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Lidar retrieval impact on Fu-Liou-Gu Radiative Transfer Model

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Abstract

The purpose of this work is to quantify the sensitivity of the Fu-Liou-Gu (FLG) Radiative Transfer Model to estimate the aerosol net radiative forcing with respect different lidar instruments/algorithms/techniques applied to the retrieval of the extinction coefficient, used as input parameter of FLG. The sensitivity analysis is carried out calculating the radiative forcing from a dust layer retrieved from lidar data with different noise level and effective vertical resolutions and from real lidar data measurements. Results of the sensitivity analysis on the Radiative Forcing (RF) estimation are quantitatively discussed.

Keywords: Radiative transfer; Lidar; Aerosols; Cirrus clouds

1. Introduction

Atmospheric extinction profiles retrieved from lidar measurements are currently used as input for radiative transfer models to assess the radiative effects of cirrus clouds (Campbell et al., 2016; Lolli et al., 2016). Nevertheless lidar extinction profiles are retrieved using different instruments and data processing techniques, i.e. Raman lidar, HSRL lidar, elastic lidar. In this study we quantitatively assess the sensitivity of the Fu-Liou-Gu (FLG) radiative transfer model (Fu & Liou 1992; Fu & Liou 1993; Fu et al., 1997) to the different lidar data processing techniques applied to a dust layer outbreak detected on 3 July 2014. Data processing and the related different smoothing techniques does not only decrease the effective vertical resolution of the output products but also influences directly the net

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radiative forcing both at surface (SFC) and Top-Of–the-Atmosphere (TOA). These differences are assessed for different sizes of the smoothing window, for retrievals at both wavelengths 355 and 532 nm.

2. Method

The dataset was collected by MUSA (Multi-wavelength System for Aerosol) lidar, deployed at CNR-IMAA Atmospheric observatory, CIAO, (40.26N, 15.72, 760 m agl), located in Tito Scalo, Italy (Madonna et al., 2011), during a Saharan dust outbreak on 3 July 2014. In Figure 1are shown the retrieved extinction lidar profiles at 355 nm and 532 nm of a detected dust layer, from 2 km to 6 km above the ground respectively for seven different de-noising window lengths. The signals are temporally averaged over 2 hours (19:35UT-21:40UT). The effect of the smoothing on lidar profile, which has an original resolution of 15 m, based in this study on the use of the 2^{nd} order low pass filter (Savitzky-Golay), depends on the window length. We smoothed the lidar profile over a minimum of 24 bins (360 m) up to a maximum of 64 bins (960 m). The larger the window, the smoother the profile appears, but with changes in the observed atmospheric signatures.

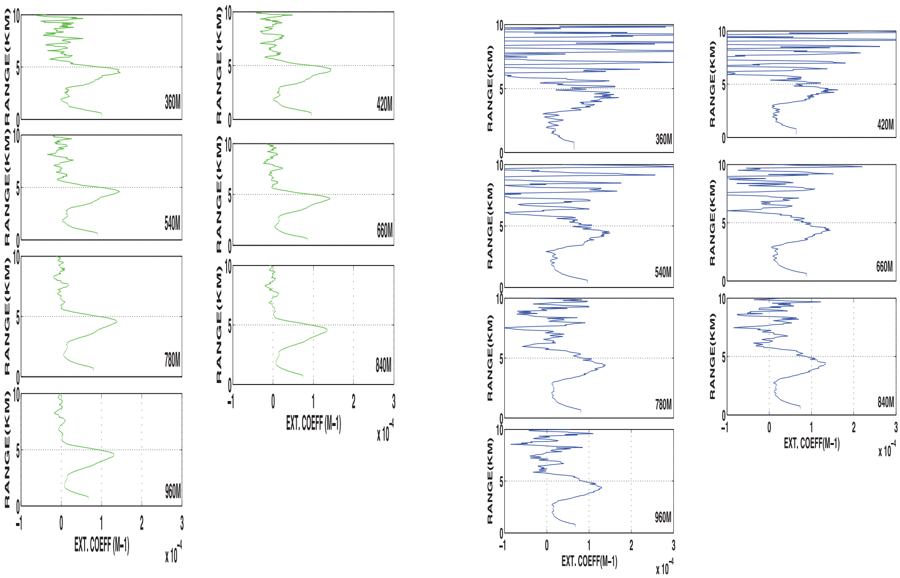

Fig. 1. Extinction coefficient retrieved from MUSA Raman lidar measurements at 355 nm (left panel) and 532 nm (right panel). A an aerosol layer that after further analysis is identified as dust, can be detected from about 2 to 6 km above the ground. The de-noising technique is depending on smoothing window length, ranging from 360 m to 960 m. The smoothing technique is then affecting the profile shape, with considerable effects on net radiative forcing

2.1 Fu-Liou-Gu radiative transfer model

The direct effect of the dust layer observed at CIAO on 3 July 2014 on radiative forcing is investigated using the FLG radiative transfer model (Fu & Liou 1992; Fu & Liou 1993; Fu et al., 1997). The vertical profiles used to constrain the model were obtained from the MUSA data described above and were taken as an average extinction at each 60 m layer.

FLG model requires as input an individual profile for each aerosol species. To calculate the net radiative forcing and heating rates for each single species extinction profile, the partial contribution to the total AOD and the value of the species optical depth at each altitude level is required as input for the model. FLG parameterization uses 18 different types of aerosols, with single scattering aerosol properties parameterized through the Optical Properties of Aerosol and Clouds (OPAC) catalogue. However for our study, two main aerosol types contributed more than 95% to the total AOD; these were dust ("transported dust" in FLG), polluted continental ("urban" in FLG). The FLG radiative transfer model does not take into account the spectral dependence of the AOD. This means that at different wavelengths, different AOD values will produce different radiative effects, i.e. for smaller particles the radiative effect will be higher at 355 nm than 532 nm.

According to Gu et al. (2003), the database also takes into account the effect of water vapour (available from the standard atmosphere atmospheric profile) on aerosols. We performed two simulations: "control", where the aerosols were excluded and "direct", where the individual aerosol species were included. The net radiative effect is obtained as the "direct" effect of aerosols minus the "control" simulation ("direct–control"). For both experiments, the mid-latitude USSA1976 standard thermodynamics profile was used. The accuracy of the aerosol net forcing is also provided using a Monte Carlo technique: FLG model is run 30 times for each aerosol extinction profile on a same number of profiles obtained from the actual extinction profile plus or minus a random error which has a magnitude lower than the random error on the extinction profile.

3. Results

Figures 2 and 3 show the net radiative effect at the Top of the Atmosphere (TOA) and surface (SFC) for dust extinction profiles retrieved at 355 nm (green) and 532 nm (blue).

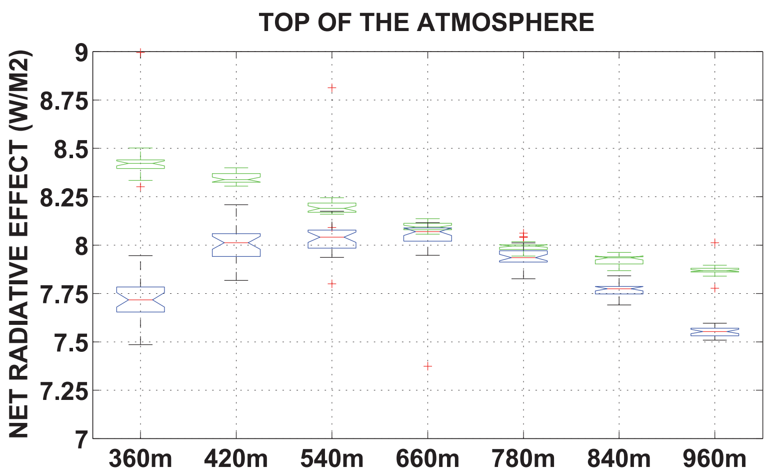

Fig. 2. Net Radiative Effect of an atmospheric dust layer detected by lidar measurement (532 nm blue, 355 nm, green) at the top of the atmosphere

It can be noticed that 532 nm profiles have typically lower signal-to-noise ratio than 355 nm (blue, see profiles in Fig. 1). This is reflected in larger whiskers in the boxplot (Fig. 2,

Fig. 3). The net radiative effect is different for each profile due to the smoothing technique that mostly changes the position and thickness of the dust layer in the atmosphere. At 355 nm, the smoothing is shifting the position of the layer towards the surface (see Fig. 1). For this reasons the net radiative effect is narrowing at TOA while growing at surface (Fig. 3).

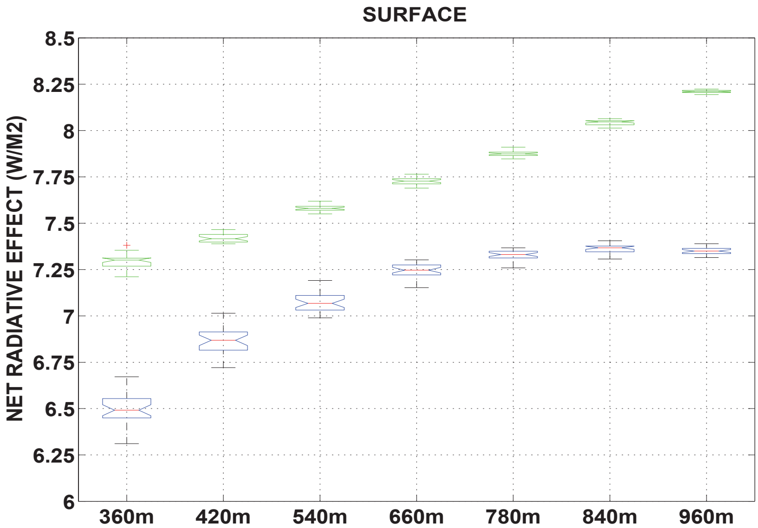

Fig. 3. Net Radiative Effect of an atmospheric dust layer detected by lidar measurement (532 nm blue, 355 nm, green) at the top of the atmosphere

At 532 nm (blue in Fig. 2, Fig. 3), the extinction profile is much more noisier than 355 nm, especially at the top of the dust layer. The smoothing technique in this case produces a non-linear response to the net radiative forcing with discordant effects with respect to the smoothing window length. At TOA, the largest differences in net radiative effect are of about 7% at 355 nm and 6% at 532 nm while at surface 12% for both wavelengths respectively.

4. Conclusions

We investigated the effects of smoothing applied on atmospheric extinction profiles retrieved by MUSA Raman lidar permanently deployed at CIAO, Tito Scalo, Italy, on net radiative effect both at surface and TOA produced by a dust layer calculated with the Fu-Liou-Gu radiative transfer model. The analysis put in evidence that the largest seen difference it is 12% between the adopted smoothing window lengths ranging from 360 m to 960m. This difference is due to the effect of smoothing on the atmospheric features of the original vertical lidar profile and should be taken into account the lidar data pre-processing if aerosol lidar products will be used to perform a radiative analysis.

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