The Simulation of Extraterrestrial Solar Radiation Based on SOTER in Zhangpu Sample Plot and Fujian Province

Zhi-qiang Chen
College of Geographical Sciences, Fujian Normal University, Fuzhou, China
soiltuqiang061@163.com

Jian-fei Chen
School of Geographical Sciences, Guangzhou University, Guangzhou, China
cjf@gzhu.edu.cn

***Abstract*—The study establishes DEMs and the computer models of daily extraterrestrial radiation in Zhangpu sample plot and Fujian province and annually extraterrestrial radiation in Fujian province using GIS base on SOTER. The results indicate that the daily extraterrestrial radiation is mainly 17-18MJ/m^2 in Zhangpu, the one is mainly 14-18MJ/m^2 and the annually extraterrestrial radiation is mainly 5000~7000MJ/m^2 in Fujian province. The influence of topographic feature is significant, in general the solar radiation in the chine is bigger than the one in the valley, and the one in the sunny slope is bigger than in the shady slope, the high radiation value appears primarily in the sunny slope with the chine as demarcation line. The method can extract daily and annually extraterrestrial radiation with high precision and speediness at small and moderate scales which don't take cloud into consideration. The orientation of future research is to improve precision by RS images and combine with SOTER.**

***Index Terms*—DEM, GIS, solar radiation model, Zhangpu sample plot, Fujian province**

I. INTRODUCTION

Solar radiation is the main energy of physical, biological and chemical processes on earth surface, is the necessary parameter in many models [1-3]. In the study of resource and environment in regional spatial scope, local terrain impact is enormous and must be considered [2]. Because of the complexity of computer models of extraterrestrial solar radiation considering terrain conditions, difficulty of terrain parameters acquisition and lack of appropriate calculation platforms, for a long time, it is neglected or simplified [1, 4]. GIS has provided the strong technical support for these work [2, 5]. Solar energy study and solar energy heat utilization are usually conducted in clear-day and extraterrestrial solar radiation models have broad scope [6], so the study took extraterrestrial solar radiation as object, took ArcGIS as platform in an experimental plot of Zhangpu sample plot as small scale and Fujian province as moderate scale, calculated the solar radiation spatial distribution law caused by hypsography under the same solar radiation in the complex topographic area of the subtropical zone and the model's applicability at small and moderate scales. The results can provide important information for solar radiation spatial-temporal distribution in the small and moderate areas, agricultural regionalization, effective utilization of solar energy and precision agriculture [1].

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Corresponding author: Jian-fei Chen

II. STUDY AREA

The study area is located in the northeast of Zhangpu county in Fujian province at 24°10′～24°15′N and 117°48′～118°00′E including Futan, Maping, Qianting and part of Baizhuhu farm, is about 8236 hm^2. Annual mean temperature is about 21℃ and annual precipitation is about 900mm, it's clear in dry and humid season; coastal plains, platform and hill appear in turn from the sea to the land; there is no big river with weak runoff regulation and poor hydrological condition; because of the long term artificial activity, the original vegetation has been destroyed and the secondary vegetation is dominated by grass with thin forest; the stratigraphies include Neogene Fotan Group, fluvial or marine or Aeolian or proluvial deposits of Pleistocene and Holocene in Quaternary, intrusive rock is early Yanshanian biotite granite, Neogene Fotan Group is basalt; the major soil types may be divided into the following six orders: Ferrisols, Vertisols, Camblsols, Ferralosols, Entisols and Anthrosols [7].

Fujian province lies between 23°32′ and 28°22′ of north latitude with a area of 121,400 km^2, is located on the southeastern coast of China characterized by subtropical climate, complicated landforms and multiple mountainous and hilly terrains which account for 87.5% of the total area of the province, leaving the remaining 10% for plains. It is always called the "Mountainous

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Region of Southeast" with complex natural conditions. It appears middle subtropical climate in the north mountain and south subtropical climate in the south coast areas. The annual mean temperature is around 15-21℃ and the accumulated temperature (≥10℃) is 5500-7500℃, the annual precipitation is around 1000-2000 mm and increases gradually from the southeast coast towards the northwest inland. The predominant natural vegetations are the south subtropical monsoon rain forest and the evergreen broad-leaved forest. Fujian has a history of over 3000 years and its long term agro-economic activities have brought about many types of land utilization, among which that of forest land accounts for 66.8%, that of cultivated land 12.7%, that of garden plots, 3.8%, herbage land 0.1%, water areas 4.4%, construction sites 3.1%, idle land 9.1% [8].

III. METHODS

A. Basic Astronomical Parameters

The method comes from the reference [9] in the paper. Some basic parameters should be established when calculating solar radiation somewhere on the earth including solar altitudinal angle, solar aspect angle, solar declination, sunrise & sunset time and so on [9, 10].

$$E_o=1.000109+0.03349\cos\theta+0.001472\sin\theta+0.000768\cos 2\theta+0.000079\sin 2\theta \quad (1)$$

Where E_o is the earth orbit correction factor, θ is day angle, $\theta = 2\pi t / 365.2422$, $t = N-N_o$, N is number of day, that is date's sequence number in a year, $N_o = 79.6764 + 0.2422 *$ （year-1985） - INT（(year - 1985)/4）.

Declination is the angle distance from the celestial equator to the sun along right ascension circle in equatorial coordinate system, it is positive when the sun is in the north of the equator and on the contrary it is negative, ranging from 0 to ±23.44. Hour angle describes the sun's movement in 24h, it is 0 at noon by local real solar time, positive in the morning and negative in the afternoon, 15 degrees per hour. Their calculation formulae respectively are:

$$\delta = 0.006894 - 0.399512\cos\theta + 0.072075\sin\theta - 0.006799\cos 2\theta + 0.00089\sin 2\theta \quad (2)$$

$$\omega = （So + Fo/60 - 12） * 15° \quad (3)$$

$$\omega 1 = \arccos(- \tan\delta * \tan\psi) \quad (4)$$

$$\omega 2 = - \omega 1 \quad (5)$$

Where δ is declination, ω is hour angle, So and Fo are hour and minute by real solar time, $\omega 1$ is sunset hour angle, $\omega 2$ is sunrise hour angle.

Solar altitudinal angle is the angle between solar ray and horizontal surface, solar aspect angle is the angle between projection of solar ray on horizontal surface and local meridian, due north is 0 degree. They are influenced by latitude, declination and hour angle. The calculation formulae are:

$$H = \arcsin(\sin\delta\sin\psi + \cos\delta\cos\psi\cos\omega) \quad (6)$$

$$A = \arccos[(\sin h\sin\psi - \sin\delta)/\cos h\cos\psi] \quad (7)$$

Where H is solar altitudinal angle, A is solar aspect angle, ψ is latitude.

B. Terrain Feature Calculation

When solar altitudinal angle and solar aspect angle are decided, slope, aspect and terrain shield are the important factors calculating extraterrestrial solar radiation especially in mountain area. Terrain shield means that: comparing the biggest horizon angle and corresponding solar altitudinal angle within a certain solar aspect angle range, if the former is bigger than solar altitudinal angle, solar radiation is 0 in shadow range or else solar radiation should be calculated. When GIS was not mature, slope, aspect and terrain shield were calculated using manual methods or complex algorithms. With the development of GIS technology, most of GIS software have the extraction function of terrain feature such as DRIVE SLOPE, DRIVE ASPECT and HILLSHADE in ArcGIS; contribute to the calculation of influence of terrain on solar radiation [1].

C. Extraterrestrial Solar Radiation Model

The solar radiation received somewhere on the earth is influenced by many factors such as terrain (elevation, slope, aspect, shadowing), soil, vegetation and weather conditions (atmospheric turbidity, cloud amount) and so on. Because of objective conditions, slope, aspect and elevation only were considered in the paper. The actual solar radiation can be calculated using revised formulae if there are more detailed ground data and weather conditions data [2]. The extraterrestrial solar radiation formula is:

$$W = I_o T E_o / 2\pi * \sum_{i=1}^{n} [\mu\sin\delta(\omega_{r,j} - \omega s_j) + v\cos\delta(\sin\omega_{r,j} - \sin\omega s_j) - \sin\alpha\sin\beta\cos\delta(\cos\omega_{r,j} - \cos\omega s_j)] \quad (8)$$

Where I_o is solar constant, T is day length, n is azimuth division number, empirical value is 36, $\omega_{r,j}$ and ωs_j are sunrise and sunset hour angles at every differential period respectively, α is slope, β is aspect.

$$\mu = \sin\psi\cos\alpha - \cos\psi\sin\alpha\cos\beta \quad (9)$$

$$v = \sin\psi\sin\alpha\cos\beta + \cos\psi\cos\alpha \quad (10)$$

Annually extraterrestrial radiation can be obtained by adding daily extraterrestrial radiation in a year.

VI. EXTRATERRESTRIAL SOLAR RADIATION SIMULATIONS

DEM is the basis of terrain basic feature parameters such as elevation, slope and aspect and so on. The scanned 1:10000 contour maps in Zhangpu and 1:250000 contour maps in Fujian province to get DEM come from Soil and terrain digital database (SOTER). SOTER is a cross or edge database and can manage attribute database, spatial database and models better [11]. SOTER is one of the global databases [12]. The International Society of Soil Science (ISSS) has developed a methodology for SOTER since 1986 whose main objective is to establish a computerized database storing attributes on topography,

soils, climate, vegetation and land use/cover, which is linked to a Geographic Information System (GIS), whereby each type of information or combination of attributes can be displayed as a separate map or overlay, or in tabular form. The database can be used for improved mapping and monitoring of changes in world soils and terrain resources, and for the development of an information system capable of delivering accurate, useful and timely information to decision-makers and policy-makers [13]. The SOTER has been carried out in many countries and areas including China, Argentina, Brazil, Cuba, Mexico, Uruguay, Venezuela, Hungary in many fields such as soil erosion, land evaluation, soil fertility, food security and so on with powerful function and advantages [14-18].

The scanned maps in Zhangpu and Fujian province were digitized whose contour distances are 5m and 50m respectively. DEM resolution should be set to generate DEM using contour maps. Based on Z.L. Li's study, the relationship between DEM resolution and contour distance on contour maps is:

$$D = K * C_i * cos\alpha \tag{11}$$

Where C_i is contour distance, α is average slope, K is constant (it is between 1.5 and 2.0 taking terrain feature into account otherwise it is between 1.0 and 1.5), D is DEM resolution. Because terrain feature is often ignored in DEM application, according to the formula above, DEM accuracy is equal to the one of 1:10000 contour map if DEM resolution is between 7 m and 42 m. The DEM resolutions in Zhangpu and in Fujian province were set to 15m and 100m respectively [10]. The digital slope model and digital aspect model can be acquired after DEM establishment, at the same time the following indicators can be calculated: sunrise and sunset angles, discrete number of available sunshine angle, sunrise and sunset hour angles and the ones at every differential period, corresponding solar altitudinal angle and solar aspect angle. The extraterrestrial solar radiation can be derived by substituting all these indicators into the formulae in Zhangpu sample plot and Fujian province.

Simulation date was March 21, 2008 that was spring equinox. The sun's meridian altitude was $h = 90 - \psi + \delta$ at noon, sunshine time was about 12 hours, the daily extraterrestrial solar radiation was calculated using DEM according to the formula, that was the digital solar radiation grid model corresponding to DEM. The daily extraterrestrial solar radiation is mainly in 17-18MJ/m^2 in Zhangpu (Fig 1 and Fig 2) and 16-18MJ/m^2 in Fujian province (Fig 3 and Fig 5). Simulation year was 2008 and the annually extraterrestrial solar radiation was calculated which is mainly in 5000~6000MJ/m^2 and 6000~7000 MJ/m^2 with the minimum 1101.4 MJ/m^2 and the maximum 6366.6MJ/m^2 in Fujian province (Fig 4 and Fig 6).

There is significant difference in spatial distribution diversity of the daily extraterrestrial solar radiation in Zhangpu sample plot and Fujian province and annually extraterrestrial solar radiation in Fujian province with strong spatial autocorrelation from the different geographical locations. In general the solar radiation value in the chine is bigger than the one in the valley, and the one in the sunny slope is bigger than in the shady slope. The high radiation value appears primarily in the sunny slope with the chine as demarcation line.

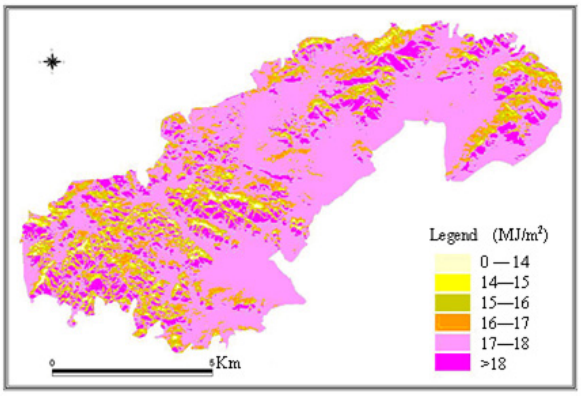

Figure1. Spatial distribution of daily extraterrestrial solar radiation in Zhangpu.

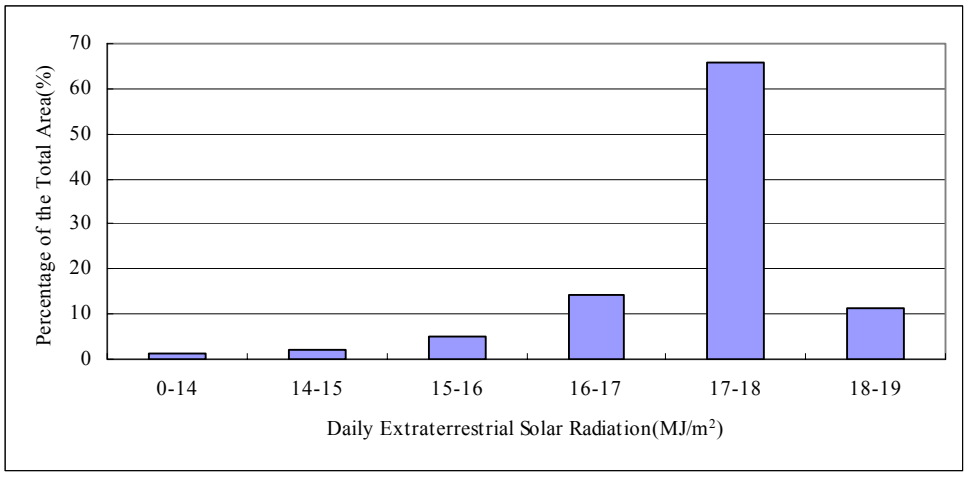

Figure2. Statistic of daily extraterrestrial solar radiation in Zhangpu.

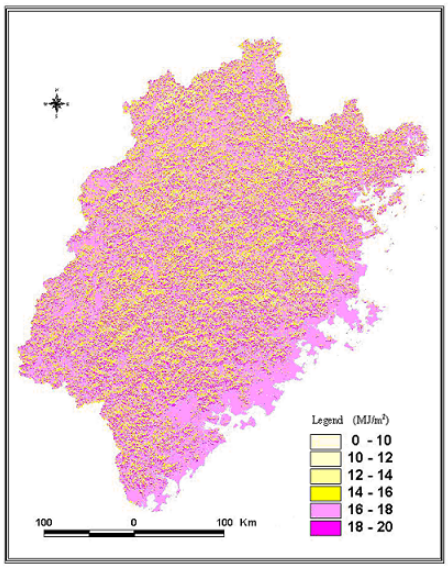

Figure3. Spatial distribution of daily extraterrestrial radiation in Fujian province.

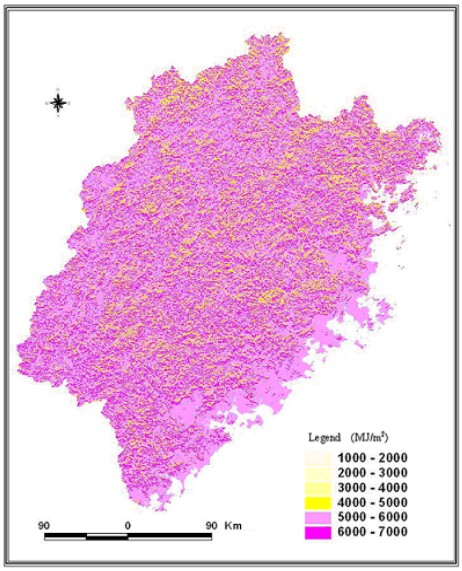

Figure4. Spatial distribution of annually extraterrestrial radiation in Fujian province.

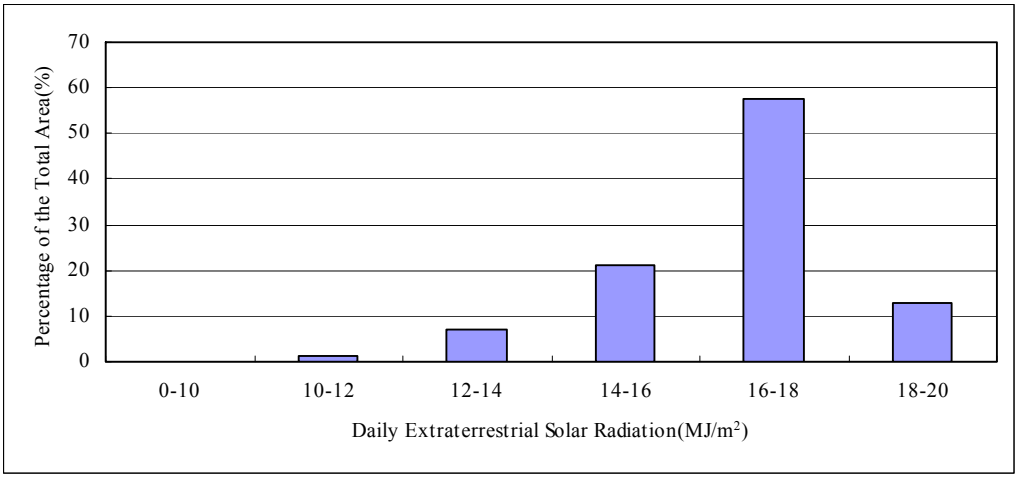

Figure5. Statistic of daily extraterrestrial solar radiation in Fujian province.

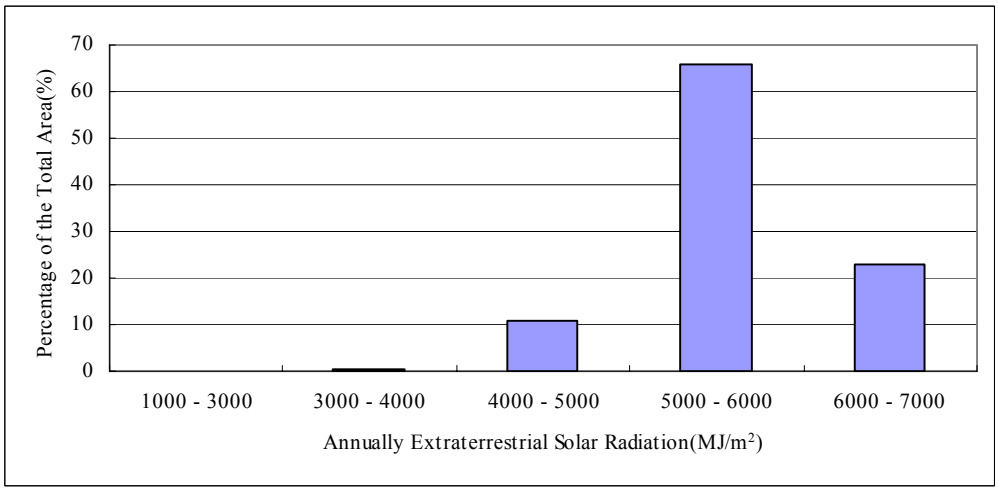

Figure6. Statistic of annually extraterrestrial radiation in Fujian province.

V. COMBINATION OF EXTRATERRESTRIAL SOLAR RADIATION AND SOTER

Nowadays, with the development of science and technology and fast growing economy, the accelerated industrialization and urbanization, difficulties encountered by researchers are how to manage, store and standardized various data efficiently, how to dig out valuable data to a great extent, and how to share the data resources. The single solar radiation could not meet the needs of users with the development of science and technology and one of the way out is combination with SOTER.

SOTER formulates a suit of regulations with systematization and standardization for the database, including not only the databases about topography and soil, but also climate, land use/cover, vegetation and reference file assistant databases. Underlying the SOTER methodology is the identification of areas of land with distinctive, often repetitive, pattern of landform, lithology, surface form, slope, parent material, and soils. The major differentiating criteria are applied in a step-by-step manner, each step leading to a closer identification of the land area under consideration. In this way a SOTER unit can be defined progressively into terrain, terrain component and soil component (Fig 7). Tracts of land distinguished in this manner are named SOTER units. Each SOTER unit represents one unique combination of terrain and soil characteristics [19].

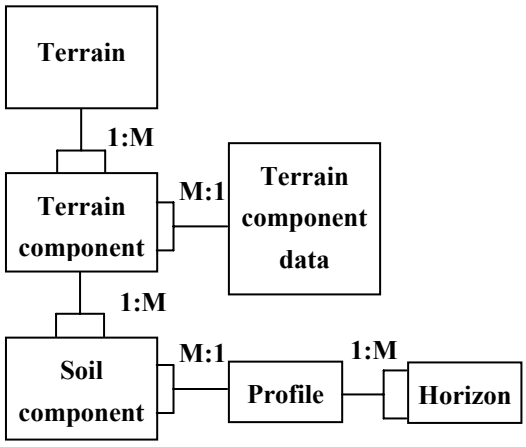

Figure7. SOTER unit structure (1:M=one to many, M:1=many to one relations).

There are two types of data in a SOTER database: geometric data and attribute data. The geometric component indicates the location and topology of SOTER units, while the attribute part describes the non-spatial characteristics. The geometric data is stored and handled by GIS software, while the attribute data is stored separately in a set of files, managed by a relational database system. There are 6 attribute files and 118 attributes. A unique code is set up in both the geometric and attribute databases to link these two types of information for each SOTER unit [19].

The climate data were based on point observations only and the link with the soils and terrain information exists by means of the geographical locations of these points. Relating to 72 climate stations in Fujian province, some climate data were interpolated using ArcGIS such as average temperature, accumulated temperature, monthly precipitation, minimum and maximum temperatures, relative humidity and evaporation besides radiation.

VI. DISCUSSIONS

The study integrated solar radiation model and DEM based on GIS, took Zhangpu sample plot in the southeast coastal hilly and platform area of Fujian province as small scale and Fujian province as moderate scale, gave full consideration to the integration of all kinds of terrain factors, explored the effects of slope, aspect and so on to the spatial distribution diversity of extraterrestrial solar radiation at two scales. The method can extract daily extraterrestrial and annually solar radiation with high precision and speediness at small and moderate scales, but there is certain error in the model which mainly comes from two aspects. On the one hand, cloud was not taken into consideration, while cloud is one of the most import parameters of solar radiation energy transmission, so there is certain deviation between calculation results and actual solar radiation value [20,21]. On the other hand, DEM is the important data in the whole model, its quality (such as DEM accuracy, resolution etc.) determines the final simulation results [1].

The methods taking cloud effect into consideration are various in solar radiation models which seldom contain space characteristics because there are no conventional observation data of cloud spatial distribution, even if there are observation data it is hard to simulate the geometric relation among sun, cloud and ground. Only using RS could effects of cloud be took into consideration in the spatial model of solar radiation [22]. The study is going to use ASTER images to extract cloud amount and ground state for improving simulation precision and meeting the needs of general solar energy engineering and science research.

The single solar radiation could not meet the needs of users with the development of science and technology. The SOTER database contains more sufficient data and can be used for a wide range of applications at different scales. At the same time, only combining with SOTER, can the climate data develop deeply and widely and the superiority of simulation of extraterrestrial solar radiation based on DEM can be shown. The approach may be used to support strategic decision-making seeking to optimize land use/cover, prioritize research, and guide conservation planning.

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Zhi-qiang Chen Fujian,china, 1978, Ph.D., specialized in GIS and land resource and land use plan. E-mail: soiltuqiang061@163.com

Jian-fei Chen E-mail:gdcjf@21cn.net