Estimation of solar radiation using GMS and DEM data for determination of suitable agricultural land

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KEY WORDS

Solar radiation, Agriculture, GMS, DEM

ABSTRACT

The objective of this study is estimation of solar radiation using GMS and DEM data. It is important to get hourly amounts of solar radiation in a large area for determination of suitable agricultural land. Especially in mountainous area, slope and solar shading affect solar radiation. The following were performed in this study; 1) recovery of missing albedo through interpolation, 2) estimation of vertical quantity of total solar radiation using cloud albedo, 3) improvement of separation of direct and diffuse components of radiation, 4) estimation of slope quantity of total solar radiation in consideration of solar shading

1. Study site and data

GMS visible images produced by Kochi University, Weather Home (http://weather.is.kochi-u.ac.jp/) were used for getting cloud albedo. Area is N30-46deg E130-146deg near Japan. Resolution is 0.02deg/pixel. Hourly data is available.

2. Interpolation of cloud albedo

A value is interpolated by using similar albedo pictures before and after missing data (Fig. 1).

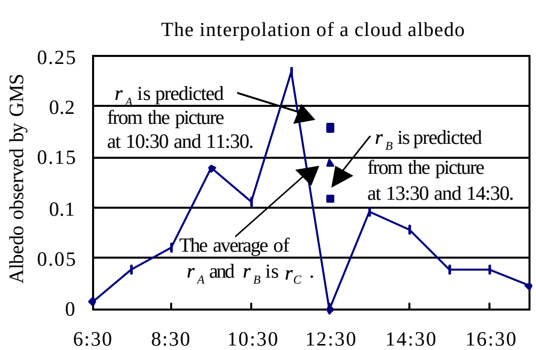


Fig. 1

The method of interpolation

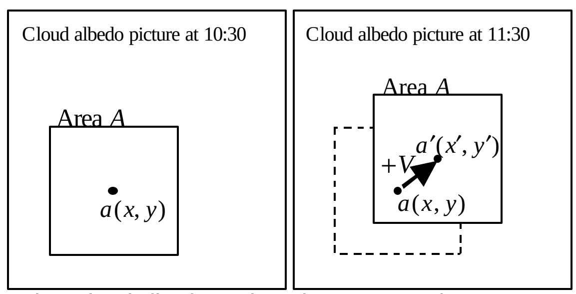


Fig. 2

A) Cloud albedo r_A in point a at 12:30 is estimated from the pictures at 10:30 and 11:30 as follows[1];

i. a move vector V of cloud is computed by estimating where the area A at 10:30 moves to at 11:30 (Fig. 2)

ii. the place where area A will exist at 12:30 is estimated by using the move vector V of cloud (Fig. 3.2)

iii. cloud albedo r_A in point a at 12:30 is equal to cloud albedo value of $a - V$ point at 11:30 (Fig. 3.1) iv.

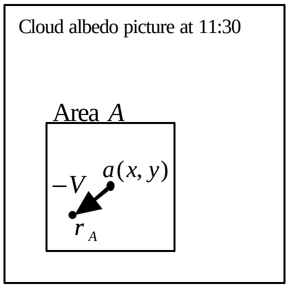


Fig. 3.1

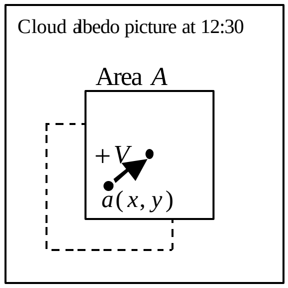


Fig. 3.2

B) Similarly, cloud albedo r_B in point a at 12:30 is estimated from the pictures at 13:30 and 14:30

C) Cloud albedo r in point a at 12:30 is given by the average of r_A and r_B (Eq. 1).

$$r = \frac{r_A + r_B}{2} \qquad \text{(Eq. 1)}$$

Table. 1
Correlation of actual cloud albedo and interpolated albedo

		Window Size[pixel]			
		81x81	91x91	101x101	111x111
Distance of search	±5pixel	0.762	0.769	0.784	0.795
	±10pixel	0.819	0.823	0.822	0.831
	±15pixel	0.813	0.836	0.822	0.814
	±20pixel	0.833	0.837	0.824	0.814

Table 1, Hiroshima Meteorological Observatory Aug. 2000

The correlation of an actual cloud albedo and the simple average of cloud albedo values before and after missing data is 0.7445. Interpolation values with high correlation can be acquired, if suitable matching size is chosen.

3. Estimation of solar radiation

Vertical quantity of total solar radiation is estimate d by using cloud albedo. The amount of by which extra-terrestrial solar radiation declines by atmosphere and clouds can be considers. The following model (Eq. 2) was created. (Eq. 3) is quoted from another paper [2].

$$I_G = T I_0 \sin h - r I_0 \qquad \text{(Eq. 2)}$$

$$T = (a_1 + a_2 \sin h_{noon})^{1/\sin h} \qquad \text{(Eq. 3)}$$

I_G : vertical quantity of total solar radiation[MJ/(m^{2}h)]
T : atmospheric transmittance[-]
I_0 : solar constant[MJ/(m^{2}h)]
h : solar altitude[deg]
r : cloud albedo[-]
h_{noon} : solar altitude of meridian transit[deg]

The 1st term, $T I_0 \sin h$ of (Eq. 2), expresses solar radiation after penetrating the atmosphere. The 2nd term, $-rI_0$ of (Eq. 3), is solar radiation reflected by clouds. Since the cloud albedo value includes the influence of change of solar altitude, it is not necessary that the 2nd term is multiplied by $\sin h$. a_1, a_2 were determined by regression analysis based on solar radiation data of meteorological observation.

Correlation of estimated- and observed-solar radiation
correlation coefficient = 0.9468
RMSE[MJ/(m^{2}h)] = 0.3415
MBE(Mean Bias Error)[MJ/(m^{2}h)] = -0.07724
Hiroshima Meteorological Observatory Aug. 2000

If this model is used, solar radiation of arbitrary points can be estimated every 2km.

4. Separation of direct and diffuse components of radiation

The work which divides vertical quantity of total solar radiation into direct solar radiation and sky solar radiation is called separation of direct and diffuse components of radiation, and various techniques are devised. Erbs and a Perez model[3-4] are evaluated for this. As for Erbs model, direct solar radiation tends to take a value smaller than the observed one during fine weather. The Perez model needs dew point temperature for calculation. In this study, regression analysis was applied for the cases $0 \le r_c \le 0.1$, $0.1 < r_c < 0.2$ and $0.2 \le r_c \le 1.0$, and the accuracy of separation of direct and diffuse components of radiation was improved.

Regression equations were obtained based on the following 12 points data. These 12 points are for observing vertical quantity of total solar radiation and normal quantity of direct solar radiation.

Table. 2

Station Name	Latitude		Longitude	
	Deg.	Min.	Deg.	Min.
SAPPORO	43	3.4	141	19.9
NEMURO	43	19.7	145	35.4
AKITA	39	42.9	140	6.2
MIYAKO	39	38.7	141	58.1
WAJIMA	37	23.4	136	53.9
MATSUMOTO	36	14.6	137	58.4
TATENO	36	3.3	140	7.8
YONAGO	35	25.9	133	20.5
SHIONOMISAKI	33	26.9	135	45.8
FUKUOKA	33	34.8	130	22.6
KAGOSHIMA	31	33.1	130	33.1
SHIMIZU	32	43.1	133	0.7

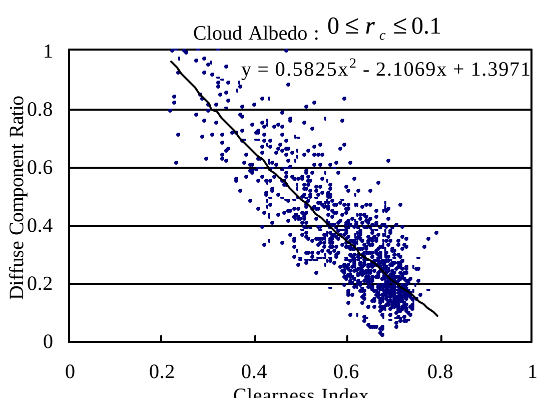
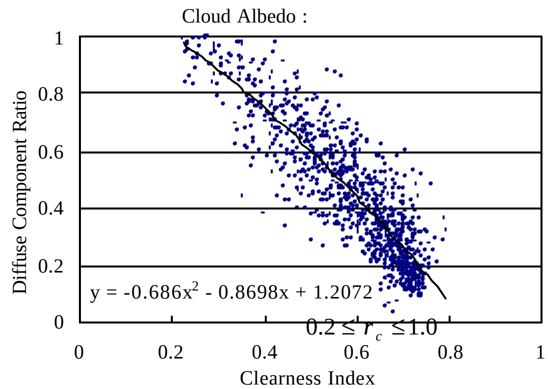


Fig. 4

$0.1 < r_c < 0.2$



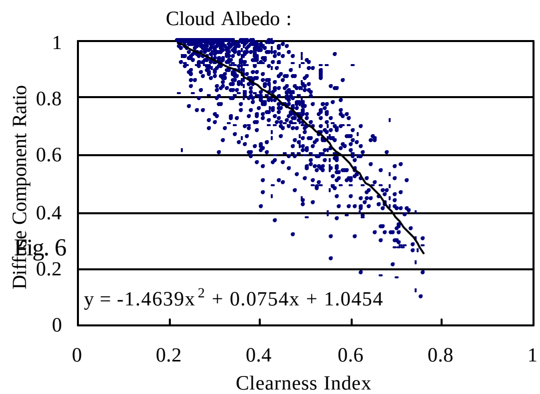


Fig. 6

Clearness Index, $K_t = \dfrac{I_G}{I_0 \sin h}$ (Eq. 4)

Diffuse Component Ratio, $R_d = \dfrac{I_d}{I_G}$ (Eq. 5)

$$I_d = I_G - I_b \sin h \quad \text{(Eq. 6)}$$

where;

I_d : vertical quantity of sky solar radiation

I_G : vertical quantity of total solar radiation

I_b : normal quantity of direct solar radiation

Each diffuse component ratio was calculated using the following techniques;

CLD(Kt) : 2nd degree polynomials with classification according to cloud albedo

DEG2(Kt) : 2nd degree polynomial without classification

DEG4(Kt) : 4th degree polynomial without classification

Erbs(Kt) : Erbs model (4th degree polynomial)

Obs. : Actual observation values

and the correlation between actual- and estimated

Table. 3

diffuse component ratio were;

	Obs.
CLD(Kt)	0.925
Erbs(Kt)	0.894
DEG2(Kt)	0.893
DEG4(Kt)	0.896
Obs.	1.000

Erbs model is expressed by the regression equation of clearness index and diffuse component ratio. High accuracy result can be obtained by using this model with classification according to cloud albedo.

5. Estimation of slope quantity of solar radiation

Slope quantity of total solar radiation is estimated by adding slope quantity of direct- and sky- solar radiation to reflected solar radiation.

$$I_{T,G} = I_{T,b} + I_{T,d} + I_{T,r} \qquad \text{(Eq. 7)}$$

where;

$I_{T,G}$: slope quantity of total solar radiation[MJ/(m^{2}h)]

$I_{T,b}$: slope quantity of direct solar radiation[MJ/(m^{2}h)]

$I_{T,d}$: slope quantity of sky solar radiation[MJ/(m^{2}h)]

$I_{T,r}$: ground surface reflected solar radiation[MJ/(m^{2}h)]

$$I_{T,b} = I_b \cos i \qquad \text{(Eq. 8)}$$

$$I_{T,d} = I_d F \qquad \text{(Eq. 9)}$$

$$I_{T,r} = I_G \frac{1-\cos b}{2} r_g \qquad \text{(Eq. 10)}$$

i : incident angle of direct solar radiation[deg]

b : slop inclination with the horizontal plane[deg]

r_g : ground albedo[-]

F is ratio of slope quantity of sky solar radiation to vertical quantity of sky solar radiation (Eq. 11). Various methods have been proposed. Here, the Perez model was used. In this study, slope quantity of solar radiation was estimated with consideration of solar shading by terrain feature.

Perez model

$$F = (1-F_1)\left(\frac{1+\cos b}{2}\right) + F_1 \frac{a}{b} + F_2 \sin b \qquad \text{(Eq. 11)}$$

$$a = \max(0, \cos i), \quad b = \max(0.087, \cos Z)$$

F_1 : circumsolar brightening coefficient[-]

F_2 : horizon brightening coefficient[-]

Z : zenith angle[deg]

The 1st, 2nd and 3rd terms express uniform sky solar radiation, circumsolar radiation and sky solar radiation from near the horizon, respectively, and are determinable from F_1 and F_2.

Improvement of Perez model

Slope quantity of sky solar radiation and circumsolar radiation are added only when there is no solar shading. $1+\cos b\ /2$ of uniform sky solar radiation is replaced with sky factor calculated from DEM data.

Now, a slope solar radiation map is under creation using 50m grid DEM data.

6. Summary

Slope quantity of solar radiation of arbitrary points can be estimated every 50m by using these procedure. Interpolation of cloud albedo, approximate expression with classification according to cloud albedo improved accuracy of estimation.

7. Reference

[1] H. Taniguchi., K. Otani and K. Kurokawa, 2001. Hourly forecast of global irradiation using GMS satellite images, Solar Energy

Materials and Solar Cells, Volume 67, Issues 1-4, pp.551-557.

[2] K. Otani et al., 1994. Solar energy mapping by using cloud images received from GMS, First World Conference on Photovoltaic Energy Conversion, WCPEC-1, Hawaii, pp.805-808.

[3] Erbs, D.G., S.A.Klein, J.A.Duffie, 1982. Estimation of the Diffuse Radiation Fraction for Hourly, Daily and Monthly Average Global Radiation, Solar Energy, Vol.28, No.4, pp.293-302.

[4] Perez, R., R.Seals, P.Ineichen, R.Estimation and R.Stewart, 1990. Modeling Daylight Availability and Irradiance Model for Tilted Surfaces, Solar Energy, Vol.44, No.5, pp.271-289.