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The research of new daily diffuse solar radiation models modified by air quality index (AQI) in the region with heavy fog and haze

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ABSTRACT

55 years (from May 1957 to November 2013) solar radiation data measured in Beijing are used to establish new daily diffuse solar radiation models (NDDSR models). Based on the comparative analysis of air quality index (AQI), fog and haze, a new method that uses AQI to modify existing daily diffuse solar radiation models and NDDSR models is proposed. The test of recent 3-years (from December 2013 to June 2016) diffuse solar radiation data validation showed that the accuracy of existing daily diffuse solar radiation models are improved based on the AQI modification. For each type of models, NDDSR models are more accurate than existing daily diffuse solar radiation models, and further improved with AQI modification, in which Chandrasekaran & Kumar model and NDDSR modified model 5 are the most accurate. Validation of solar radiation data measured in multiple cities shows that NDDSR models and their modified models have a certain applicability to different regions. If not considering AQI modification, the applicability of NDDSR models is best in Guangzhou, followed by Lanzhou, and Shenyang is relatively worse. If considering AQI modification, the correction effect of NDDSR modified models is best in Shenyang, followed by Guangzhou, and Lanzhou is relatively worse.

1. Introduction

The design, simulation and performance evaluation of the solar system require accurate solar radiation data [1–3], in which diffuse solar radiation is the key determining the building cooling load and air conditioning equipment selection [4,5]. Since the measurement of beam solar radiation and diffuse solar radiation are difficult, many meteorological stations only provide global solar radiation data instead of diffuse solar radiation data [6,7]. Therefore, establishment of diffuse radiation models is extremely important [8,9]. At present, lots of beam and diffuse separation models are available in literature, which can be divided into five categories: (1) linear models [10–13]; (2) polynomial models [14,15]; (3) two piecewise polynomial models [16–18]; (4) three piecewise polynomial models [19–22]; and (5) other models. For the last models (other models), it is used few because of the complexity; and the first four models are common in literature, which have good applicability in many areas. In recent years, because of air pollution, there are extremely low visibility and severe haze in many Chinese cities [23–25]. It has a significant scattering - weakening effect to solar radiation [26,27]. To solve this problem, solar radiation data recorded from May 1957 to November 2013 in Beijing have been used to establish new daily diffuse solar radiation models (NDDSR models). On this basis, a new method (AQI correction) is proposed to amend the existing daily diffuse solar radiation models and NDDSR models. Solar radiation and air quality data measured from December 2013 to June 2016 in Beijing, Guangzhou, Shenyang and Lanzhou are used to validate the applicability of NDDSR models and their modified models in different regions.

2. Variation of atmospheric conditions and solar radiation

2.1. Variation of Chinese atmospheric conditions during recent years

In recent years, a growing number of cities suffered from serious air pollution, which leads to extremely low visibility, severe fog and haze. A typical distribution of atmospheric conditions is

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Nomenclature

a, b, c, d, e, f, c_1, c_2	fitting coefficients of daily diffuse solar radiation model (dimensionless)
AQI	Air Quality Index (dimensionless)
$AQI_{average}$	the average Air Quality Index in recent years (dimensionless)
BP_{Hi}	high value of the concentration limit value which is close to mass concentration of pollutant n (mg/m^3 for CO and μg/m^3 for other pollutant)
BP_{Lo}	low value of the concentration limit value which is close to mass concentration of pollutant n (mg/m^3 for CO and μg/m^3 for other pollutant)
c_a	is the average calculated values (MJ/m^2 in this paper)
c_i	is the ith calculated value (MJ/m^2 in this paper)
C_p	mass concentration of pollutant p (mg/m^3 for CO and μg/m^3 for other pollutant)
H_0	daily extraterrestrial global radiation on horizontal surface (MJ/m^2)
H	daily global solar radiation on horizontal surface (MJ/m^2)
H_d	daily diffuse solar radiation on horizontal surface (MJ/m^2)
$IAQI$	Individual Air Quality Index (dimensionless)
$IAQI_p$	Individual Air Quality Index of pollutant p (dimensionless)
$IAQI_{Hi}$	Individual Air Quality Index of BP_{Hi} (dimensionless)
$IAQI_{Lo}$	Individual Air Quality Index of BP_{Lo} (dimensionless)
k_d	the slope of daily global solar radiation variation in the past decades (dimensionless)
k_a	the slope of annual global solar radiation variation in the past decades (dimensionless)
K_t	daily clearness index, $K_t = H/H_0$ (dimensionless)
K_t'	daily clearness index modified by Air Quality Index (dimensionless)
K_d	daily diffuse ratio, $K_d = H_d/H$ (dimensionless)
m_a	is the average measured values (MJ/m^2 in this paper)
m_i	is the ith measured value (MJ/m^2 in this paper)
n	number of days in a year or number of calculated and measured values (dimensionless)
p	pollutant's item (dimensionless)

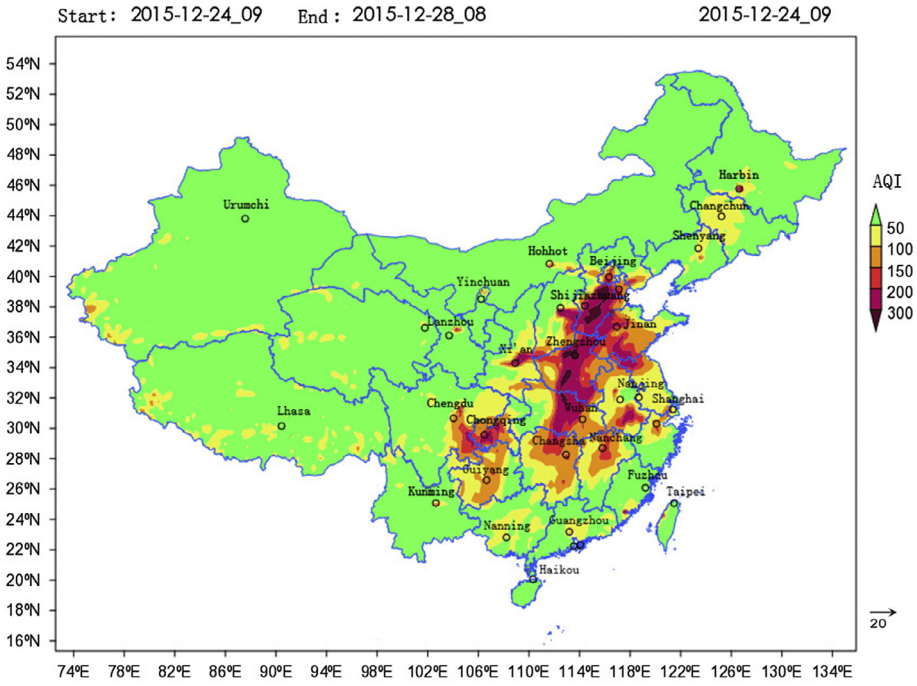

Fig. 1. The distribution of Chinese air quality index (AQI). (Date from Ministry of Environmental Protection of the People Republic of China [29] and Air quality historical data query website [30].)

shown in Fig. 1. The fog and haze of the Beijing-Tianjin-Hebei region is particularly serious [25,28], and the annual distribution of air quality grade of this region in 2015 is shown in Fig. 2. Proportion of days which air quality was poorer than light pollution is 46.55% in 2015 (Fig. 2). Therefore, Chinese air pollution (especially fog and haze) is serious [25,28].

2.2. Variation of solar radiation during recent years

The scattering and weakening effect of fog and haze to solar radiation is serious. For instance, the global solar radiation in Beijing decreased by an average of 14.19% during recent 55 years, and the variation of global solar radiation is shown in Fig. 3. Solar energy systems designed based on conventional meteorological data are very difficult to meet the current demand, which inevitably affects the development and utilization of solar energy resources. Therefore, there is an urgent need to provide solar radiation data and the corresponding calculation models considering the influence of fog and haze.

3. Data collection

In this paper, the authors collected the daily and annual data of global, beam and diffuse solar radiation from Beijing, Guangzhou,