APPLICATION OF SOLAR ENERGY SIMULATION FOR RAINFOREST ENVIRONMENT

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Working Group IV/6

KEY WORDS: DTM/DEM/DSM, Multi-temporal, Simulation, Information extraction, Modeling, Applications

ABSTRACT

This paper describes the method of the solar energy simulation as one of the topographic analyses for rainforest environmental monitoring. Almost of all the radiation energy on the earth is from solar radiation energy. The photosynthesis that plant leaves receive the form of energy from the sun is indispensable for the growth process. However, it is difficult to measure and interpret the amount of solar radiation energy in large areas and during long time periods because of the movement of the sun, topographic effects and observation points etc. In this study, the method how to simulate solar energy was proposed through topographic analysis using a multi-temporal shaded relief images data set generated by DEM. Also, the spatial distribution and seasonal changes of the simulated solar energy amount caused by the topographic effects were clarified for understanding the environmental dynamics in rainforest.

1 INTRODUCTION

Various meteorological and geomorphologic factors etc. influence into the growth processes of forest plants. Especially, the solar radiation energy that plant leaves directly receive is indispensable for the photosynthesis. It is important to know the seasonal change of the sun and to obtain the amount of solar energy for understanding the production activities and dynamics of plants. However, the solar energy amount, which the topographic surface receives, dependent upon the sun altitude, azimuth, topographic effects and atmosphere conditions over a large area.

In this study, the simulation of solar energy amount using Digital Elevation Model (DEM) was carried out focusing on a geometric relation between sunlight and topographic surface. Also, the relationship between the seasonal change of the simulated solar energy amounts and the topographic effects (slope/ aspect) was examined.

2 STUDY AREA AND DEM

The study area is Kubah National Park, Sarawak, Malaysia, which is covered with rainforest. It is an area of 10km x 6km, from north to south and east to west direction respectively. The latitude and longitude of the southwest corner are 1°33' 1" N and 110°8' 52" E respectively (figure 1). The DEM (figure 2) used for this study was based on an existing topographic map with 1/50000 scale, and generated by measuring each elevation value of 50m interval on the topographic map. The minimum elevation is about 7meters, and the maximum is about 883meters.

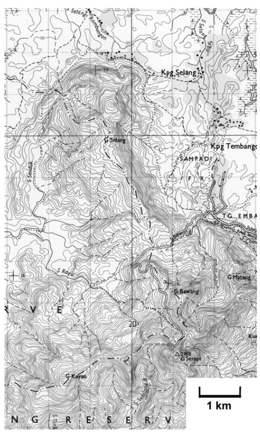

Figure 1. Study area

Figure 2. 50m DEM

3 METHODS

Figure 3 shows the flowchart of this study. The simulation of solar energy was based on a multi-temporal shaded relief images data set. The left part of this figure shows generating the multi-temporal shaded relief images data set, and the right part shows the step of simulating daily and annual solar energy amount.

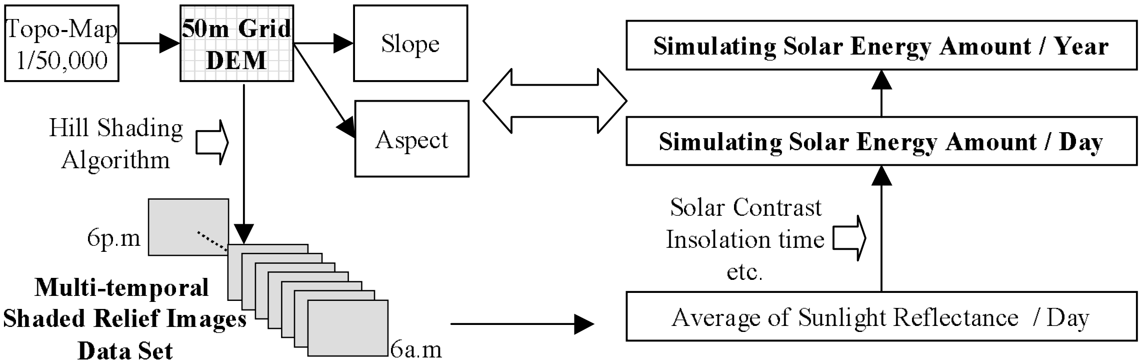

Figure 3. Flowchart of this study

3.1 Generation of Multi-Temporal Shaded Relief Image Data Set

In this paragraph, the hill shading algorithm and the computation of sun altitude and azimuth are explained. The model of the hill shading is illustrated in figure 4.

The effect of hill shading is defined as cosine of the angle θ between surface normal vector and incident light vector with the assumption that the earth's surface is a perfect diffuser (S. Murai, 1998). The cosine θ is shown as darkness and brightness by the reflectance of incident light from the sun.

A surface normal vector $\boldsymbol{n}$ can be introduced by the DEM. And, an incident light vector $\boldsymbol{s}$ is shown by sun altitude α and sun azimuth As (ERSAS, Inc., 1997).

Incident sun angle (α, As) can be calculated by using solar calendar of 'Science Chronological Table 1997' (Y. Ogura, 1984).

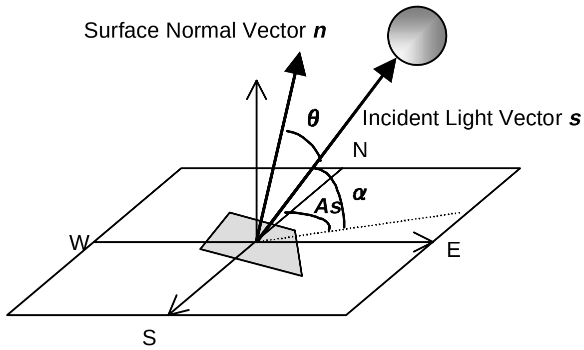

Figure 4. Model of the hill shading

The sun altitude angle for the selected time periods can be calculated by declination which is shown in 'Science Chronological Table 1997 (solar calendar)', the latitude of the point in an object area and hour angle. The sun altitude angle is defined as:

$$\sin \alpha = \sin \phi \sin \delta + \cos \phi \cos \delta \cos h \qquad (1)$$

where α : sun altitude angle, ϕ : latitude, δ : declination, h: hour angle

The hour angle h is defined by the time difference how many hours passed from the noon of local time. When the sun is located due south, the hour angle is defined as zero degree. The earth rotates at 15 degrees in one hour, the hour angle h is defined from:

$$h = 15° \times (t - 12) \qquad (2)$$

where t : local time

The sun azimuth As can be calculated from the latitude / longitude, hour angle and declination. The equation of sun azimuth is defined as follows:

$$As' = \tan^{-1} \{\sin h / (\tan \delta \cos \phi - \sin \phi \cos h)\} \qquad (3)$$

where : If As' is negative and $h < 0$, $As = - As'$

If As' is positive and $h < 0$, $As = 180 - As'$

If As' is negative and $h > 0$, $As = 180 - As'$

If As' is positive and $h > 0$, $As = 360 - As'$

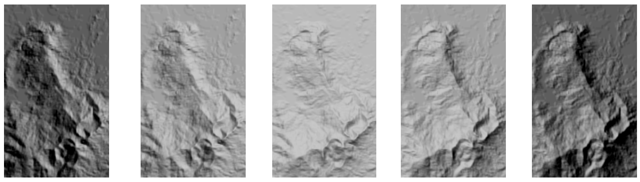

Figure 5. Shaded relief images (Jun-21)

In order to generate the multi-temporal shaded relief images data set, one specific day of every month was selected as a representative day. The vernal equinox day, summer solstice day, autumnal equinox day, and winter solstice day were included among the twelve representative days.

For each representative day, the sun altitude and azimuth were calculated at thirty minute intervals during the range from 6 AM to 6 PM local time.

Using DEM and respective calculated incident angle (α , As) , totally twenty-three or twenty-five shaded relief images in each representative day were generated because the sun altitude α is under zero at 6AM and 6PM on some representative days.

Figure 5 shows five shaded relief images of summer solstice day (Jun-21-97) as an example.

3.2 Simulation of Solar Energy Amount

Each cell value of the multi-temporal shaded relief images indicate the reflectance from the sun at a respective time on the supposition that the surface is a perfect diffuser and atmospheric influence is not taken into account. Therefore, on a given day, it is possible to estimate the amount of solar energy the surface receives by using insolation time and solar contrast.

The followings are the steps of solar energy amount simulation:

Step 1: Calculation of the daily average reflectance from twenty-five shaded relief images in each representative day

Step 2: Calculation of the solar energy amounts per each representative day by multiplying solar contrast, the inverse square of the distance between the sun and the earth, and insolation time to each the average reflectance

Step 3: Accumulation of all the solar energy amounts per days in a year

Additional details about Step 2 are described as follows.

The solar contrast, which is obtained by integrating the spectral irradiance for all wavelength regions, is normally taken as 1.39 kWm^{-2} (1.39 $kJm^{-2}s^{-1}$). In this study, in order to apply for DEM with 50m interval (50m x 50m), the solar contrast was converted to the solar energy unit mesh per hour as 12.51×10^9 J / mesh/ hour.

The earth orbits around the sun elliptically. The distance between the sun and the earth changes seasonally, and solar energy also changes. For this reason, each inverse square of the distance between the sun and the earth $(\text{average distance / real distance})^2$ of every representative day is multiplied to the solar contrast.

As for insolation time, the sun altitude angle is zero at the time of the sunset and sunrise. When $\alpha = 0$, equation (1) becomes as follows:

$$-(\sin \phi / \cos \phi)*(\sin \delta / \cos \delta) = \cos h \qquad (4)$$

from equation (2),

$$\text{Sunrise Time: } t = 12 - (h/15), \qquad \text{Sunset Time: } t = 12 + (h/15) \qquad (5)$$

Equation (4) and (5) introduce the insolation time of each representative day.

4 RESULTS AND DISUCUSSION

4.1 Solar Energy Amount

Figure 6 shows the results of daily simulated solar energy amount during the mentioned range from 6 AM to 6 PM on each twelve representative day.

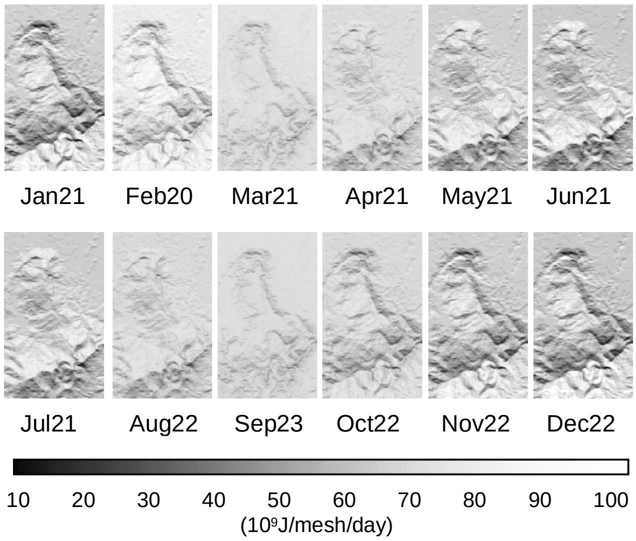

Figure 6. Daily simulated solar energy amount

According to figure 6, the amount of the difference of solar energy is the largest during the time period between Jun-21 and Dec-22 (summer and winter solstice days). On the other hand, the amount of the difference is the least between Mar-21 and Sep-23 (vernal and autumnal equinox days).

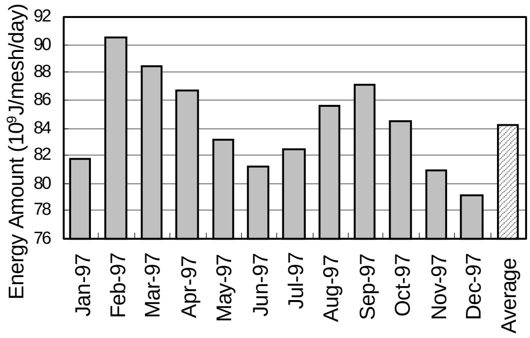

Figure 7. Average solar energy amount per day in whole study area

The graph shown in figure 7 is the average amount of solar energy in the whole study area using accumulated data per each representative day.

From figure 7, the surface area in whole receives the largest amount of solar energy in February and the least amount is in December.

The annual simulated solar energy amount is shown in figure 8. On figure 8, it can be identified that the largest amount area is in flat area. And also, the difference of the maximum and minimum amounts of solar energy is about $13x10^{12}$J/mesh/year.

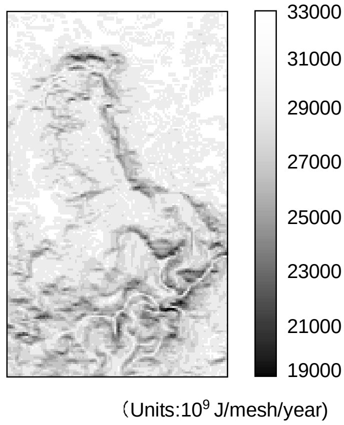

Figure 8. Annual simulated solar energy amount

4.2 Simulated Solar Energy Amount and Topographic Effects

This study area is located near the Equator. The sun irradiates the north slope area at the noon in the period from the vernal equinox day (Mar-21) to autumnal equinox day (Sep-23), in contrast, irradiates the south slope area from the opposite direction in the period from autumnal equinox day to vernal equinox day. Similarly, the solar energy amount changes at various topographic surfaces seasonally. Here, the seasonal change and difference of the solar energy amounts are clarified by the relationship between topographic effects (slope/aspect) and simulated solar energy amounts of twelve representative days.

The slope and aspect for each cell were introduced from DEM. The slope was classified to 9 classes in every 5 degrees except flat area (figure 9). The aspect was classified to 8 classes except flat area (figure 10). The right description in

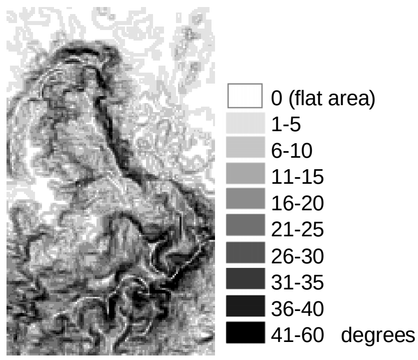

Figure 9. Slope 9 Classes

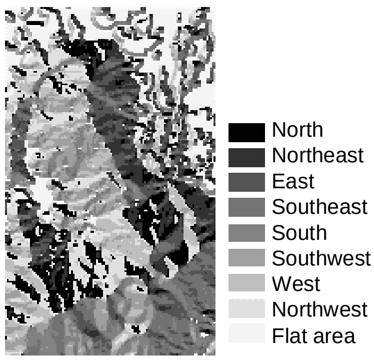

Figure 10. Aspect 8 classes

each figure is the legend of classification. Two classified images were combined and then 72 combinations of each aspect and slope classes and flat area were reclassified.

These graphs shown in figure 11 are the seasonal changes of solar energy amounts at each slope class in each aspect class (72 combinations of 8 aspect classes and 9 slope classes). Figure 12 and 13 show the graphs of the average and standard deviation of twelve daily solar energy amounts at every 72 combined classes respectively. The standard deviation of solar energy indicates the seasonal difference.

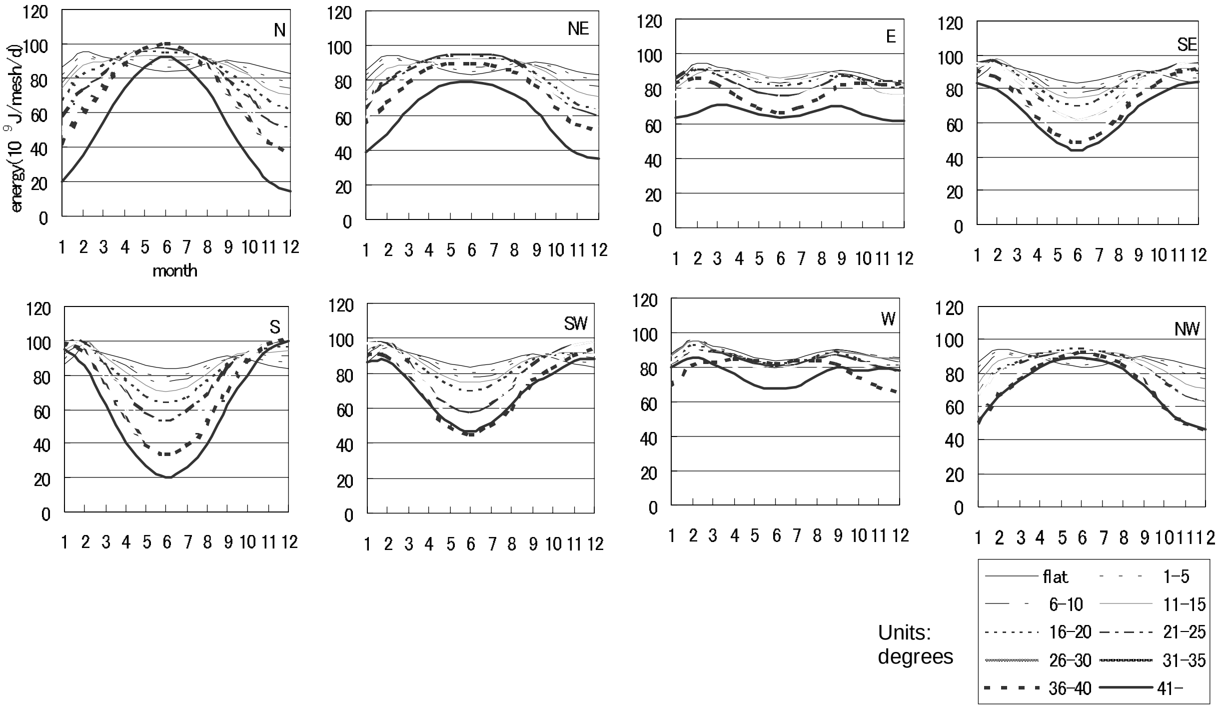

Figure 11. Seasonal changes of solar energy amounts at each slope class in each aspect class

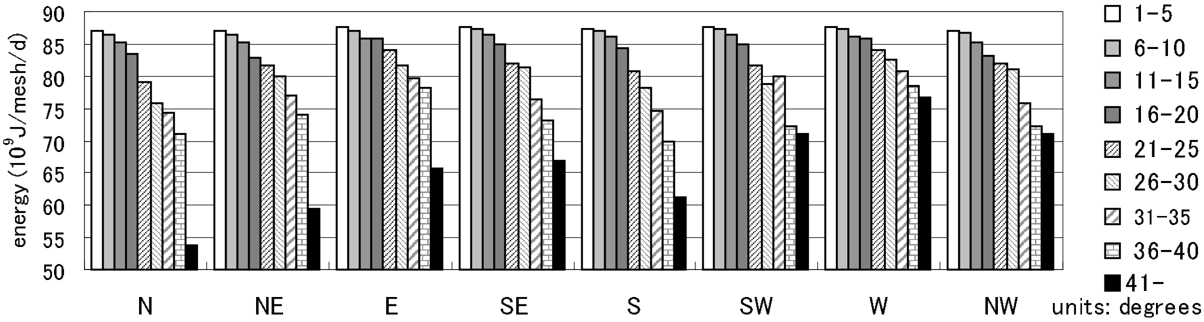

Figure 12. Average of 12 daily solar energy amounts at each slope class in each aspect class

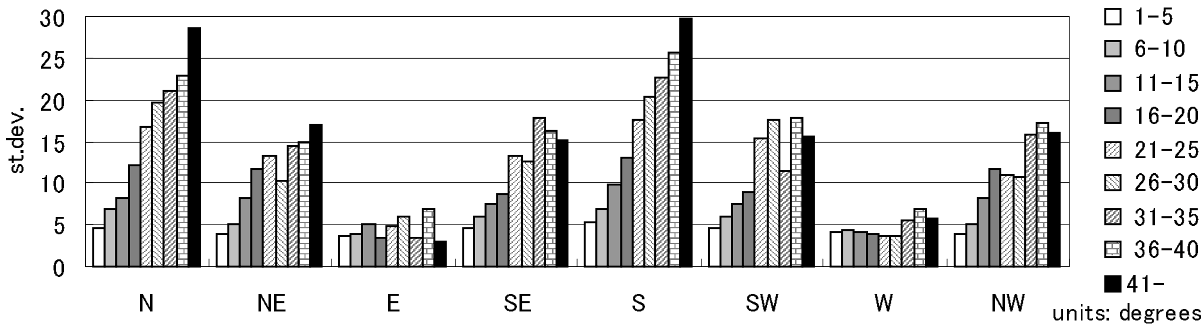

Figure 13. Standard Deviation of 12 daily solar energy amounts at each slope class in each aspect class

From figure 11, 12 and 13, some followings about the relationship between the solar energy amounts and the topographic effects are summarized;

1) In north or south aspect and very steep slope (more than 36 degrees) surfaces, the seasonal change and difference of solar energy amounts are larger, and the average is lower. However, the solar energy amounts on summer and winter solstice day (Jun-21 and Dec-22) are temporally larger.

2) In east and west aspect surfaces, the seasonal change of solar energy amounts is steady, and the difference is a little. As this reason, it is supposed that the sun constantly irradiates the east and west aspect surfaces in every morning and evening.

3) In every aspect surfaces, the average solar energy amount decreases as the slope becomes steep.

5 CONCLUSIONS

As one of approaches to understanding the environmental dynamics of rainforest, the method how to simulate solar energy was proposed by using multi-temporal shaded relief images data set generated by DEM.

Through this study, the spatial distribution of daily and annual solar energy amounts and the seasonal change were clarified.

As the other applications, it is proposed that the method of solar energy simulation should be applied to the other landuse /cover areas, for example cultivating area, in complex terrain. Also, the solar energy amounts simulated by this method could be one of the geographical indexes for recognizing land condition.

In the future, the relationship among the simulated solar energy amounts, various remotely sensed satellite data and the real on-site conditions at ground level will be examined.

This study was performed with the support of Grant-in-Aid for Creative Basic Research in ' An integrative study on biodiversity conservation under global change and bio-inventory management system' of The Ministry of Education, Science, Sports and Culture and 'Mechanisms of Atmosphere-Ecosphere Interaction in Tropical Forest Canopy' of Core Research for Evolutional Science and Technology (CREST) Project by the Japan Science and Technology Corporation.

REFERENCES

YAMASHITA, M., YOSHIDA, T., YOSHIMURA, M. and NAKASHIZUKA, T., 1999. Application of Topographic Animation for Solar Energy Simulation. In: International Archives of Photogrammetry and Remote Sensing, Onuma, Japan, Vol. XXXII-Part5-3W12, pp.203-206.

Yoshimitsu Ogura, 1984. General Meteorology. Tokyo University Press, Japan, pp.108-120.

National Astronomical Observatory Japan, 1997. Science Chronological Table 1997. Maruzen, Japan, pp.3-33.

Shunji Murai, 1998. GIS WorkBook. Japan Association of Surveyors, Japan, pp.168-171.

ERDAS, Inc., 1997. ERDAS FIELD GUIDE. USA, pp.343-351.