Atmospheric Environment 97 (2014) 486–492

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Technical note

Development of a polarization optical particle counter capable of aerosol type classification

Hiroshi Kobayashi [a,*], Masahiko Hayashi [b], Koichi Shiraishi [b], Yoshinobu Nakura [c], Takayuki Enomoto [d], Kazuhiko Miura [d], Hiroshi Takahashi [e], Yasuhito Igarashi [e], Hiroaki Naoe [f], Naoki Kaneyasu [g], Tomoaki Nishizawa [h], Nobuo Sugimoto [h]

[a] *University of Yamanashi, 4-4-37 Takeda, Kofu 400-8510, Japan*
[b] *Fukuoka University, 8-19-1 Nanakuma, Jonan-ku, Fukuoka 814-0180, Japan*
[c] *Yamanashi Gijyutsu Kobo, 595-2 Kuruwada, Minami-Alps 400-0311, Japan*
[d] *Tokyo University of Science, 1-3 Kagurazaka, Shinjuku-ku, Tokyo 162-8601, Japan*
[e] *Meteorological Research Institute, 1-1 Nagamine, Tsukuba 305-0052, Japan*
[f] *Japan Meteorological Agency, 1-3-4 Otemachi, Chiyoda-ku, Tokyo 100-8122, Japan*
[g] *National Institute of Advanced Industrial Science and Technology, 16-1 Onogawa, Tsukuba 305-8569, Japan*
[h] *National Institute for Environmental Studies, 16-2 Onogawa, Tsukuba 305-8506, Japan*

HIGHLIGHTS

- A polarization optical particle counter (POPC) was developed.
- Classification rule for aerosol types was determined from the pulse height and polarization ratio.
- POPC is suitable for Asian dust monitoring.
- POPC-measured air pollution concentration correlated with black carbon particles.

ARTICLE INFO

Article history:
Received 4 September 2013
Received in revised form
21 March 2014
Accepted 2 May 2014
Available online 4 May 2014

Keywords:
Polarization
Particle shape
Mineral dust
Aerosol type
Optical particle counter

ABSTRACT

We developed a polarization optical particle counter (POPC) for measuring the concentrations of aerosol types, which were classified using polarization information from particle-scattered light. Polarization sensors that detect P and S polarization components of scattered light were placed at a scattering angle of 120°. The polarization ratio is calculated as the ratio of the S component to the sum of the S and P components, and it is used to help distinguish proposed aerosol types. The POPC field observation was conducted in Fukuoka, located in the western part of Japan, in 2012. The classification rule for three aerosol types (mineral dust, air pollution, and sea-salt particles) was determined empirically on the basis of measurements during typical conditions dominated by each aerosol type. The mass concentration of each aerosol type was estimated from the POPC measurement with some assumptions. The results indicate independent seasonal variation in each aerosol mass concentration. Using black carbon as an indicator of anthropogenic aerosols, we show a correlation of 0.770 with our estimated pollution aerosol type.

1. Introduction

Optical particle counters are widely used for continuous aerosol particle monitoring because of their ease of operation and relatively low cost (Chun et al., 2001; Iwasaka et al., 2003; Kim et al., 2004). These devices measure light scattered from an individual aerosol particle illuminated by a laser beam. The aerosol number concentration is determined from the number of scattered light pulses, while the aerosol particle size is determined from the pulse height. A general optical particle counter represents the aerosol number concentration in discrete size bins. However, these particle counters cannot distinguish between different aerosol types (i.e., Asian dust versus anthropogenic pollution). When the incident light is polarized, the polarization properties of light scattered by a particle

---

[*] Corresponding author.
E-mail address: kobachu@yamanashi.ac.jp (H. Kobayashi).

http://dx.doi.org/10.1016/j.atmosenv.2014.05.006
1352-2310/© 2014 Elsevier Ltd. All rights reserved.

can be used to determine the particle's shape. For example, if the particle is spherical, the particle-scattered light has the same polarization plane as the incident light. Conversely, non-spherical particles depolarize the scattered light, resulting in a decrease in the original polarization and an increase in polarization in the perpendicular plane. Previously, polarization properties of light scattered by non-spherical particles have been measured (Muñoz and Hovenier, 2011; Perry et al., 1978; Volten et al., 2001; West et al., 1997). Recently, Glen and Brooks (2013) measured optical properties of dust using the Cloud and Aerosol Spectrometer with Polarization (CASPOL).

In this study, we developed a bench-top polarization optical particle counter (POPC) that measures the P and S polarization components of particle-scattered light to individually monitor the abundance of each aerosol type, especially mineral dust such as Asian dust. The P component is horizontal (with respect to the plane of the scattering angle), and the S component lies in the vertical plane. Each aerosol particle type is classified using a combination of the particle's shape information estimated by measuring each polarization component and the particle's size. To establish the classification rule for each aerosol type, POPC measurements were taken under various atmospheric conditions. Further, we report the time series for the mass concentration of each aerosol type.

2. Methods

2.1. Design of the polarization optical particle counter

Fig. 1 shows a schematic diagram of the POPC. The optical geometry was determined using a simulation based on the Mie scattering theory for spherical polystyrene latex beads. Three parameters – the acceptance angle of the polarization detector, the plane of the incident light's polarization, and the scattering angle – were considered. The simulation results are described in Section 3.1. The light source is a 50-mW semiconductor laser of wavelength 780 nm operating in continuous-wave mode. The width and height of the laser spot directed at the sample airflow were 0.8 mm and 0.03 mm, respectively. The laser beam covered the entirety of the airflow. An arrow indicates the polarization plane in Fig. 1. The detector, placed at a 60° scattering angle, detects the pulse height for the particle-scattered light to determine the particle size. The size was calibrated using standard particles composed of polystyrene latex beads. Therefore, the particle size is the effective diameter of a spherical polystyrene latex bead. Four size bins (with ranges 0.5–1.0 μm, 1.0–3.0 μm, 3.0–5.0 μm, and 5.0–10.0 μm) were used. Light scattered at 120° was separated into P and S components using the polarizer, and each component signal was detected at each sensor. These sensors consist of photodiodes. To cover a wide range of output signals, two different gain amplifiers were used for the 60° detector. These output signals were digitized using a high-sampling-rate digitizer (U2531A, Agilent, Inc.) connected to a personal computer via USB. The sampling rate and the resolution were 2 megasamples per second and 14 bits, respectively. Fig. 2 shows an example of each pulse signal. The half-value width of the 60° detector's output signal was 35 μs. The sampling rate satisfied the conditions necessary for pulse signal processing, and the digitized data were processed using LabVIEW (National Instruments, Inc.). The pulse signal was sampled in 1 s, and the data transfer to the computer and the signal processing required about 1.2 s. After repeating this cycle for 5 min, the processed data were stored on a storage device. The repeat count is typically about 130, and therefore the actual sampling time is essentially 130 s in 5 min. The depolarization ratio, which is generally used for Lidar measurements, is the ratio of the S component to the P component. However, the value calculated from the POPC measurement diverged in the smaller size bins because the pulse height was close to the digitizer's noise level, and its value approached zero; division by a value approaching zero results in divergence. Therefore, we used the polarization ratio, which is defined as the ratio of the S component to the sum of both components. To avoid coincidence loss, the air sample (flow rate = 0.4 LPM) was diluted with filtered clean air (flow rate = 0.6 LPM). If the aerosol number concentration increases up to 150,000 particles per liter and the particles are homogeneously distributed, the detector is expected to measure 1000 pulses per second, which means there is one pulse every 1000 μs. Because the full pulse width shown in Fig. 2 is less than 200 μs, the POPC has sufficient capacity to prevent coincidence loss for the assumed high concentration. The total sampling volume in one cycle of data processing is about 0.9 L. If the concentration of coarse particles is only 10 particles per liter, the POPC is expected to count nine pulses in 5 min. To prevent particle adhesion from contaminating the optical system, the sample air was wrapped in a filtered sheath airflow with a flow rate of 1.0 LPM.

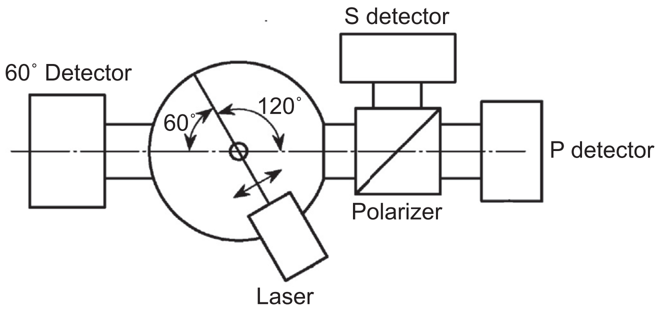

Fig. 1. Schematic diagram of the polarization optical particle counter (POPC).

2.2. Observation

The POPC observations were conducted at Fukuoka University (33.550°N, 130.364°E) in Fukuoka, Japan. The measurement began on February 22, 2012. The ambient air was sampled from an inlet

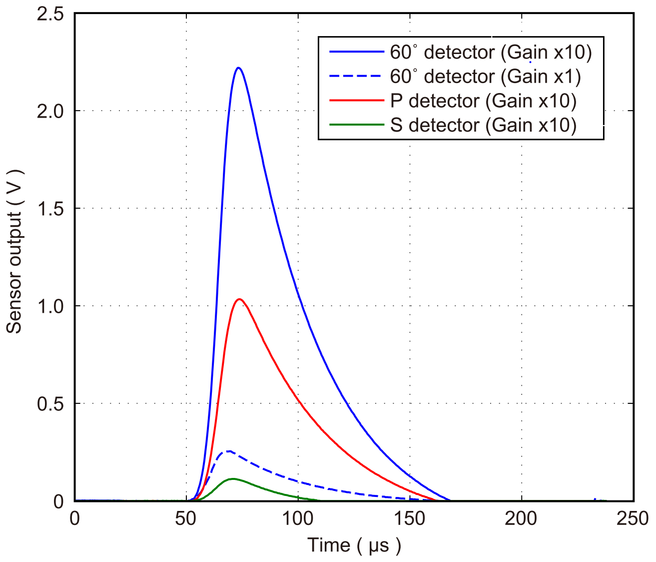

Fig. 2. Signal waveform examples for each sensor output: the 60°, the P-component, and the S-component detector. The output signal of the 60° detector is shown with two different amplifier gains of one and ten.