Temporal variability of diffuse fraction of surface solar radiation in an East Asian megacity, Seoul.

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**Abstract**

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**1. Introduction**

Currently, more than half of the world's population lives in cities, and by 2050, the proportion of urban residents is expected to increase by about 70%, mainly in developing countries in Asia and Africa (UN, 2017). Most anthropogenic activity and energy consumption are occurring in an urban area, resulting in intensive emissions of air pollutants, greenhouse gases, and waste heat. For the last half a century, East Asia has undergone rapid urbanization, and recently it has experienced severe air pollution issues, including yellow-dust and smog events. There is a lack of research on how air pollution affects local and regional climate changes in East-Asia region, due to the relatively complex coastline and mountainous topography with heterogeneous land-cover and land-use.

The aerosols can have a significant impact on of the quality of the solar radiation via scattering, absorbing, and aerosol-cloud interactions and the global radiative forcing by atmospheric aerosols is about -0.9 W m-2 (IPCC, 2013). Solar radiation, which is more scattered by aerosols, has an increased fraction of diffuse solar radiation. More scattered radiation provides more homogeneous irradiance condition which is advantageous for increasing the light use efficiency of vegetation (Gu et al., 2003; Niyogi et al., 2004; Oliveira et al., 2007; Mercado et al., 2009) and decreasing the surface albedo at the urban canyon (Harman et al., 2004).

The purpose of this study is to investigate the temporal variability of the quality of solar radiation over an urban area in East Asia. In this area, yellow dust originated from the Gobi Desert in spring and smog caused by local heating in winter. Following the westerlies prevailing throughout the year, the influence propagates to the east, therefore, the whole of this region. In summer, heavy precipitation (Changma in Korea, Meiyu in China, and Baiu in Japan) frequently occurs due to the influence of East Asian monsoon, which reduces air pollution and the insolation of solar radiation.

Our research aims to focus more on the fraction of diffuse solar radiation, based on the two-year of surface observation data, which include in-situ observation of global and diffuse solar radiation, meteorological conditions (humidity, precipitation, and cloudiness), and particulate matter less than 10 μm (PM10) concentration, remote sensed aerosol optical depth (AOD). Cho et al. (2000) reported that the fraction of diffuse solar radiation is larger in clear day (in <20% of cloudiness) than in cloudy day (>80% of cloudiness) throughout two-year (1996 – 1997) of observation in Seoul. The fraction was 39% and 73% for clear and cloudy day, respectively. Detailed information for observation is presented in Section 2, and the time-series and relationship between variables are shown in Section 3.

**2. Data and methods**

(Figure 1)

(Table 1)

**2.1. Solar radiation**

(Figure 2)

The global and diffuse solar radiation measurement was conducted at the top of the building in the EunPyeong residential area in the northwestern part of Seoul (37.6350°N, 126.9287°E; Fig. 1). A solar tracking system (Solys2, Kipp&Zonen, Netherlands) was installed with two radiometers (CMP10, Kipp&Zonen, Netherlands; Fig. 2). 10-min averaging global radiation and diffuse radiation were recorded by a data-logger (CR3000, Campbell Scientific, USA). The measurement system was checked daily via teleconnection, and lens cleaning and data retrieval were done on site every two weeks. For quality control, we adjusted the nocturnal observations to zero, which were usually less than |±5| W m-2.

**2.2. Meteorological condition**

The selected synoptic weather station is the Seoul observatory (37.5714oN 126.9658oE), which is located at the central area of Seoul. Quality-controlled measurement data and metadata are opened through the National Climate Data Portal of Korea Meteorological Administration (KMA) (http://data.kma.go.kr/). Meteorological data include relative humidity, precipitation, and cloudiness, and the time-resolution is an hour.

**2.3. Aerosol optical depth**

During the study period, AOD have been observed using the AERONET sunphotometers (https://aeronet.gsfc.nasa.gov/) installed in Yonsei University (37.5640oN 126.9345oE). The aerosol optical depth for seven channels (340, 380, 440, 500, 675, 870, and 1020 nm) are computed using AERONET3 retrieval algorithm (Eck et al., 2018). This algorithm is including removal of cloud impact (Smirnov et al., 2000) and its uncertainty for individual channels is reported by Eck et al. (1999). In this study, we are using AOD of 500 nm for investigating the relationship between AOD and fraction of diffuse solar radiation.

**2.4. Surface PM10 concentration**

Surface PM10 concentration from 38 monitoring stations across the metropolitan area of Seoul is used in this study. All monitoring stations have sampling rates of five-minute with averaging periods of an hour. Measurements method is a β-ray absorption (PM-711, KIMOTO, Japan). Quality assurance was applied based on guidelines for the air quality monitoring network of the Korean Ministry of Environment (KME 2016).

**3. Results**

**3.1. Climatology**

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**3.2. Effects of cloudiness and solar elevation angle**

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**3.3. Light use efficiency by diffuse radiation fraction**

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**4. Summary**

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**Acknowledgments**

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**Appendix. Estimation of solar elevation angle**

Iqbal (1983) introduced the following equations for computing the solar elevation angle (*θ*):

(A. 1)

, where *δ* is the solar declination angle, *ϕ* is the latitude, and *ω* is the hour angle. To calculate *δ* and *ω*, the day angle *Γ* is necessary,

(A. 2)

(A. 3)

The maximum error of *δ* is 0.0006 rad (< 3’). Following equation presents *ω* in radian:

(A. 4)

, where *UT* is the universal time in minutes, *λ* is the longitude, and *Et* is the equation of time in minutes.

(A. 5)

**Reference**

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**Table Captions**

**Figure Captions**

Figure 1. The

**Table 1**. .

**Figure 1**. Location of surface stations in Seoul (from Google Earth).

**Figure 2**. .