Comparison of atmospheric particle concentration measurements using different optical detectors

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***Abstract*—Simultaneous measurements of aerosol number concentrations, size distributions and mass concentrations were performed between autumn 2013 and winter 2014 at an urban background site in Lecce (Italy). These were carried out by using different optical aerosol detectors: an OPC GRIMM (mod. 1.109), an OPC FAI (Multichannel Monitor), an optical photometer Mie pDR-1200. A good agreement (R^2=0.99 and R^2=0.98) was found between particle number concentrations measured by FAI and GRIMM in accumulation (0.28÷0.90μm) and coarse (1.10÷10μm) modes, even if FAI showed large number concentrations in coarse size range with respect to GRIMM. PM10, PM2.5 and PM1 mass concentrations calculated from optical devices were compared with gravimetrically and β–ray measurements.**

***Index Terms*—OPC, photometer, size distributions, β–ray attenuation.**

I. Introduction

Atmospheric aerosol particles are an important component of ambient air because they have an important role in human health, air quality and climate.

The physical and chemical properties of particulate matter are important for estimating the magnitude of their effects. Both PM mass concentration and size distribution should be measured to provide a comprehensive assessment of air quality and to investigate links between air pollution and health effects [1]. Consequently, several approaches to estimate these parameters have been developed in the last years. Real time measurement techniques, based on light scattering, can provide both the number and the mass concentration of particles in different size range with high time resolution. These devices are based on the fact that when a particle passes through a beam of light, some of the light is scattered. The relationship between particle size and scattered intensity is defined for spherical particles by Mie theory. Particle number can be determined simply by counting the pulses of scattered light reaching the detector. However, it is possible to obtain much more information using optical scattering techniques than just number. The intensity of scattered light such as the spatial scattering pattern are related to the size and shape of the scattered particles respectively so those are other parameters which can be measured with optical instruments [3]. Data analysis by the aerosol optical detectors is relatively fast and this methodology, coupled with meteorological parameters, allows to evaluate spatial and temporal variations in particle concentrations providing reasonable approximations of real exposure in various situations and sites [3].

In the framework of the I-AMICA project, it was carried out an inter-comparison campaign among optical aerosol samplers used in air quality applications. Limited literature data are available concerning the comparison of different light aerosol detection techniques. In this work we present the results of the inter–comparison of two optical particle counters, one photometer and a β–ray attenuation sampler (SWAM Dual Channel for PM2.5 and PM10) examining their performance and comparability in urban background aerosol conditions. The performances test was based on inter-comparison of particle number concentrations, size distributions, and capabilities to evaluate particle mass concentrations.

II. Experimental

A. Site Description

Measurements were taken between 14th November 2013 and 6th February 2014 on the roof of the ISAC institute, about 13m above the ground, at the CNR research area of Lecce (Italy). The site is located inside the University Campus (N 40° 20' 10.8", E 18° 07' 21.0" WGSA), at about 3.5 km SW of the town of Lecce and can be considered an urban background site [4]. During the experimental campaign meteorological data (temperature, air pressure, relative humidity, and wind speed and direction) were collected by a Vaisala automatic weather station located beside the used instruments. Meteorology during the sampling period was characterized by the typical Mediterranean climate with mild autumn-winter seasons. The daily average temperature varied in the range of 5.0°C to 16.7°C and the daily average relative humidity (RH) from 52% to 93% with very high values especially during the night-time. Some periods of fog were identified during the experimental campaign. The conditions of high RH or fog are very challenging for optical detection of aerosol given their influence on size and optical properties of particles.

B. Instruments Setup

Measurements were performed by an OPC GRIMM (mod. 1.109) which classifies particles in 32 size intervals (diameters in the 0.25÷32μm range), an OPC FAI (Multichannel Monitor) which classifies particles in 22 size intervals in the 0.28÷10μm range and an optical photometer Mie pDR-1200 (Thermo

Electron Corp.) used in active sampling and equipped with a 2.5 µm cut-off cyclone at the 4 l/min flow-rate used for measuring real-time concentration of PM2.5. The FAI and GRIMM OPCs operate respectively with a 1 L/min and 1.2 L/min volume flow rate. The instruments were operated at 1 min temporal resolution.

The main differences between the two instruments are the used laser diode (λ= 655 nm and 40 mW in OPC GRIMM while λ= 630 nm and 35 mW in OPC FAI) and the different sample treatment at the inlet. The conditioning of the sample passing through the measurement chamber is a fundamental key in optical sensors. The RH value is kept low using dilution (1:3) with clean dried air and a smart heater, placed in the diluter along the mixing chamber, is used only if needed in FAI OPC. The GRIMM OPC is equipped with a sample pipe with integrated heater that is always on. Conversion from number to PM mass concentration, in both OPCs, is performed using the integrating algorithms provided by the constructors of the instruments.

PM10 and PM2.5 mass concentration measurements were performed by gravimetric method and by β–ray attenuation method using a low volume (2.3 m^3/h) FAI SWAM 5a-Dual Channel Monitor. Aerosol samples were collected on 47 mm quartz fiber filters (Whatman QMA) which were pre-fired (500°C for 2 hours) and weighted pre and post sampling.

III. Results

A. Comparison of number particle concentrations

Daily particle concentrations measured by FAI and GRIMM OPC were compared considering accumulation mode (Na= 0.29-0.90µm in GRIMM and 0.28-0.90µm in FAI) and coarse mode (Nc= 1.15-11.25µm in GRIMM and 1.10-10µm in FAI) concentrations. As the two OPCs detect particles in different size range, only 0.29÷11.5µm size range of GRIMM were considered. A very close resemblance in correlation coefficients and regression line slope obtained considering accumulation and total mode (not shown) indicate that the fine fraction contributes for more than 95% of the total number concentration [5]. In Figs.1a-b are plotted daily accumulation and coarse mode number concentrations of FAI versus GRIMM. A very good correlation coefficients (R^2=0.99 and R^2=0.98) was obtained for Na and Nc respectively. The regression line slopes (0.88 and 1.79) suggest that GRIMM, on average, detects about 10% more fine particles than FAI while the last one counts higher number concentrations than GRIMM in coarse fraction. The difference in the estimation of coarse fraction is clearly reflected in number size distribution as showed in Fig. 2 which reports the comparison of corresponding GRIMM (black dots) and FAI (red dots) number size distribution, averaged over the entire study period.

This discrepancy between the two instruments might be due to the consequently different response of the instruments as they operate at different laser wavelengths as well as to possible coincidence errors at high particle concentrations [6]. Given that the measurement period was characterised by high RH values it is also possible that the different samples treatment at the inlet could influence the measurements.

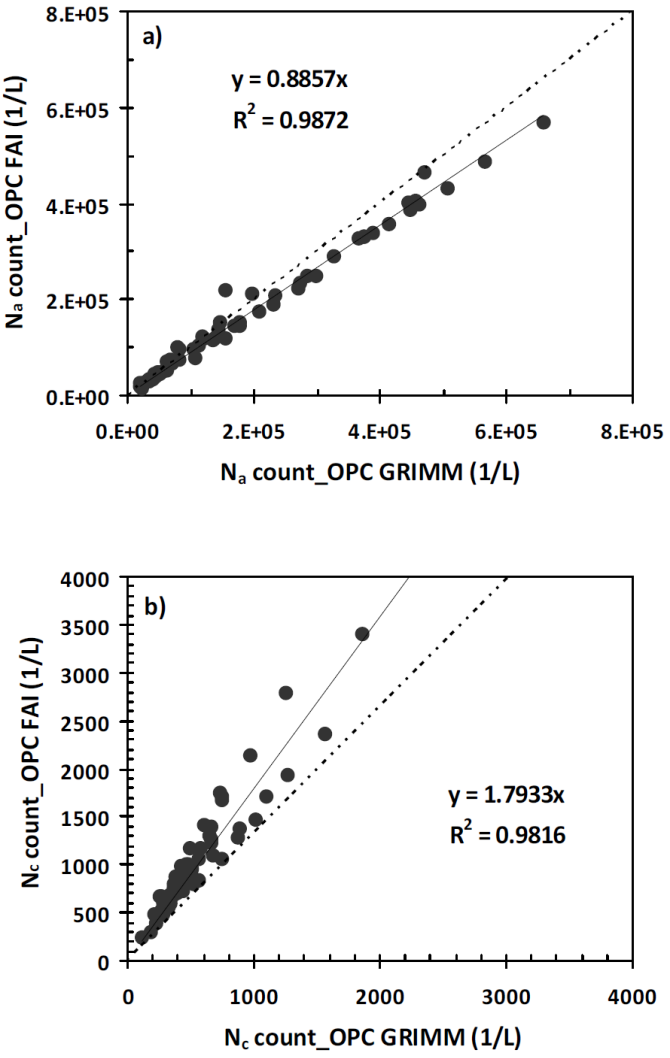

Fig. 1. a-b: Scatter plot of daily accumulation and coarse mode concentrations between the two OPCs. Regression lines are also reported.

Diurnal trends of aerosol number concentrations (Figs. 3ab), averaged over the entire sampling campaign, were compared considering accumulation and coarse fractions separately. Temporal variations of data obtained at 30 minute intervals revealed a well-defined diurnal pattern with relatively higher values during the night and early morning periods, followed by a gradual decrease in the daytime, particularly evident in accumulation fraction (Fig.3a). Diurnal trends of aerosol number concentrations is very similar in both OPCs even if the concentration levels of particles are much more similar in fine fraction with respect to coarse fraction where FAI shows higher number concentrations than GRIMM. In coarse fractions the traffic contribution is clearly visible early in the morning (around 7:00 AM) and evening (around 19:00) with a larger extension in time on the evening peak. Looking at the fine fraction it is only slightly visible in the morning but

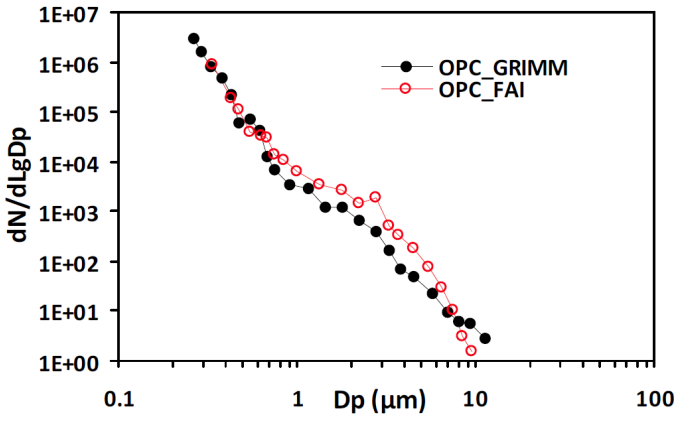

Fig. 2. Comparison of number size distributions measured by the two OPCs.

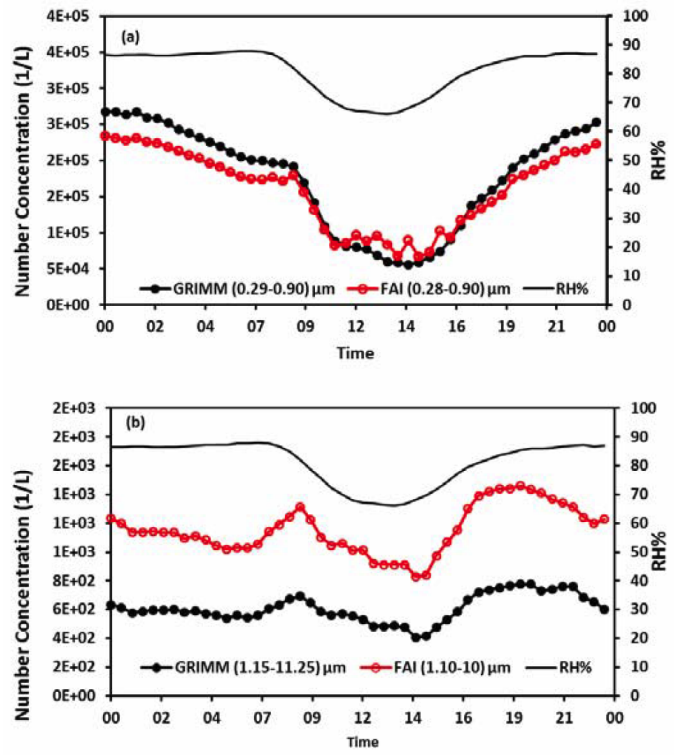

Fig. 3. Comparison of diurnal trend of fine (a) and coarse (b) number concentrations measured by the two OPCs.

essentially not relevant in the evening.

B. Comparison of mass concentrations

During the sampling campaign daily PM10 and PM2.5 mass concentration measurements were performed by gravimetric and β–ray methods. A comparison of the results obtained with the two methods is reported in Figures 4a-b for PM10 and PM2.5. The two methods gave very similar results (R^2= 0.97 for PM10 and R^2= 0.98 for PM2.5) in both fractions showing that β–ray data could be used as a reference in this intercomparison exercise. Figures 5a-e give the comparison of the mass concentrations obtained from the different optical

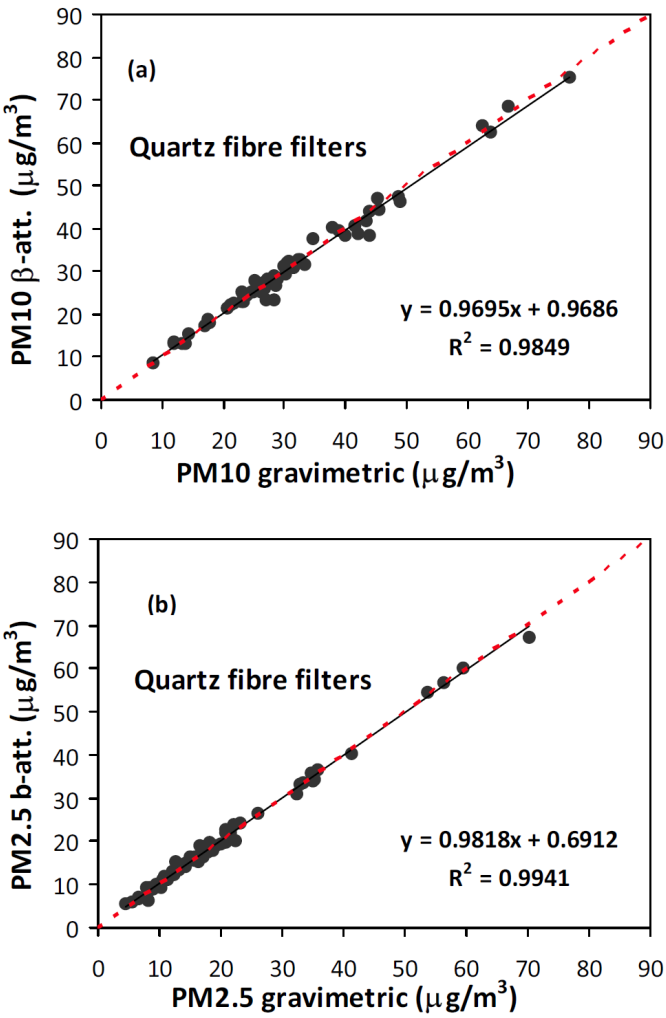

Fig. 4. Comparison of PM10 (a) and PM2.5 (b) concentrations measured with the gravimetric method and with the SWAM instrument.

detectors and the SWAM device relative to daily PM10 (a-b), PM2.5 (c-d-e). Figure 5f reports the inter-comparison of daily PM1 concentrations measured by the two OPCs.

A good agreement between GRIMM OPC and SWAM is found both in PM10 and PM2.5 fractions respectively as evidenced by the correlation coefficients (R^2=0.76 and R^2=0.97) and the regression line slopes, 1.06 and 1.07 (Figs 5ab). FAI OPC instead showed a larger scatter in both datasets PM10 and PM2.5 mass concentrations.

During the sampling campaign were often recorded high values of relative humidity which could have influenced the optical measurements cite6. Therefore, to PM2.5 daily mass concentrations measured with the pDR-1200 photometer was applied a polynomial function [7] to correct the effects due to high RH (RH¿70%). The comparison between pDR-1200 and SWAM revealed greater discrepancy (an underestimation of pDR-1200) with respect to SWAM measurements that could be due to the different operating principle of the instruments. Even if both use scattered light to detect aerosol the pDR-1200 photometer uses volume scattering without counting single

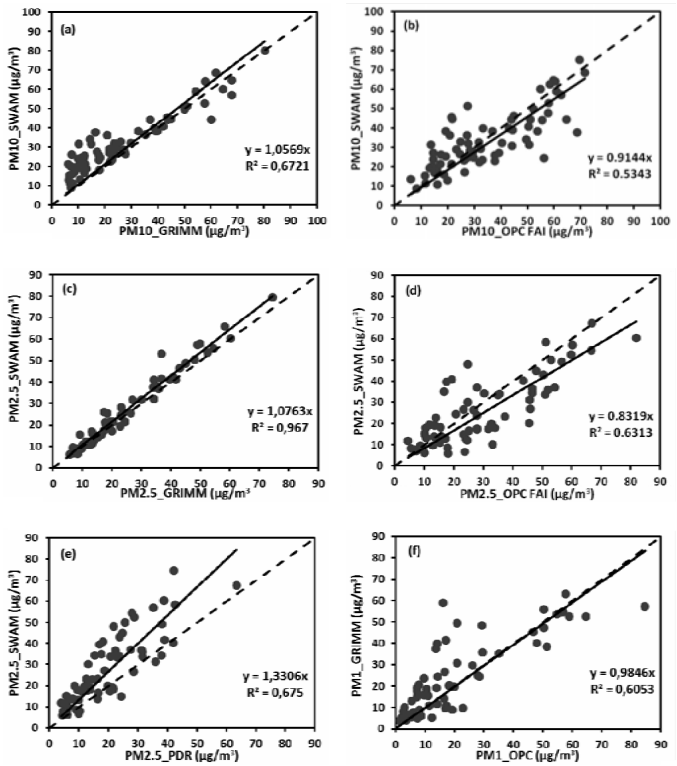

Fig. 5. Scatter plot of GRIMM and FAI versus SWAM relative to PM10 (a-b) and PM2.5 (c-d), pDR-1200 versus SWAM (e) and GRIMM versus FAI (f) relative to PM2.5 and PM1 respectively. Regression lines are also reported.

particles with classification of their size. This implies that it is likely more sensitive to the optical properties and to chemical composition of aerosol with respect to the OPCs. In other sites the comparison between the pDR-1200 photometer measurements and the gravimetric measurements showed a better correlation [8]. The comparison between OPC and GRIMM showed a relatively larger scatter in PM1 fraction compared to that observed on particle number concentration in the accumulation fraction. The diurnal trends of mass concentrations averaged over the entire sampling campaign (not shown) showed a similar pattern between the different instruments in all PM fractions with a well-defined diurnal variation similar to that observed for the number concentrations.

IV. Conclusions

A comparison campaign among different optical aerosol detectors (two optical particle counters and one photometer) were conducted between autumn 2013 and winter 2014 in an urban background site in Lecce (Italy). Number concentrations, size distributions and particle mass concentrations were compared to test the efficiency of samplers in terms of particle counting in the respective size ranges such as their suitability to measure PM mass concentrations. A good correlation was found between GRIMM and FAI OPC related to daily values of accumulation (Na) and coarse (Nc) mode concentrations. The results obtained suggest that GRIMM on average detects 10% more fine particles than FAI while in coarse fraction FAI counts higher number concentrations than GRIMM. Measurements of 24h PM mass concentrations were compared with measurements performed by gravimetric and β–ray methods. Good agreement between GRIMM and SWAM is found both in PM10 and PM2.5 fractions while FAI showed higher PM10 and PM2.5 mass concentrations probably due to the overestimation of the coarse particles number. The pDR- 1200 photometer revealed greater discrepancy respect to SWAM measurements underestimating PM2.5 mass concentrations compared to SWAM. Diurnal trends of aerosol number concentrations and PM mass concentrations showed a similar behavior with a well-defined diurnal variation with relatively higher values during the night and early morning followed by a decrease in the daytime. This trend could be attributed to the dynamic of atmospheric boundary layer as well as to high RH values in nocturnal conditions.

V. Acknowledgment

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