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Study of aerosol optical properties at Kunming in southwest China and long-range transport of biomass burning aerosols from North Burma

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ABSTRACT

Seasonal variation of aerosol optical properties and dominant aerosol types at Kunming (KM), an urban site in southwest China, is characterized. Substantial influences of the hygroscopic growth and long-range transport of biomass burning (BB) aerosols on aerosol optical properties at KM are revealed. These results are derived from a detailed analysis of (a) aerosol optical properties (e.g. aerosol optical depth (AOD), columnar water vapor (CWV), single scattering albedo (SSA) and size distribution) retrieved from sunphotometer measurements during March 2012–August 2013, (b) satellite AOD and active fire products, (c) the attenuated backscatter profiles from the space-born lidar, and (d) the back-trajectories. The mean AOD_{440nm} and extinction Angstrom exponent ($EAE_{440-870}$) at KM are 0.42 ± 0.32 and 1.25 ± 0.35, respectively. Seasonally, high AOD_{440nm} (0.51 ± 0.34), low $EAE_{440-870}$ (1.06 ± 0.34) and high CWV (4.25 ± 0.97 cm) during the wet season (May – October) contrast with their counterparts 0.17 ± 0.11, 1.40 ± 0.31 and 1.91 ± 0.37 cm during the major dry season (November–February) and 0.53 ± 0.29, 1.39 ± 0.19, and 2.66 ± 0.44 cm in the late dry season (March–April). These contrasts between wet and major dry season, together with the finding that the fine mode radius increases significantly with AOD during the wet season, suggest the importance of the aerosol hygroscopic growth in regulating the seasonal variation of aerosol properties. BB and Urban/Industrial (UI) aerosols are two major aerosol types. Back trajectory analysis shows that airflows on clean days during the major dry season are often from west of KM where the AOD is low. In contrast, air masses on polluted days are from west (in late dry season) and east (in wet season) of KM where the AOD is often large. BB air mass is found mostly originated from North Burma where BB aerosols are lifted upward to 5 km and then subsequently transported to southwest China via prevailing westerly winds.

1. Introduction

Atmospheric aerosols from natural and anthropogenic sources have important impacts on climate, air quality and human health. To understand these impacts, it is essential to characterize aerosol optical, physical, and chemical properties at different locations because of their highly temporal variability and spatial inhomogeneity. Ground-based remote sensing of aerosols is one of the important tools in accurately characterizing column-integrated aerosol optical and physical properties. Ground-based network of remote sensing aerosol optical properties using sunphotometer goes back to 1960s in America and Europe (Volz, 1965; Holben et al., 2001 and references therein). Several international and regional ground-based sunphotometer networks have been established during recent decades, for example, the Aerosol Robotic Network (AERONET) (Holben et al., 1998), SKYradiometer NETwork (Uchiyama et al., 2005), the Global Atmosphere Watch Precision Filter Radiometer network (Wehrli, 2005), and China Aerosol Remote Sensing Network (CARSNET) (Che et al., 2009). The data have been widely used by the aerosol community to characterize aerosol optical properties, to evaluate satellite retrievals and model simulations, and to study aerosol effects on climate (Holben et al., 2001).

Column-integrated aerosol optical and physical properties based on ground-based remote sensing data were widely studied in east China (Xia et al., 2007), the North China Plain(Che et al., 2014; Xia et al., 2005) and the Tibetan Plateau (Huang et al., 2007; Li et al., 2011 and references therein). Xia et al. (2005) showed that the monthly mean aerosol optical depth (AOD) at 750 nm in spring could range from 0.32 to 0.68 in North China. In the urban region of North China Plain, AOD

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seasonal variation can be more distinct and the annual mean AOD at 550 nm can reach 0.8 (Li et al., 2007). Equally high values of the annual mean AOD were also observed over south China, such as 0.7 in the Sichuan Basin (Luo et al., 2001; Tao et al., 2013).While the atmosphere over the Tibetan Plateau is pristine in general, it can be occasionally affected by long-range transport of dust aerosols from the Taklimakan Desert in summer and anthropogenic aerosols from South Asia in spring (Huang et al., 2007; Xia et al., 2008). However, the study of ground-based remote sensing of aerosol optical properties in southwest China is still quite limited.

It is expected that aerosol properties in southwest China should be quite different from those in other regions of China because of differences in topography, regional climate, and aerosol sources. Due to the high elevation (exceeding 1 km) and the low latitude, the climate in southwest China is characterized by a few interesting features, for example, year-long intense solar radiation and large diurnal variation, small monthly variations of temperature and the two distinct seasons, namely the wet season (May–October) which contributes 85% of the annual rainfall (Qin et al., 2010) and the dry season (November–April) with an average of 20 days of sunshine in a month. It therefore can be hypothesized that the aerosol hygroscopic process may render different aerosol properties between the dry and wet seasons.

Biomass burning (BB) in Asia is an important contributor to air pollution in the region (Streets et al., 2003; Sahu and Saxena, 2015). Many studies show its influence on regional gaseous pollutant (Zhao et al., 2015) and aerosol properties such as particle matter (PM) concentration and chemical compositions (Deka and Hoque, 2014; Wang et al., 2015). Although some studies found that aerosol and gases from BB in South and Southeast Asia can be transported to Southeast China and the northwestern Pacific (Zhang et al., 2012; Jacob et al., 2003), few studies highlighted possible impact of emission from South and Southeast Asia on air quality and regional climate in southwest China. On the basis of aerosol chemical speciation data (Hao and Liu, 1994; Streets et al., 2003), the BB aerosols from long-range transport are found in southwest China. However, the impact of such transport on the column-integrated aerosol optical properties in southwest China is limited in part due to the lack of ground-based observations. To overcome this limitation and evaluate the importance of aerosol hygroscopicity in regulating the characteristics of aerosol properties, in 2012 we have established a sunphotometer site at Kunming (KM), the capital of Yunnan Province, southwest China.

This study presents, for the first time, the ground-based sunphotometer measurements of aerosol optical properties and aerosol types at KM in southwest China, including their seasonal variations and the attribution of different processes (such as long-range transport vs. local emission and hygroscopicity) to these variations. While accurate, sunphotometer measurements are nevertheless taken at only one location (point) and hence lack spatial coverage. To tackle this challenge, a combined analysis of aerosol data from ground-based and satellite remote sensing measurements as well as the back-trajectories is conducted. The data and methods are introduced in Section 2. Sections 3 and 4 present the results of aerosol properties and process analysis, respectively. The discussion and conclusions are given in Section 5.

2. Site, data and methodology

2.1. Site

The sunphotometer site (25.01°N, 102.65°E) is located west of KM, with an elevation of 1889 m a.s.l. The instrument is established at the observation field of the Kunming Xishan district Meteorological bureau. This field is surrounded by grass and crops without serious pollution sources nearby. For the mean climate, there are two abrupt jumps of the monthly precipitation. Monthly precipitation increases dramatically from 24 cm in April to 98 cm in May and decreases from 80 cm in October to 42 cm in November (Qin et al., 2010) that is associated with monsoon onsets in May and withdraws in October (Yan et al., 2013).

Fig. 1 shows the seasonal wind, pressure and relative humidity (RH) at surface (995 sig level) of the National Center of Environmental Prediction (NCEP) reanalysis monthly data in wet and dry seasons during 2012–2013. The southwest and southeast winds are the prevailing winds in both seasons, and the westerly wind speed is normally larger than the easterly wind. The RH is about 90% and 70% in wet and dry season, respectively. Interestingly, KM on average is at the north edge of the inter-tropical convergence zone (ITCZ) in its wet season (Fig. 1), and hence, both the emission and the transport of aerosol from the south of KM have strong seasonal variations. Since biomass burning events occurred more frequently in the late of dry season (also the transition period from dry to wet) in Southeast Asia, we further divide the period of November–April (the dry season) into the major dry (November–February: dry1) and late dry (March–April, also biomass burning period: dry2) seasons.

2.2. Data

2.2.1. Aerosol optical properties from CE-318 sunphotometer observation

The column-integrated aerosol optical properties are derived from CE-318 sunphotometer measurements at KM from March 2012 to August 2013. Therefore, the observations in March–August are from two years, and the other months from one year. The instrument performs direct sun extinction measurements at 340, 380, 440, 500, 675, 870, 940 and 1020 nm and sky radiance measurements at 440, 675, 870, and 1020 nm (the nominal wavelength). The sun direct measurements at 340, 380, 440, 500, 675, 870 and 1020 nm wavelengths are used to calculate AODs based on Beer Law. Measurements at 940 nm are used to derive the columnar water vapor (CWV) in centimeters (Holben et al., 1998). Aerosol microphysical and optical properties like size distributions, refractive indices, and single scattering albedos (SSA) were retrieved by using sky radiance almucantar measurements and direct sun measurements following the AERONET procedures described in Dubovik and King (2000) and Dubovik et al. (2006). The cloud-screened algorithm of Smirnov et al. (2000) is adopted to produce Level 1.5 aerosol products. The suspicious Level 1.5 aerosol products are finally quality controlled using surface meteorological data.

The instrument was calibrated before and after the observation period using the calibration facility of Chinese Academy of Meteorological Sciences (Che et al., 2009; Tao et al., 2014).The sun direct calibration was made via inter-comparison with the master sunphotometers at Beijing. The master sunphotometers were calibrated using the Langley method at either the Izaña, Spain (28.31°N, 16.50°W, 2391.0 m a.s.l) or the Mauna Loa, USA (19.54°N, 55.58°W, 3397.0 m a.s.l) (Che et al., 2014). The sphere calibration methods and protocols for the CARSNET have been described by Tao et al. (2014). The CARSNET sphere calibration results were compared with the original values provided by the Cimel manufacturer, showing differences of ~3–5% at infrared wavelengths (1020 and 870 nm) and ±3% at visible wavelengths (440, 500, and 675 nm).

The comparison of AOD between CARSNET with AERONET in Beijing showed the difference is about 0.01 at 440 nm (Che et al., 2009), which is consistent with the expected accuracy of 0.01–0.02 for the AERONET AOD (Holben et al., 1998; Eck et al., 1999). CWV amount is retrieved with uncertainty of <10% (Holben et al., 1998). Three extinction Angstrom exponents (EAE) are calculated from spectral AOD at 440 and 870 nm ($EAE_{440-870}$), from AOD at 440 and 675 nm ($EAE_{440-675}$), and from AOD at 675 and 870 nm ($EAE_{675-870}$) (Ångström, 1929). Similar to EAE, the absorption Angstrom exponent (AAE) is calculated from spectral absorption AOD (AAOD) at 440 nm and 870 nm. AAOD is calculated from AOD and SSA. The SSA uncertainty is estimated to be less than 0.03 for AOD at 440 nm > 0.4 and the uncertainty increases for lower AOD (Dubovik and King, 2000; Dubovik et al., 2000, 2002).