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Aerosol optical properties at the Lulin Atmospheric Background Station in Taiwan and the influences of long-range transport of air pollutants

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HIGHLIGHTS

- Seasonal patterns of aerosol optical properties at LABS were reported.
- BB aerosols in the Southeast Asia source region were studied during spring in 2013.
- Effects of long-range transport on aerosol optical properties were investigated.
- Origins of aerosols transported to LABS in different seasons were characterized.
- Observations at LABS were compared with other high-altitude measurements.

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ABSTRACT

The Lulin Atmospheric Background Station (LABS, 23.47°N 120.87°E, 2862 m ASL) in Central Taiwan was constructed in 2006 and is the only high-altitude background station in the western Pacific region for studying the influence of continental outflow. In this study, extensive optical properties of aerosols, including the aerosol light scattering coefficient (σ_s) and light absorption coefficient (σ_a), were collected from 2013 to 2014. The intensive optical properties, including mass scattering efficiency (α_s), mass absorption efficiency (α_a), single scattering albedo (ω), scattering Ångström exponent (Å), and backscattering fraction (b), were determined and investigated, and the distinct seasonal cycle was observed. The value of α_s began to increase in January and reached a maximum in April; the mean in spring was 5.89 $m^2\ g^{-1}$ with a standard deviation (SD) of 4.54 $m^2\ g^{-1}$ and a 4.48 $m^2\ g^{-1}$ interquartile range (IQR: 2.95–7.43 $m^2\ g^{-1}$). The trend was similar in α_a, with a maximum in March and a monthly mean of 0.84 $m^2\ g^{-1}$. The peak values of ω (Mean = 0.92, SD = 0.03, IQR: 0.90–0.93) and Å (Mean = 2.22, SD = 0.61, IQR: 2.12–2.47) occurred in autumn. These annual patterns of optical properties were associated with different long-range transport patterns of air pollutants such as biomass burning (BB) aerosol in spring and potential anthropogenic emissions in autumn. The optical measurements performed at LABS during spring in 2013 were compared with those simultaneously performed at the Doi Ang Kang Meteorology Station, Chiang Mai Province, Thailand (DAK, 19.93°N, 99.05°E, 1536 m a.s.l.), which is located in the Southeast Asia BB source region. Furthermore, the relationships among α_s, α_a, and b were used to characterize the potential aerosol types transported to LABS during different seasons, and the data were inspected according to the HYSPLIT 5-day backward trajectories, which differentiate between different regions of air mass origin.

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1. Introduction

Atmospheric aerosol particles are among the most variable components of the climate and radiation budget of the Earth. They can scatter and absorb radiation directly (direct effect) or act as cloud condensation nuclei to change the properties of clouds, thus affecting solar radiation levels (indirect effect). According to the Fifth Assessment Report of Intergovernmental Panel on Climate Change, the effective radiative forcing caused by direct (aerosol-radiation interactions) and indirect effects (aerosol-cloud interactions) are estimated to be −0.45 Wm^{-2} (−0.95 to +0.05) and −0.45 Wm^{-2} (−1.2 to 0.0), respectively (Stocker et al., 2013), with large uncertainty relative to all the other climate forcing factors (Pachauri et al., 2014). The magnitude of the radiative impact of aerosols depends largely on their optical properties; and high uncertainty results from the inhomogeneous spatial distribution and strong temporal variation of atmospheric aerosols (Andrews et al., 2011; Delene and Ogren, 2002; Deng et al., 2013). These optical properties are closely related to various physical and chemical properties, which are influenced by heterogeneous chemical reactions, photochemical aging, coagulation with preexisting aerosols, and the condensation of nitrates, sulfates, and organic matter during transport in the atmosphere (Adler et al., 2011; Bambha and Michelsen, 2015; Hand and Malm, 2007; Kondo et al., 2011; McMeeking et al., 2011; Sayer et al., 2016; Titos et al., 2012; Zhong and Jang, 2014; Zieger et al., 2013).

In past decades, rapid industrialization and urbanization have led most atmospheric aerosol studies in Asian countries, such as the campaign study of the Asian Pacific Regional Aerosol Characterization Experiment (Clarke et al., 2004; Doherty et al., 2005; Kim et al., 2005) and Cheju Asian Brown Cloud Plume-Asian Monsoon Experiment (Flowers et al., 2010) to focus on the impact of anthropogenic aerosols. More recently, several studies conducted in the Lulin Atmospheric Background Station (LABS) have suggested that biomass burning (BB) pollutants are transported from their source regions to East Asia because of the prevailing Westerlies occurring at higher elevations in spring (Lin et al., 2013, 2014; Sheu et al., 2010; Tsay et al., 2016; Wai et al., 2008). Sheu et al. (2010) demonstrated that emissions including anthropogenic pollutants and BB in East Asia may affect both gaseous and particulate mercury. Lin et al. (2013) further indicated that measurements of gaseous species and aerosol chemical composition are influenced by BB plumes. However, few studies have reported the impacts of different aerosol sources on optical properties over East Asia.

The optical properties and atmospheric lifetimes of carbonaceous BB aerosols depend strongly on their size distribution, composition, mixing state, and morphology, all of which evolve with age (Flowers et al., 2010). Fresh and aged BB aerosols have different effects on local air quality (i.e., visibility) and regional climate (Hsiao et al., 2016; Lin et al., 2013; Tsay et al., 2013, 2016). They also contribute to radiative forcing. To elucidate how regional and global radiative forcing are influenced by long-range transported BB aerosols, it is essential to conduct further investigations on the optical properties of aerosols in BB sources and receptor regions, such as the scattering coefficient (σ_s), absorption coefficient (σ_a), and single scattering albedo (ω). LABS was built to study the impact of regional and long-range transported air pollutants in Taiwan, complementing the network of the Global Atmospheric Watch in the East Asia region.

This study was conducted as part of the Seven Southeast Asian Studies (7-SEAS) campaign, which measured the chemical, physical, optical, and radiative properties of BB aerosols and related air pollutants in Southeast Asian BB sources and receptor regions (Lin et al., 2014; Tsay et al., 2013). The objectives of this study are as follows: 1) to investigate the climatology of the extensive and intensive optical properties of aerosols at LABS by using ground-based measurements, and 2) to study the effects of the long-range transport of air pollutants on the optical properties of aerosols as observed at LABS. These 2-year measurements can provide temporal variation information and reveal the influences of long-range transport on the optical properties of aerosols. Our findings may have fundamental implications for climate modeling and could further the current understanding of the radiative effects of BB aerosols on regional and global scales.

2. Methods

2.1. Observation sites

The optical properties of aerosols were measured at two sites (Fig. 1): One was LABS, Taiwan (LABS, 23.47°N, 120.87°E, 2862 m above sea level, a.s.l.), and the other one was the Doi Ang Kang Meteorology Station (DAK), Chiang Mai Province, Thailand (19.93°N, 99.05°E, 1536 m a.s.l.). LABS is located at the border between Nantou County and Chiayi County in Central Taiwan and is the first high-elevation baseline station in East Asia. Its altitude is high enough to avoid the influence of local pollution, and it is situated 2 km from the nearest major road. DAK is located in Northern Thailand, in a BB source region near the Myanmar border. Local residents customarily burn their fields in preparation for agricultural activity during the dry season from late February to mid-April. Thus, DAK is an excellent site for investigating the characteristics of fresh BB aerosols.

2.2. Measurement method

The aerosol observation system at LABS was built by the National Oceanic and Atmospheric Administration. Aerosol samples were obtained from the top of the sampling stack, which is approximately 10 m above ground level. The stack had a cap to prevent foreign material, including rain and insects, from entering the sampling system. The total airflow through the stack was 1000 liters per minute (lpm) and was divided into a sampling flow of 150 lpm and sheath flow of 850 lpm. A heater was attached to the sampling air to achieve a relative humidity of below 40%. The sampling flow was further split into five sampling lines of 30 lpm each. A switched impactor was used to measure the aerosol properties of PM_{10} and $PM_{1.0}$. A valve alternated every 30 min between the 10-μm and 1.0-μm aerodynamic diameter cutpoint impactors (Jefferson, 2005). A detailed description of this system has been presented by Sheridan et al. (2001) and Delene and Ogren (2002).

The extensive optical properties of the aerosols measured at LABS included the aerosol light scattering coefficient (σ_s) and light absorption coefficient (σ_a), and the data with PM_{10} size-selective inlet were used in this study. A three-wavelength (450, 550, and 700 nm) nephelometer (model 3563, TSI) was used to measure σ_s (Anderson et al., 1996). The nephelometer illuminated the sample volume from the side with a halogen lamp and measured the light scattered by particles and gas molecules. The integrated scattered light at three different wavelengths from 7° to 170° for total light scattering and from 90° to 170° for backscattering was collected by photomultiplier tubes. The coefficient σ_a was measured with a three-wavelength (467, 530, and 660 nm) particle soot absorption photometer (PSAP, Radiance Research). Aerosols were sampled and deposited on the filter, and the change in light transmission was related to the absorption coefficient (Bond et al., 1999). Corrections to the PSAP measurements had been done to obtain final value for absorption coefficient (Bond et al., 1999; Ogren, 2010). In the present study, absorption data with filter transmissions below 0.6 were rejected. The $PM_{2.5}$ mass concentration was sampled through