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Influence of biogenic pollen on optical properties of atmospheric aerosols observed by lidar over Gwangju, South Korea

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HIGHLIGHTS

- ► For the first time, optical properties of biogenic pollen were retrieved by lidar.
- ► Pollen particles were only detected during daytime within the PBL.
- ► Pollen particles result in the increase of aerosol optical depth.
- ► Pollen particles decrease the Ångström exponent of aerosol during pollen periods.
- ► The contribution of biogenic pollen to the total aerosol optical depth was 2–34%.

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ABSTRACT

For the first time, optical properties of biogenic pollen, i.e., backscatter coefficients and depolarization ratios at 532 nm were retrieved by lidar observations. The extinction coefficient was derived with the assumption of possible values of the extinction-to-backscatter (lidar) ratio. We investigate the effect of the pollen on the optical properties of the observed atmospheric aerosols by comparing lidar and sun/sky radiometer measurements carried out at the lidar site. The observations were made with a depolarization lidar at the Gwangju Institute of Science & Technology (GIST) in Gwangju, Korea (35.13°N, 126.50°E) during an intensive observational period that lasted from 5 to 7 May 2009. The pollen concentration was measured with a Burkard trap sampler at the roof top of the Gwangju Bohoon hospital which is located 1 km away from the lidar site. During the observation period, high pollen concentrations of 1360, 2696, and 1952 m^{-3} day^{-1} were measured on 5, 6, and 7 May, respectively. A high lidar depolarization ratio caused by biogenic pollen was only detected during daytime within the planetary boundary layer which was at 1.5–2.0 km height above ground during the observational period. The contribution of biogenic pollen to the total backscatter coefficient was estimated from the particle depolarization ratio. Average hourly values of pollen optical depth were retrieved by integrating the pollen extinction coefficients. We find average values of 0.062 ± 0.037, 0.041 ± 0.028 and 0.067 ± 0.036 at 532 nm on 5, 6, and 7 May, respectively. The contribution of pollen optical depth to total aerosol optical depth was 2–34%. The sun/sky radiometer data show that biogenic pollen can affect optical properties of atmospheric aerosol by increasing aerosol optical depth and decreasing the Ångström exponent during daytime during the season of high pollen emission.

1. Introduction

Airborne pollen is a form of biogenic air pollution and is recognized as one of the major agents of allergy-related diseases such as asthma, rhinitis, and atopic eczema (Esch and Bush, 2003). These negative effects of airborne pollen on human health are increasing due to the impact of climate change on biota (Beggs, 2004; D'Amato and Cecchi, 2008; Shea et al., 2008). The onset of pollen transport and the duration of pollen emission in the air during the year may change due to temperature changes that in turn can cause a change in the time when plants grow (Frei, 1998; Teranishi et al., 2000). The intensity of pollen transport and

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changing patterns of pollen transport may be caused by changes in main wind directions. Precipitation events may reduce the concentration of pollen in the atmosphere as a result of wash-out of pollen in the planetary boundary layer (PBL). The type of pollen can change, too, as the type of trees and grass that grow in various regions may change due to changing weather and climate conditions, which in turn may cause allergic reactions in human beings previously not exposed to specific types of pollen (D'Amato et al., 2007). For these reasons, there has been a growing interest in research of pollen in recent years.

Studies on pollen have started in the United States and Europe already in the 1960s. Niklas (1985) investigated pollen emission mechanisms. Potter and Cadman (2006) studied the relationship between pollen and allergic diseases. Other research dealt with the seasonal and regional dispersion of pollen (Damialis et al., 2005; Stach et al., 2007; Vázquez et al., 2003). Hjelmroos (1992), Mandrioli et al. (1984), Raynor et al. (1975) and Sofiev et al. (2006) studied the diffusion and long/short range transport of pollen on the basis of computer simulations. Raynor et al. (1974) investigated the transport and dispersion of pollen and the vertical distribution of pollen concentrations from their source regions along their transport path using an aircraft-mounted isokinetic sampler.

Pollen is injected into the air during the pollination period and can act as environmental pollutant by decreasing the visibility through scattering of sun light. One effect of the scattering of sun light by suspended airborne pollen is a corona that becomes visible around the sun. Parviainen et al. (1994) reported that coronas with a regular vertically-oriented elliptical shape were observed only on days with high pollen counts. Volz (1993) observed that the intensity of the corona increased during high pollen concentration in the atmosphere. Tränkle and Mielke (1994) showed with simulations that coronas may even be used as a simple indicator of the existence and the concentration of pollen because the shape of the corona is strongly correlated with the shape of the pollen.

Pollen can be an important source of natural aerosol pollution in the atmosphere during certain times of the year and specific regions on the globe, and can have considerable influence on the light scattering in the atmosphere during that time. However, there is only little literature available regarding the optical properties of pollen. Only Sassen (2008) reported on measurements of pollen in the lower atmosphere over Fairbanks (64.86°N, 147.84°W), Alaska. He found that tree pollen can generate a strong depolarization of laser-light emitted by a polarization lidar at 694 nm. Noh et al. (2012b) reports on the vertical distribution of pollen observed with lidar and the diffusion of pollen resulting from diurnal variations of the meteorological conditions (temperature, relative humidity, and wind speed).

In this contribution we report for the first time on pollen backscatter coefficients which were obtained by separating the pollen backscatter coefficients from the total aerosol backscatter coefficients using the lidar depolarization technique (Sakai et al., 2003; Sassen, 1977; Shimizu et al., 2004). The pollen-induced optical depth was inferred from the pollen backscatter coefficient, too. In addition, we investigated the effect of the observed pollen on some optical properties of the total atmospheric aerosols by comparing the results from our lidar observations to sun/sky radiometer measurements carried out at the lidar site.

Section 2 describes the instruments used in this study: pollen sampler, lidar and sun/sky radiometer, and the retrieval method of pollen optical depth. Section 3 presents the pollen optical depth. Section 4 discusses the effect of the pollen on optical properties of atmospheric aerosols. Section 5 contains the summary and conclusions.

2. Measurement and methodology

2.1. Pollen sampling

The pollen concentration was measured by the Burkard 7-Day Recording Volumetric Spore Sampler at the roof top of the Gwangju Bohoon hospital at an elevation of 216 m above sea level (asl). The building is located 1 km away from the lidar site. The spore sampler is normally used to monitor and analyze airborne biological particles. The performance of the standard spore sampler model is similar to the trap described by Hirst (1952). The Burkard trap sucks about 10 L of air per minute through a narrow, horizontal slit at the front of the sampling device. Behind the slit, inside the trap, a rotating drum is mounted. A sticky tape covers the drum, so that particles which are carried with the air through the slit stick to the tape. The effect of wind speed on the sampling efficiency is not known with high accuracy (Faegri et al., 1989). The sampling efficiency decreases for particle less than 5 μm in diameter (Willeke and Macher, 1999).

2.2. Depolarization lidar (DPL) system

The vertical distribution of the pollen was observed with the depolarization lidar system (DPL) of KOPRI (Korea Polar Research Institute) at the Gwangju Institute of Science & Technology (GIST) Gwangju, Korea (35.13°N, 126.50°E) at an elevation of 53 m asl from 5 to 7 May 2009. The DPL allowed us to measure vertical profiles of the linear volume (aerosol + molecule) depolarization ratio and the volume aerosol backscatter coefficient at 532 nm. The volume depolarization ratio is useful for identifying non-spherical particles, as for example mineral dust particles and biogenic pollen.

The light source of the DPL is a pulsed Nd:YAG laser that emits pulses at 532 nm wavelength with a power of 170 mJ. The pulse repetition rate is 30 Hz. The laser beam is expanded 5-fold using a beam expander which reduces the laser beam divergence to less than 0.2 mrad. The system has a coaxial configuration between receiver telescope and the laser beam. The backscattered light is collected with an 8 inch Schmidt–Cassegrain telescope. A polarizing beam splitter cube is used to separate the backscattered laser beam into its parallel and cross-polarized components. These two polarized beams are detected by photomultiplier tubes (PMT) which then transform the light pulses into electronic signals in the data acquisition system. An analog to digital converter (ADC) is used to digitize the output from the PMTs. The sampling rate is 60 MHz. Each measurement cycle consists of 3600 laser shots (2 min) that are used to produce vertical profiles with 2.5 m vertical resolution.

The linear volume depolarization ratio ($\boldsymbol{\delta}$) at 532 nm is obtained by taking the ratio of the total backscatter signals (from aerosols and molecules) that are linearly polarized with respect to the plane of polarization of the emitted laser to the total backscatter signals. In this paper we define $\boldsymbol{\delta}$ as

$$\delta = \frac{P_s}{P_p + P_s}. \tag{1}$$

The terms P_p and P_s are the backscatter signal intensities with respect to the parallel and the perpendicular plane of polarization of the outgoing laser beam. However, the total depolarization ratio depends on the concentration of aerosol particles. It decreases with decreasing aerosol particle concentration, as the depolarization effect from the molecules increases.

In order to estimate the contribution of the pollen to the total backscatter signals, the particle depolarization ratio ($\boldsymbol{\delta_p}$) is more appropriate. $\boldsymbol{\delta_p}$ is estimated from the scattering ratio. We apply the equation used by Sakai et al. (2003):