EPJ Web of Conferences **176**, 06009 (2018) https://doi.org/10.1051/epjconf/201817606009
ILRC 28

LIDAR FOR WIND AND OPTICAL TURBULENCE PROFILING

Shlomo Fastig[1]*, Omer Porat[1], Abraham Englander[1]

Detlev Sprung[2], Karin U. Stein[2], Erik Sucher[2]

*1 SOREQ NRC, Israel, *fshlomo@soreq.gov.il*

2 Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

ABSTRACT

A field campaign for the comparison investigation of systems to measure wind and optical turbulence profiles was conducted in northern Germany. The experimental effort was to compare the performance of the LIDAR, SODAR-RASS and ultrasonic anemometers for the measurement of the above mentioned atmospheric parameters. Soreq's LIDAR is a fiber laser based system demonstrator for the vertical profiling of the wind and turbulence, based on the correlation of aerosol density variations. It provides measurements up to 350m with 20m resolution.

1 INTRODUCTION

Wind and turbulence height profiles data are needed for different applications: meteorology, wind energy, atmospheric model verification, aviation safety, air pollution etc.

The Atmospheric Sensing group at Soreq NRC had developed for many years techniques and systems for the remote sensing of wind turbulence and atmospheric optical refraction [1-2]. Active, laser-based systems [3] and passive technique based on video camera measurement of naturally illuminated scene [4] were developed for the measurement of the path-average crosswind and atmospheric turbulence. These techniques utilize the spatial-temporal fluctuations of light caused by the passage through the turbulent atmosphere, in order to estimate the path-average atmospheric parameters.

Wind profile measurements with LIDARs are based on transmitting short laser pulses and measuring the aerosol backscattered light. Using the time-of flight method the range resolved profiles are derived.

Doppler wind LIDARs use the frequency shift of the scattered light to derive the radial wind component. In order to measure the transverse wind components, the LIDAR beam must be scanned or transmit multiple laser beams.

Correlation wind LIDAR, are based on the measurement of the aerosol density variations. A train of laser pulses is transmitted to the atmosphere at a frequency high enough (hundreds of Hz), to match the atmospheric coherence. The measured fluctuations in the backscattered light signal from the aerosols, enables the calculation of the wind and turbulence.

This paper briefly presents the LIDAR demonstrator which was developed in Soreq and deployed for a multi-sensor comparison experiment conducted in northern Germany in collaboration with Fraunhofer IOSB [5].

2 LIDAR FOR WIND AND TURBULANCE PROFILING

Soreq's wind LIDAR is a concept demonstrator which was designed based on the following principles:

- Configuration which provides maximum working range.
- Provides measurement of the spatial-temporal variations on the imaged spot of the laser.

2.1 System Configuration

The LIDAR is constructed co-axially so that the lines of sight of the receiver and the transmitter are parallel (Figure 1). In this configuration the optical signal scattered from any distance reaches the receiver, the minimum range is determined from the forward blocking by the transmitter and the maximum range is determined from the minimum signal to noise ratio of the detector. In order to increase the working range the image plane of the receiver is fixed around the maximum range.

The receiver is composed of a $F_{\#}=5$, f=773mm Maksutov telescope. The tip of a bundle of three optical fibers is placed at the image plane of the receiver. The fibers are arranged to form a triangle and each is connected to a Si APD detector. This configuration acts as a 2D array of detectors that measure the spatial-temporal variations of the laser returns, thus enabling 2D wind vector calculation.

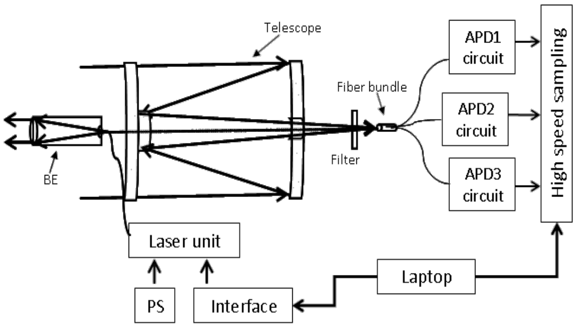


Figure 1 Block diagram of the wind LIDAR

The transmitter is a pulsed fiber laser manufactured by Raycus, transmitting 1.064µm pulses at 20 kHz repetition rate and 100nsec pulse width. The beam divergence is adjusted with a beam expander to about two-thirds of the entire field of view of the receiver (~700µRad).

The electronic signals which are created by the three detectors are sampled by a high speed digitizer – the PicoScope 5000 – at 12bit depth. The data are transferred to a laptop computer for processing. Data downloading time determines the measurement rate of the LIDAR.
The LIDAR is operated using a laptop computer which initiates the measurement procedure, synchronizes between the transmitter and the receiver and carries out data download and analysis.

Finally, a scope and a video camera are installed parallel to the laser line of sight to assist with LIDAR aiming and safe operation.

A picture of the LIDAR aimed horizontally is presented in Figure 2 and key parameters of the LIDAR demonstrator are provided in Table 1.

Table 1 Key parameters of the LIDAR

Parameter	Value	Parameter	Value
Wavelength	1.064µm	Receiver FOV	700µrad
PRF	20kHz	Operation range	50-350m
Output power	20W	Range resolution	15-20m
Pulse width	100nsec	Measurement duration	1.5sec
Beam divergence	300-500µrad	Measurement rate	1-5mins

Figure 2 The wind and turbulence profiling LIDAR

2.2 Method

The wind range profile is derived using the aerosol in the atmosphere as an extended target. The back scattered laser light measured from a range r, is used to calculate the temporal cross-correlation function between the detectors from which wind speed can be derived. The back scattered signal characteristic can either have large peaks, short duration and be sparse in time, or have small peaks with a smooth transition in time, depending on the atmospheric conditions. We believe the first case is typical for large and low density aerosols (upper graph in Figure 3), while the second one is typical for small, high density aerosols (bottom graph in Figure 3). According to the scattering type the dominant frequency of the intensity fluctuations is measured using the number of zero crossings technique [1]. This value is averaged over the three detectors, from which the wind speed is calculated.

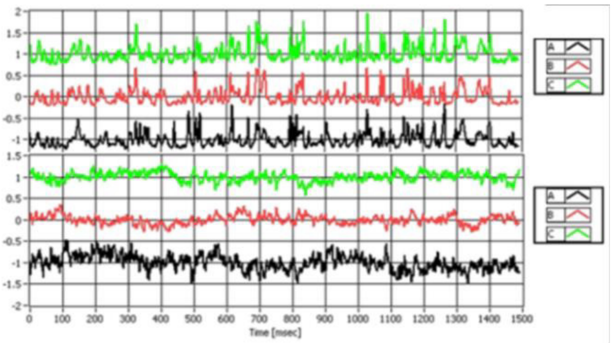


Figure 3 A series of 1500 returning pulses from one range slice as measured by the three detectors (labeled A, B and C) in the LIDAR (intensity is normalized to the series average and detector are shifted to provide clearer view). Top – data recorded in northern Germany: short large peaks, cross-correlation is clearly evident. Bottom – data recorded in central Israel: the intensity fluctuations show small peaks with smooth transition in time.

The transverse wind direction is estimated using the cross-correlation function of the intensity fluctuations measured by the detectors. For each pair of detectors the cross-correlation function is calculated (Figure 4) and the location of the peak of the correlation is determined. The ratio between the movements of the correlation function (the location of the peak) of different pairs of detector is proportional to the ratio of the wind components along the pairs. Thus, using all three pairs the transverse wind direction is given by:

$$\alpha = artan\left(\frac{3\sqrt{3}}{2}\cdot\frac{\frac{CC_{BC}}{CC_{AC}}+1}{1-\frac{CC_{BC}}{CC_{AC}}-2\cdot\frac{CC_{AB}}{CC_{AC}}}\right) \quad (1)$$

Where CC_{ij} is the location of the peak of the cross-correlation function of detectors i and j.

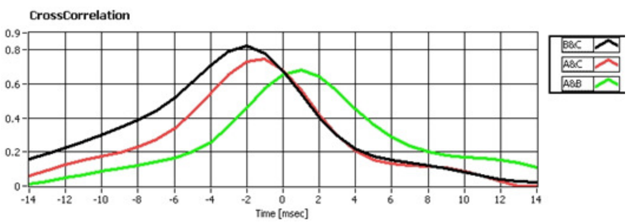


Figure 4 Temporal cross-correlation function between signals in adjacent detectors measured in a single range slice. Using the ratio between the locations of the peak of different pairs the wind direction is estimated.

The turbulence strength is calculated from the temporal variance of the intensity of the signal of each of the detectors measured over one pulse burst (1.5 secs).

The transverse wind speed and direction and the turbulence strength are calculated, as detailed above, for each available range slice to provide a range profile.

3 RESULTS

3.1 Experiment Site

The experiment took place in a area which is part of the German Federal Armed Forces Technical Center (WTD 91) near the city of Meppen (Figure 5). It is the location of the Vertical Turbulence Measurement (VerTurM) experiment – a long term study of the profiles of optical turbulence and meteorological parameters performed by Fraunhofer IOSB [7].

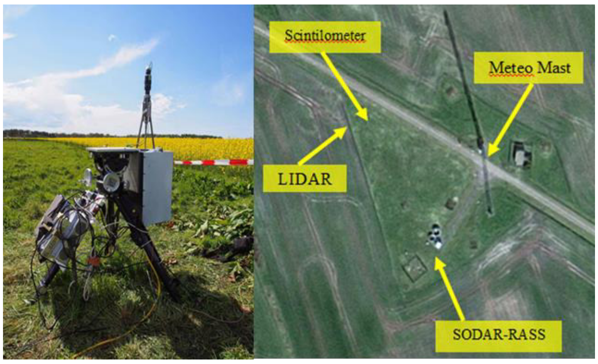
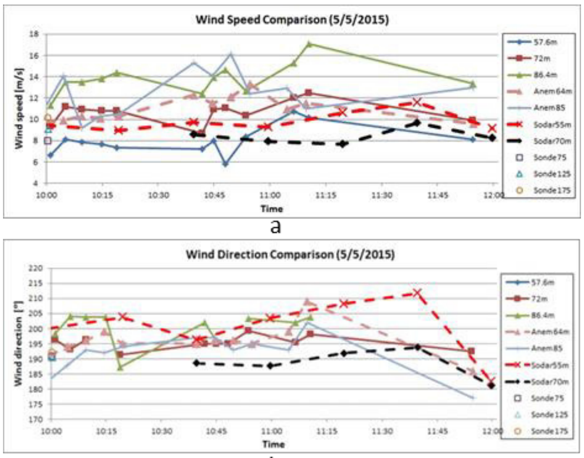


Figure 5 Setup of the field experiment in Germany: right – aerial photo of the site, left – Soreq's LIDAR during measurements in the site

3.2 Comparative Measurements

The measurements of vertical profiles of the wind and the optical turbulence are shown in Figures 5-7. These include the data collected on May 5th using the anemometers, scintillometer, SDAR-RASS, radiosondes and the LIDAR. The LIDAR measurements were calibrated using a reference measurement at 64m height. Generally the fit between the LIDAR and the other system for wind speed and turbulence strength is quite good at certain periods of time (around 10:00, 10:45, 12:00) within ±1.5m/s and not as good at other periods time when the LIDAR indicates stronger wind (+4-6m/s). This could be explained by the difference in the integration time of the instruments. While for the LIDAR measurement it is of the order of 1sec and thus more sensitive to wind gusts, the other instruments average over a few minutes time thus smoothing out gust effect. The wind direction fits better during the entire measurement period within ±5^0.



a

b

Figure 5 Comparison of the vertical transverse wind speed profile (a) and direction (b), as measured on May 5th by the LIDAR (solid lines) and the VerTurM instruments (annemometers, SODAR-RASS and radiosonde at 10:00, broken lines).

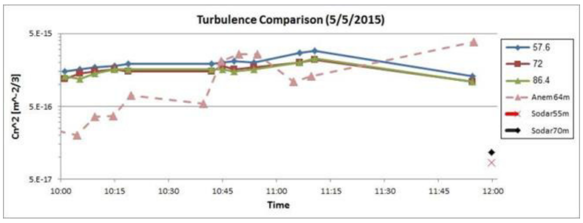


Figure 6 Comparison of the optical turbulence profile as measured on May 5th by the LIDAR (solid lines) and the VerTurM instruments (annemometers, SODAR-RASS at 12:00, broken lines).

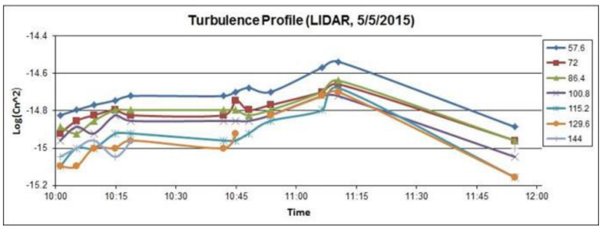


Figure 7 Optical turbulence vertical profiles as measured by the LIDAR on May 5th up to 144m.

4 CONCLUSIONS

A 3-day field experiment for comparison of the LIDAR measurements with commercially available reference systems was held in northern Germany in May 2015. The LIDAR was deployed in the site of the vertical turbulence measurement experiment (VerTurM) which comprises a SODAR-RASS, meteorological mast, scintillometer and etc. and a long-term data collection system.

Due to bad weather conditions which included fast meteorological changes from clear sun shine sky to heavy clouds, strong gusts and intense shower rains, the collected data was insufficient for a more quantitative conclusion. However, the data from two relatively calm morning measurements indicate reasonable fit, for the wind speed and the optical turbulence measurements and good fit for wind direction. Additional field experiments are required in order to fully evaluate the performance of the LIDAR at various conditions particularly at times of variable wind.

References

[1] J. Shapira, O. Porat, M. Livneh, Z. Wies, D. Heflinger, Y. Glick, A. Engel (2010): Atmospheric cross-wind and turbulence measurements using turbulence –induced scintillations, *Laser Radar Technology and Applications XV*, Proceedings of the SPIE, Volume 7684, pp. 76841L-76841L-11.

[2] A. Engel, O. Porat, J. Shapira, A. Englander (2014): Experimental evaluation of optical crosswind measurement systems, *Remote Sensing of Clouds and the Atmosphere XIX; and Optics in Atmospheric Propagation and Adaptive Systems XVII*, Proceedings of the SPIE Volume 9242, pp.92421K.

[3] G. Machavariani, J. Shapira, U. Talmud, O. Porat, Sh. Fastig (2010): Remote qualitative profiling of the cross-wind flow with lidar, *Laser Radar Technology and Applications XV*, Proceedings of the SPIE, Volume 7684, pp. 76841M-76841M-9.

[4] O. Porat, J. Shapira (2010): Crosswind sensing from optical-turbulence-induced fluctuations measured by a video camera, *Applied Optics*, Volume 49, Issue 28, pp. 5236-5244.

[5] K. Steina , E. Suchera, D. Sprunga A. Englander, S. Fastig, O. Porat (2016): Instrumental intercomparison investigating Vertical profiles of optical turbulence and wind speed in the lower atmospheric boundary layer during frontal passages in northwestern, *Optics in Atmospheric Propagation and Adaptive Systems XIX*, SPIE Proceedings Vol. 10002