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Research Progress of Solar Radiation Estimation Model

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Abstract

Solar radiation (Rs) is the main source of energy for physical, biological and chemical processes on Earth, and is a necessary parameter for the simulation of ecological water cycle processes, as well as an important factor for calculating reference crop evapotranspiration (ET0). Due to the limitation of observation cost and other reasons, conventional meteorological data are usually used to estimate solar radiation. This paper reviews the current mainstream solar radiation estimation methods at home and abroad, including theoretical models, empirical models, machine learning models and remote sensing inversion models. The problems existing in the existing solar radiation estimation methods are summarized, and the future research trends are prospected.

Keywords

Solar Radiation; Estimation Models; Research Review.

1. Introduction

Solar energy is a basic energy source, and all civilizations and life on earth benefit from the energy provided by the sun. People's production and life are inseparable from various forms of solar energy. Wind, biomass, water, and more all come from the sun. At this stage, the solar energy sources that can be directly used are divided into two categories: photoelectric and photothermal energy. Among them, photothermal energy is the thermal radiation energy brought by sunlight, that is, solar radiation [1-4] (solar radiation, Rs). Although only one billionth of the total radiant energy radiated by the sun to the entire universe is received by the earth, it is the main source of energy in the earth's atmosphere. However, only a small number of meteorological stations in the world can directly observe the amount of solar radiation, and most regions need to rely on various solar radiation estimation models to obtain the amount of local solar radiation. The accurate estimation of solar radiation not only directly affects the estimation accuracy of the reference crop evapotranspiration (ET0) by the Penman-Monteith formula method, but also has a great impact on the research on crop simulation models, solar energy development and utilization, and climate change. In this paper, a solar radiation estimation model based on basic meteorological data is analyzed and summarized, so as to improve the accuracy of solar radiation estimation.

At present, solar radiation estimation models can be divided into four categories: theoretical models, empirical models, machine learning models, and inversion based on satellite images.

2. Theoretical Model

The theoretical model refers to the analysis and simulation of a series of scattering and absorption of solar radiation in the process of entering the earth's atmosphere and reaching the surface, taking into account the local atmosphere and surface environment. Because the theoretical model needs to take

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into account many factors, such as the absorption and scattering of solar radiation by clouds in the atmosphere, the scattering of aerosols in the air, and the reflection of it by the surface, it requires a more solid physical foundation to build a more complex complex. Model. And these factors are relatively more difficult to obtain, which limits the generalization of theoretical models to a certain extent.

The most commonly used theoretical models are the Hottel model, the ASHRAE sunny solar radiation model, and the MODTRAN model. The Hottel model [5] needs to input the local latitude and longitude and the direct solar scattering transmittance. It is mainly suitable for the estimation of solar radiation under clear sky conditions at altitudes below 2500m and atmospheric visibility greater than 23km. It is not very good for bad weather. The ASHRAE sunny solar radiation model [6] also takes into account the change in the atmospheric transparency that leads to the change in the proportion of direct sunlight. Although the accuracy is average in the calculation of dry areas, it has higher accuracy in wet and low latitude areas. The atmospheric transparency coefficient in its input parameters varies from region to region, and it is not suitable for regions with insufficient meteorological data; the MODTRAN model [7] originated from the low-resolution atmospheric radiative transmission (LOWTRAN, Low Reeloution transmission) model, and selected 9 altitudes. Air pressure, temperature, dew point, and horizontal visibility at 08 are used as input parameters, which not only improves spectral resolution, but also uses multiple scattered radiation calculations to improve accuracy [8], and for different atmospheric aerosols, transmittances The model provides more choices, so it can estimate the amount of solar radiation more accurately, but at the same time, it is difficult to obtain various meteorological parameters at different heights at the same site, which makes it difficult to popularize this method.

3. Empirical Models

The empirical model refers to building a model through the relationship between solar radiation and conventional meteorological variables such as temperature, relative humidity, rainfall, sunshine hours, cloud cover, etc. to estimate the amount of solar radiation. These parameters are relatively easier to obtain than those in the theoretical model, and the empirical model construction is simpler. Empirical models can be divided into three categories: sunshine percentage-based, temperature-based, and cloud-coverage-based models. Because of the differences in the number of factors considered, the number of models based on sunshine percentage and temperature is more than that based on cloudiness.

Temperature-based models generally believe that the amount of solar radiation reaching the ground is related to the difference between the maximum and minimum temperatures. For example, the H-S model and the B-C model both use the maximum and minimum temperatures as input parameters and correction coefficients based on local climatic conditions. Models based on cloud cover such as Wen Xiaohang [9] in 2008 analyzed the daily cloud cover data and visibility data from 729 conventional meteorological observation stations across the country from 1961 to 2000, and constructed an estimated solar radiation model.

The model based on the percentage of sunshine is widely used due to its high accuracy and simple form. The number of sunshine hours is the routine observation data of each weather station and is easy to obtain. The first solar radiation estimation model based on the percentage of insolation and the ratio of clear-sky radiation to solar radiation was proposed by Angstrom [10] in 1924. More than ten years later, Prescott [11] modified the clear-sky radiation to the more accessible top-atmospheric radiation as Now the most commonly used Angstrom-Prescott (A-P) formula method, it is one of the most widely used solar radiation estimation models [12], and its form is:

$$R_s = \left(a_s + b_s \frac{n}{N}\right) R_a \tag{1}$$

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In the above formula: n represents the actual sunshine duration in one day, h; N represents the maximum estimated sunshine duration that can be accepted at a fixed location on the earth under cloudless and sunny conditions, h; as and bs are both derived from the sun The empirical parameters of radiation Rs, FAO recommended coefficients as=0.25, bs=0.5.

The subsequent empirical models of solar radiation are mostly variants of this method or introduce other meteorological factors, such as the Bahel model that is also based on the percentage of insolation.

4. Machine Learning Models

In the field of agrometeorology, although traditional theoretical formulas and empirical models have been well applied in long-term calculations, due to the different integrity of time series of meteorological observation data in different regions when estimating solar radiation, some data are missing. Therefore, the above theoretical formulas and empirical models are difficult to meet the different needs of different regions. With the development of computer technology, many studies have shown that the machine learning model can simulate solar radiation with high accuracy, and the machine learning model has a flexible combination of input meteorological factors and is suitable for different environments.

Lopez et al. used [13] used several input meteorological factors such as temperature, relative humidity and wind speed to estimate solar radiation in Chile using artificial neural network (ANN). Chen and Li [14] estimated the solar radiation based on the support vector machine (SVM), using sunshine hours, air temperature, relative humidity and water vapor pressure as input parameters. The combination accuracy of the numbers is low, and the accuracy is significantly improved when the temperature-related parameters are added to the combination. Sun et al. [15] used the random forest model (RF) to estimate the solar radiation with the air pollution index as the input parameter, and the estimation results were significantly improved compared with the empirical model. [16] based on Adaptive neuro-fuzzy inference systems (ANFIS), ANFIS with grid division (ANFIS-GP) and ANFIS with subtractive clustering (ANFIS-SC) and M5 model tree (M5Tree) These methods use the sunshine hours, air pressure, temperature, water vapor pressure and relative humidity of 21 meteorological stations in China as input parameters to estimate solar radiation. Xiang Youzhen et al. [17] used the Bristow-Campbell (B-C) method, the Hargreaves (Harg) method and the support vector machine three methods to input the maximum temperature, minimum temperature, relative humidity, rainfall, and radiation as input parameters. The combination is compared, and it is concluded that the support vector machine model is better than the B-C method and the Harg method in the southern region. The support vector machine model is generally better than the B-C method and the Harg method. Li Jing et al. [18] used three machine learning models, Random Forest (RF), Artificial Neural Network (ANN) and Support Vector Machine (SVM), to estimate the sun in the Loess Plateau. Radiation, with air pressure, cloud cover, cloud optical thickness, ozone, precipitable water vapor, DEM, slope, aspect, etc. as input parameters, it is found that the RF model has the best simulation effect in the Loess Plateau and surrounding areas.

It can be seen that the accuracy of machine learning models with different input parameter combinations is different, and there is a lack of systematic comparison between the same models. It is necessary to compare and estimate the accuracy of different combinations of input meteorological factors for different regions. At present, many studies focus on the entire Chinese mainland as a whole or focus on a specific area, and there are few comparative studies and analysis of different climate regions.

5. Inversion based on Satellite Image Information

In recent years, some scholars have used satellite data to invert meteorological parameters such as clouds, temperature, humidity, and aerosols in the surface atmosphere, providing favorable conditions for the estimation of direct solar radiation. Chen Weimin [19] and others used the vertical detector inversion data of the Chinese sounding station, NOAA meteorological satellite data, and ozone data, etc., and established satellite measurements to retrieve the solar radiation and scattered radiation at various heights of the atmosphere through the discrete ordinate method. Zhang Chungui [20] et al. obtained aerosol data through MODIS to invert solar radiation, and concluded that the application of satellite data to estimate solar radiation in Fujian has high accuracy and meets the requirements of practical applications. Liu Yonghong[21] and others used CERES satellite data as the input parameters of MODTRAN 4.0 model to simulate the solar radiation in clear sky more accurately. Due to the vast territory of my country, in areas where meteorological stations are sparsely distributed, the accuracy of the solar radiation model in this area based on conventional ground meteorological data is not good, while the radiation model constructed by using satellite image information can be refined with higher accuracy. Radiation distribution across the region.

6. Conclusion and Outlook

Scholars have different researches on solar radiation estimation models. They obtain theoretical models by simulating the solar radiation process, construct empirical models for the relationship between solar radiation and conventional meteorological variables, and obtain different combinations of input meteorological factors according to local conditions. Machine learning models, as well as models based on inversion of satellite imagery information, found that models with sunshine percentage and temperature as input variables were more accurate. In addition, there are still some aspects that need further research to improve the accuracy of solar radiation estimation: for example, when calculating the empirical model, the coefficients in the model need to be further optimized according to the climate and environmental conditions of different study areas, so as to improve the scope of application of the model as much as possible; The model and machine learning model are combined in order to improve the accuracy of the model; although the satellite remote sensing inversion model has high accuracy, it can also be suitable for different geographical environments, but due to too few solar radiation observation sites, it is difficult to verify the remote sensing inversion results. There are limitations in estimating solar radiation using any model. It should be adapted to local conditions, taking into account the climatic and environmental characteristics of the study area, conducting multi-party comparisons, and selecting the most suitable local method or using a combination of methods for calculation.

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