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Supplement of

Studying the vertical aerosol extinction coefficient by comparing in situ airborne data and elastic backscatter lidar

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Supplementary Material: Ceilometer retrieval of the mixing layer height (MLH)

At the San Pietro Capofiume ground station an automated LIDAR-ceilometer (Jenoptik CHM15K "Nimbus") was deployed to get an estimate of the mixing layer height at a certain time. The analysis is performed by manually evaluating the MLH by a skilled operator's visual analysis of three plots obtained by the pre-processing of the ceilometer signal. The data was also compared to radio sounding measurements performed at 11 UTC and vertical profiles of the potential temperature (Θ) recorded aboard the Zeppelin NT.

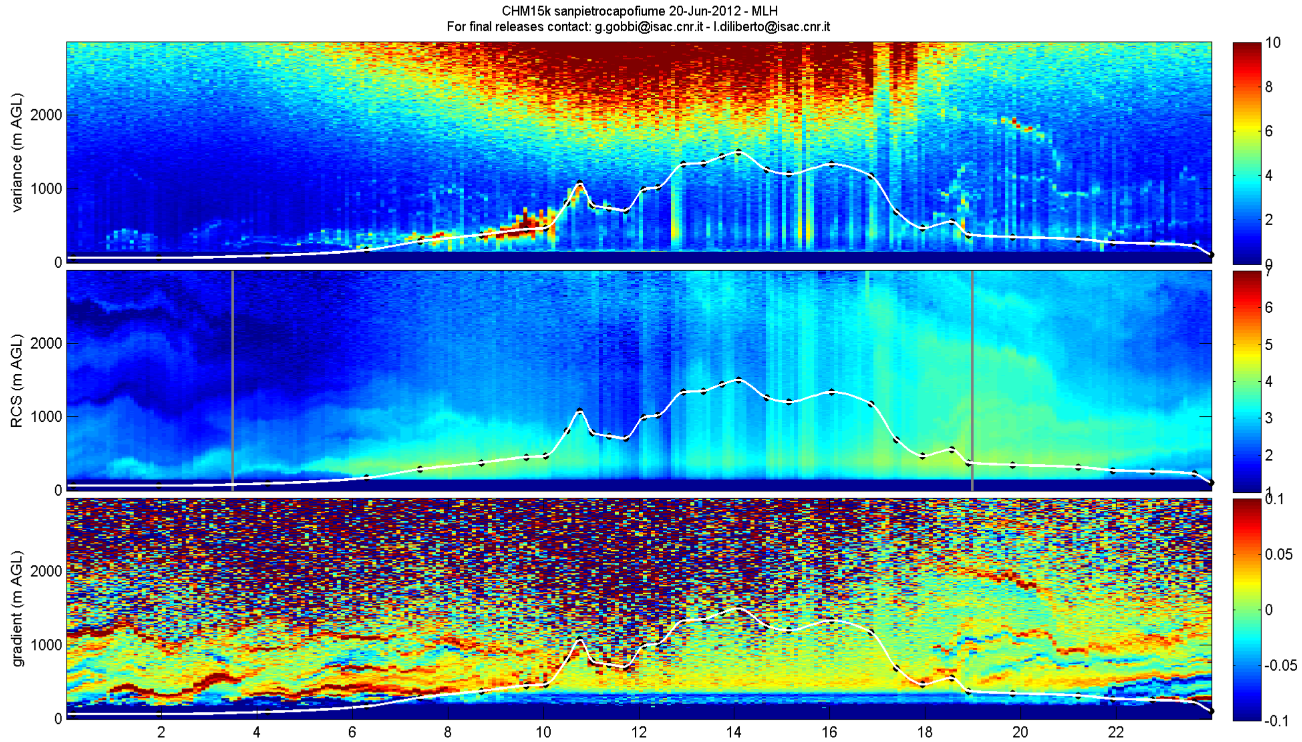

Figure 1: Three plots obtained by the pre-processing of the ceilometer signal. The white line represents the spline fit to the black dots marked by the operator while considering all the information from the three plots. The first panel illustrates the signal's variance plot (e.g. Angelini et al., 2009), the second the range corrected signal (RCS) plot and the third the signal's gradients plot.

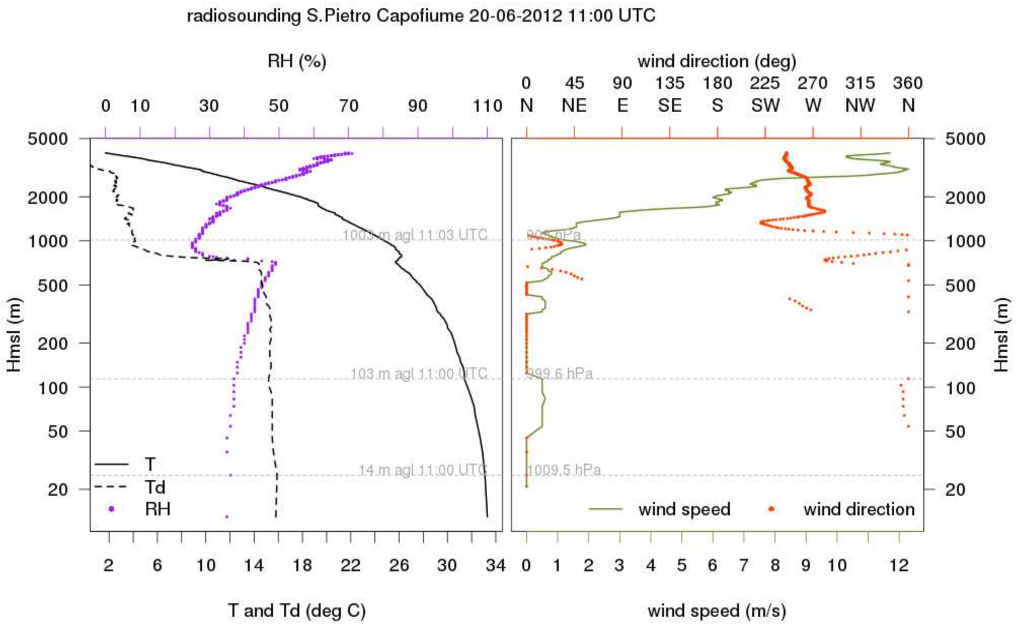

Figure 2: Radio sounding at San Pietro Capofiume at 11 UTC. The left panel illustrates the temperature T, dew point Td, and relative humidity RH as functions of altitude. The right panel shows wind speed and wind direction. The radio sounding yielded a MLH of 753 m.

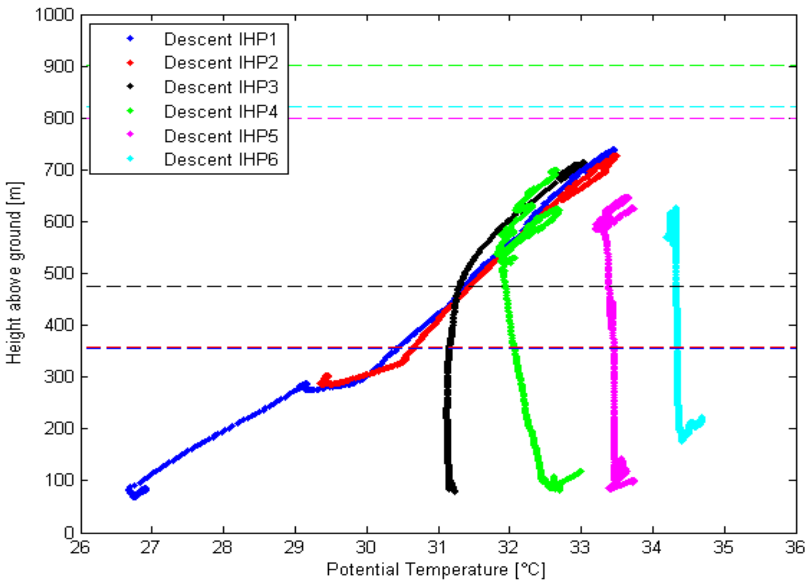

Figure 3: Height profiles of the potential temperature (Θ) measured aboard the Zeppelin NT during the flight on 20 June 2012. Each color represents the descents of height profiles 1-6 (IHP1-6), respectively. The horizontal lines depict the estimated mixed layer height (MLH) from the ceilometer retrieval during the six height profiles. A clear vertical structure of Θ is visible for the first two profiles, while the last four show very little or no altitude dependence at all. This indicates that the sub-layers in the PBL where still separated at the beginning of the flight and that a fully mixed layer was probed at the end. The estimated MLH retrieved from the ceilometer shows comparable results with a low MLH of approximately 350 m above ground in the morning that evolves to over 800 m above ground later during the day.

Supplementary Material: LIDAR data analysis

The LIDAR used in the present study is a small portable LIDAR that measures polarized and depolarized elastic backscatter. It is also equipped with an acquisition channel for detecting Raman backscattering, which is used solely to reconstruct the LIDAR signal from the lowest layer of the atmosphere, as detailed in the manuscript (partial FOV correction). The weak intensity of the Raman signal does not allow to extend the Raman profile much beyond the 2 km range maintaining a satisfactorily S/N, even if averaged over several hours at night-time, so it is not possible to use it for a Rayleigh-Raman extinction retrieval, as usually done on larger and more performing LIDAR systems. Raman profiles are thus not routinely acquired during each measurement session, but only on the occasion of LIDAR setup and alignment, for the sole scope of partial FOV reconstruction.

Lidar polarized and depolarized backscatter data are acquired in both photon counting and current mode, in two acquisition channels, every 30 s and further averaged over 600 s.

A common profile for each channel is computed by gluing the two acquisition modes in a merging region where both are considered reliable (photon counting channel far from saturation, current channel still sufficiently sensitive), generally taken between 3 and 7 km depending on light background conditions. In the particular setup of the data presented in the submitted manuscript, the gluing region was chosen above 7 km due to some unwanted noise in the photon counting acquisition mode, present in the timeframe of the campaign.

Let $S_{par}(z)$ and $S_{cross}(z)$ be the raw data of the polarized and depolarized acquisition channel respectively. In order to derive the volume depolarization DR, when it is possible to detect a region of atmosphere supposedly free of aerosol (the “calibration region” at z_0), we choose a suitable parameter K so to pose the volume depolarization DR(z),

$$DR(z)=K*(S_{cross}(z)/S_{par}(z)),$$

equal to DR_0 (the value expected for a purely molecular atmosphere) in correspondence of the z_0 region. As reported in the manuscript, the DR_0 value is assumed from literature, and depends, among other factors, on the LIDAR instrumental setup. However, there are cases when it is not possible to find such a calibration region within the useful LIDAR range, i.e. where the noise affecting the depolarized signal is deemed acceptable. In such cases, DR(z) is calculated by computing the relative gains of the two acquisition channels, retrieved from cases when a calibration region was defined. Generally, the calibration region approach works fine for night-time measurements, while the relative gain approach is used for diurnal measurements.

Correction for partial FOV overlap is made by multiplying $S_{par}(z)$ by an overlap function FOV(z) to reconstruct the signal in the lower layers of the atmosphere

$S'_{par}(z)=FOV(z)*S_{par}(z)$

This is displayed in Fig. 4, where the black line reports the uncorrected data, and the red line the partial FOV corrected ones.

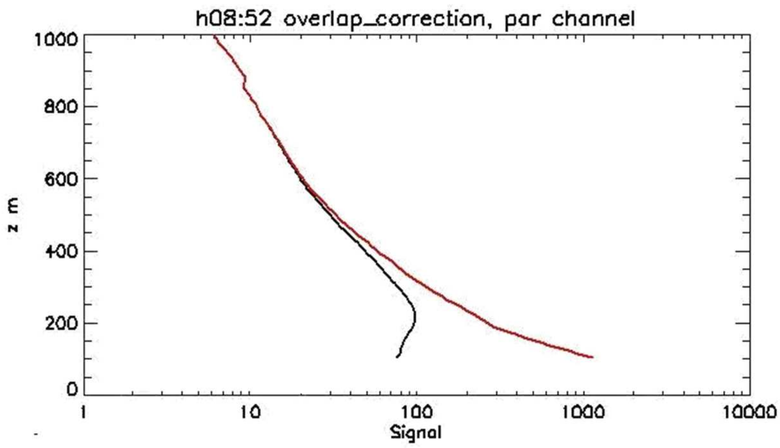

Figure 4: Profile raw $S_{par}(z)$ in black, and FOV corrected $S'_{par}(z)$ in red.

The extinction correction is made by using the molecular volume backscattering coefficient profile rho(z) as ancillary data, and iteratively choosing the parameter C to pose the total backscatter ratio R(z)

$R(z)=C*(S'_{par}(z)*(1+DR(z))/(1+DR_0))/rho(z)$

equal to 1 in a region of atmosphere supposedly free of aerosol. Iterations are made by computing the extinction along the profile by means of tentative R(z)s, using piecewise constant backscatter-to-extinction ratio (LR(z)) along the profile, whose values are chosen accordingly to the values of R(z) and DR(z) as detailed in the manuscript, and repeating the process until the value of R(z) remains stable between two successive iterations.

Figure 5 presents the result of such an inversion for a particular profile among those used in the analysis reported in the manuscript (8:52 UTC, 10 minutes average). It is worth noting the presence of thick layer of aerosol close to 4km, which has been identified as Saharan dust, based on its optical properties. There, LR has been fixed to the value expected for such kind of particles while elsewhere it has been fixed to values expected for polluted continental aerosol (see table 1 in the manuscript).

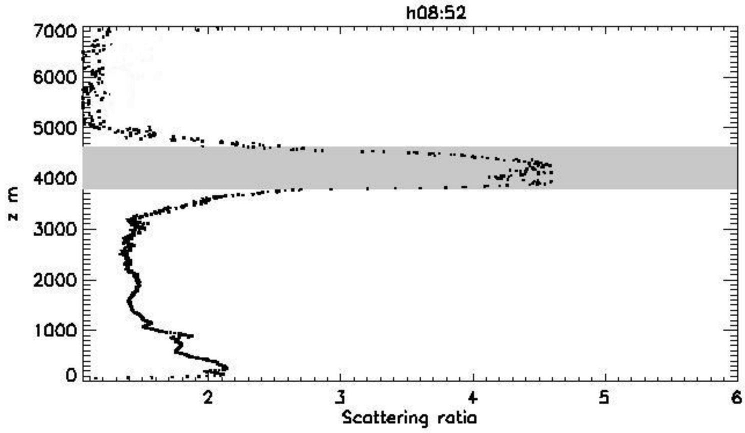

Figure 5: Scattering ratio. The grey region highlights a layer of Saharan dust.

Aerosol extinction is then computed: (z)=(R(z)-1)*rho(z)*LR(z)

In order to further support the choice of LR(z) based on the aerosol optical characteristics, we present a back trajectory study based on the Flexpart lagrangian system driven by GFS meteorological input. Back trajectories were released in correspondence of the measured profile from the 0m-2000m (Fig. 6, left panel) and 3000m-5000m (Fig. 6, right panel) vertical layers. The images show the footprint (residence time, in ns, of particles on each geographical bin) of the cluster in shaded colors and the position of the center of mass with black dots. Lower panels report the height of the center of mass during its flights backward in time.

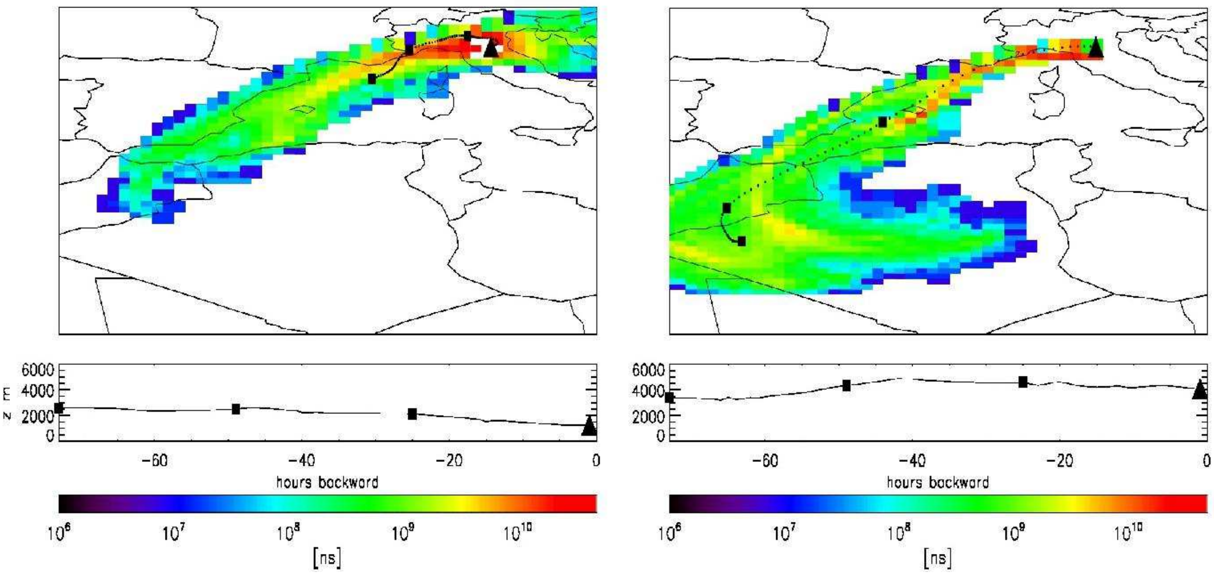

Figure 6: Flexpart footprint (in colors) and trajectories center of mass position (black dots) for the 0m-2000m release (left) and 3000m-5000m release (right). Lower panels indicate the center of mass height backward in time. Black triangle highlights the release point and black squares the mean position each 24 hours.

Figure 6 shows that, in the 0m-2000m layer, air masses are mostly influenced by local air and air coming from the sea, confirming the choice of a non – dust LR for this vertical interval. Between 3000m and 5000m heights instead back trajectories reach North Africa, involving a possible transport of Saharan particles to SPC. The identification of dust for this layer, derived by the optical parameters, is therefore also supported by the lagrangian analysis.

As pointed out in the text, changes in the assumption of LR have two consequences:

i) a "global" one on the retrieval of the backscattering coefficient profile (and the backscatter ratio profile R(z)), whose values decrease with increasing LR, the more the further down from the calibration altitude;

ii) a "local" one on the extinction retrieval, as the latter is simply linearly proportional to the backscattering coefficient, everywhere.

In order to determine the relative amount of the two counteracting effects, a sensitivity study has been performed by fixing the LR from 30 to 50 to 70 sr everywhere along the profile (irrespective of optical particle classification, to simulate the worst case). Figure 7 shows the effect of different LR choices on the backscatter ratio (left panel) and on the extinction coefficient (right panel) for one of the profiles used in the manuscript (8:52 UTC, 10 minutes average). Black, blue and red lines represent respectively the LR 30, 50, 70 sr and the black square indicates the calibration region.

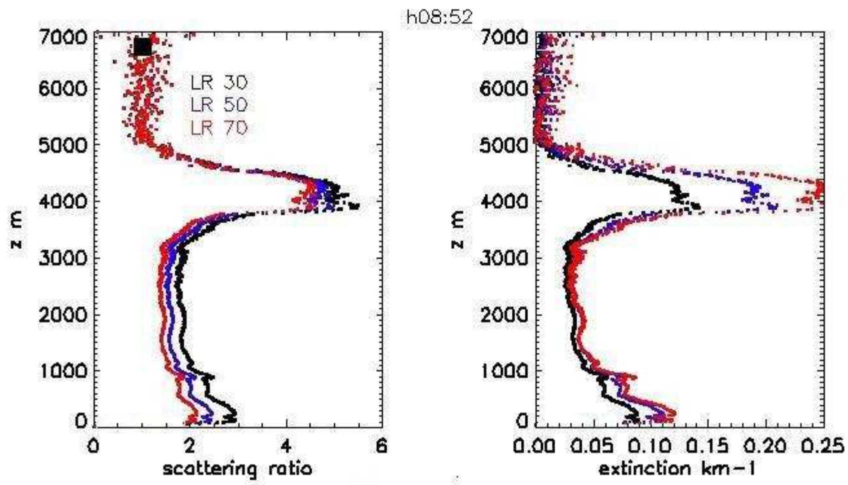

Figure 7: Left panel, Scattering ratio, right panel extinction coefficient. Red, blue and black show respectively the 70, 50 and 30 LR choice. Black square represent the calibration altitude range.

In the case studied, the "global" effect on R(z) can be clearly seen to increase the further down from the calibration altitude, not perceptible above 500m and causing a 100% variation on the aerosol scattering ratio

$R(z)$ -1 in the PBL. As expected, the larger the LR, the smaller the $R(z)$. This effect reverses its sign when looking at the extinction coefficient, where the “local” effect prevails, more markedly at the Saharan dust level, centered at 4 km, (100% from 30 to 70 sr), slightly less in the boundary layer (around 50% variability). A comprehensive analysis of the meteorology and transport regimes of the summer 2012 Po Valley PEGASOS campaign, associated with aerosol characterization, will be presented in Bucci et al., Transport regimes analysis over Po Valley during summer 2012: impacts on Planetary Boundary Layer variability and aerosol content, to be submitted to Atmos. Chem. Phys. Discuss