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A Representativity Test on the Pyranometer Measurement of Surface Solar Insolation Through Satellite Observation

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Abstract : Surface Solar Insolation is important for vegetation productivity, hydrology, crop growth, etc. In this study, Surface Solar Insolation is estimated using Multi-functional Transport Satellite (MTSAT-1R) in clear and cloudy conditions. For the Cloudy sky cases, the surface solar insolation is estimated by taking into account the cloud transmittance and multiple scattering between cloud and surface. This model integrated Kawamura's model and SMAC code computes surface solar insolation with a 5 km × 5 km spatial resolution in hourly basis. The daily value is derived from the available hourly Surface Solar Insolation, independently for every pixel. To validation, this study uses ground truth data recorded from the pyranometer installed by the Korea Meteorological Agency (KMA). The validation of estimated value is performed through a match-up with ground truth. Various match-up with ground truth. Various match-up window sizes are tested with 3×3, 5×5, 7×7, 9×9, 10×10, 11×11, 13×13 pixels to define the spatial representativity of pyranometer measurement, and to consider drifting clouds from adjacent pixels across the ground station during the averaging interval of 1 hour are taken into account.

Key Words : Surface Solar Insolation, MTSAT-1R, SMAC, window-size.

1. Introduction

Solar Surface Insolation (SSI) is very important parameter in earth radiation budget studies enhancing our understanding of climate process and surface heat flux. Data of the solar Surface Insolation enables us to derive information for processing of solar energy system. Nevertheless, in many countries, the available information on the solar surface insolation is rather limited, which fail to capture its spatial variability. For the retrieval of Surface Solar insolation, we used Multi-functional Transport Satellite (MTSAT-1R) having channel data with high spatial and temporal resolution for any within the sensor coverage. MTSAT satellite data, which has used to observe the cloudy attribution (major error affecting Surface Solar Insolation), offers the opportunity to establish a long-term, global climatology of ocean surface solar irradiance (Frouin *et al.*, 1991).

The satellite-based methods of estimating surface insolation can be separated into two classes: empirical methods such as those used by Fritz *et al.* (1964),

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Tarpley (1979), and Klink and Dollhopf (1986); Gautier, Diak, and Masse (1980), and Kizu (1995), and Kawamura (1998). The empirical methods are regressions analysis using instantaneous values between Surface Solar insolation and ground station measurement, while physical models interpret satellite measured radiances in terms of scattering, reflection, and absorption parameters that are subsequently used in radiative transfer models or parameterized models to determine atmospheric transmittance (Li *et al.* 1992). But Most simplified models use the atmospheric factors depending on constant or empirical value (e.q., it can induce the estimation error) to parameterize individual transmittances. In this study, Kawamura' simple physical model is used for parameterization such as Rayleigh scattering, ozone absorption, water vapor absorption, and aerosol scattering transmittance

Hourly MTSAT-derived Surface Insolation was compared with hourly ground measurement over Korean peninsula from August 1, 2005 to July 31, 2006. The comparison method was performed using the root mean square error (RMSE) which is normally utilized for statistical analysis for the comparison of satellites based value and measured insolation. Hammer (2000) has shown that instantaneously measured and spatially averaged insolation for 3×3 pixels correlates better with ground measurements. In this study, several matching-up window sizes are compared with 3×3, 5×5, 7×7, 9×9, 10×10, 11×11, 13×13 pixels to define the spatial representativity of pyranometer measurement.

2. Data and Method

1) Multi-functional Transport Satellite (MTSAT-1R) and Pyranometer data sets

MTSAT-1R, built by Japanese Civil Aviation Bureau (JCAB) and Japanese Meteorological Agency (JMA), was successfully launched in February 26, 2005. From its geosynchronous orbital position at 140 degree East longitude, MTSAT satellite will provide meteorological Data for researcher throughout the entire Asia-Pacific region. Full disk images are relayed to ground receiving stations approximately 25-28 times per day, providing up to half hourly temporal coverage during some periods of the day. Table.1 summarizes some important channel information about MTSAT meteorological payload on one satellite. There are four channels on MTSAT: one visible (0.55-0.90μm), two thermal infrared channels (8-14μm), and a channel sensing thermal radiation emitted by the strong water vapor rotation band at 6.3μm. The spatial resolution of visible channel normally provided by MTSAT is 1 km, while the infrared channels have a reduced resolution of 4 km. In this study, we has used 1hourly interval channel data (VIS, IR1, IR2) for period from August 1, 2005, to July 31, 2006. Those channels utilized in present research have 0.05°×0.05° spatial resolution for the domain of 10-40°N and 80-170°E. A ground-based match-up data set is defined as a pair of the pyranometer measurement data which are obtained from the Korea Meteorological Agency (KMA) and surface solar insolation derived by MTSAT satellite channel data. Fig. 1 was represented the ground-based stations of 22 pyranometer observation sites over Korean peninsula. The comparisons between surface solar insolation and ground-based measurement were very difficult for ocean area because the buoy measurements were instantaneous values and the sensors were not well calibrated (Endoh *et al.*, 1987). Moreover validation data set in ocean almost does not exit around the Korean peninsula. So matching-up the ground-based true data and the satellite data in ocean will be performed in the future work.

Table 1. Channel characteristics of MTSAT-1R.

Channel and Wavelength (μm)	Visible 0.55-0.90	IR 1 10.3-11.3	IR 2 11.5-12.5	IR3 6.5-7.0	IR 4 3.5-4.0
Spatial resolution	1 km (VIS) and 4 km (IR) at the sub-satellite point				
Brightness levels	10bits for both VIS and IR channels (1,024 gradations)				
Frequency	S-band (Reception: 2006-2035MHz, Transmission: 1677-1695MHz) UHF (Reception: 402MHzTransmission:468MHz)				

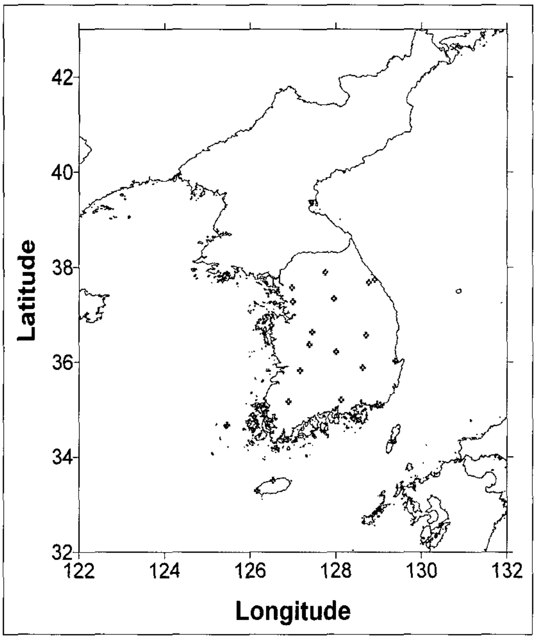

Fig. 1. Location of observation stations over Korean peninsula.

2) Algorithm to retrieve the Surface Solar Insolation using Atmosphere factor

The Surface solar Insolation retrieval algorithm is based on research by Gautier, Diak, and Masse (1980) and Kizu (1995), and Kawamura (1998). The algorithm used in this study to produce the Surface Solar Insolation is represented fig. 2. The first step for products includes a correction for the solar zenith angle and the varying distance between the earth and the sun. It can be easily calculated using Julian day and time information. Then, MTSAT-1R image pixels are separated into clear sky or cloudy sky according to cloud mask information using visible and infrared channel. For clear pixels, Surface Solar

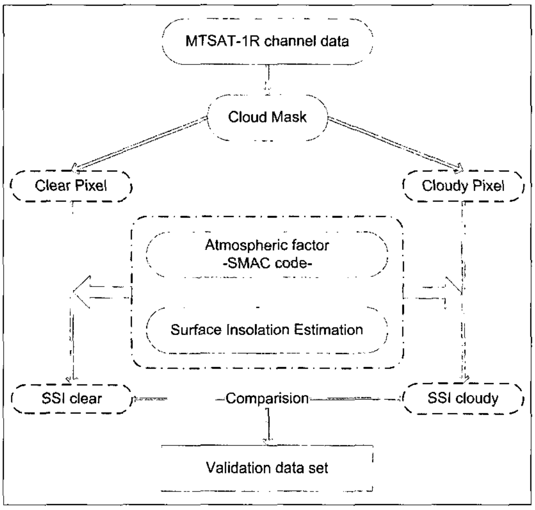

Fig. 2. Algorithm for the Surface Solar Insolation.

Insolation is calculated by multiplying the Top-Of-Atmosphere (TOA) radiation flux by the solar geometry factor, the atmospheric transmittance, and diffuse transmittance. Transmittance due to Rayleigh scattering of atmospheric parameterizations was replaced with physical equation which is derived by SMAC code than empirical method using constant value. For cloudy pixels, Surface solar insolation is calculated by multiplying The TOA flux by the geometrical factor, the atmospheric transmittance for the clear sky condition, and the cloud factor. Cloudy sky Insolation relies on cloud factor which was determined with respect to cloud albedo and TBB using MTSAT-1R visible and infrared (IR1) data (Table 2). It is known that designation and classification of the clouds are critical for the retrieval if Surface Solar Insolation using clear sky and cloudy

Table 2. Cloud attenuation coefficient table with respect to cloud top albedo and TBB from Kawamura 2001 *et al.*

TBB (K)	Albedo (%)							
	10	20	30	40	50	60	70	80
200								1.2
210							1.2	1.2
220						1.2	1.2	1.2
230					1.16	1.18	1.2	1.2
240				1.14	1.16	1.18	1.2	1.2
250			1.12	1.14	1.16	1.18	1.2	1.2
260		1.1	1.12	1.14	1.16	1.18	1.2	
270		1.1	1.1	1.12	1.16	1.18	1.2	
280	0.7	0.9	1.06	1.1	1.13	1.16	1.18	
290	0.5	0.7	1.05	1.1	1.13	1.16	1.18	
300	0.3	0.5	0.9					

sky condition. In the present scheme, the successive physical processing steps were operated to the image on a per-pixel basis to classify cloudy pixels. For the cloudy pixel, the value of the Surface Solar Insolation attenuation coefficient by cloud has been assigned according to the type of cloud. Under cloudless conditions, the Surface Solar Insolation can be obtained through the following equations:

$$S_r = S_I + S_R + S_A \qquad (1)$$

$$S_I = S\tau_O\tau_R(1-\alpha_w)\tau_A \qquad (2)$$

$$S_R = S\tau_O(0.5(1-\tau_R))\tau_A \qquad (3)$$

$$S_A = S\tau_O\tau_R(1-\alpha\omega)F_C\omega_O(1-\tau_A) \qquad (4)$$

$$S = I(d_M/d)^2\cos\theta \qquad (5)$$

In these formulas, S_S is the total insolation, S_I the direct irradiance, S_R the diffuse irradiance due to Rayleigh scattering and S_A the diffuse irradiance due to scattering by aerosols. In order to estimate the cloudy sky transmission, the surface solar insolation is estimated by taking account of the effects of reflection and absorption by the cloud. Cloudy sky surface solar insolation can be follow equation:

$$S_S = (S_I + S_R + S_A)(1 - a\cdot A) \qquad (6)$$

A is cloud albedo, a is insolation attenuation coefficient by cloud that was calculated using relationship for cloud albedo and TBB. The insolation attenuation coefficient under cloudy condition is shown with respect to albedo and TBB in Table 2. The transmittance due to absorption by ozone was estimated by Lacis and Hansen (1974) like this:

$$\tau_O = 1 - 0.02118(U_m)/(1 + 0.042(U_m) + 3.23\times 10^{-4}(U_m)^2) + 1.082U/(1 + 138.6(U_m))^{0.805} - 0.0658(U_m)/(1 + (103.6(U_m))^3) \qquad (7)$$

The low spatial resolution of the used ozone data (1° × 1°) from the Earth Observing System Data and Information System, Distributed Active Archive Center, at Goddard Space Flight Center is modified by expanding the rows and columns by interpolating with an 20 × 20 mean filter to increase the spatial resolution. The relative air mass, m, is calculated by Kasten's (1996) formula:

$$m = 1/(\cos\theta + 0.15(93.885 - \theta)^{-1.253}) \qquad (8)$$

The transmittance due to attenuation by aerosols is given by Macher (1983) like this:

$$\tau_A = 0.12445\alpha - 0.0162 + (1.003 - 0.125\alpha)\times \exp(-\beta m(1.089\alpha + 0.5123)) \qquad (9)$$

Spectral optical characteristics of atmospheric aerosol may be change rapidly with time and weather conditions. It is needed for detailed modeling to determine aerosol optical thickness, but such measurements are few. Insufficient information for aerosol data justifies the use of a simplified methodology, namely the modified Angstrom approach, which, as given by Iqbal, (1983), are set to α=1.3, and β=0.1 (for November-March) and is equal to 0.2 (for April-October) in all weathers, which correspond to the visibility of about 28 and 11 km. In the near infrared spectrum, water vapor is by far the most importance absorber. Therefore, the accurate determination of water vapor transmittance is very important for atmospheric parameterization. The absorptance of water vapor for the cloud-free conditions is given by Lacis and Hans (1974) as Eq. (10)

$$\alpha_W = 2.9Wm/((1 + 141.5Wm)^{0.635} + 5.925Wm \quad (10)$$

To determine estimation of the absorptance of water vapor, α_W, the precipitable water, W, should be derived using MTSAT-1R infrared (IR1) data, through the spit-window algorithm (Chester *et al.*, 1987) for clear sky pixel as (Eq. (11)).

$$W = (1/0.095)[(1/\sec\theta)\ln[(T_1 - T_a)/(T_2 - T_a)] - 0.025] \quad (11)$$

For a molecular atmosphere, The transmittance due to Rayleigh scattering is given by:

$$\tau_r = \tau_m \cdot p_r(\xi)/4\cos(\theta_s)\cos(\theta_v) \quad (12)$$

Where $p_r(\xi)$ is the molecular scattering phase function. The phase function specifies the angular scattering of light by the atmosphere that gives the differential probability of the scattered radiation going in a given direction.

$$\tau_m(P) = \tau_m(P_0) \cdot P/P_0 \quad (13)$$

Where $\tau_r(P_0)$ is the molecular optical depth at some reference level (P_0 = 1013.25 hpa for standard conditions) and P is the observed pressure.

$$P_r(\xi) = 1 \cdot 5\frac{(1-\delta)}{2+\delta}(1 + \cos^2(\xi)) + 3\frac{\delta}{2+\delta} \quad (14)$$

$$\cos(\xi) = -[u_s \cdot u_v + \sqrt{(1 - u_s^2)(1 - u_v^2)} \cdot \cos(\Delta\Phi)] \quad (15)$$

τ_m is molecular optical depth, ξ is the scattering angle, δ is the depolarisation factor (δ = 0.0139).

3. Results

The present study has generated hourly surface solar insolation over Korean peninsula from August 1, 2005, to July 31, 2006. The image in Fig. 3 was represented, Fig. 4 was represented the output data file of the Surface Solar Insolation product for MTSAT-1R scene of 05/08/2005 at 0530 UTC. The Fig. 4 represents the output data file of the Surface

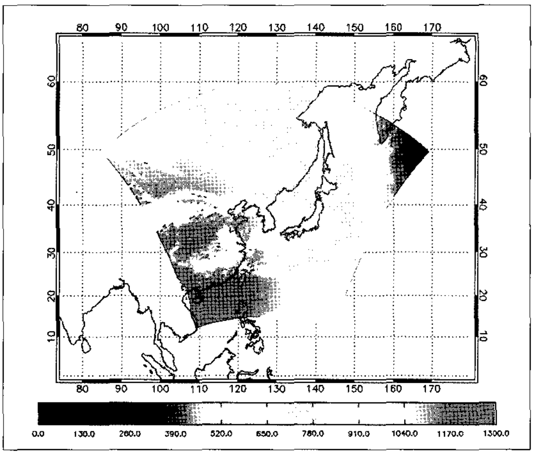

Fig. 3. Surface solar insolation from MTSAT-1R at 5, Aug. 2005.

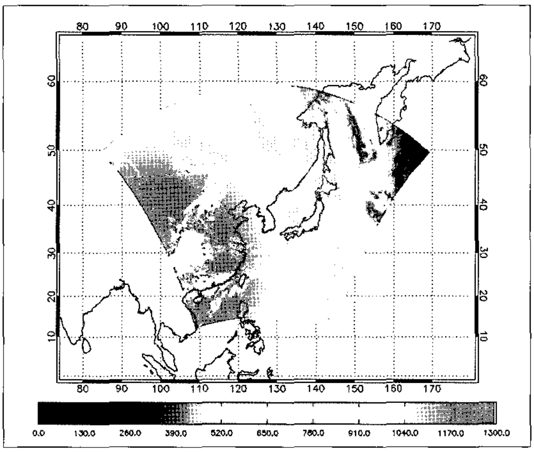

Fig. 4. Surface solar insoalation from MTSAT-1R at 22, Aug. 2005.

Solar Insolation product at 22/08/2005, at 0530 UTC. It totally depends on the solar position via a factor of cosine of the solar zenith angle. The clouds systematically affect the values of Surface Solar Insolation. We average the satellite based insolation to 3×3, 5×5, 7×7, 9×9, 10×10, 11×11, 13×13 to compare them with hourly ground station measurements. Using averaged value for each window sizes, drifting clouds from adjacent pixels across the ground station during the averaging interval of 1 hour are taken into account. The root mean square error (RMSE) i.e. deviation of predicted to the measured values, has been calculated for each spatially averaged insolation, on the whole period. Fig. 5 was represented the scatter plot of situation in the collocation files over the clear sky condition. Comprising, the retrieval method slightly underestimates the surface solar insolation for the all of the spatial window sizes. Fig. 5 (a), which has 3 × 3 window pixel sizes shows RMSE of 112.217 W/m^2 when directly compared ground value. The other side, in Fig. 5 (f), RMSE for 13 × 13 on same ground station is 92.987 W/m^2. As match-up window sizes for comparing with ground measurement increase,

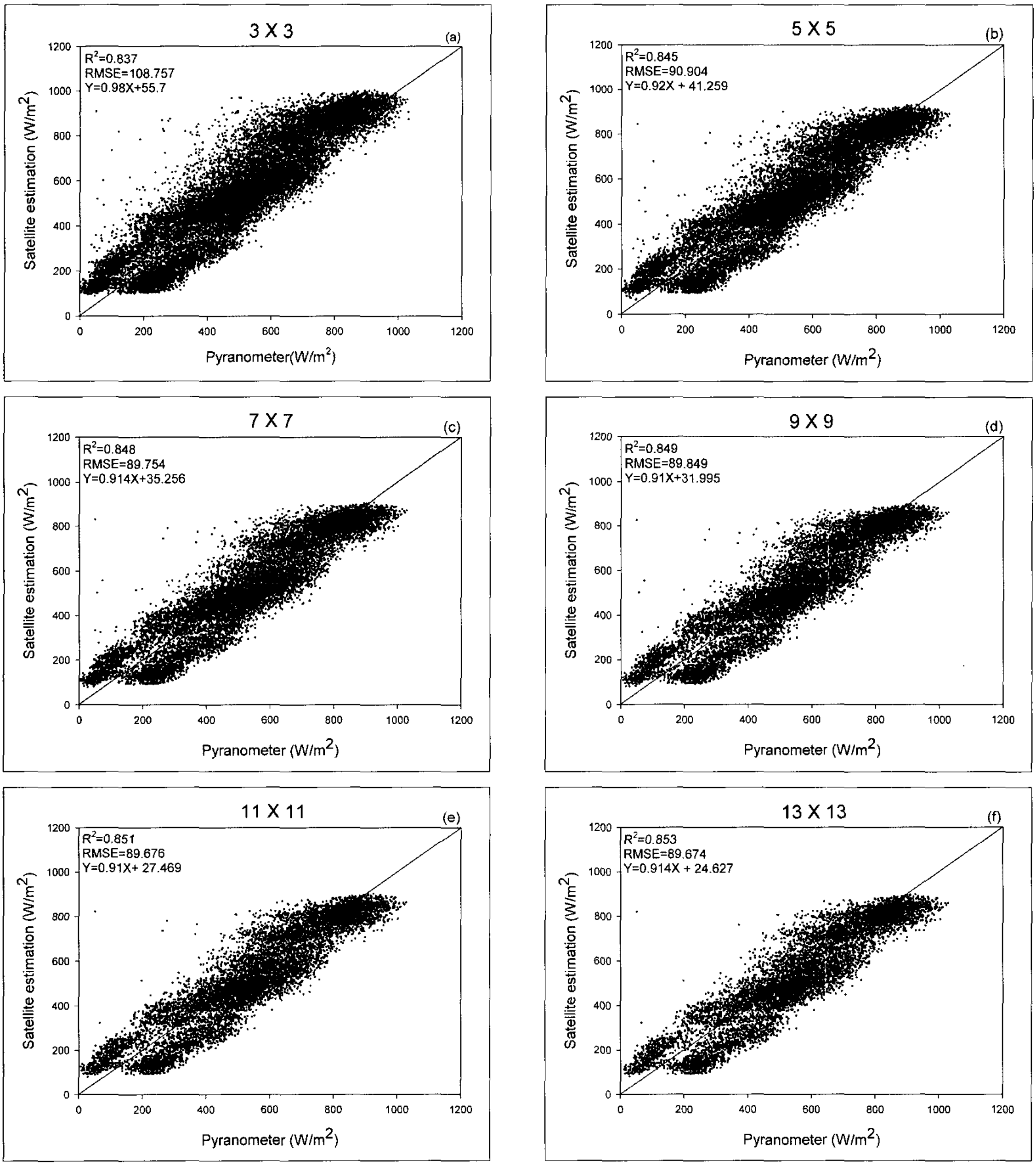

Fig. 5. Satellite-derived versus measured hourly values for clear sky, cloudy condition from August 1, 2005, to July 31, 2006 for 22 sites.

RMSE was decreased by 92.987 W/m^2. In the validation work, this statistical result doesn't represent the accuracy of the estimated values. Now, validation work is processing and is going to be analyzed further.

4. Summary

We used the MTSAT-1R satellite data to retrieve Surface Solar Insolation over Korean peninsula from August 1, 2005, to July 31, 2006. SMAC code produces not only the surface reflectance for solar spectrum channel but atmospheric parameterization for Rayleigh scattering, ozone absorption, water vapor absorption, and aerosol scattering transmittance. The estimate of Surface Solar Insolation has been improved using Transmittance due to Rayleigh scattering which is retrieved by SMAC code. By using SMAC code, it can easily be produced and applied in operational preprocessing system. To define the spatial represnetativity of pyranometer measurement, various window sizes (3×3, 5×5, 7×7, 9×9, 10×10, 11×11, 13×13) was tested. As window size for satellite-derived value increase, RMSE was decreased by 94.25 W/m^2. It could form the input a number of applications, such as use of meteorological predicts model, vegetation productivity, hydrology, crop-simulation model for yield forecasting. There is a need to analysis output data and to validate the estimated value in the ocean.

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