POSTER 13

Estimating Daily Solar Radiation Using Angstrom-Prescott Equation in Korea

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I. Introduction

One of the major input variables for crop models is solar radiation. However, observation data of solar radiation is often available at less number of sites than those for a sunshine duration as well as a temperature and a precipitation. Different approaches have been developed to estimate solar radiation using variables available at more weather stations. For example, the Angstrom-Prescott model, which depends on empirical coefficients, has been used to estimate solar radiation using sunshine duration (Besharat *et al.*, 2013). Although empirical parameters of Angstrom-Prescott model can be determined using a long-term observation data of solar radiation, it would be challenging to obtain such parameters at a specific site. The objective of this study was to examine if the Angstrom-Prescott model with a single set of empirical parameters would be useful to obtain reliable estimates of solar radiation in a region.

II. Material and Methods

Daily solar radiation was estimated using sunshine duration at 19 sites in Korea. Although Angstrom-Prescott model was originally developed to estimate monthly solar radiation, Liu *et al.*(2009), *Choi et al.*(2010) reported that the use of daily data would allow reliable estimation of daily solar radiation. Empirical coefficients a and b, which represent clear sky transmissivity, were used for the Angstrom-Prescott model as follows:

$$\frac{H}{H_0} = a + b\left(\frac{s}{s_0}\right)$$

where H and H_0 are the global and extraterrestrial solar radiation (MJ m^{-2} d^{-1}), respectively. S and S_0 represent the actual and the theoretical sunshine duration, respectively. Frere and Popov(1979) suggested that 0.18 and 0.55 would be reasonable for the values of a and b for cold and temperate climate zones, respectively. Still, those coefficients could be calibrated using long-term solar radiation data.

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Data of daily solar radiation and sunshine duration were collected for 31 years at weather stations operated by the Korean Meteorology Administration. WiseDownloader, which is a data client for web-based weather database (Lee *et al.*, 2015), was used to retrieve daily data at 19 sites.

The statistics of the degree of agreement including concordance correlation coefficient (CCC) and normalized root mean square error (NRMSE) were calculated between observed and estimated solar radiation. Estimates of solar radiation were analyzed by month, site, and year. R was used to calculate solar radiation using a customized script that implemented the Angstrom-Prescott model. The values of CCC and NRMSE were also obtained using R.

III. Result and Discussion

When the coefficient values suggested by Frere and Popov(1979) were used, reasonable estimates of solar radiation were obtained in Korea. For example, the values of CCC between estimated and observed solar radiation ranged 0.87 to 0.92 for monthly estimation (Fig. 1). In spring periods, the values of CCC tended to be higher than other periods in a season. Still, the CCC values were greater than 0.9 during summer and autumn periods. On the other hand, the value of NRMSE was relatively higher during summer than other periods.

The degree of agreement statistics differed by year. For example, the values of CCC ranged from 0.87 to 0.95 for 31 years (Fig. 2). The NRMSE for the periods in recent years, *e.g.*, after 1990, was considerably lower than that for the past. Spatial variation of the statistics for the degree of agreement was relatively small. For example, the values of CCC ranged from 0.89 to 0.95. The NRMSE values tended to be lower in rural areas than urban areas. For example, the NRMSE values tended to be greater than 7, in Suwon, Incheon, and Busan. In contrast, the values of NRMSE was relatively low at weather stations near the major crop production areas, e.g., Jeonju, Seosan, and Gwangju (Fig. 3).

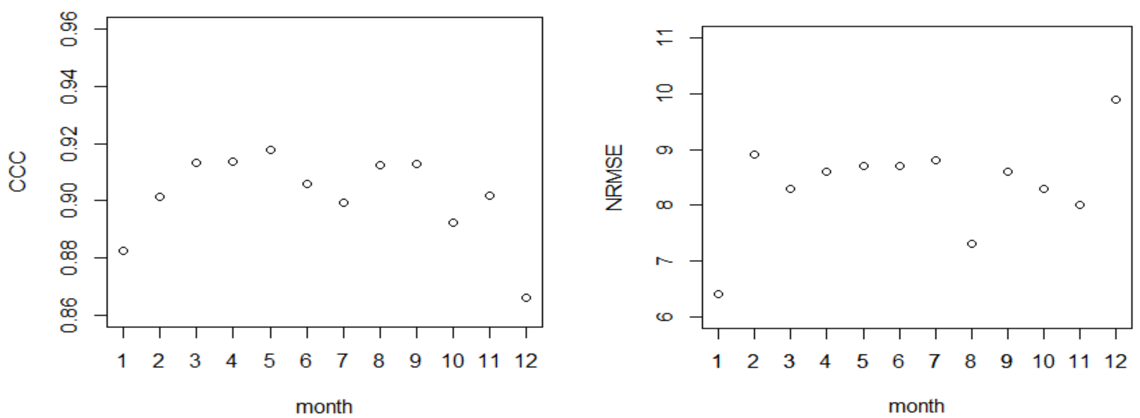

Fig. 1. Concordance correlation coefficient (CCC) and normalized root mean square error (NRMSE, %) between observed and estimated solar radiation using the Angstrom-Prescott model by month.

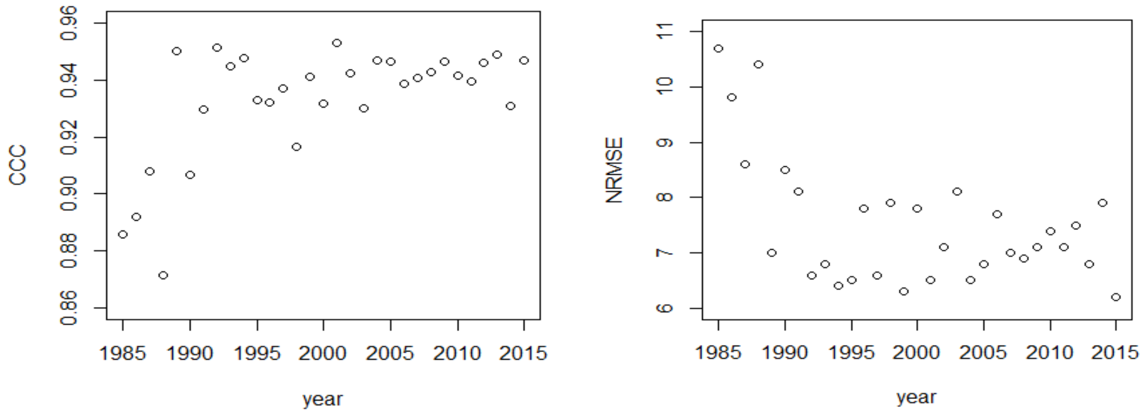

Fig. 2. Concordance correlation coefficient (CCC) and normalized root mean square error (NRMSE, %) between observed and estimated solar radiation using the Angstrom-Prescott model by year.

Our results indicated that Estimates of solar radiation using the coefficients suggested by Frere and Popov (1979) tended to result in large errors when observed solar radiation was low. For example, non linear relationship between observed and estiamted solar radiation was found when estimated solar radiation was < 7.5 MJ m^{-2} d^{-1} in July. Low solar radiation would occur during monsoon periods. In winter, sunshine duration is usually shorter than other seasons. These would result in relatively large errors occurred during summer and winters. Choi *et al.*(2010) also reported that the coefficient of regression line differed by the length of sunshine duration. Thus, another set of empirical coefficient would be needed to improve accuracy of solar radiation estimates using the Angstrom-Prescott model, which merits further studies in identifying additional coefficients.

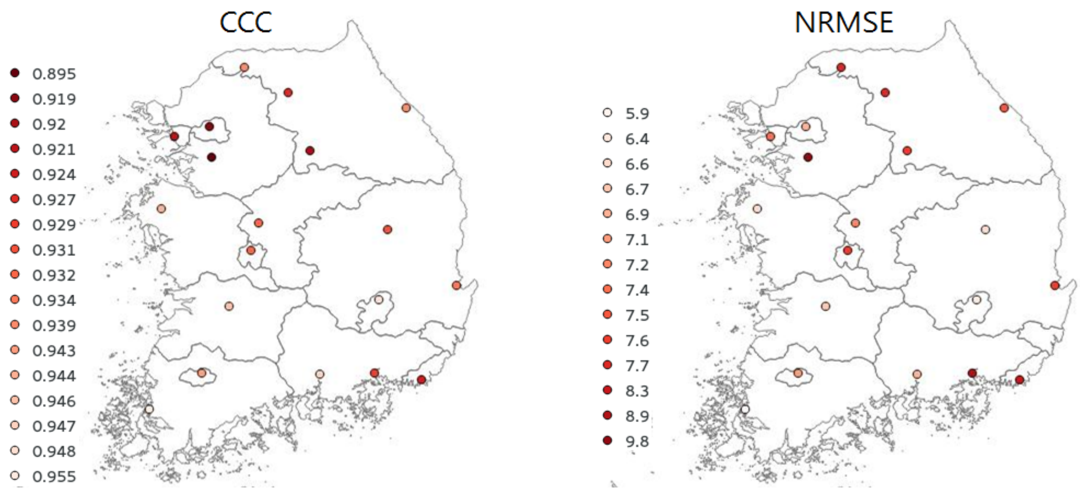

Fig. 3. Concordance correlation coefficient (CCC) and normalized root mean square error (NRMSE, %) between observed and estimated solar radiation using the Angstrom-Prescott model by weather station.

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