MONITORING OF AEROSOLS WITH THE NEAR-IR LIDAR

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INTRODUCTION

Aerosol spectrometry is one of major problematics in radiative transfer models. Atmospheric optical properties at each given wavelength depend on microphysics of aerosols (shape, size, chemical composition) and concentration, and the gaseous (molecular) contribution.
In contrast to UV, in near-IR spectra (notably at 1.54μm) the contribution of molecular absorption and scattering is negligible. Moreover, the light absorption by aerosols at 1.54μm is typically within only a few percents compared to 50-60% in UV band [1,5].
Near-IR Lidar has a potential for aerosol transport and diffusion survey, as well as the detection of emission sources, day and night, through the entire mixing layer depth.

LIDAR WLS

WINDCUBE-100S is a coherent (heterodyne) pulsed near-IR Doppler Lidar developed by Leosphere* [3]
Wavelength 1.54μm
Pulse duration 200 ns
Pulse repetition frequency 10 KHz
Max scanning range 6km
Horizontal 360^o (PPI) and vertical 180^o (RHI) scans of 1^o $\times$ 50m resolution (ex, **Fig 1- 2**). Here the horizontal scans are set to 3^o inclination of the laser beam
Limitation: no return signal and no wind measurements in pure molecular troposphere
Advantage: no molecular correction is required to retrieve the aerosol optical properties

OBJECTIVES

(a) To retrieve the atmospheric optical properties from Lidar measurements. These are the *extinction coeff* (α) and the *backscatter coeff* (β).
(b)To validate the retrieval method: first for well mixed events where α and β are $const$ in horizontal plane within the lowest 200m.
(c) To define experimentally the shape of instrumental (overlap) function $F(R)$. An automatic correction of Lidar measurements by $F(R)$ would allow an operational 3D monitoring of particulate matter content.
(d) To verify whether $F(R)$ evolves in time.
(e) To assess the relationship between α and β at 1.54 μm vs PM2.5 and PM10.

METHODS

Single scattering **lidar equation**, as formalized by [3,4] from the radiative transfer equation, looks as follows :

$$P(R)_{rec} = \frac{P_{tr} K F(R) \beta(R) \exp^{-2\int_0^R \alpha \partial R}}{R^2} \quad (1)$$

where R is the scanning range [m], $P(R)_{rec}$ is a range dependent echo [Watt], P_{tr} is the power of transmitted signal [Watt], $\beta(R)$ is the *volume backscatter coeff* of the atmospheric layer at distance R in [m^{-1} sr $^{-1}$], $\alpha(R)$ is the *extinction coeff* at R in [m^{-1}], $F(R)$ is the overlap function [dimensionless] that depends on beam focalization (that should be defined experimentally), and K is the instrumental constant [m^3 sr]. In vertical plane $\int_{surface}^{top} \alpha \partial R$ is the optical depth. Lidar measurements provide the Carrier-to-Noise Ratio (**CNR**) in [dB]:

$$CNR(R) = 10 log_{10} \frac{P(R)_{received}}{P_{transmitted}} \quad (2)$$

In a perfectly *well mixed* boundary layer α is $const$, and thus a classic slope method can be used to deduce α value for each horizontal scan PPI. So far $2\int_{surf}^{top} \alpha \partial R$ can be simplified to $2\alpha R$.

$$CNR(R) \frac{ln10}{10} + 2lnR + 2\alpha R = lnF(R) + ln(K\beta) \quad (3)$$

After removing αR from $CNR(R)$, the residual (left side of **Eq 3**) is then composed of the instrumental function $F(R)$, common for a group of scans (over a week or year), and an unknown constant $K\beta$ that is individual for each scan.

MEASUREMENTS

Continuous CNR measurements were hold in Dunkerque (July 2013 - Aug 2014), in Paris (Sept 2014 - Nov 2014), in Senegal (March 2015)

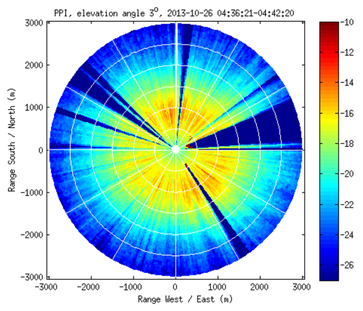

Figure 1: PPI

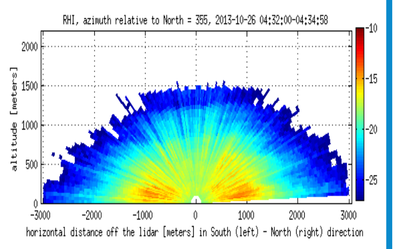

Figure 2: RHI. Example of a well mixed event, with an accent on the lowest 300m

As is it obvious from **Fig 1- 2** an adapted filtering should be applied to CNR prior to retrieval of atmospheric optical properties.

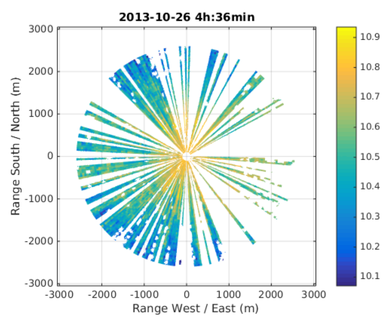

Figure 3: $2\alpha R + ln(K\beta(R))$

The first filtering criteria is the following. If the distribution of 360 $CNR(R)$ values at the same distance R is narrow (inter-quartile spread criteria) and symmetric (skew criteria) then the air is likely well mixed at given altitude (distance).

The second filtering criteria is a symmetry of RHI within the lowest 300m. Third: CNR profiles with large peaks (localized pollution or signal noise) are removed.

INSTRUMENTAL CORRECTION F(R)

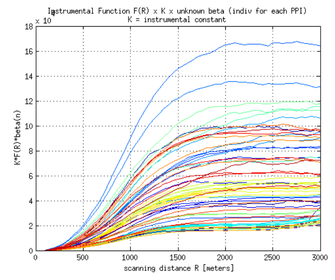

Figure 4: $F(R) \times K \times \beta$

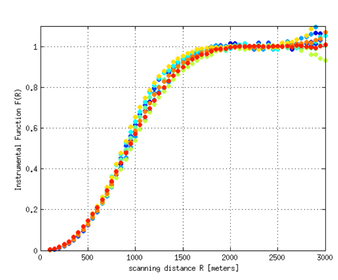

Figure 5: 35 weekly $F(R)$'s

Fig 4 reflects the shape of $F(R) \times K \times \beta$ **(Eq 3)**, where β is individual for each horizontal scan (and *const* along R), while K is the same for a group of scans. Each curve reflects one particular horizontal scan. All potentially homogeneous PPI between July 2013 and Oct 2013 are illustrated. Depending on aerosol composition and concentration, α and β change between different days. Differences in $F(R)K\beta(R)$ are mostly due to vertical changes in α and β (3^o inclination), α error, and a larger uncertainty in CNR further away from the instrument, rather than the evolution of $F(R)$ in time (**Fig 5**). There is never a perfectly well mixed air over an industrial site.

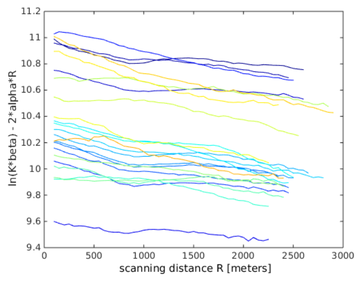

Figure 6: $2\alpha R + ln(K\beta)$ residual

Once removed the known $F(R)$ from $CNR(R)$, the residual becomes only a function of αR (see **Eq 3**). So far, αR value can be recalculated for the entire 0-3km scanning range, and each well mixed scan. In **Fig 6** each curve reflects the residual $2\alpha R + ln(K\beta)$ for one individual 360^o scan.

RESULTS AND CONCLUSIONS

Aerosol *extinction coeff* α is retrieved with the slope method for well mixed events (more than 1000 in one year). α values demonstrated here are the average for a portion of PPI (ex. **Fig 3**). 10-min spatially average (6km $\times$ 6km $\times$ 200m height) Lidar retrievals of light extinction compare well with the hourly ATMO PM10 measurements 2km away to the west (**Fig 9**, St Pol site) and PM2.5 measurements 4km away to the south (**Fig 8**, Cappelle-La-Grande site), and 2km away to the east (**Fig 7**, Malo site). The relationship between PM2.5 (PM10) and the aerosol optical properties seems to vary from month-to-month (**Fig 7- 9**, **Table 1**).

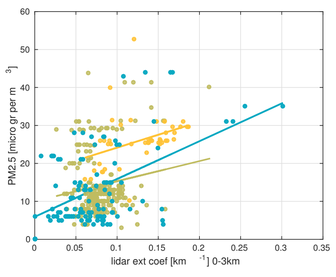

Figure 7: PM2.5 (Malo) vs Lidar α, Sept2013 (blue), March2014 (green), Apr2014 (orange)

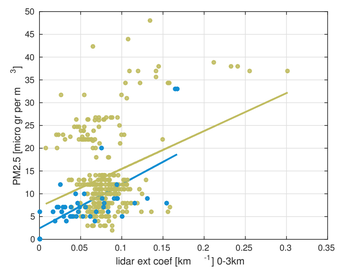

Figure 8: PM2.5 (at Cappelle-la-Grande) vs Lidar α, Aug2013 (blue), March2014 (green)

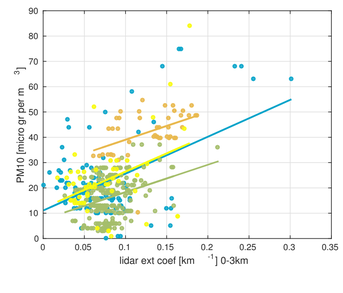

Figure 9: PM10 (at St-Pol) vs Lidar α, Sept2013 (blue), March2014 (green), Apr2014 (orange), July2014 (yellow)

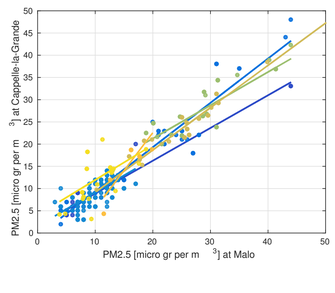

Figure 10: PM2.5 at Malo vs PM2.5 at Cappelle-la-Grande. Aug2013 (blue), Mar2014 (green), Apr2014 (brown), Jul2014 (yellow)

Table 1: **Statistics for the linear regression between (a) the hourly PMx observations and (b) 10-min average 6km x 6km x 200m mean Lidar α estimate at three measurement sites in Dunkerque, month by month.**

month	stats	Malo (PM2.5)	Capp-la-Grande (PM2.5)	St-Pol (PM10)
Aug 2013	corrcoef	-	0.63	-
	p-val	-	0.01	-
	r^2	-	0.4	-
	nb events	-	42	-
Sept 2013	corrcoef	0.4	-	0.59
	p-val	0.01	-	0.01
	r^2	0.15	-	0.34
	nb events	66	-	66
March 2014	corrcoef	0.62	0.7	0.72
	p-val	0.01	0.01	0.01
	r^2	0.38	0.5	0.52
	nb events	49	49	49
April 2014	corrcoef	0.37	-	0.48
	p-val	0.01	-	0.01
	r^2	0.14	-	0.23
	nb events	45	-	45
July 2014	corrcoef	-	-	0.82
	p-val	-	-	0.01
	r^2	-	-	0.67
	nb events	-	-	12

Even during well mixed events differences exist in PM2.5 over a 6km distance (**Fig 10**), ranging within 2-15μgr m^3.

FUTURE RESEARCH

It is of interest to refine our knowledge on relative sensitivity of the boundary layer optics at 1.54 μm to PM2.5/PM10, aerosol chemistry, air humidity, and high/low pollution levels. The aerosol chemistry affects somehow the lidar signal absorption by particles (introducing the α error of max 10%), the air moisture affects the particle size and shape.
Our results indicate that 1.54μm wavelength is the most appropriate for the measurements of air optics during high pollution events; to be investigated further.
The magnitude of α is very small at 1.54μm (**Fig 7- 9**) compared to UV and VIS spectra, with an important uncertainty (not shown here). This limitation can be lifted if constraining the obtained α value by the Lidar Ratio ($\frac{\alpha}{\beta}$) deduced from the AERONET Sun Photometer inversion when available (well mixed events).
Application of 1.54μm Lidar measurements to a stratified atmosphere and dust plumes should be developed further (both for PPI and RHI). In this case the AERONET Sun Photometer data won't help much, and so, a novel data and methods should be employed.

ACKNOWLEDGEMENTS

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