On mean wind and turbulence profile measurements from ground-based wind lidars

limitations in time and space resolution with continuous wave and pulsed lidar systems - a review

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On mean wind and turbulence profile measurements from ground-based wind lidars: limitations in time and space resolution with continuous wave and pulsed lidar systems - a review

P.O. 171

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Abstract summary

Two principal different coherent laser Doppler wind lidar anemometers have recently become available to the wind energy industry for ground-based vertical mean wind and turbulence measurements:

1) continuous wave (cw) wind lidar's, and

2) pulsed wind lidar.

Although build on recent communication technology 1.55 telecom fibre technology, some principal differences emerge regarding their temporal and spatial resolution capabilities for atmospheric boundary layer wind and wind energy assessment studies.

Objectives

A review of these two systems fundamental special and temporal resolution characteristics is therefore fundamental for interpretation of lidar measured mean wind, mean shear and turbulence profiles in the surface layer.

An inter-comparison of the specific sounding volume characteristics is considered for two commercial available wind lidar systems:

I) A cw wind lidar ZephIR (National Power U.K.)

II) A pulsed wind lidar WindCube (Leosphere, Fr.)Risø DTU has

Methods

Continuous wave (cw) lidar:

The spatial resolution of wind measurements obtained with an ideal cw lidar has been investigated by several independent authors, among others: Sonnenschein and Horrigan (1971) [1], Lawrence et al. (19 72) [2] and Smalikho (1995) [3]. The lidars radial weighting function is determined by the transmitted radiation intensity along the beam axis z'. For Gaussian beams this function can be approximated by a standard Lorentz distribution function

$$Q_{S\,cw}(z'') = \frac{1}{\pi}\frac{z_R}{z_R^2 + (z'')^2} \qquad (1)$$

where $z'' = z' - R$ is the relative distance to the range *R*, and z_R denotes the Rayleigh length defined by $z_R = \lambda/\pi\, R^2/a_0^2$. Here, a_0 is the radius where the intensity has dropped to a value and the wavelength. The quantity denotes the optical systems focal depth and also the cw lidar's Full Width Half Maximum: $FWHM_{CW\,Lidar} = 2\,z_R$

Pulsed lidar system:

In a pulsed wind lidar the Doppler signal is generated from individually transmitted pulses and the sounding volume is therefore determined by the spatial extent of the transmitted pulse and the distance the pulse travels by the speed of light *c* during the range gates sampling time [4]. The pulsed lidar spatial resolution is derived e.g. by Banakh and Smalikho (1997): [4] To second order accuracy a pulsed coherent lidar's radial wind velocity estimate is determined from a convolution of the transmitted laser pulse intensity function with the sampling time gate window , viz.:

$$V_{Pulsed\,Lidar} = \int_{-\infty}^{\infty} dt\;\; P_T(t)\frac{1}{\tau}\int_{-\tau/2}^{\tau/2} dt'\, V_r\left[R + \frac{c}{2}(t + t')\right] \qquad (2)$$

R is the range to the center of the sampling gate and $V_r\,[ms^{-1}]$ is the instantaneous radial wind speed. A Gaussian shaped sounding pulse is assumed for the transmitted laser pulse

$P_T(t) = \frac{1}{\sqrt{\pi\sigma_{e^{-1}}}} e^{-t^2/\sigma_{e^{-1}}^2}$ where $\sigma_{e^{-1}} = t_p$ is the pulse duration in time [s] so that $\Delta r \sim 2t_p c$ is the pulse width in space and t_p is defined via $P_T(t_P/P_T(0) = e^{-1}$. Inserting in Eqs (2) and evaluating the integral leads to $< V_{Pulsed\,Lidar} > \; = \; \int_{-\infty}^{\infty} dz'\; Q_S(z')V_r(r')$

where $$Q_{S_{Pulsed\,Lidar}}(z') = \frac{1}{\tau c}\left[Erf\left(\frac{2}{ct_p}(z' - R) + \frac{\tau}{2t_p}\right) - \; Erf\left(\frac{2}{ct_p}(z' - R) - \frac{\tau}{2t_p}\right)\right]$$

is the function that describes the radial resolution of the sounding volume. By defining the radial width of the sounding volume: $\Delta z \; = \; \int_{-\infty}^{\infty} dz'\;\; Q_S(z')/Q_S(R) = Q_S^{-1}(R)$ the pulsed lidars effective radial sounding volume is given by

$$\Delta z = \frac{c\tau}{2}\Big/ Erf(\tau/2t_p) \qquad (3)$$

i.e. an expression that encompasses both the effect of the pulse length and the effective distance the pulse probes during the gate sampling time. The corresponding Full Width Half Maximum for the pulsed lidar can be calculated to be: $FWHM_{Pulsed\,Lidar} = 0.95\,\Delta z$

ZephIR and WindCube parameters

The Rayleigh length of a standard ZephIR have previous been estimated to be ~ 8.5 m (Harris et al. 2006) at the 100 m range. The corresponding effective aperture radius of the ZephIR's 3" telescope of 200 mm focal length is = 24 mm. For a range of 100 m, the FWHM ZephIR @ 100 m is [5] ~17.0 m. At 150 m range, the radial size of the sounding volume have been estimated to be: FWHM ZephIR @ 150 m is ~38.5 m.

A WindCube's range resolution is constant at all ranges. The intensity as function of time of the transmitted pulse approximately Gaussian shaped with a FWHM ~200 ns (i.e. 60 m long pulses). The corresponding pulse time parameter can then be estimated to be ~120 ns. As a WindCube's sampling time per range gate is preset to 200 ns its overall effective radial sounding length becomes from Eqs. (3): $FWHM_{WindCube} = 37.5\,\text{m}$

Results

Comparison of a ZephIR and a WindCube's radial sounding resolution at range R =150 m:

Both lidar's Full Width Half Maximum are equal and about 37- 38 meters at this range, but their spatial weighting distributions is sees to be quite different.

The stippled and narrower red curve represent the ZephIR at 100 m range.

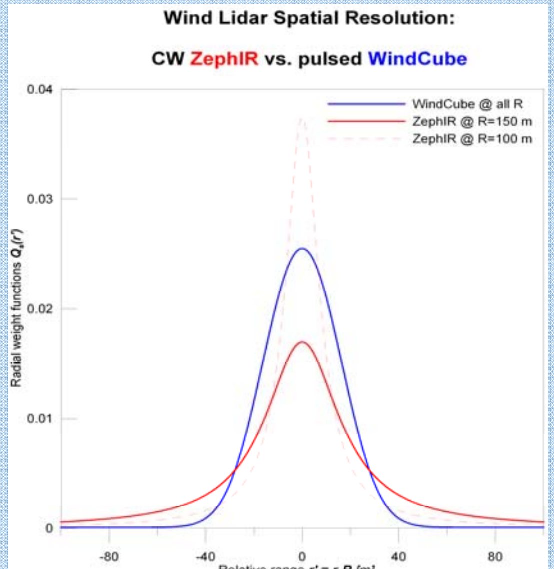

Fig. 1

ZephIR and WindCube radial wind speed weight functions calculated at range 150 m.

Conclusions

The cw and pulsed lidar have very different spatial range resolution properties. This circumstance must seriously be considered and taken into account when mean , shear and turbulence properties in the atmosphere are measured with these remote sensing devises.

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