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CORRELATIVE ANALYSIS OF THE RELATIONSHIP BETWEEN CHANGES IN SURFACE SOLAR RADIATION AND HAZE POLLUTION (ATMOSPHERIC TURBIDITY INDEX) IN BEIJING FROM 1961 TO 2011

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ABSTRACT

Increased aerosol or haze is the reason that solar radiation decreases, but there is no evidence to support this theory. This research aims to quantitatively analyze the contribution of air pollution to surface solar radiation (SSR) reduction in Beijing. Because there is no long-term serial ground observational aerosol data, in order to reflect the atmospheric pollution and aerosol levels, we developed an atmospheric turbidity index (ATI).Monthly and annual variations in the ATI are significantly correlated with aerosol optical depth (AOD), and ATI could well reflect the change of air pollution. The ATI and SSR are significantly negatively correlated. The changes in the Beijing SSR presented a clear decreasing trend. From the inter-annual variability, the SSR exhibited a rapidly declining trend from 1960 to approximately1990 and a gradual increasing trend after 1990. The atmosphere turbidity index in the Beijing area was the main factor which indicated the change in SSR.

Keywords: Surface Solar Radiation, Atmospheric Turbidity Index, Atmospheric pollution, Haze pollution

1. Introduction

In the past half century, many studies have analyzed and discussed various regional and global terrestrial surface solar radiation (SSR)variations and their influencing factors by analyzing observed radiation data (Wild *et al.*, 2005; IPCC 2007; Ding *et al.*, 2014; Qi *et al.*, 2014). The results of these studies showed that SSR decreased by approximately 10% from 1960 to 1990 during a period known as the “Global dark"; since the late 1980s, SSR has started increasing in many regions, which is known as the “Global brighten" (Wild *et al.*, 2005). Wang *et al.* (2010) observed the relationship between radiation change and atmospheric haze (aerosol content) in China. Haze is an atmospheric phenomenon that is characterized by visibility of less than 10 km due to complex material that is suspended in the air, such as dust, smoke and other fine particles (Zhuang *et al.*, 2014). When haze occurs, there must be the existence of aerosols. However, when aerosols exist in the air, there is not necessarily appeared haze. In addition to the adverse health effects in humans, haze induced urban and nonurban haze can change the radiation balance of the earth, damage forests and crops, and contaminate lakes and rivers (Zhuang *et al.*, 2014). Previous research showed the

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appearance of haze made to reduce solar radiation reaching the ground. The study by Qi *et al.* (2015) showed that haze pollution / aerosol air pollution is the main factor contributing to the reduction of SSR in the eastern region of China. Thus, the main reason for this decrease is an increase in total suspended particles in the atmosphere. These studies suggested that increased aerosol or haze was the reason for a reduction in radiation, but there is no evidence to support this theory.

Because there were no long-term serial ground observational aerosol data, direct radiation and scattering radiation were used to obtain the atmospheric turbidity index, which reflects atmospheric pollution and aerosol levels. The haze in Beijing has increased in recent years; determining whether the haze weather could reduce SSR requires further evidence. In this study, the annual variation of SSR in Beijing from 1961 to 2011was investigated based on available surface solar radiation data. To quantitatively analyze the contribution of air pollution to changes in SSR, identifying the correlation between SSR and air pollution was the primary aim of this study.

2. Data and methods

2.1 Data

The SSR data used in this paper were collected from the site (39.8° N, 116.28° E)in Beijing, China, over the entire 1961-2011 period, including direct and diffuse radiation measurements. In addition to SSR data, conventional meteorological data were obtained from the same Beijing sites, including precipitation, sunshine percentage, sunshine duration, temperature, total cloud cover, and low cloud cover. The aerosol optical depth (AOD) data over Beijing were from the MODIS Land Standard Products MOD08_M3 by NASA during the 2001-2012 periods.

2.2 Methods

2.2.1 The atmospheric turbidity Index (ATI)

This study calculated atmospheric turbidity index using meteorological observational data due to the short time series of aerosol data. Atmospheric turbidity reflects the change in aerosol content (Qi *et al.*, 2015). We developed methods to measure the atmospheric turbidity index (ATI) based on direct solar radiation (DSR) and diffuse radiation (DR). ATI was formulated as:

$$\mathrm{ATI}=\frac{\mathrm{DSR}}{\mathrm{DR}} \tag{1}$$

The atmospheric turbidity mainly depends on the content of atmospheric aerosols under the same solar altitude on a sunny day. The ATI value is very small when the atmosphere is clean (low aerosol content), and higher atmospheric turbidity corresponds to greater ATI values. The relationship between atmospheric turbidity and surface solar radiation (SSR) is defined in the following equation.

$$\mathrm{SSR}=\mathrm{DSR}+\mathrm{DR} \tag{2}$$

By comparing formula (1) with formula (2), the following was found:

$$\frac{\mathrm{SSR}}{\mathrm{ATI}}=\mathrm{DR}+\frac{\mathrm{DR}^2}{\mathrm{DSR}}$$

SSR/ATI and *DR* are quadratic equations, and the SSR and ATI are two non-independent variables. The SSR and ATI were tested by the MODIS Land Standard Products MOD08_M3 (Level-3 MODIS Atmosphere Daily Global Product).

2.2.2 Trend analysis, significance Test

The annual time-series of the indices were calculated for each station. The annual variation trends of the indices were estimated using linear trends for each station, incorporating all available years within the

1961-2011 timeframe. Using the statistical significance test, the trends were evaluated at the 5% level against the null hypothesis (Wei, 2007).

3. Results and discussion

3.1 The AOD and ATI relation shipanalysis

The monthly variation patterns of the ATI and AOD of Beijing from 2000 to 2011 are shown in Figure1. The variations in the trends of the ATI and AOD are roughly the same. The ATI and AOD values are lower in autumn and winter than in other seasons. From the average annual variation, the highest values of ATI and AOD were observed in 2008, and the lowest values were observed in 2004. Both the monthly and annual ATI and AOD are significantly correlated, with a correlation coefficient of 0.285/0.541 using the significance test at the 0.01/0.05 level. Thus, the atmospheric turbidity can be used to reflect atmospheric conditions.

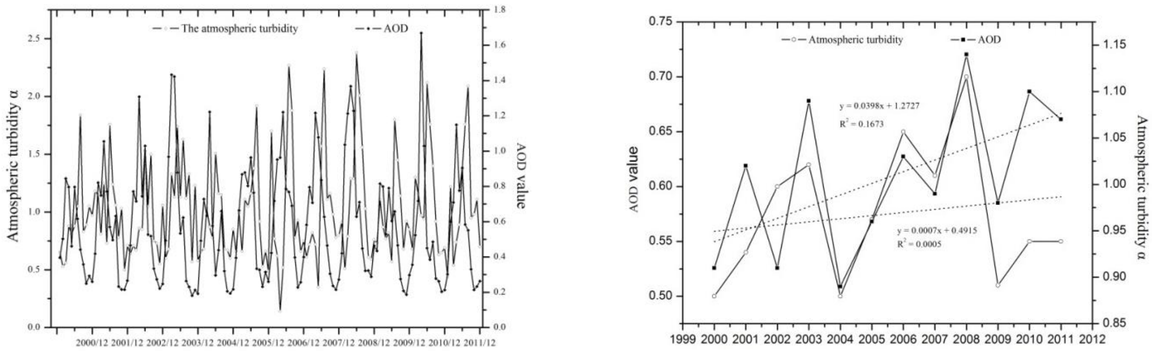

Figure 1. The monthly (left) and annual (right) average distributions of ATI and aerosol optical depth AOD (550 nm) from 2000 to 2011 in Beijing

3.2 Relations between SSR and meteorogical elements

The meteorological factors significantly affect SSR variation. Several existing studies (Chen *et al.*, 2005; Che *et al.*, 2006; Zhang *et al.*, 2004; Elminir *et al.*, 2006) have shown that the aerosol factor due to human activities is the main factor influencing SSR variation. Shao *et al.* (2009) found that SSR decreased with the increase of PM10 concentration in North China.

The correlation coefficients between precipitation, low cloud cover, total cloud cover, sunshine percentage, atmospheric turbidity and SSR are presented in Table 1.From 1961 to 2011, the correlation relationship between SSR and low cloud cover and turbidity are negative. During this time period, the simple correlation coefficient of these variables passed the 0.01 significance level test. There were no significant correlations between SSR and precipitation, total cloud cover. The ATI and SSR demonstrate a significant negative correlation relationship.

Table1. The simple correlation coefficients of SSR and climatic factors.

	Precipitation	Sunshine percentage	Low cloud cover	Total cloud cover	Atmospheric turbidity
Simple correlation	-0.131	0.793**	-0.577**	-0.133	-0.530**

*Values significant at a 0.01 probability level

3.3 The relationship between ATI and SSR

Aerosols are important components that can result in changes in SSR (Qi *et al.*, 2014; Qi *et al.*, 2015; Zhang *et al.*, 2004). Because there are no long-term serial ground observational aerosol data, direct radiation and scattering radiation were used to determine the ATI, which reflects the atmospheric pollution and aerosol levels. Zhang *et al.* (1997) studied the relationship between solar radiation and changes in air pollution in cities and found that the trend of change of the ATI can reflect changes in atmosphere pollutants well. The increase in atmospheric turbidity by an average of 0.036/10a is attributed to the aerosol content, which caused SSR to decrease (Figure 2).The atmospheric turbidity and SSR were significantly negatively correlated, which can be seen from partial and simple correlations (table 2). This result showed that among the many factors that resulted in the decrease in SSR, the atmosphere turbidity index in the Beijing area was the main factor.

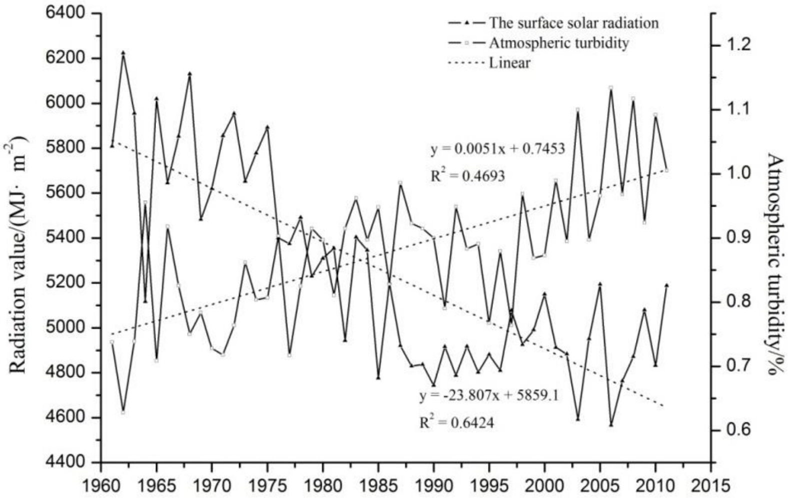

Figure2. The distributions of SSR and ATI from1961 to 2011 in Beijing

4. Conclusions

This study analyzed the annual variation in SSR in Beijing during the 1961-2011 period and the correlation between SSR and atmospheric pollution. The variations in SSR and AOD are very small and decreased slightly over Beijing. Yet, SSR and AOD were significantly correlated. The changes in trends of the ATI and AOD were similar. The monthly and annual ATI and AOD were significantly correlated, so the atmospheric turbidity could reflect the atmospheric conditions well. The average changes in the SSR in Beijing exhibited a downward trend; the inter-annual Beijing SSR was different for each year and showed a decreasing trend. From the inter-annual variation, SSR decreased prior to the 1990s before transitioning to a trend that slowly increased. Among all of the factors that influenced the change in SSR, the atmosphere turbidity index in the Beijing area was the main factor.

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