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Evolution of size-segregated aerosol mass concentration during the Antarctic summer at Northern Foothills, Victoria Land

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HIGHLIGHTS

- First direct gravimetric measurements of PM_{10} fractions in Antarctica.
- Tri-modal distribution of size-segregated aerosol mass fractions.
- Seasonal variations of sub-10 μm fractions and total measured PM_{10}.

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ABSTRACT

Within the framework of the Italian National Programm for Antarctic Research (PNRA), the first direct gravimetric measurements of size-segregated aerosol fractions were carried out at Faraglione Camp, ~3-km far from the Italian station "M. Zucchelli" (Terra Nova Bay, Ross Sea), during the 2014–2015 austral summer. A six-stage high-volume cascade impactor with size classes between 10 μm and 0.49 μm, and, in parallel, for comparison purposes, a PM_{10} high-volume sampler (50% cut-off aerodynamic diameter of 10 μm) were used. A 10-day sampling strategy was adopted. Aerosol mass measurements were carried out before and after exposure by using a microbalance specifically designed for the filter weight and placed inside a glove bag in order to maintain stable temperature and humidity conditions during weighing sessions. Measured atmospheric concentrations (referred to the "actual air conditions" of mean temperature of 268 K and mean pressure of 975 hPa) of size-segregated aerosol fractions showed the following values, given as size range, means (interquartile range): $D_p < 0.49$ μm, 0.33 (0.26–0.34) μg m^{-3}; 0.49–0.95 μm, 0.20 (0.19–0.24) μg m^{-3}; 0.95–1.5 μm, 0.16 (0.13–0.21) μg m^{-3}; 1.5–3.0 μm 0.075 (0.05–0.11) μg m^{-3}; 3.0–7.2 μm 0.12 (0.02–0.19) μg m^{-3}; 7.2–10 μm 0.06 (0.01–0.03) μg m^{-3}. The average mass concentration of the total PM_{10} at Faraglione Camp for the entire sampling period was 0.92 (0.67–1.1) μg m^{-3}. Although a great variability, the aerosol mass concentration showed a tri-modal distribution, with an accumulation mode (in the range 0.1–1.0 μm) and two coarse modes (CM1 in the range 1.0–3.0 μm, and CM2 in the range 3.0–10 μm). From 50% to 90% of the PM_{10} mass comes from particles of a size smaller than 1.0 μm. The two coarse modes represented from ~5% to ~35% of the PM_{10}, showing opposite seasonal trends (CM1 decreased while CM2 increased). During summer, PM_{10} mass concentration increased to a maximum of ~1.6 μg m^{-3} at mid-December, while in January it decreased to values that are typical of November. Both accumulation and upper super-micron fractions showed a maximum in the same period contributing to the PM_{10} peak of mid-summer.

1. Introduction

Studying atmospheric aerosols is of great concern in environmental research. Aerosol effects on climate, Earth radiative balance (directly by absorbing or scattering sunlight radiation (Charlson et al., 1992) and, indirectly, by acting as cloud condensation nuclei or modifying cloud radiative properties and cloud lifetimes (Albrecht, 1989)), biogeochemical cycles and public health have been widely recognized.

Besides the determination of the total content of atmospheric particulate matter and of its chemical composition, also airborne particle size distribution is of growing interest (Davidson and Osborn, 1986), with particular attention to the finest granulometries, because of their greater capability to enter into respiratory systems (ICRP, 1994) and the possibility of adsorbing toxic substances due to their higher specific absorbing surfaces. Moreover, size

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distribution patterns allow to obtain information on the sources of aerosol particles and on the atmospheric processes occurring during long-range transport (Bates et al., 1998; Raes et al., 2000; Willeke and Withby, 1975).

Because of its distance from continents (where local sources such as wind-blown dusts, biogenic emissions from soils and vegetation, or anthropogenic emissions dominate), Antarctica is an ideal site to study the aerosol background concentrations and natural processes in order to assess the impact of anthropogenic sources on the atmosphere and to achieve a better understanding of the local and long-range transport processes of aerosol particles.

Many studies of atmospheric aerosol in both coastal and continental areas of Antarctica were carried out (Shaw, 1988; Tomasi et al., 2007; Wolff et al., 1998). Among these, several studies reported size-segregated aerosol sampling programs carried out in different stations over the Antarctic continent; e.g. at the Italian "Mario Zucchelli" station, formerly Terra Nova Bay (Hillamo et al., 1998), at Dumont D'Urville (Jourdain and Legrand, 2002), at Aboa (Asmi et al., 2010; Kerminen et al., 2000; Teinila et al., 2000), at Maitri (Chaubey et al., 2011; Gadhavi and Jayaraman, 2004), at Neumayer (Teinila et al., 2014); at Halley (Rankin and Wolff, 2003), in the Antarctic Peninsula (Artaxo et al., 1992; Correia et al., 1998), and in the Central Antarctica, at Dome C (Becagli et al., 2009) and South Pole (Cunningham and Zoller, 1981; Maenhaut et al., 1979).

According to our knowledge, very few authors (Correia et al., 1998; Gadhavi and Jayaraman, 2004; Kerminen et al., 2000; Teinila et al., 2000) performed direct gravimetric measurements of the size-segregated aerosol mass. Generally, aerosol mass is indirectly estimated from the major aerosol constituents (Cunningham and Zoller, 1981; Dick, 1991; Maenhaut et al., 1979; Wagenbach et al., 1988), but, as showed by different studies (Annibaldi et al., 2007, 2011; Teinila et al., 2000) on direct measurement of PM_{10}, this procedure can underestimate the real mass of the sampled atmospheric aerosol.

Correia et al., 1998, continuing the work of Artaxo et al., 1992, measured the aerosol mass concentration of the fine (particle diameter, D_p; $< 2\ \mu m$) and the coarse ($2\ \mu m < D_p < 10\ \mu m$) fractions by gravimetric analysis of the filters. Samples were collected with stacked filter units (SFUs) every 5–8 days from 1985 to 1993 at the Brazilian Antarctic station "Comandante Ferraz", on King George Island, Antarctic Peninsula. The authors reported average values of 3.78 ng m^{-3} during summer and 2.92 ng m^{-3} during winter for the fine fraction; and values of 6.52 ng m^{-3} during summer and 5.04 ng m^{-3} during winter for the coarse fraction.

Kerminen et al., 2000 and Teinila et al., 2000 at the Finnish station Aboa, in western Queen Maud Land, collected different size-segregated aerosol samples using a small deposit area low-pressure impactor, a virtual impactor and a low-volume impactor; the latter was the only sampling instrument from which the mass of particles was determined by gravimetric analysis. This impactor divided the collecting particles into three size fractions which showed values of mass concentrations in the ranges 0.72–2.66 $\mu g\ m^{-3}$ ($D_p < 2\ \mu m$), 0.06–0.21 $\mu g\ m^{-3}$ ($2\ \mu m < D_p < 6\ \mu m$), and $<0.2\ \mu g\ m^{-3}$ ($D_p > 6\ \mu m$).

Gadhavi and Jayaraman, 2004 at the permanent Indian Antarctic Station, Maitri, carried out direct gravimetric determinations of the size-segregated aerosol mass collected by using a quartz crystal microbalance cascade impactor provided with 10 impaction stages covering a range of particle diameters from 0.05 to 25 μm. They measured an average mass concentration of the PM_{10} (particulate matter with particle diameter below 10 μm) of $9 \pm 6\ \mu g\ m^{-3}$, with a coarse fraction ($1\ \mu m < D_p < 10\ \mu m$) that contributed for 63% to the total, an accumulation-mode fraction ($0.1\ \mu m < D_p < 1\ \mu m$) that was 21% of the total and, finally, a nucleation-mode fraction ($D_p < 0.1\ \mu m$) that was a 16% of the total.

Direct measurement of the size-segregated aerosol mass represents a great challenge because of different problems (electrostatic charge of the filters, humidity and temperature of the weighing environment) which researchers have to face with, first of all the extremely low mass content of the different aerosol fractions (Truzzi et al., 2005; Annibaldi et al., 2011). Nevertheless, the study on atmospheric aerosol cannot exclude the determination of the aerosol mass concentration, which is a parameter essential to the assessment of the aerosol chemical composition, as well as the better comprehension of transport processes, deposition mechanisms and source apportionment (Röhrl and Lammel, 2001; Truzzi et al., 2005).

In this paper, the direct gravimetric determination of the particulate mass of size-segregated aerosol fractions was carried out at a coastal Antarctic site of the Victoria Land, during the 2014–2015 austral summer for the first time. Measurements included also the total mass concentration of PM_{10} aerosol, as well as aerosol mass size distributions. Our principal goals were i) to measure the extremely low mass content of different PM_{10} fractions by using a differential weighing procedure, previously applied with success by our group to Antarctic PM_{10} samples (comprising those samples collected in the plateau of central Antarctica, with an aerosol content of 2–4 mg (Annibaldi et al., 2011)); ii) to evaluate the aerosol mass distribution over different size-segregated fractions during summer, as well as the contribution of these size-fractions to the total PM_{10}; and iii) to assess the seasonal evolution of the different aerosol fractions and the total PM_{10} content in a coastal Antarctic site.

2. Experimental

2.1. The study area

During the 2014–2015 austral summer, Antarctic atmospheric particulate matter was collected at Faraglione Camp (74.7161°S – 164.1150°E), about 3 km southern from the "Mario Zucchelli" Italian Station (MZS). Fig. 1 shows a map of the area near MZS, where Faraglione Camp is located, and the wind rose with the prevailing wind direction highlighted.

The sampling site (Fig. 1) is a promontory and the collection place is located at an elevation of 57 m above sea level (a.s.l.) and at ~250 m far from the sea (which was extraordinarily covered with ice until the second half of January 2015).

Meteorological parameters (air temperature, relative humidity, ambient pressure, wind speed and direction) were continuously registered at time intervals of 1 h by the Automatic Weather Station (AWS) sited close to the sampling site. Daily means of the different weather parameters are reported in Fig. S1 in the supporting information. Measured temperatures were typical of summer season at Terra Nova Bay (Grigioni et al., 1992), varying between −16 °C and +4 °C, with an average value of about −5 °C. An increasing trend in daily mean temperature is observed during the summer, reaching values that oscillated around −0.8 °C at the end of the sampling period (e.g. January the 13th 2015). As usual, after this period, temperature decreased to values that are typical of the Antarctic autumn.

Relative humidity (RH) average for the entire studied period was around 53%, showing the dryness of the continent. It varied from very low values (~19%), at the beginning of the Antarctic summer, to a ~98% in the first decade of January, when a consistent snowfall occurred.

The mean daily pressure at Faraglione Camp was 975 hPa, being ~980 hPa during the normal days and slightly decreased to ~970 hPa during the snowfall of the first half of January.

Surface winds were generally calm to moderate (~23%) with average speed values of ~5 knots (~3 m s^{-1}), but during the