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Observation of vertical variability of black carbon concentration in lower troposphere on campaigns in Poland

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HIGHLIGHTS

- Two measurement schemes for obtaining black carbon vertical profiles are proposed.
- Vertical profiles of black carbon were measured from unmanned aerial vehicles.
- Smog conditions in mountain valley where measured during hiking experiment.
- Measurements were conducted with micro-aethalometer.

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ABSTRACT

This study presents two methods for observation of black carbon (BC) vertical profiles in lower troposphere based on the micro-aethalometer AE-51. In the first method micro-aethalometer was carried by observer along trail on slope of mountain valley. Second method uses unmanned aerial vehicle as a platform for collecting data up to 1500 m above ground. Our study presents vertical profiles collected in and above Subcarphatian Wislok valley. Profiles measured on trial on slopes of Wislok valley, were collected during strong smog conditions during autumn/winter season, when BC concentration reached values above 60 μg/m^3. The smog intensive layer is usually close to the surface (up to 100 m) as a results of surface inversion and the mountain breeze circulation, which during the night transports air pollution emitted from houses toward the valley's bottom. Usually the vertical profiles of BC concentration show significant reduction with the altitude, however, some multilayered structures are also observed during night time inversion conditions. It has found that smog condition can develop in clean air mass, and in those cases local pollution has significant impact on the columnar aerosol properties. During such conditions the aerosol optical depth shows diurnal cycle which is rather not observed in the long-term data.

UAV flights in the lower troposphere were conducted during two sessions, one with clean polar air masses (BC concentration < 1 μg/m^3) and second with moderate aerosol conditions (BC concentration 1–5 μg/m^3). Profile of BC concentration shows stratification of absorbing aerosols in a shape of multi-layer structures similarly to the lidar/ceilometer signals.

1. Introduction

Black carbon (BC) plays important role in Earth's climate due to its influence on solar radiation and a set of complex interactions with various types of clouds and Earth's surfaces with different albedo (Bond et al., 2013). The complexity of those interactions, simplified descriptions in models and too few observations result in the fact that the issue of BC influence on climate still remains unclear (IPCC, 2013; Koch and Del Genio, 2010; Samset et al., 2014; Wang et al., 2014; Myhre and Samset, 2015).

The factor which has a major impact on radiative transfer and climate system is the vertical distribution of BC in the atmosphere

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(Samset and Myhre, 2011; Samset et al., 2013; Zarzycki and Bond, 2010; Cook and Highwood, 2004). Vertical profiles of strongly absorbing aerosols have much more significance for radiative forcing than vertical distribution of scattering particles. In the first approximation, vertical distribution of the non-absorbing aerosols has negligible impact on radiative forcing (Meloni et al., 2005). It is worth mentioning that vertical profiles of BC are crucial not only because of their direct effect on radiation, but they also contribute to semi-direct and indirect effects. For example, the presence of an absorbing aerosol below or above clouds layer could lead to completely different effects on weather and climate (Ban-Weiss et al., 2012; Koch and Del Genio, 2010; Podgorny and Ramanathan, 2001).

Small number of measurements of absorbing aerosols all over the world is related to the lack of reliable remote sensing methods to describe their quantity and distribution. The approach taken by AErosol RObotic NETwork (AERONET) and satellite retrieval is bound to rely on a substantial number of assumptions about aerosol parameters (physical, chemical, optical) and homogeneity of their composition (Levy et al., 2004; Dubovik et al., 2000). Algorithms used by AERONET are restricted only to a limited range of conditions such as clear sky cases, solar zenith angles higher than 50° and relatively high aerosol optical depth (AOD) of 0.4 at 440 nm (Arola et al., 2011). Additionally, all of widely used remote sensing methods deliver only column-integrated quantities. In the case of multi-wavelength lidars some information about vertical profiles may be retrieved (e.g. single scattering albedo), but the extent of uncertainties is usually too large for accurate radiative forcing estimation (Waquet et al., 2009).

In the face of many a weakness of remote sensing methods, in-situ measurements are necessary. Those were primarily carried out during full-scale airplane experiments (Wofsy and Team, 2011), however due to the high costs, methods involving smaller airborne platforms were proposed. Ramanathan and Carmichael (2008) presented results from an experiment on vertical profiles of BC and other aerosols in which he used an autonomous unmanned aerial vehicle (UAV) over the Indian Ocean. This type of experiment led to development of miniaturized sensors (Roberts et al., 2008; Corrigan et al., 2008) to be deployed as payload in UAVs. Together with the sensors, flight schemes of UAV's were developed and extended so that researchers could organize campaigns where multiple autonomous flying platforms were operated simultaneously to acquire data from different layers of atmosphere, located below, above and at the level of clouds (Ramana et al., 2007). Another method for profiling lower atmosphere aerosols and collecting vertical profiles of BC bases on tethered balloons as platforms for carrying sensors (Ferrero et al., 2010, 2011).

What motivated our study is the deficit of BC profiles measurements over Europe, as they were collected mostly only in Southern Europe by Ferrero et al (2012, 2014). Poland, located in the center of Europe, is especially interesting for study of vertical profiles of absorbing aerosols, as it is there where air masses from different origins (polar from North, continental from East, African from South and Atlantic from West) are registered and where AOD are relatively high. BC concentrations during late autumn and winter are high there due to local emissions from combustion of wood and coal for household heating (Zawadzka et al., 2013). Those local emissions and complex orography Carpathian Mountains and their valleys with their specific local circulation result in large horizontal and vertical differences of BC concentration. During winter season, extremely high BC concentrations occur in the valleys, creating specific smog conditions.

In this study, we present vertical profiles of BC collected by two simple, low-cost and easily re-applicable methods, which use micro-aethalometer. In the first one, the profiles were measured during hikes from bottom to the top of one of the Subcarpathian valleys, along a path on slopes of the valley. The second method involved micro-aethalometer carried by light, electric-powered and semi-autonomous UAVs, with total take-off mass below 7 kg. Apart from the profiles, we were also focused on meteorological conditions and additional data on aerosols' single scattering properties, acquired from remote sensing devices (AOD, range corrected signals from lidars). The place of measurements, elevation model and relation of collected vertical profiles to the land form is described in Section 2. Next section is dedicated to campaign instrumentation, with information on ground sensors, flying platforms and sensors included. Data collection schemes and data processing are explained in Section 4. Sections 5 and 6 present the results that (1) describe vertical structure of BC concentration during smog conditions over Strzyzow valley, (2) focus on measurements from flight campaigns held at SolarAOT station above Strzyzow valley. Final thoughts and a brief summary are presented in the Section 7.

2. Location

Most measurements were conducted in the surroundings of SolarAOT field station, located in South Eastern Poland in Podkarpackie region (49.8786°N, 21.8613°E, 443 m a.s.l.) (Fig. 1a). This site is located 25 km south from capital of the state, Rzeszów (population: 180 000), and 5 km east from Strzyzow (county capital, population: 8500). The nearest buildings are 200 m away and 30 m below the station facilities, while the nearest local road is about 300 m away. The station is located on a hill, around 200 m above the bottom of Wislok river valley, surrounded by fields and forests, far away from industry and urban areas. In the perimeter of 10 km, Strzyzow is the only village with population higher than 700 inhabitants. In this area, man-made pollution comes mainly from road transportation, heating of water and houses (during autumn and winter) and from burning of organic matter on agriculture fields (between spring and autumn). The SolarAOT station is a part of AErosol RObotic NETwork (AERONET), Poland-AOD aerosol measurement network (http://www.polandaod.pl/). This site is equipped with aerosol in-situ and remote sensing instruments, radiation sensors, as well as weather devices. This location allows for using the measurements from station as a source background data for aerosol and climatic studies.

Fig. 1b presents vertical profile along the transect, from SolarAOT station located at the peak of a hill above Wislok valley to the lower area, Strzyzow station, where a part of the experiment was made.

Part of the experiment was conducted in the north slopes of Wislok valley in the area of Strzyzow town. The profile of the trail (Fig. 1c) has 120 m difference of altitude between the highest and lowest point and its length is 2.2 km. The lowest point of the trail is located almost in the center of the town, on the level of Wislok river. The highest point is on the southern slope of the hill surrounding the city from the north. In the upper part of the trail, where there are only single houses, most of potential pollution sources are located only in the area of the first 70 m of trail altitude.

3. Equipment

The data on vertical distribution of absorbing aerosols was supported by ground-based measurements: columnar aerosol optical properties from sun photometer, range corrected profiles from lidar, ceilometer and in-situ ground measurements of BC mass concentration, as well as aerosol single scattering properties.