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Long-term atmospheric visibility, sunshine duration and precipitation trends in South China

Wenhui Liao [a,b], Xuemei Wang [a,*], Qi Fan [a], Shengzhen Zhou [a], Ming Chang [a], Zhimin Wang [a], Yu Wang [a], Qiulan Tu [a]

[a] School of Environmental Science and Engineering, Sun Yat-Sen University, Guangzhou 510275, PR China
[b] GuangDong University of Finance, Guangzhou 510521, PR China

HIGHLIGHTS

- This paper first introduces DCCA to analyze the effects of air pollution.
- Long-term atmospheric visibility, sunshine and precipitation trends were analyzed.
- Significant decreasing trends were found.
- The cross-correlation of the visibility and rainfall was found.

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ABSTRACT

The fast industrialization and urbanization in South China have led to increasing concentration of aerosols, which has caused the degradation of atmospheric visibility and substantially impacted on cloud properties and the initiation of precipitation in this region. Therefore, it is valuable to study the spatial and temporal trends of atmospheric visibility, sunshine duration and precipitation in recent years in the region to understand how aerosols affect the environment. In this article, meteorological data of 28 stations in South China were obtained from the China Meteorological Data Sharing Service System and were analyzed using several different statistical methods. The stations were divided into four categories: prefecture, county, neighbor, and remote stations. The data show a decrease of visibility in 93% of the stations during 1980–2012, among which the neighbor stations have recorded the fastest average decrease of −1.8 km/decade. The average visibility for all the stations over the 33 years is 16.8 km and the total average decreasing rate is −1.3 km/decade. The percentages of "high" visibility in prefecture, county and neighbor stations decreased dramatically, while the percentages of "low" visibility in aforementioned stations were much higher than those in the remote stations. As for the sunshine duration, the neighbor stations have recorded the rapidest decrease in the recent 30 years, while the data of the prefecture stations showed the most significant change during 1957–2012. The annual average daily rainfall of rainy days shows a significant increase during 1978–1985 in the dry seasons and 1990–2000 in the wet seasons, respectively. The percentage of rainy days per year had been decreasing linearly during 1980–2010. Light rain days had been decreasing in all the types of stations, though such change is the smallest in remote stations. Meanwhile, torrential rain and rainstorm days have been increasing, especially in the prefecture stations. By using the empirical orthogonal function (EOF) and detrended cross-correlations analysis (DCCA), we may conclude that visibility and rainfall have cross-correlation, which shows more complex multifractal structure in Guangzhou (a prefecture station) than in Gaoyao (a neighbor station) and Lianping (a remote station).

1. Introduction

Atmospheric aerosols is technically defined as the suspension of fine solid or liquid particles, which can cool or warm the

* Corresponding author.
E-mail address: eeswxm@mail.sysu.edu.cn (X. Wang).

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atmosphere and impair atmospheric visibility by scattering or absorbing solar radiation (Cohen and Wang, 2014; Chung and Seinfeld, 2005; Cohen et al., 2011). Along with rapid urbanization and city sprawl, tremendous amounts of gaseous pollutants and aerosols have been emitted into the atmosphere. The aerosol loadings have been increasing rapidly, which are reported to have exerted significant impact on the weather and climate system (Menon et al., 2002). Urbanization also has greatly changed the urban land-use/land-cover. In turn, land-use/land-cover change has been affecting the transport and dispersion of pollutants as well as the regional climate (Wang et al., 2007, 2009a, b). Aerosols, served as cloud condensation nuclei (CCN), have a substantial effect on cloud properties and the initiation of precipitation (Rosenfeld et al., 2014). Human-made aerosols can decrease or increase rainfall as a result of their radiative and CCN activities (Daniel et al., 2008).

Visibility, the indicator of air transparency, has become a major concern in the studies of air pollution and climatology (Mahowald et al., 2007; Molnar et al., 2008; Deng et al., 2011). Intrinsically, visibility is related to atmospheric fine particle concentrations and constituents. Since it's hard to obtain the data of long term aerosol concentrations, it is plausible to use the visibility trend as an alternative to represent the variation trend of aerosols. Numerous studies have been carried out to study the visibility trends and their causes in almost all the major urban agglomerations in China, including the Sichuan Basin (Chen and Xie, 2012), the Pearl River Delta (PRD) region (Deng et al., 2008; Chang et al., 2009), the Yangtze River Delta (YRD) region (Gao et al., 2011), and the Beijing–Tianjin–Hebei (BTH) region (Fan and Li, 2008; Zhao et al., 2011). Wu et al. (2012) analyzed the trends of visibility in the sunny days in China of the last 50 years. Deng et al. (2012) studied the long-term atmospheric visibility trend in the Southeast China during 1973–2010. Che et al. (2007) analyzed the visibility trends across the entire China during 1981–2005, and found a rapid decrease (−2.1 km/decade) in visibility from 1990 to 2005.

Recently, numerical models have been employed to study the impact of urbanization on regional climate. Miao et al. (2009) suggested that urbanization has a great impact on heavy rainfalls in Beijing. Wang et al. (2009a, 2014) showed that the rapid urbanization in the YRD and the PRD regions has changed local climate together with the increase of surface temperature and boundary layer mixing. However, these studies are either focused on a single weather event or only covered a limited period of time, such as a single season of a year. Therefore, more observational and modeling works are required to improve the basic understanding on the impact of urbanization on weather and climate change. In this paper, long-term visibility, sunshine duration and precipitation trends in South China have been investigated and discussed. The relationships between visibility, sunshine duration and precipitation are evaluated via five different statistical methods. The focus of the research given here is on the effect of urban-enhanced aerosols on sunshine duration and precipitation. The results can provide useful benchmarks to understand how urbanization impacts on climate and can help policymakers to make positive strategies to improve air quality.

2. Data and methods

2.1. Data

The study region located in South China includes Guangdong province and Guangxi Zhuang Autonomous Region (Fig. 1) which has been undergoing a high speed of industrialization and urbanization, especially in the PRD region. However, there are also some remote areas in this region that are completely non-industrialized. The uneven development has provided us with a good opportunity to study how urbanization influences on climate. Due to the deficiency of the long-term observation data of aerosols, the visibility data were used as an alternative.

Atmospheric visibility during 1980–2012 and meteorological data (sunshine duration, precipitation and relative humidity (RH) during 1957–2012) were obtained from the China Meteorological Data Sharing Service System for all the 28 monitoring stations in the region (Fig. 1). The stations were divided into four categories based on their locations and population: 6 prefecture stations (located in central cities with a population over 1,500,000), 7 county stations (located in county-level cities with a population over 500,000 yet less than 1,500,000), 6 neighbor stations (located in the peripheral neighborhood of the prefecture stations, undertaking industrial transfer from those big cities), and 9 remote stations (located in remote areas). The visibility data obtained at a RH less than 90% during no-rain days were selected to carry out the analysis as suggested by Deng et al. (2012). Finally, 56.4% of the total data met the above-mentioned criteria, which may avoid the rapid hygroscopic increase of particles under humidy environment, e.g. around five or more times compared with in dry environment. The range of wet-to-dry scattering coefficient ratios values at 90% RH varied from a low of about 0.99–1.06 to a high of about 2.24–3.17, then visibility would be seriously distorted (Malm and Day, 2001). The correlation coefficient of −0.41 between the aerosol optical depth (AOD)/The Moderate Resolution Imaging Spectroradiometer (MODIS) and the surface visibility in Guangzhou was similar with that in Hong Kong (−0.42) (He et al., 2008), and the correlation coefficient can reach −0.48 when the data obtained at high RH (>90%) and in rainy days were excluded.

2.2. Methods

In this study, five statistical methods were adopted: (1) ridit analysis; (2) the percentages of "high" visibility days and "low" visibility days; (3) spline interpolation; (4) EOF and (5) DCCA. Brief descriptions of the five methods are described in Sections 2.2.1–2.2.5. More detailed explanations are offered in the related reference. The site-average is defined as the average value of annual mean visibility of all the 28 stations in South China. Similarly, remote-average, neighbor-average, county-average and prefecture-average are defined as the average values of annual mean visibility of the 9 remote stations, 6 neighbor stations, 7 county stations and 6 prefecture stations, respectively.

2.2.1. Ridit analysis

Ridit analysis, which has been widely used in trend analysis, is especially suitable for the hierarchical data (Deng et al., 2012). Ridit is the abbreviation for "relative to an identified distribution unit". It was used to determine whether or not the strategy was effective through comparing the representative slopes of ridit before and after the implementation of a pollution control strategy. More detailed description on the ridit analysis is stated by Doyle and Dorling (2002). In the article, ridit analysis was used to compare the change trend of visibility for all types of sites, because visibility is hierarchical. Three stages of visibility were defined: 0–10 km, 10–20 km, and >20 km. Visibilities of all the individual years were compared to those from the reference distribution which included all of the visibilities during the entire period at each station.

2.2.2. Percentages of "high" visibility and "low" visibility

The percentages of "high" visibility days ($\geq$20 km) and "low" visibility days ($\leq$10 km) were quantified to show the change in visibility (Gomez and Smith, 1987). Generally, "high" and "low" visibility draws more public attention than moderate visibility. Additionally, visibility lower than 10 km is a key indicator of the