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Contrast in column-integrated aerosol optical properties during heating and non-heating seasons at Urumqi — Its causes and implications

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Aerosol optical properties were retrieved from two years' worth of Sunphotometer measurements at Urumqi, an urban station in western China. Distinct seasonal variations of aerosol optical properties were revealed. During the heating season, mean aerosol optical depth at 550 nm (τ_a), Angstrom exponent calculated from aerosol optical depth at wavelength of 440 and 870 nm (α) as well as $PM_{2.5}$ concentration were 0.58 ± 0.33, 1.11 ± 0.34 and 79.5 ± 69.6 μg m^{-3}, respectively, which contrasted their counterparts during the non-heating season of 0.32 ± 0.22, 0.79 ± 0.26, and 35.0 ± 20.1 μg m^{-3}. Seasonal variations of τ_a and $PM_{2.5}$ at Urumqi contrasted with corresponding values in eastern China. Enhancement of τ_a was associated with fine mode radius (r_f) exceeding 0.15 μm. Relative humidity frequently exceeded 80% during the heating season, which probably resulted in $r_f > 0.15$ as a result of the hygroscopic growth under the humid environment. r_f was larger than value assigned to the fine-mode dominated aerosol models used in the dark-target algorithm of the Moderate Resolution Spectroradiometer (MODIS). Annual mean single scattering albedo at 550 nm (ω) was 0.87 that was close to the value assigned to the absorption aerosol model in the MODIS algorithm. ω increased as τ_a increased, probably as a result of the growth of aerosol size. ω of dust aerosols at Urumqi was slightly lower than that in dust source and downwind regions. Substantial differences in aerosol optical and physical properties and their seasonal variation between western and eastern China require maintaining long-term ground based remote sensing aerosols, which would be expected to play an important role in studying aerosol's effects on weather, climate and atmospheric environment.

1. Introduction

Further understanding of spatial and temporal variation of aerosol is fundamental for the study of its effects on climate and environment. Ground based remote sensing is one of important methods to retrieve aerosol optical properties with high quality and therefore has been playing an important role in characterizing aerosol properties. Ground based remote sensing networks have been established since 1990s and one representative is the Aerosol Robotic Network (AERONET) (Holben et al., 1998, 2001). In China, Chinese Aerosol Remote Sensing Network (CARSNET) was established in 2002 and expanded to be composed of over 60 stations across China (Che et al., 2009, 2015). A brief introduction to the development in ground-based remote sensing of aerosol optical properties in China was reviewed (Xia et al., 2016). Much progress has been made on understanding of aerosol optical properties in Northeast China (Cheng et al., 2006; Zhao et al., 2015), in the North China Plain (Xia et al., 2013), in the Yangtze Delta region (Pan et al., 2010; Wang et al., 2015), in the Hexi Corridor (Ge et al., 2011), in the Taklimakan Desert (Che et al., 2014; Huang et al., 2009). Most of these results were obtained over eastern China. Very few studies have been performed in Xinjiang Uygur Autonomous Region (XJ) so far although it covers 17.3% of territory of China (Fig. 1).

XJ is located in northwest China, one of major sources of dust aerosols in East Asia. Dust aerosols can transport long distance by the prevailing westerlies and thereby affect climate through their direct and indirect effects (Huang et al., 2006, 2008). Oases in the fringe areas of two Deserts (Gurbantunggut and Taklimakan Desert, Fig. 1) are crucial to the survival of human being and economy there. This region has

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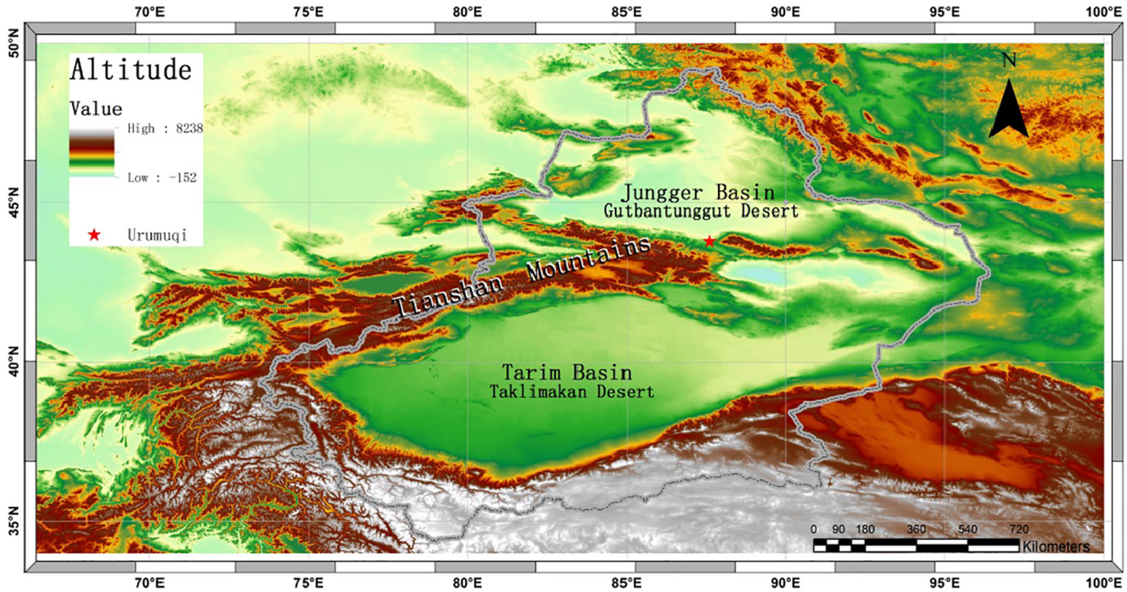

Fig. 1. Spatial distribution of elevation height (m) in which Urumqi is represented by a red star. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

experienced rapid economic growth over the past two decades, characterized by expanding industrialization and explosive growth in anthropogenic activities (Wei and Wang, 2009; Li et al., 2015). Researches on aerosol optical properties there are still very limited (Li, 2006). Specifically, column-integrated aerosol size and absorption was never reported as far as we know. It was widely suggested an important role played by the aerosol-radiation-cloud-precipitation interactions in the regional climate change and the hydrological cycle (Li et al., 2011). Regional pollution might be enhanced by the aerosol feedbacks (Gao et al., 2015). Further understanding of these issues certainly needs aerosol optical properties with high quality. The objective of this paper is to characterize seasonal variation of aerosol optical properties and study its potential causes, which is achieved based on two years' worth of ground based sunphotometer measurements. Differences and similarities in aerosol optical properties between this and other regions are presented. Potential contribution of the hygroscopic growth to aerosol loading, size and absorption is discussed.

2. Site, measurement and data

2.1. Site description

Urumqi (86°38′–88°58′E, 42°46′–44°08′N), the capital of XJ, is located in the western interior of China. It situates at the northern lee of Tianshan Mountain and in the southern edge of Jungger Basin (Fig. 1). The city is surrounded by rather steeply rising mountains and hills ranging from 1397 m to 5445 m above the sea level (a.s.l.) on nearly three sides, while the urban altitude gradually descends towards northwest with an average altitude of 800 m a.s.l.

With the rapid growth of economy during the past 20 years, the population of Urumqi exceeds 3.11 million by the end of 2011. A large number of factories, including power plants, petroleum chemicals and cement production, have been set up in the northern and southern suburbs of Urumqi. The emissions of SO_2 and PM_{10} (particles < 10 μm in diameter) at Urumqi have been assessed to be 67,400 ton and 77,200 ton per year, respectively. The coal consumption in winter amounts to two thirds of total yearly consumption (Wei and Wang, 2009) that often leads to heavy air pollution. In addition, dust aerosols occasionally impact Urumqi, especially in spring (Li et al., 2005; Li et al., 2015).

The climate at Urumqi is characterized by hot and dry summers and cold and wet winters, which is reflected in daily temperature, precipitation and relative humidity (RH) during 2008–2009, the measurement period of sunphotometer (Fig. 2). Seasonal variation of wind speed is evident with relatively lower wind speed in winter. The heating period at Urumqi starts on October 15 and ends on April 15 next year that is shaded in Fig. 2. The heating period is characterized by higher RH (generally >60%) and lower wind speed (generally <2 ms^{-1}), which contrasts with corresponding values during the non-heating period (RH < 60% and wind speed > 2 m s^{-1}). Urumqi is frequently controlled by stagnant weather condition with particularly low wind speed in the stable boundary layer in winter, which is closely related to the interaction between the southeasterly foehn at heights between 480 and 2100 nm and the cold air pool located in Jungger Basin, surrounding to the Mongolian High. Such weather condition prevents vertical mixing of atmospheric pollutants and thereby leads to heavy air pollution (Li et al., 2015).

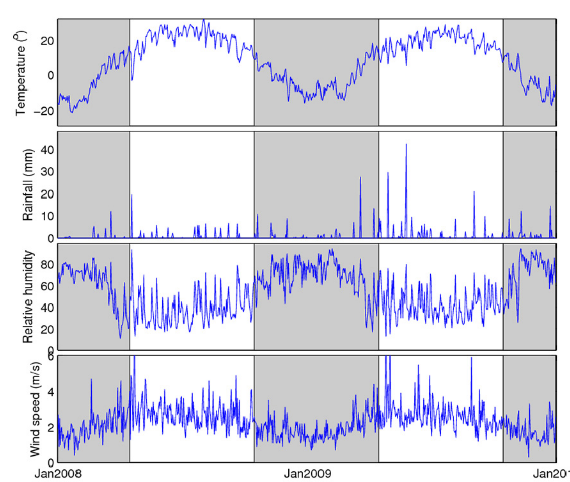

Fig. 2. Daily temperature (°), rainfall (mm), relative humidity (%) and wind speed (m s^{-1}) at Urumqi from top to the bottom during January 2008 to December 2009. The shading area indicates heading period that starts on October 15 and ends on April 15 next year.