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AUTOMATED COMPACT EZ LIDARS FOR AEROSOL AND CLOUD TRACKING AND WIND PROFILING

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1. INTRODUCTION

Compact, robust, turn-key and eye-safe EZ LIDARS™ offer atmospheric researchers, operational meteorological networks and pollution agencies standardized tools which can be easily integrated on all-weather platform.
The EZ Aerosol LIDAR™ developed in a partnership with LSCE CEA/CNRS has been successfully employed in several dedicated campaigns, e.g. for pollution tracking during the LISAIR in May 2005 in Paris, France Sauvage (2005), African monsoon observations at the AMMA in January 2006 in Niamey, Niger Chazette (2006), as well as during validation campaigns against the AERONET sunphotometer in July 2005 and the SIRTA lidar in April 2006 both in Palaiseau, France Stachlewska (2006), and recently validated by instrumentation of the SGP ARM Site in Lamont, Oklahoma, USA.
The EZ Wind LIDAR™ an innovative pulsed coherent Doppler lidar prototype was developed in a partnership with the ONERA/DOTA and it is operated currently under the test and validation phase at CEA in Palaiseau, France Sauvage (2006).
In this paper both systems with respective data evaluation schemes are described and selected examples of recently obtained results are presented.

2. EZ Aerosol LIDAR™

The EZ Aerosol LIDAR™ (Fig.1) is a compact eye safe system dedicated to remote observations of highly resolved structures of tropospheric aerosols and clouds.
The system is based on 355nm Nd:Yag pulsed laser operating at 16mJ with 20Hz repetition rate. The conceptual simplicity of the lidar scheme ensures easy utilisation of the lidar during field campaigns even under tough conditions. This easy to transport system, is mounted in two temperature and humidity controlled modules (10kg+35kg). The design allows measurements at fixed location (zenith, at an angle, scanning) or from mobile platforms (car, aircraft, ship). The system can be controlled directly or remotely controlled via TCP-IP. Safety features as detectors protection, temperature and humidity control are assuring full control over the system.
The system in zenith-aiming automated operation is powerful enough to cover the range from full overlap (150m) up to the Tropopause level (15km) providing information on PBL structures and Cirrus clouds at the same time (Fig.2). The retrievals are obtained typically with 1.5m/1s resolution in PBL and 15m/30s above 5km.
The standard system is designed for easy upgradeability for 355nm cross polarisation detection enabling the information on shape of the particles, and detection of the water vapour detection at 408nm which will provide the mixing ratio profiles in PBL (up to 2km/10min integration).
Different types of deliverables are assessed from the measured level of the electrical signal using various dedicated automatic post-treatment algorithms.
As primary products calibrated raw lidar signal at 355nm [mV] and range and background corrected lidar signal [mVm^2] are obtained. As secondary products PBL height (Fig.3) [m], cloud base height [m], bottom and top of optically thin clouds [m], total and particle backscatter [$m^{-1}sr^{-1}$] and extinction [m^{-1}] coefficient profile, backscatter ratio profile (ratio of total-to-molecular backscatter profile), optical depth integrated over all lidar range and over distinct layers (PBL, residual layer, cloud).
The calculation of these deliverables is done automatically for each acquired signal which is an addition of lidar backscattered radiation, sky background radiation and electronic noise.
Hence, the first and essential step is to extract the actual lidar signal from the raw signal by applying various corrections: instrumental parameter, background offset, smoothing for signal-to-noise ratio improvement, range correction by multiplication with squared range vector, zenith angle correction, overlap correction.
The second step is a precise determination of valid data by checking each acquired signal for presence of detector saturation and clouds, and determination of the signal range restricted by the condition of the existence of the sufficient signal-to-noise ratio, which is set to a threshold value of 3 Kovalev and Eichinger (2004).

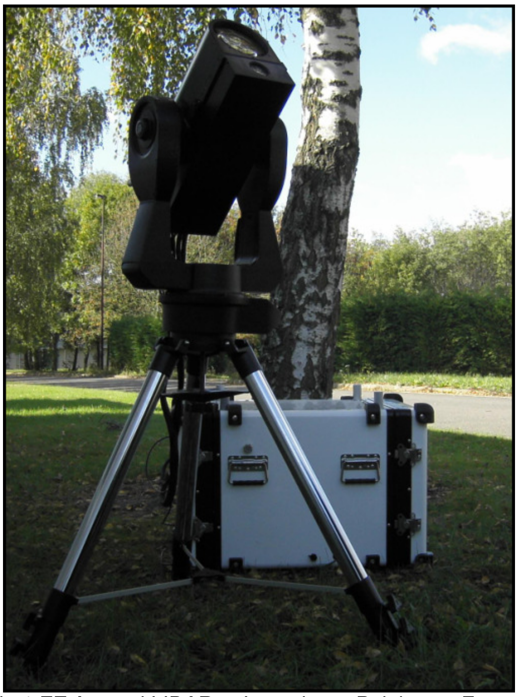

Fig.1 EZ Aerosol LIDAR at Leosphere, Palaiseau, France.

The third step is the data treatment for retrieval of the structural and optical parameters of atmospheric particles.
The characterization of the height of tropospheric aerosol and cloud structures is obtained using the threshold value of the range and background corrected lidar signal but can be also done using one of the three following methods: signal gradient method applied for the thick cloud detection, signal inflection point method applied mainly for the mixing height layer detection corresponding to the boundary layer, or signal logarithm gradient method applied for the residual boundary layer, the elevated decoupled aerosol layers and the thin Cirrus clouds detection. Determination of entrainment zone thickness at the top of the boundary layer can also be performed according to Flamant (1997).

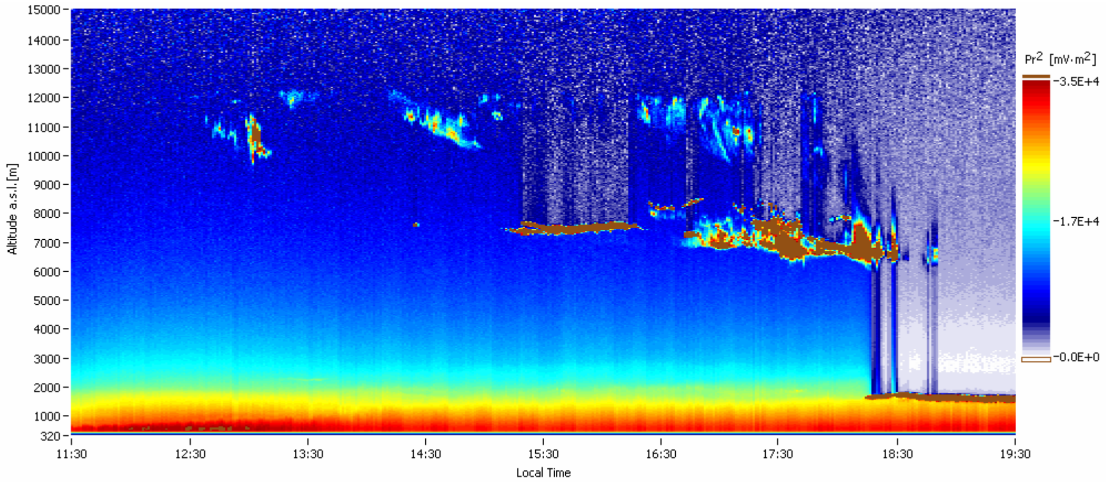

Fig.2 *Simultaneous observations of the boundary layer aerosol, Cumulus and Cirrus clouds at the special resolution of 1.5m and integration times of 30s acquired on 24th October 2006 during EZ Lidar Performance Validation IOP at the SGP ARM Site at Lamont, Oklahoma, USA. This measurement will be used for the extensive inter-comparison of EZ Lidar performance with the SGP ARM Site instrumentation (Micro Pulse Lidar, photometers, Raman Lidar).*

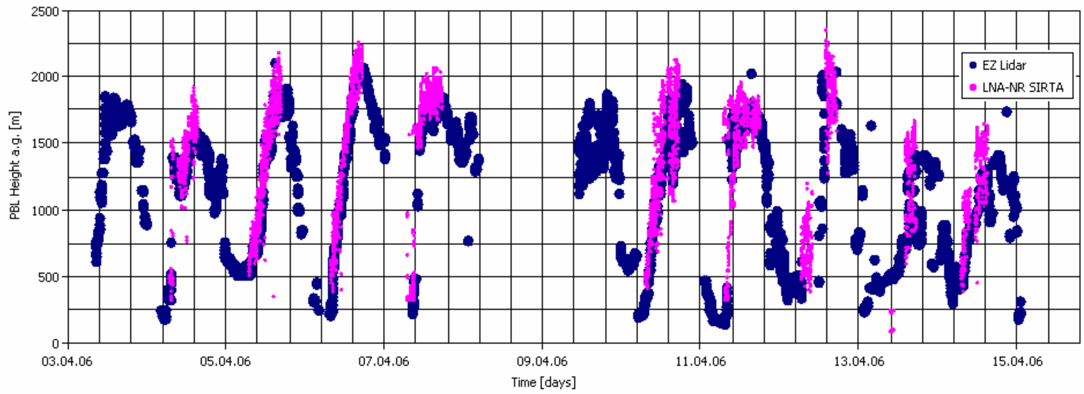

Fig.3 Comparison of the PBL height measured directly by unattended operating EZ ALS300 Lidar (blue dots) plotted against the post-retrieved LMD Near Field Lidar SIRTA (data provided by M.Haeffelin). The PBL heights averaged over 5 min show very high correlation (above 95%) during the whole measurement period (systems were operated at a distance of ~400m) for a period over 13 days in April 2006 at Palaiseau, France.

The main challenge of retrieval of backscatter or extinction coefficient from the acquired elastic lidar signals is the mathematical ill-posedness of the problem due to the existence of two unknowns in one equation, problem tackled already in the 80s' Klett (1981), Klett (1985), Fernald (1984), Sasano et al. (1985). Nowadays evaluation theories and uncertainty schemes are well established Measures (1984), Young (1995), Kovalev and Eichinger (2004), although still can be improved Stachlewska (2006).

The backscatter and extinction coefficient profiles are retrieved from the range and background corrected signals using Klett-Fernald-Sasano constrains with an assumption of altitude dependent Lidar Ratio defined as the particle extinction coefficient to the particle backscatter coefficient ratio [sr]. The values of this ratio are loaded from Lidar Ratio Data Base containing values for different types of atmospheric aerosols and clouds (sea salt aerosols, polluted aerosols, desert dust, arctic air) obtained from recent and past remote and in-situ measurements and from model calculations Ackermann (1998), d'Almeida et al. (1991), Kovalev and Eichinger (2004), Mishchenko (2002), Papalardo et al. (2004). Aerosol-free atmosphere ratio is assumed to be equal to 8.04 theoretical value of molecular extinction-to-backscatter coefficient Measures (1984).

The backscatter and extinction coefficient retrievals are calibrated at the aerosol-free range using dependent on geographical position standard atmosphere density and temperature profiles. If available, data from Radio/Ozone Atmospheric Sounding can be used for this calculation and the accuracy of the extinction calculation at the UV wavelength can be improved by application of the Ozone absorption correction.

From the obtained extinction profiles the optical depth are integrated over the whole available range as well as integrated over the aerosol and thin cloud layers defined by the structure deriving routines.

The uncertainties of the obtained parameters are calculated according to the error propagation and stored in data files.

3. EZ Wind LIDAR™

The EZ Wind LIDAR™ prototype (Fig.4) is an eye safe, robust, easily portable (60x60x60cm^3/45kg) coherent wind lidar dedicated to measurements of the vertical profiles of wind speed and wind direction. This pulsed heterodyne lidar comprises fibre-optic laser based on 1.54µm wavelength operating at 10µJ with 20kHz repetition rate. Pulsed system enables the Doppler shift all along the space-time path probed by the laser pulse.

As the relevant information is in the frequency domain the spectral densities of the signal windows centred on the distances of interest are computed firstly and the Doppler shift is obtained from this set of spectral densities by applying the Fourier transform maximum likelihood estimator Valla (2005).

In addition to the average spectral density of the signal two other data vectors are injected in the MLE algorithm, i.e. the average spectral density of the noise and the pulse shape. Then, an iterative process of adjustment of the physical parameters we are looking for (frequency shift and carriage to noise ratio and dispersion) is undertaken by the MLE algorithm.

Fig.4 EZ Wind LIDAR at Leosphere, Palaiseau, France.

The value found is trusted only if both the signal statistics and the frequency dispersion computed by the MLE algorithm are mathematically converging to the stable solution. In the final result only retrievals with the physical meaning (sufficiently low noise) are used.
As the Doppler shift is proportional to the radial component of the wind speed, the calculations are done directly without need of calibration. Unlike for the continuous-wave wind lidar this system provides constant range resolution.
The horizontal wind speed and direction are reconstructed from measurements at four lines of sight.

All mentioned above calculations are done automatically by the integrated internal software and display retrieved results on the front panel of the acquisition system allowing immediate interpretation of wind measurements with very high accuracy.
Applied approach proved feasible for quasi-continuous wind profiling. The range of wind profiles obtained with this prototype is between 45-650m with vertical resolution of 15m/30m for integration times of 2Hz in ligne of sight. It is able to measure the wind speed in the range between ±30m/s.
An example of radial wind speed profile with corresponding carrier-to-noise ratio are shown in Fig.5 and in Fig.6 result of recent validation with an ultrasonic is shown.
In the near future, additionally to the computation of the wind shear, the system will utilise also scanning option for vortex detection.

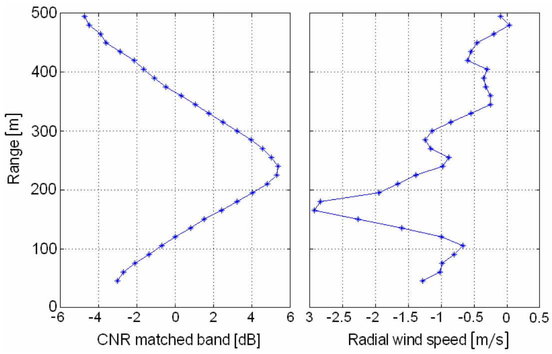

Fig.5 Radial wind speed retrieved from EZ Wind LIDAR measurements during one of the internal validation campaigns on the 13rd of July 2006, Palaiseau, France.

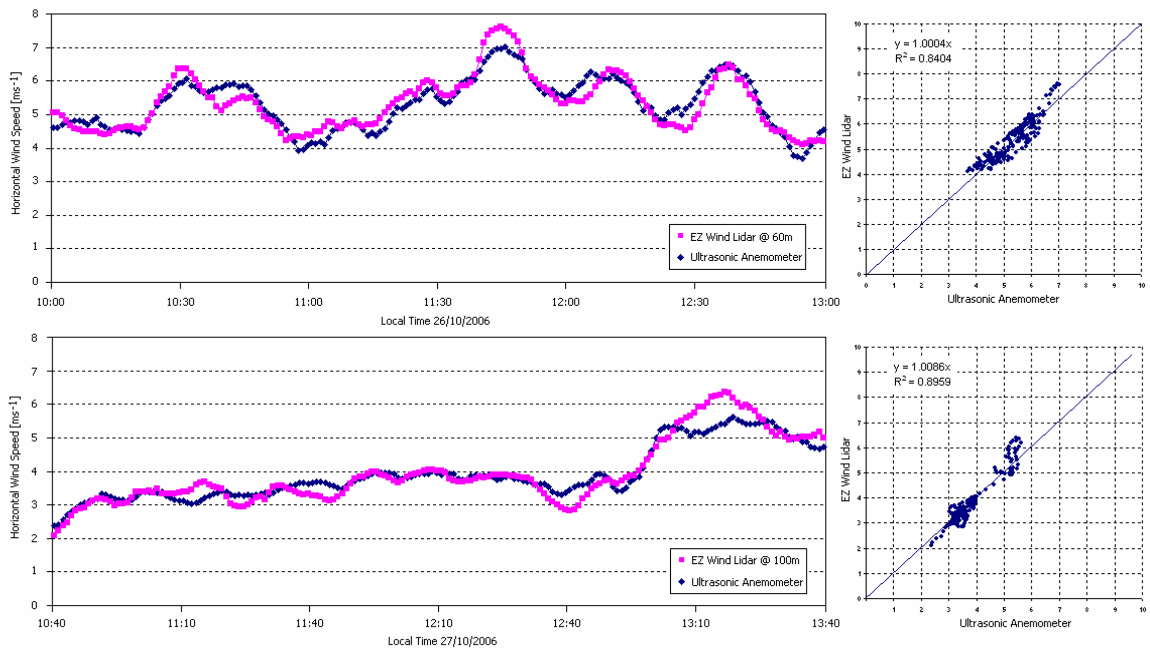

Fig.6 Simultaneous observations of the wind speed by Ultrasonic Anemometer and EZ Wind Lidar prototype on two days during the validation campaign at CEA Palaiseau, France. Ploted results were obtained for 10 min average wind speed [m/s] and updated every minute. High correlation on both days at different height layers and for various weather conditions were abtained. Top: 26/10/2006 at 60m height, partly cloudy, T ~ 20℃, RH ~ 75%. Bottom: 27/10/2006 at 100m height, directly after morning fog (visibility ~200m), T° ~ 15℃, RH ~ 90-95%.

4. SUMMARY

The EZ Aerosol and Wind LIDARs proved robust and useful during field campaigns at different meteorological conditions. Both lidars show good agreement in validation experiments against different aerosol and cloud parameters instrumentation and wind speed sensors. Hence, both lidars prove to be of great use in order to improve for continuous meteorological and pollution measurements in the future.

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