AUTOMATED AEROSOL LIDAR AND WIND LIDAR DETECTION

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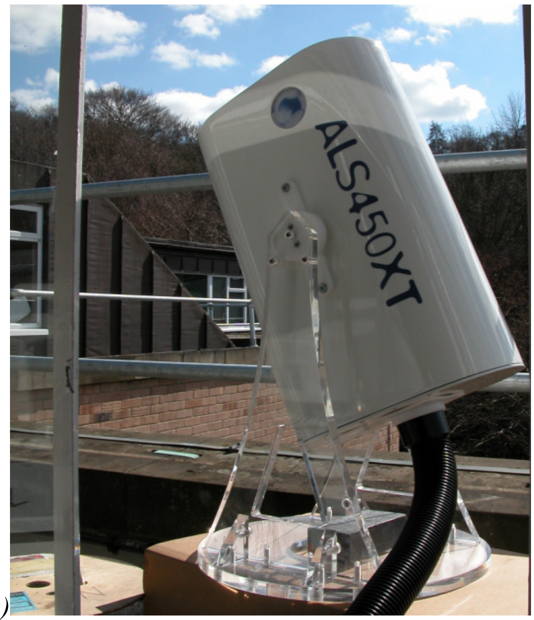
ABSTRACT

The Climate and Environment Sciences Laboratory (CEA/CNRS) and LEOSPHERE jointly developed an eye safe, rugged and unattended, high resolution scanning lidar "EASY_AEROSOL_LIDAR"™ (www.lidar.fr). Since May 2005 the system has been successfully used in several campaigns, e.g. for pollution tracking (LISAIR, Paris, France), African monsoon observations (AMMA, Niamey, Niger), long term air quality measurements (Beijing, China), as well as during validation campaigns (SIRTA, Palaiseau, France). Additionally, in partnership with the Aerospace National Agency (ONERA/DOTA) a prototype of compact automated coherent wind lidar "EASY_WIND_LIDAR"™ was developed, and it is currently operating under test and validation phase. In this paper general description of both instruments and selected examples of results obtained during mentioned scientific and validation campaigns are presented.

1. LIDARS DESCRIPTION

"EASY_AEROSOL_LIDAR"™ is a compact, rigid and eye safe (EN60825-1) system dedicated to remote observations of highly resolved structures of tropospheric aerosols and clouds [1].
The system is based on linearly polarised 355nm Nd:Yag pulsed laser wavelength operating at pulse energy of 16mJ with 20Hz repetition rate. The conceptual simplicity of the backscattering lidar scheme ensures easy and trouble free utilisation of the lidar during field campaigns even under tough conditions (e.g. highly polluted, desert).
This light weight and easy to transport system, is mounted in two temperature and humidity controlled modules. Small Optical Head (60x28x20cm^3/10kg) comprises a laser head, directing and receiving optics and electro-optical detectors. In Electronics and Acquisition Module (60x60x60cm^3/35kg) the laser control and cooling unit and the data control and acquisition system and are installed.
The design allows a fixed location measurements (Fig. 1a) with vertical and horizontal scanning option (e.g. scanning of pollution within the city), as well as the operation from an available mobile platform, a car, ship, and/or an aircraft (Fig.1b). Independently on the operational mode the system requires as standard 220V or 110V with 400W.



(a)

(b)

Fig.1. The EASY LIDAR Optical Head mounted on manual scanning device during stationary observations in Durham, UK (a) and installed onboard ultralight aircraft (b).

The system in automated vertical measurements configuration is powerful enough to cover the range from full overlap at 75m (50m with post processing) up to the Tropopause level (15km), i.e. providing the information on PBL structures and Cirrus clouds at the same time.
As deliverable the profiles of the range and background corrected signals, backscatter and extinction coefficient (calculation using backward Klett-Fernald approach [2,3] with height dependent

lidar ratio assumption for locally representative aerosol type) are provided with very high resolution definition. The retrievals are usually obtained with 1.5m spatial resolution, and integrated for aerosol detection over 1s in PBL, 5-30s in troposphere below 5km, and between 30s to 1min above 5km (Cirrus). Additionally, the PBL height, the cloud bottom height and the particle optical depth are provided automatically.

The raw lidar data are acquired using analog and/or photon counting detection and processed for mentioned calculations by internal software, hence no additional software development is required.

Retrieved results are displayed on the front panel of the acquisition system allowing for an immediate interpretation. Raw and processed data are accessed by TCP-IP protocol which allows using the system remotely from desired computer.

During automated measurements several safety features are assuring full control over the system. They cover as simple functions as the control of the system's internal temperature and power, through the detection of photomultiplier saturation due to low clouds, high background and/or direct sun radiation, to as sophisticated as pulse repetition rate control for the purpose of serving as the laser flash-lamp life time saver (Fig.2).

The standard aerosol system is designed for easy upgradeability to the detection of the 355nm cross-polarisation enabling the information on shape of the measured particles, e.g. spherical particles as aerosols from biomass burning or anthropogenic pollution, or non-spherical as silicate aerosols from Saharan dust or ice particles of Cirrus.

Another important evolution of the system, currently under development, is the implementation of the Raman nitrogen and water vapour detection channels. The latter one will provide the mixing ratio profiles in PBL (up to 2km / 10min integration).

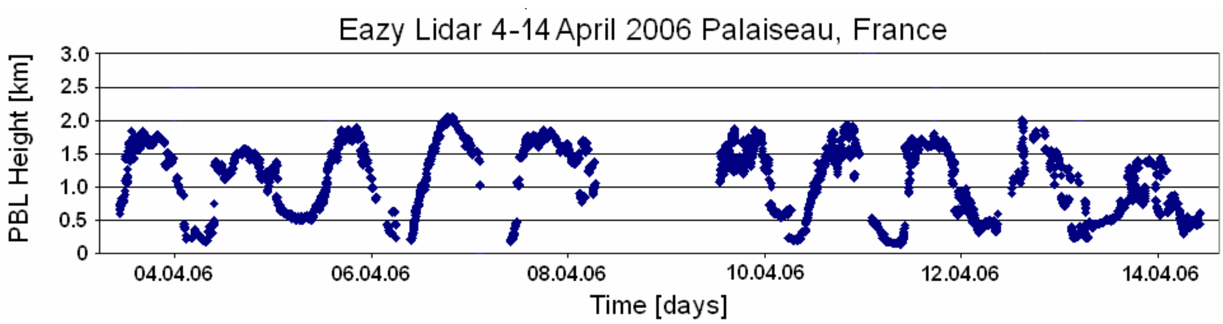


Fig.2. Unattended, continuously running Easy Lidar measurements of the Planetary Boundary Layer height evolution for a period over 10 days in April 2006 at Palaiseau, France. The control software automatically stopped the measurement on midday on 8 May (saturation of the PMT due to low clouds) and restarted on midday on 9 May.

As complementary to the automated aerosol system the "EASY_WIND_LIDAR"™ coherent wind lidar prototype was developed in partnership with the Aerospace National Agency ONERA/DOTA team, taking the advance of the latter one high level know-how in heterodyne lidar technology for both airborne and ground based systems.

This eye safe (EN60825-1), robust, easily portable (80x80x80cm^3/45kg), operating by required power of 500W for 220V or 110V prototype is dedicated to measurements of the vertical profiles of the wind speed and wind direction. It utilises pulsed heterodyne technique comprising a high spatial and spectral quality Erbium doped optic-fibre laser based on 1.54µm wavelength and operating at 10µJ and 10kHz repetition rate. As the Doppler shift is proportional to the radial component of the wind speed, e.g. 1ms^{-1} results in 1.3MHz shift for 1.55µm, the calculations are done directly without need of calibration.

Large number of FFTs is averaged to provide the radial wind speed profile (Fig.3) by utilising the maximum likelihood estimator [4].

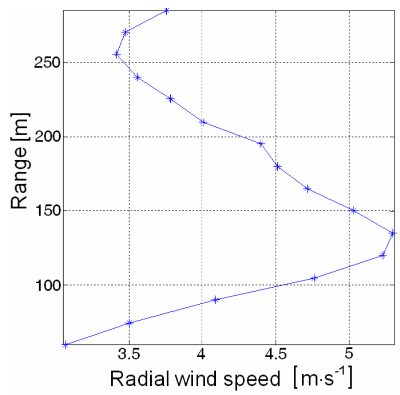


Fig.3. The radial wind speed at 30° with constant range resolution of 15m obtained from the Easy Lidar wind measurement on 15 February 2006 at Palaiseau, France.

The horizontal wind speed and direction are reconstructed from measurements at four lines of sight. All 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. In future the system will utilise also scanning option for vortex detection.
The wind measurement range of the prototype is between 50-300m (in near future up to 500m). Unlike for the continuous wave wind lidar, here constant range resolution of 15m/30m (for pulse length of 100ns/200ns, respectively) for integration times of 1Hz is provided (Fig.3). The system is able to measure the wind speeds in the range between ±15m/s. The estimated absolute accuracy of the wind measurements is ±0.1m/s.

3. EASY LIDAR VALIDATION

The Easy Aerosol Lidar was validated against the results from the different instruments during several campaigns. In this section the comparison results with the AERONET sunphotometer data (Fig.4) and the SIRTA lidar (Fig.5) are presented.

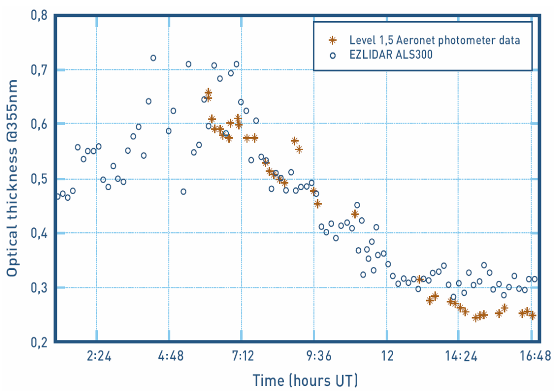


Fig.4. The comparison of the sunphotometer with the Easy Lidar total optical depth. The sunphotometer data (red crosses) were provided by P.Goloub, AERONET, France. The Easy Lidar results (blue dots) were obtained by automated software without need of post processing. Around noon the sunphotometer data were not available due to passing subvisible clouds hindering retrieval.

The sunphotometer total optical depth obtained at two channels 340nm and 380nm was interpolated with the wavelength evolution prior to the data comparison. It agrees well with the total optical depth of the Easy Lidar obtained using a standard evaluation scheme of the automated software (no post processing required). In Fig.4 around 12:00 UT the sunphotometer data were not available due to passing subvisible clouds. However, in the case of the Easy Lidar the retrieval was possible.

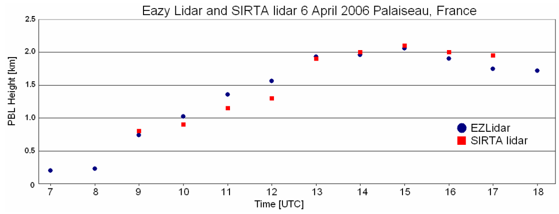


Fig.5. The height of the Planetary Boundary Layer obtained on 6 April 2006 from the near field 532nm SIRTA lidar measurements (red squares) provided by M.Haeffelin, SIRTA, Palaiseau, France agree well with the 355nm Easy Lidar results (blue dots).

The comparison of the Easy Lidar with the SIRTA lidar retrieval of the PBL height performed during several days in April 2004 at Palaiseau show good agreement despite the use of different measurement wavelength and PBL height retrieval algorithms.

4. EASY LIDAR CAMPAIGNS

Several field campaigns were conducted over large cities around the world to improve understanding of the mechanisms of formation, transport and decay of anthropogenic pollutants. Novel monitoring strategies consider an unattended lidar observation as curtail for resolving the dynamical structure of atmosphere, providing an information on the PBL height and on integrated over it particle optical depth. The Easy Lidar proved able performing high quality measurements of mentioned parameters.
In spring 2005 during the LISAIR campaign in Paris, France (Fig.5) an evolution of the aerosol load enhancement due to the traffic pollution during early morning hours over the Paris Ring with the particle optical depth above 0.25 were observed [1].

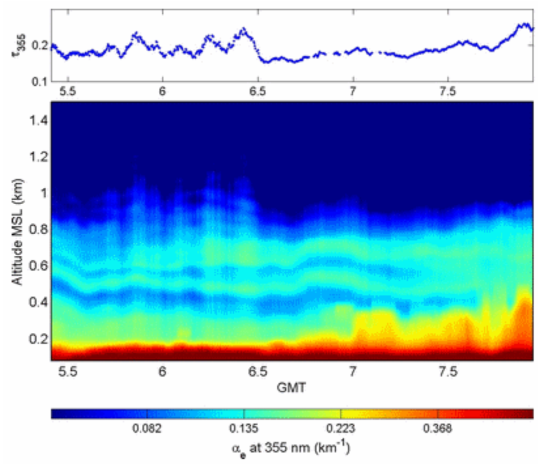


Fig.5. The evolution of the particle extinction coefficient due to the traffic pollution over the Paris Ring with corresponding integrated over the PBL particle optical depth on 26 May 2005 during the LISAIR campaign.

During similar measurements also addressing the air quality issues and performed during autumn 2005 in Beijing, China extremely high values of the particle extinction coefficient and the PBL particle optical depths as high as 1 were probably caused by smog over the city (Fig.6).

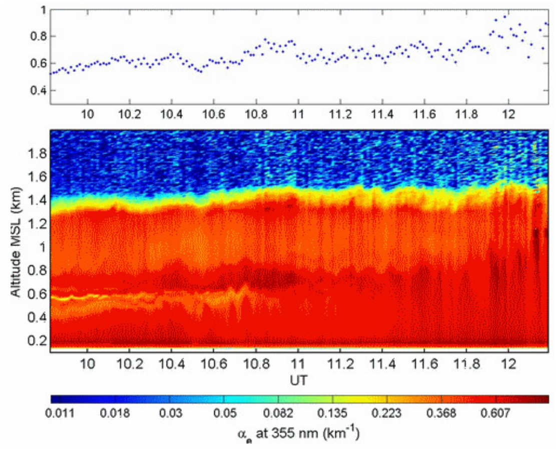


Fig.6 The particle extinction coefficient due to smog over Beijing on 29 June 2005. The particle optical depth integrated over PBL reached values as high as 1.

The research goals of the African Monsoon Multidisciplinary Analysis (AMMA) campaign focus on reasons for rain deficits in Niger. In the frame of this campaign both stationary and aircraft observations of the particle extinction coefficient structures and the optical depth associated with different aerosol types were performed by the Easy Lidar (Fig.7).

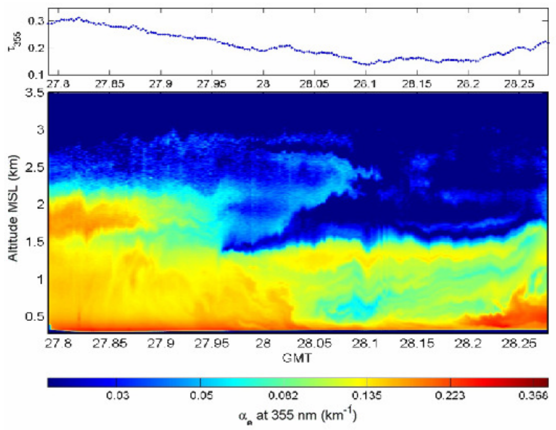


Fig.7. Observation of the particle extinction coefficient structures associated with high aerosol loads obtained during the night measurements 27/28 January 2006 at AMMA campaign in Niamey, Niger. Multilayered, wavy structures indicate strong dynamical variability of air.

4. SUMMARY AND CONCLUSIONS

The Easy Lidar proved robust and useful during aerosol field campaigns even at extreme weather and meteorological conditions. Good agreement was obtained by validation of the aerosol structures and the PBL height against SIRTA lidar and the optical depth with AERONET sunphotometer.

The lidar should be of great use in the next future in order to improve continuous meteorological and pollution measurements and constrain micro-scale dispersion models enabling Air Quality monitoring strategy at an urban and regional scale, as well as for urban security matters.

Upgraded with the depolarisation and water vapour detection lidar will help bringing evidence of humidity influence on emitted urban aerosol, as this parameter is most important for the health impact assessment.

On the other hand the soundless wind lidar shall find great use for wind profiling by providing continuous very accurate wind profiles, wind shear and turbulence information, while replacing or complementing the meteorological masts.

Additionally, the use of the scanning option will allow for the vortex detection studies in future.

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