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Editorial

Black Carbon in Atmosphere: Instrumentation, Chemical-Physical Behavior, Human Health Implications

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Abstract: Carbonaceous aerosol is the most significant contributor to the particulate matter in the atmosphere. It is composed of a complex mixture of compounds containing carbon atoms and is usually classified into two main fractions: black carbon (BC) and organic carbon (OC). BC is essentially a primary pollutant emitted in particulate form, and its chemical stability excludes chemical transformations during its lifetime in the atmosphere. Therefore, it should be considered a tracer for the long-range transport of anthropogenic air pollution. OC has both primary and secondary origins: primary OC particulate is formed during combustion and emitted mainly as submicron particles, whereas secondary OC particulate originates from gas-to-particle conversion processes. This SI aims to deepen the state of the art on this important topic ranging from theory to the development of new instrumentation useful for this determination, to the chemical–physical problems in the atmosphere, to the health and toxicological implications related to exposure to these pollutants as well as papers showing historical data series both in urban, rural, and remote areas are also appreciated.

Keywords: black carbon; organic carbon; carbonaceous aerosol; instrumentation; thermal properties; optical properties; chemical speciation; cultural heritage; photochemical pollution; human health

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Carbonaceous particles (or Total Carbon, TC), the largest contributor to atmospheric particulate matter (PM), are composed of two main fractions, Black Carbon (BC) and Organic Carbon (OC) [1,2]. BC (or elemental carbon, EC, or soot) has a graphitic-like structure and is essentially a primary pollutant emitted in particulate form, and its chemical stability excludes chemical transformations during its lifetime in the atmosphere. OC represents a large variety of organic compounds, e.g., aliphatic, aromatic compounds, alcohols, acids, etc., and has both primary and secondary origin: primary OC particulate (OC_{prim}) is formed during combustion and emitted mainly as submicron particles [3], whereas secondary OC particulate (OC_{sec}) originates from the gas-to-particle conversion of volatile organic compounds in the atmosphere, either as result of the condensation of low vapor pressure organic compounds or from the physical and chemical adsorption of gaseous species in aerosol surfaces [4]. Through the coagulation processes, these primary particles will spread throughout the aerosol size distribution and accumulate in sizes ranging between 0.05 and 0.5 µm in radius as other fine particles where atmospheric residence times have their maximum. Therefore, in long-range transport, the studies of the size of carbonaceous material distribution and how it changes over distance from the source area will be of considerable interest. The BC/OC ratio in the urban area aerosol in the presence of known anthropogenic sources may provide information to develop strategies for controlling particulate carbon emission reduction [5]. Describing the spatial–time evolution of urban pollution is a challenging task [6,7]. This is due to the simultaneous presence of emissions and physical–chemical transformation processes coupled with turbulent diffusion and advective processes.

The use of such methodology is important for different reasons: it is fundamental for the evaluation of atmospheric pollution from combustion processes; it can be used as a specific index of car traffic pollution; it is very significant for the protection of human health due to the high permanence of the carbonaceous particles in the atmosphere and the numerous chemical–physical transformation processes that they can undergo in the atmosphere [8]; the separation between BC and OC is of fundamental importance for the study of pneumoconiogenic effects and, more generally, for the toxic effects and the study of the mechanisms of formation of photochemical pollutants.

Submissions to this Special Issue closed on January 2022, and it was viewed by 7092 scientists. It is formed of six papers that highlight different topics. Each paper is full of data (some papers display supplementary material showing the dataset), important and novel observations, and interesting discussions that can provide new ideas and stimulate future studies. In this way, the Guest Editor would like to thank all of the participants and briefly illustrate the different manuscripts.

Tan et al. [9] published the first paper in this SI: they dealt with the effect of BC in the atmosphere on the formation of surface ozone. They used the concentration levels of different pollutants (BC, O_3, $PM_{2.5}$, PM_{10}, CO, NO_2, and SO_2) as well meteorological data to interpret the (diurnal and) daily correlation between BC and ozone (CBO) during the period from 2015 to 2018 in Nanjing, China. The main findings reported by the authors show a significantly positive CBO proportion ($0.5 < CBO < 0.8$) in summer, 38.7% on average, nearly twice of that in the other seasons (19.2%). Further, the analysis of the pollutant concentration distribution under different CBO levels showed that the average BC, $PM_{2.5}$ and NO_2 concentrations under positive CBO were lower than those under negative CBO. The authors noted that the surface ozone began to ascend when CBO was up to 0.2, with $PM_{2.5}$ and NO_2 decreasing and BC steady. Ezani et al. [10] reported an interesting paper investigating the characteristics and the source apportionment of BC in a suburban area in Malaysia. In particular, they characterized the concentrations and diurnal profiles of BC and its source apportionment in a suburban area of Klang Valley from January to May 2020. Further, they investigated the association between BC with other air pollutants (NO_2 and $PM_{2.5}$), traffic mobility data and meteorological variables. The authors determined the mean concentration of BC before the MCO, 2.34 μg m^{-3}, and during MCO, 1.45 μg m^{-3}, with a decrease of 38%. Further, the BC was found to be strongly correlated with NO_2 ($R = 0.71$), another marker of traffic emission, but less strongly with $PM_{2.5}$ ($R = 0.52$). The authors underlined that this paper was the first study of BC and its source apportionment in Malaysia. The same authors stated that future research is necessary to focus on how spatial and temporal variations from combustion-related emissions (traffic and biomass burning) can cause health effects. Finally, according to the authors, another interesting peculiarity of this paper concerns the fact that the measurements coincided with the implementation of a Movement Control Order (MCO) in Malaysia in response to COVID-19, providing an unexpected opportunity to analyze the impact of the MCO on BC. Zhao et al. [11] focused their attention on BC concentration and particle size characteristics in snow during the winter of 2015 in Beijing, China. For this aim, they used the Single Particle Soot Photometer (SP2) method, which is a method developed by McConnell et al. [12] able to directly measure BC particles, with a detection efficiency of more than 90%, effectively eliminating the interference of sample filtration, OC, carbonate, and other factors. They achieved the highest BC recovery rate under the ultrasonic mode because the large particles produced by the BC condensation during the storage process are broken by the ultrasonic wave. Further, the average BC concentration in snow in Beijing is 82 ng mL^{-1} (ranging between 62.9 ng mL^{-1} and 210.6 ng mL^{-1}), whereas the BC particle size in snow and ice is mostly concentrated in the range of 70–400 nm. Finally, the BC concentration in snow is highly susceptible to meteorological conditions and local pollution levels. Leyte-Lugo et al. [13] investigated the BC concentration variations in two sites in Mexico. They monitored the BC concentrations in two sites in Mexico in 2017, Juriquilla (semi-urban site) and Altzomoni (high-altitude site); after, they compared the data with those found by one of the authors in

2015 to evaluate the changes in BC concentration between the two years. The measurements were carried out employing a photoacoustic extinctometer using a modulated diode laser (1500 Hz) to simultaneously measure the in situ light absorption (B_{abs}) and scattering (B_{scat}) of aerosol particles. Basically, data analysis shows an increase in annual BC concentrations in 2017 compared to 2015 at two sites in Mexico (12% in Juriquilla and 114% in Altzomoni). On the other hand, the highest BC concentration was observed during the dry–cold season due to the accumulation of atmospheric particles in the boundary layer, and the season with the lowest concentration was the rainy season. The authors stated that the results are worrying because BC concentrations increased regardless of the site analyzed, even though the values are lower than those reported for other urban and semi-urban sites in Mexico. Caponi et al. [14] presented a new instrument, GIANO_BC$_1$^{TM}, to sample the airborne PM while monitoring the BC atmospheric concentration. This instrument, designed, built, developed and patented by the authors themselves, is compliant with the CEN standard and is based on the coupling of a standard low-volume PM sampler with an optical module: this occurrence allows the simultaneous determination of BC and PM as well as the related correlation. Finally, the last paper, by Chen et al. [15], dealt with the important topic regarding the BC emissions and associated health impacts of gas flaring in the United States: their starting point was that the gas flaring from oil and gas fields was a significant source of BC emissions. This PM component damages health and warms the climate. First, the authors stated that approximately 17.2 billion cubic meters of gas flared from upstream oil and gas operations in the United States in 2019: this amount corresponded to 16,600 tons of BC emitted, meaning that gas flaring is a significant BC source. The authors applied three different models to determine the emissions: their conclusions reported that gas flaring reduced the direct venting of methane and other hydrocarbons, but the related BC emissions were harmful and deadly. The associated mortalities in 2019 in the United States were probably dozens, with uncertainty in the estimates deriving from the uncertainty in the BC emission factor determination. The authors suggested that models could be useful tools to estimate the impacts of numerous dispersed emissions sources. However, other studies were necessary to estimate the knowledge of the BC emission rate from flares.

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