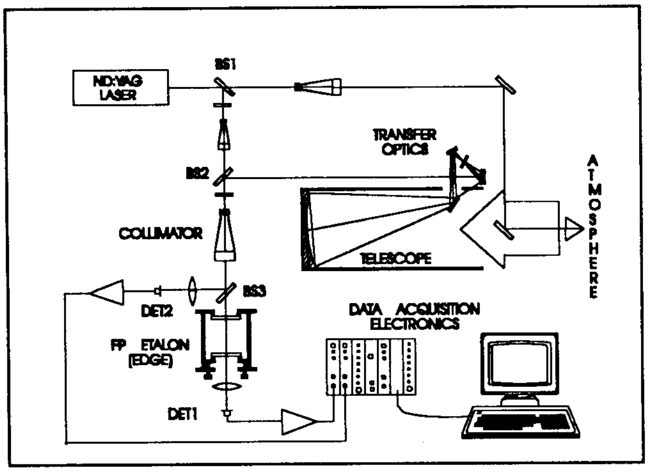

Figure 1 - Block diagram of the optical layout for a lidar using the edge technique.

resolution (FWHH) of 0.0033 cm^{-1}. The outgoing laser frequency is determined by measuring its location on the edge of the filter. This is done by sending a small portion of the outgoing beam to the edge detection setup (Figure 1) where the light is split into an edge filter and an energy monitor channel. The energy monitor signal normalizes the edge filter signal for amplitude. The laser return backscattered from the atmosphere is collected by a 40 cm diameter telescope and directed through the edge detection setup to determine its frequency in a similar manner for each range element. The Doppler shift, and thus the wind, is determined from a differential measurement of the frequency of the outgoing laser pulse and the frequency of the laser return backscattered from the atmosphere.

The differential frequency technique used to measure the Doppler shift renders the measurement insensitive to laser and filter frequency jitter and drift. The Doppler shift can be measured to an accuracy that is of the order of 100 times better than the spectral bandwidth of the measurement. The edge measurement is also insensitive to the spectral width of the laser provided the width is smaller than the half-width of the edge filter. We have demonstrated these characteristics with laboratory measurements at an accuracy level of 10 cm/sec [2]. The relatively broad laser spectral width that can be used with the edge technique permits a proportionately shorter (100 times) transform limited temporal pulse width and a corresponding improvement in spatial (vertical) resolution. A lidar system utilizing the edge technique in the visible or near infrared would obtain orders of magnitude larger signal than in the thermal infrared. At ultraviolet wavelengths, the Rayleigh backscatter would provide an even larger signal.

We have simulated the performance of our ground based wind lidar system operating at 1.06 μm using high efficiency silicon avalanche photodiode detectors with a quantum efficiency of 40 %. The central fringe of the Fabry-Perot etalon is used as a high resolution edge filter to measure the shift of the aerosol return. The edge technique does not require a spectral scan since the edge filter is used as a static spectral filter which allows the laser energy to be located on that portion of the edge which has high sensitivity to the Doppler shift. The sensitivity is the fractional change in the normalized edge signal for a velocity of 1 m/sec. For an etalon with a spectral width of 0.0033 cm^{-1} (FWHH) at 1.06 μm, the sensitivity is 4% per m/sec at the etalon half-width. Thus, a 1% measurement of the normalized edge filter signal corresponds to a velocity accuracy of 25 cm/sec. The error ϵ in the line of sight wind velocity at a given position on the edge can be found from the sensitivity, Θ, and the signal to noise for the differential edge measurement, S/N, as $\epsilon = 1/(S/N \times \Theta)$.

Figure 2 shows simulations of measurement accuracy for the horizontal component of the wind in the troposphere and lower stratosphere. The backscattered atmospheric signals are calculated for the ground-based lidar system at 1.06 μm with an elevation angle of 50 degrees, a pulse energy of 0.8 J, a 0.4 m diameter telescope, and an etalon with a spectral width of 0.0033 cm^{-1} (FWHH). The simulations are for a linear scale clear air aerosol model which has a backscatter which is intermediate between the AFGL clear air aerosol model and the GLOBE northern hemisphere backscatter data. The velocity errors are shown for measurements with the Doppler shifted laser frequency located on the edge at 0.5, 1.0, and 2.0 etalon half widths (HWHH) from the center of the etalon fringe. For a vertical resolution of 100 m and a 100 shot average, an accuracy of better than 0.5

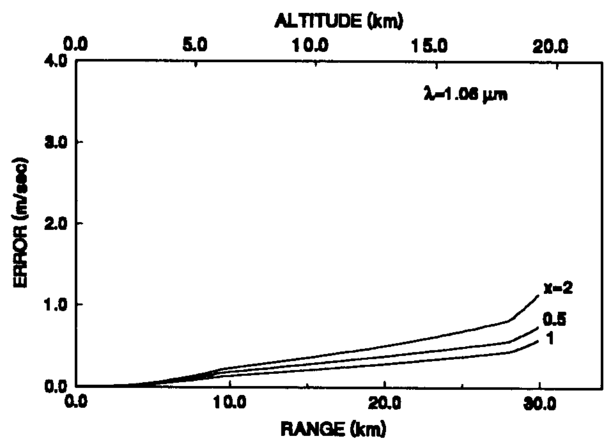

Figure 2 - Errors in the wind velocity at 1.06 μm for a 100 m spatial resolution and a 100 shot average for the laser frequency located on the edge of an etalon fringe with a width of 0.0033 cm^{-1}.

m/sec is obtained for a measurement near the half-width.

Figure 3 shows simulations of high spatial resolution measurements of the vertical component of the wind in the boundary layer. For a vertical resolution of 20 m and a 2 shot average, an accuracy of better than 15 cm/sec is obtained for a measurement near the half-width.

The wind lidar system will be described with most recent results.

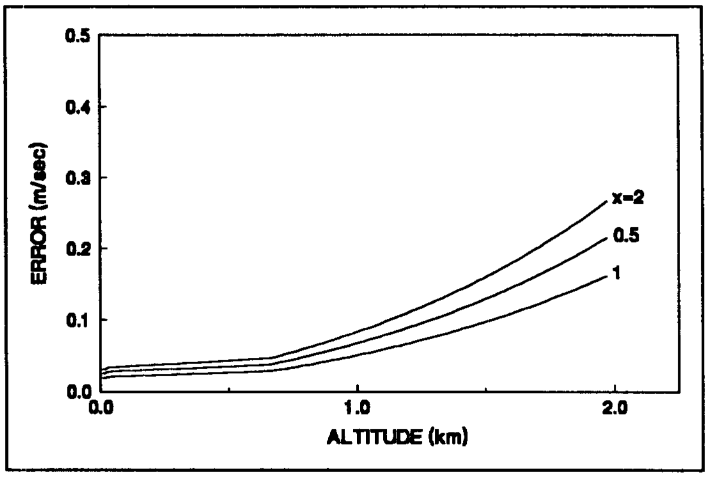

Figure 3 - Errors in the vertical wind velocity at 1.06 μm for a 20 m spatial resolution and a 2 shot average for the laser frequency located on the edge of an etalon fringe with a width of 0.0033 cm^{-1}.

REFERENCES

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