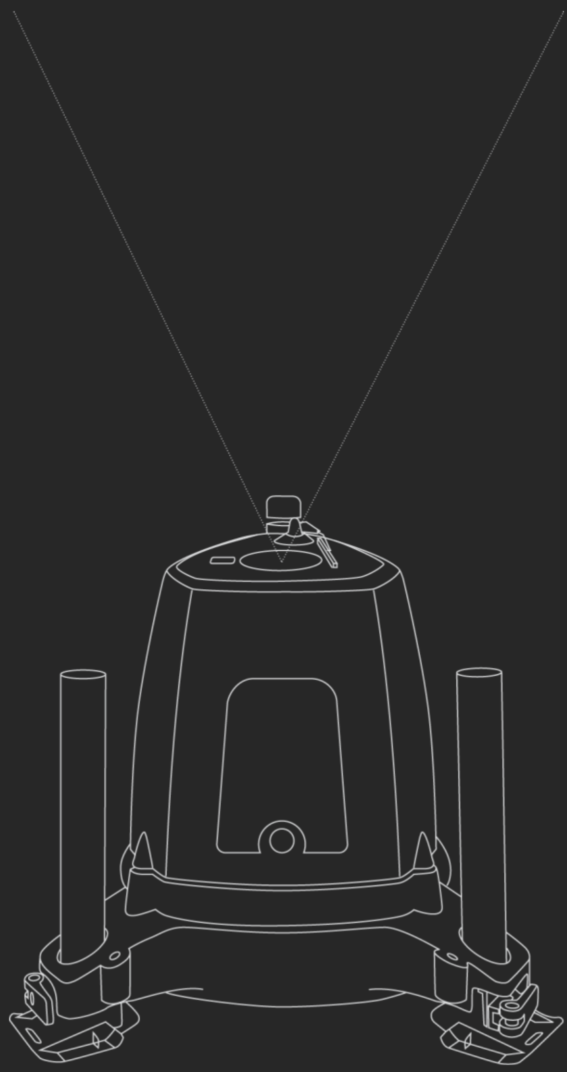
ZephIR Lidar
wind speed at light speed

ZEPHIR SENSITIVITY

IN CLEAR AIR, LOW TEMPERATURES, AND HIGH LATITUDES

V1.04



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May 2nd 2014

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1 INTRODUCTION

The increasing number of ZephIR deployments in more extreme environments provides the means to demonstrate Z300's ability to retain high availability in very cold conditions and in extremely clear atmospheres. This report covers the theoretical limits of CW lidar sensitivity with range, and aerosol concentration and presents results from a long (>12 months) continuous Z300 campaign at high latitude exhibiting extremes in temperature and air clarity.

2 VARIATION OF SENSITIVITY WITH RANGE

ZephIR's uniformly high sensitivity in trials can be studied by theoretical analysis. This topic has been analysed in detail since the earliest days of wind lidar, and the following conclusions are well established by many subsequent studies and experiments. In the earliest analysis [1], the sensitivity is characterised by the signal-to-noise ratio (S/N), and both CW and pulsed lidars have been analysed for the case of a uniformly scattering infinite atmosphere. This forms a very close approximation to typical conditions for wind measurement.

Figure 1 below (adapted from [1]) shows the variation of S/N with focus location for a focused CW lidar system. ZephIR operates in a regime close to the left hand side of this plot, giving virtually no change in S/N from its minimum to maximum range.

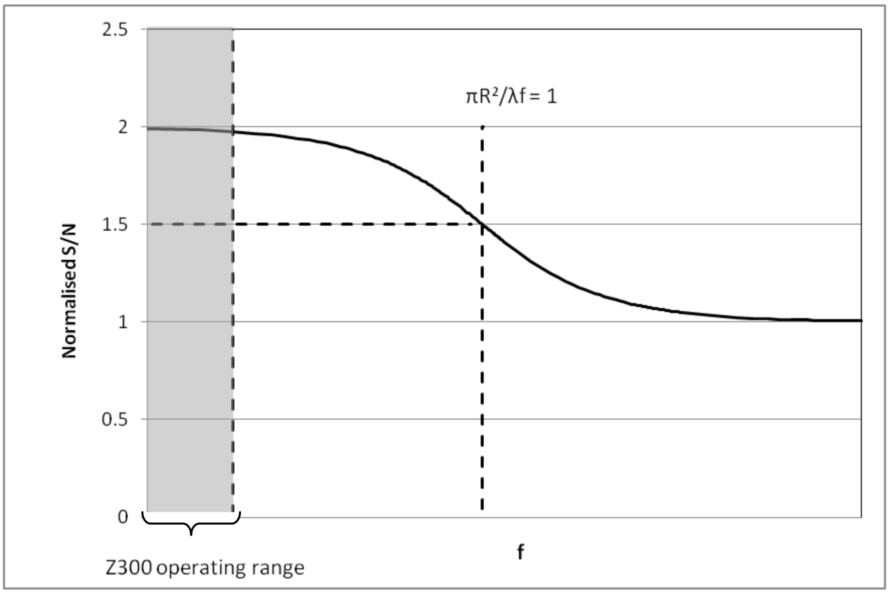

Figure 1: Variation of S/N with location of focus for CW system and an infinite scatterer

The corresponding plot (Figure 2, adapted from [1]) for pulsed lidar is shown below, indicating the variation of S/N as the focus position is varied. In practice pulsed systems operate at a fixed focal distance, so that the S/N peaks at this chosen range, dropping as the range moves away on either side.

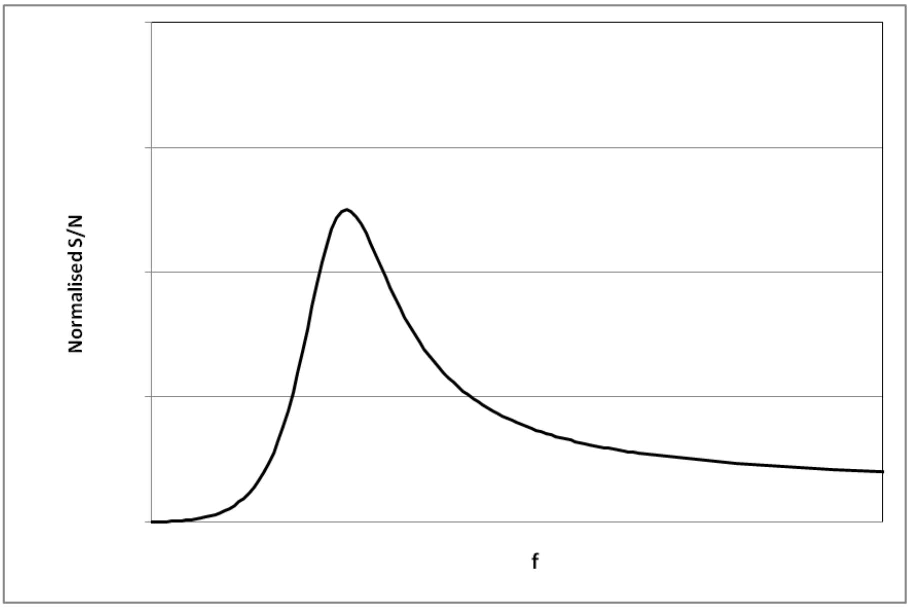

Figure 2: Variation of S/N with location of focus for Pulsed system

3 VARIATION OF SENSITIVITY WITH AEROSOL CONCENTRATION

A detailed discussion of sensitivity relative to aerosol concentration can be found in [2] for continuous wave coherent lidar. The relationship between the transmitted power (P_T) and returned power (P_S) backscattered from aerosols, can be closely approximated by:

$$P_S = \pi P_T \beta(\pi) \lambda$$

Where λ is the laser wavelength and $\beta(\pi)$ is the backscatter coefficient, which is a measure of the aerosol concentration. Note that to this order, the relationship is independent of range. From the configuration of a Z300, assuming a transmitted intensity of 1 W and a 20ms integration time, it is possible to derive a minimum $\beta(\pi) \sim 10^{-9}$ (m sr)$^{-1}$ necessary for ZephIR operation. This value is shown in the next section to be at the lower limit of naturally occurring aerosol concentrations in the boundary layer.

4 ZEPHIR AVAILABILITY IN HIGH LATITUDE

A long (>12 months) and continuous data set from a Z300 deployed at high latitude (60° N) in Scandinavia was analysed for low temperatures and aerosol concentrations. ZephIR availability was calculated as the percentage of valid 10-minute wind speeds measurements relative to the total 10-minute measurements returned by the ZephIR at each height. The ZephIR's internal algorithms perform quality checks on the data and flag each measurement as valid or invalid. The deployment covers dates December 2011 to February 2013. ZephIR data availability shows no significant variation with time of year (Figure 3).

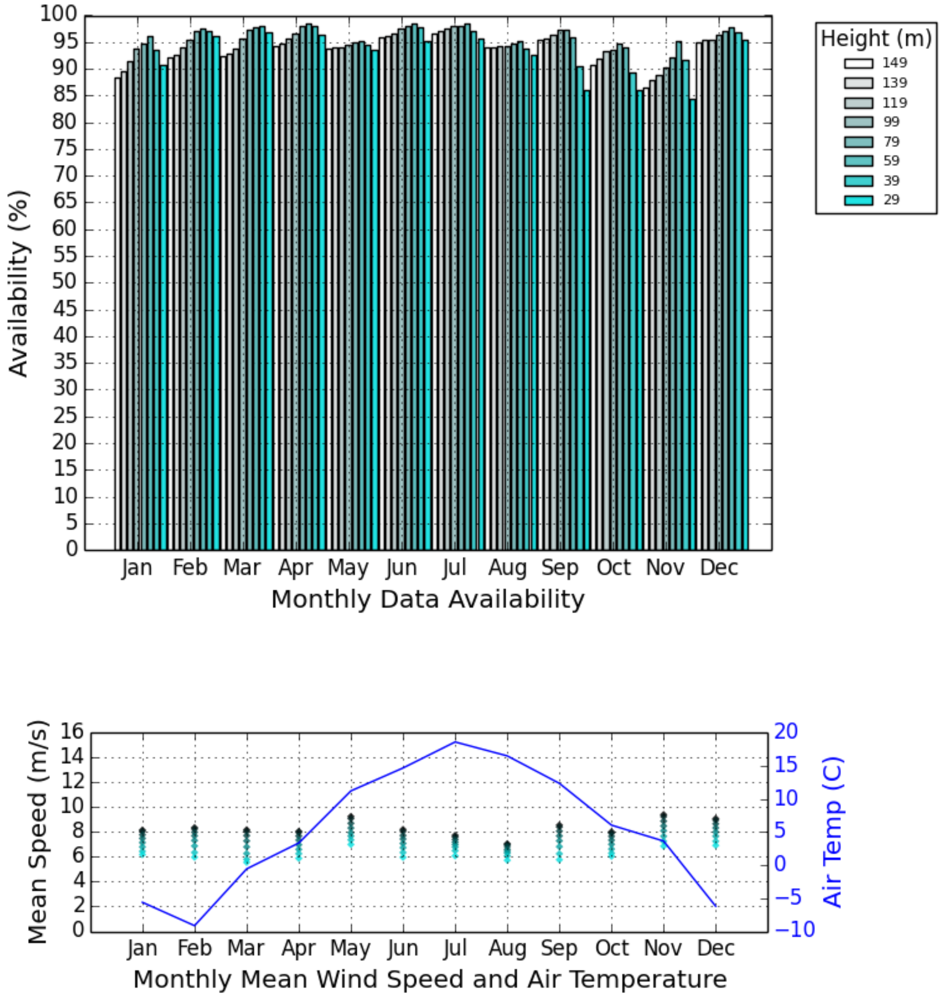

Figure 3: Upper panel: Monthly data availability
Lower panel: Monthly mean wind speed and temperature

4.1 Sensitivity vs Temperature

Z300s are rated down to -40 °C (thermal jacket is advised below -25 °C). The ZephIR actively manages the internal temperature of the system to ensure that essential components are fully functional and therefore operating correctly. ZephIR availability for the high latitude deployment binned by ambient temperature (Figure 4) remained very high (>90%) at all heights for below freezing temperatures and shows no strong variations across the full range of temperatures.

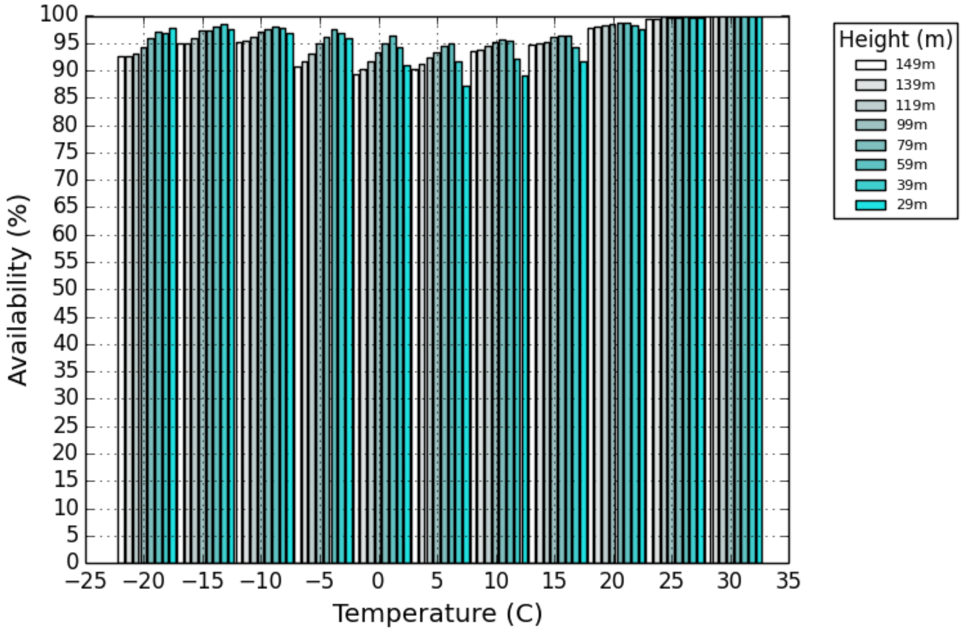

Figure 4: Availability vs temperature

Very cold atmospheres are often associated with low aerosol concentration because airborne water molecules (one of the main aerosols responsible for backscattering the ZephIR emitted signal) will be frozen out of the air. ZephIR operation in low aerosol density environments is covered in the next section.

4.2 Sensitivity vs Low Aerosol Concentration

ZephIR data can provide a measure of aerosol concentration via a backscatter parameter. The estimated minimum required backscatter [2] is $\beta(\pi) \sim 10^{-9}$ (m sr)$^{-1}$, or, in terms of the units returned by ZephIR, $\beta(\pi) \sim 7\text{x}10^{-4}$ (1.3e-6 m sr)$^{-1}$. Data availability binned by backscatter levels (Figure 5) show no significant variation with aerosol concentration. Data availability remains very high (>90%) at all heights, even for the lowest recordable levels. The variations in availability shown in Figure 5 are caused by other quality control filters applied automatically to the data.

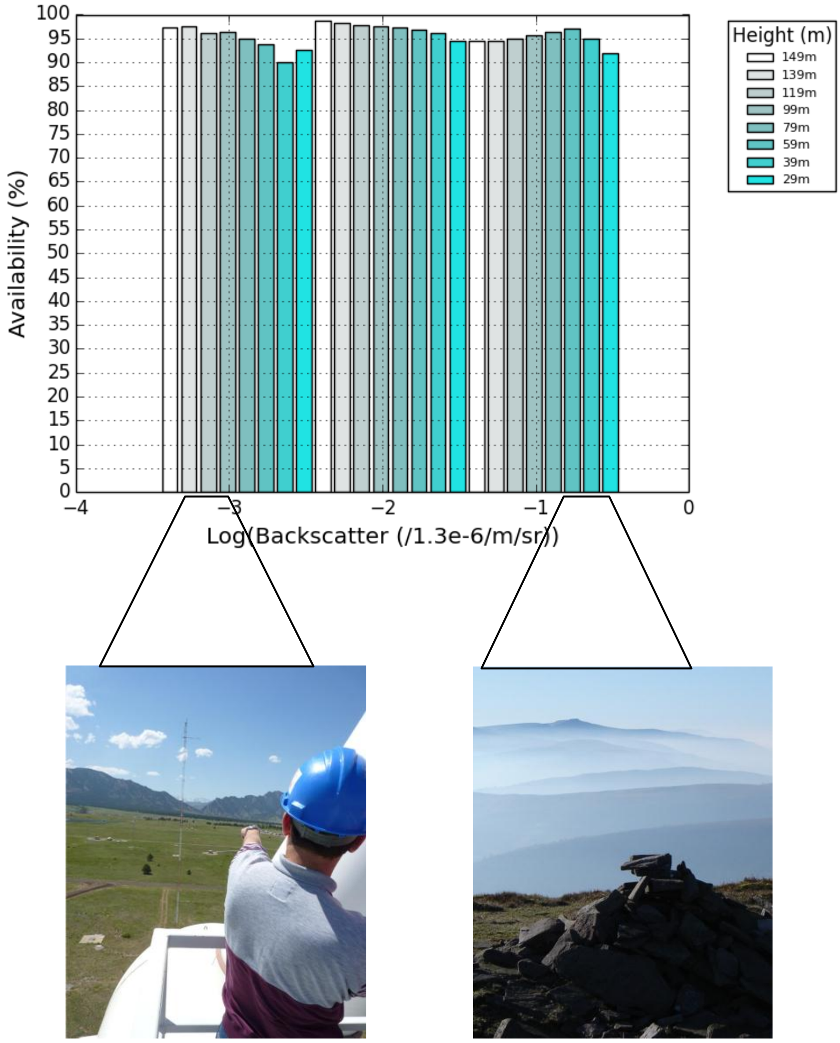

Figure 5: Availability vs backscatter. Availability at all heights is reported for each of three backscatter bins. Photos are shown as reference to give an indication of air quality for variation backscatter bin.

5 REFERENCES

[1] "Signal-to-noise relationships for coaxial systems that heterodyne backscatter from the atmosphere", C M Sonnenschein & F A Horrigan, Applied Optics Vol. **10**, No. 7, 1600-1604 (1971)

[2] "Introduction to continuous-wave Doppler lidar", M. Harris, *Remote Sensing for Wind Energy*, A. Peña and C. B. Hasager (Eds), Risø DTU, (2010)