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Modeling and comparison of hourly photosynthetically active radiation in different ecosystems

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ABSTRACT

Long-term hourly observations of photosynthetically active radiation (PAR), global solar radiation (E_g) and meteorological variables [air temperature (T_A), relative humidity (R_H), dew point (T_D), water vapor pressure (V_W), air pressure (P_A)] observed at different types of ecosystems (agricultural farmland, wetland, forest, bay, grassland, desert and lake) in China are reported for developing and validating PAR estimating models. Three improved Artificial Neural Network (ANN) methods, Multilayer Perceptron (MLP), Generalized Regression Neural Network (GRNN), and Radial Basis Neural Network (RBNN) are proposed in this study for predicting the hourly PAR using the combinations of above meteorological variables as model inputs. The ANN models have been compared with an efficient all-sky PAR model (ALSKY) through statistical indicies root mean square errors (RMSE) and mean absolute errors (MAE) at each station. The effects of meteorological variables on the hourly PAR predictions are further analyzed for investigating the main influencing factors for each model. The results indicate that there are large differences in model accuracy for each model at each ecosystem, for example, the MLP and RBNN models whose inputs are the E_g and T_A (RMSE, MAE and R^2 are 7.12, 5.24 and 98.90, respectively) perform better than the GRNN and ALSYK models at the agricultural farmland AKA station, while the GRNN model (RMSE and MAE are 12.47 and 8.98, respectively) performs better than other methods at DHL station. The model inputs also play different roles in different ecosystems for each ANN model, for example, T_A and P_A generally have more effects than the R_H, T_D and V_W variables in the farmland stations, while R_H is more important for hourly PAR prediction than the other variables in the bay stations. Finally, the overall rank of the model accuracy is obtained, MLP and RBNN models are more accurate for estimating hourly PAR at various ecosystems in China.

Contents

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1. Introduction

Photosynthetically active radiation (PAR), defined as solar radiation between 400 and 700 nm [1,2], is an important component of global solar radiation (E_g) reaching the surface because it is one of the key factors driving the process of photosynthesis and therefore the production and storage of organic carbon [3]. Photosynthesis is a basic process involved in plant growth and contributes to the primary productivity of natural ecosystems and crop production [4]. Accurate estimation of PAR is understandably crucial for investigating the exchange of CO_2, water and energy in the planetary soil–plant–atmosphere system [5], which play improtant roles in understanding the impacts of changing climate, atmospheric chemistry and land use on regional to global scale biogeochemical cycling [6]. PAR is therefore a key determinant of global water and carbon balance and the regional and global climate change [7,8]. Besides their importance to numerous ecophysiological and climate models, accurate determination and clear understanding of the PAR solar components are also required in many solar energy applications (e.g. renewable energy development and management) due to the increasing global energy demands [9,10].

Despite its importance, there are relatively few places around the world where PAR is routinely measured due to the great difficulties in conducting accurate observations (maintaining the sensors and quality control) and high cost, unlike other meteorological variables such as air temperature, precipitation and sunshine hours [11–13]. Thus, PAR has to be estimated through semi-empirical methods, radiative transfer models or satellite-based observations from a prescribed atmospheric state [14]; for example, Mizoguchi et al. [13] estimate the PAR values in a temperate humid area using atmospheric pressure, air temperature and relative humidity; Tan and Ismail [15] compare different PAR models in equatorial Singapore using direct observations; Janjai and Wattan [16] developed a model for estimating PAR from geostationary satellite in a tropical environment (Thailand); Li et al. [17] develop a method for estimating PAR in China by combining geostationary and polar-orbiting satellite data. It is known that PAR solar irradiance is reduced while passing through the atmosphere because part of it is absorbed and scattered by molecules and substances, including water vapor, dust particles and various gases, and in particular the presence of cloud which varies temporally and spatially, so the model results are greatly affected by local climatic and geographic conditions up till now (e.g. optical properties of the atmosphere) [18,19]. These methods should be further recalibrated to account for local characteristics like cloudiness, water vapor and aerosol loadings [20,21]. Despite Wang et al. [22] developed an all-sky PAR model by investigating its dependence on clearness index (K_t) and cosine of solar zenith angle (μ) based on observations from Chinese Ecosystem Research Network (CERN) during the 2006–2012 period. This method has not been compared with other PAR models, and the model accuracies also differ greatly from different observation stations. It is still essential to set up as many PAR observation networks as possible and develop and compare different models for improving the accuracy of PAR estimations [23,24].

PAR related studies in the literature are mainly focused on daily or monthly scales because the direct instantaneous measurements of the PAR component are very scarce worldwide [25–27]. There

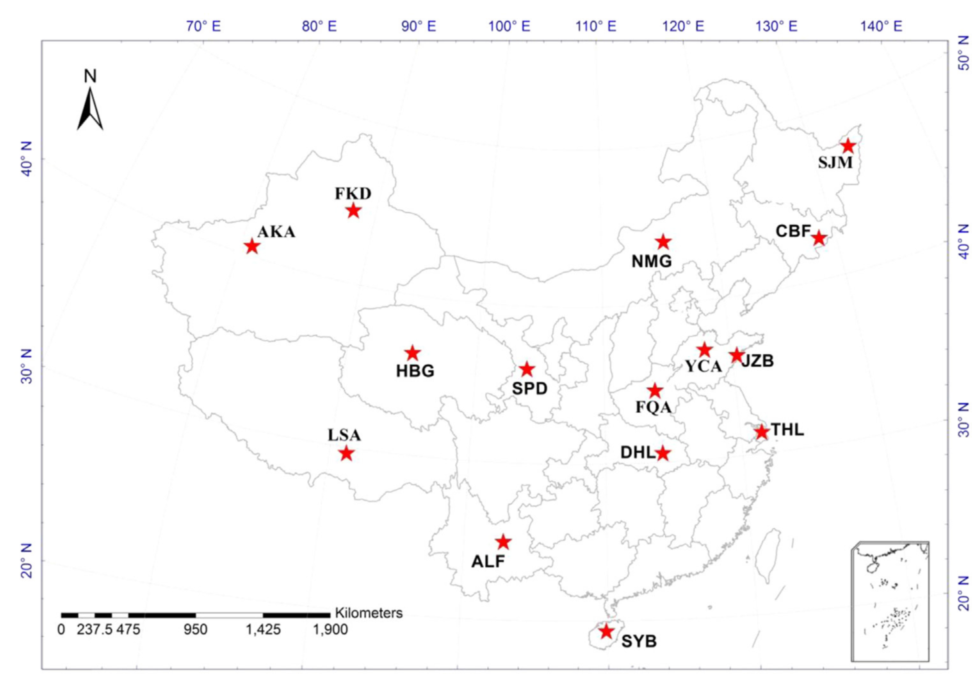

Fig. 1. Spatial distribution of the PAR observation stations at different ecosystems in China.