Monitoring and Discrimination for Sky Conditions using Multi-temporal Whole Sky Imageries

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Abstract: Solar radiation is known as the origin of energy on earth surface. Therefore, to estimate the radiation is the indispensable for understanding the radiation and carbon balances in one of the environmental problems. However, the radiation is affected by various sky conditions especially caused by the existence of clouds. Authors have been considering the methodology how to estimate total solar radiation which includes direct and defuse radiations using whole sky images. We have proposed the method to extract the cloud area and estimate cloud cover using Sky Index (SI) which we developed so far. Here, as one of the applications by using multi-temporal whole sky imageries in order to understand the relationship between the solar radiations and sky conditions, we describe the results of sky conditions monitoring and discrimination using the Enhanced Sky Indexes.
Keywords: Sky Conditions, Enhanced Sky Indexes, Whole Sky Imageries, Cloud effects, Solar Radiations

1. Introduction

The solar radiation is the origin of energy. Thus estimating solar radiation is needed in not only atmospheric science but various fields such as carbon exchange, energy budget, water cycling and productivities of forest and agriculture. On the other hand, total incoming irradiance is influenced by clouds at the surface. On the condition of the clear sky, which means cloudless, it is possible to estimate solar radiations using cosine of sun zenith angle and some existing models. However in reality, the clouds usually appear, move, change the shapes and disappear, that influence to the atmosphere and radiation environment at the same time. Therefore, in order to estimate the global radiation, it is necessary to understand the effects by clouds as input parameters. Especially, monitoring and discrimination of sky conditions which are clear (i.e., cloudless) sky, existence of clouds with or without direct sun shine, whole sky covered with clouds and so on are important.

Authors have proposed how to detect the cloud area and estimate cloud cover using Sky Index which shows the blueness of sky area in whole sky images so far [1]. In this study, we suggest the methodology of monitoring sky conditions and its discrimination using multi-temporal whole sky imageries. We present, in this paper, the whole sky observation system, Enhanced Sky Indexes (ESI) for understanding sky conditions, and the relationship Photosynthetically Active Radiation (PAR) and sky conditions recognized by ESI. As our future works, we have to examine the detail relationships between multi-temporal PAR/solar radiation and sky conditions in order to estimate solar radiation considered clouds effect using multi-temporal whole sky imageries.

2. Observation system and Enhanced Sky Indexes

2.1 Whole Sky Observation System

Automatic-capturing Digital Fisheye Camera (ADFC) is one of the observation instruments to take and accumulate the whole sky imageries. Mainly ADFC consists of digital camera (Nikon, Coolpix4500) with fisheye lens (Nikon, Fisheye Converter FC-E8), waterproof hard case and remote controlled cable from PC. The neutral density filter (FUJIFILM, ND1.0), which has 13% transparency, puts between the digital camera and the fisheye lens in order to decrease the influence caused by the strong sun light for CCD. The camera is set up to take imageries at every two minutes intervals by fixed exposure of the aperture as F2.6 and shutter speed as 1/500s. Taken the whole sky images have 2204pixels x 1704lines image size with RGB colors and JPEG (1/8 compressed) format. ADFC has installed on the roof of Research Institute for Humanity and Nature (RIHN) in Kyoto city. Also, as the radiations observation, global/ defuse pyranometer, global/ defuse spectral radiometer and sunphotometer are installed. Whole sky imageries and the other radiations data have been accumulated with time synchronization since March of 2005. This sky observation system is installed as one of the stations in Phenological Eyes Networks [2]. Fig.1 shows the overview of observation system and ADFC.

Fig.1 Overview of the whole sky observation system (left) and ADFC (right) at RIHN

2.2 Enhanced Sky Indexes (ESI)

As for the methodology of monitoring and discrimination for sky conditions using the whole sky imageries, we use Sky Index (SI) and Brightness Index (BI) which are calculated from RGB channels of the image. SI shows the blueness in the sky area and BI shows the brightness in the whole sky. Here, we call both indexes as Enhanced Sky Indexes (ESI). ESI are expressed by equations (1) and (2).

$$\text{Sky Index (SI)} = (DN_{Blue} - DN_{Red}) / (DN_{Blue} + DN_{Red}) \qquad (1)$$

$$\text{Brightness Index (BI)} = (DN_{Blue} + DN_{Green} + DN_{Red}) / 3*255 \qquad (2)$$

where DN_{Blue} = digital number of blue channel
DN_{Green} = digital number of red channel
DN_{Red} = digital number of red channel

SI values have the range between -1.0 and 1.0 from Eq. (1). The blue sky area in the RGB image has the high digital number in blue channel and the low digital number in red channel. On the other hand, clouds show white or grey on the image. Theoretically, high value of SI shows bluer sky, the value of near zero means clouds and sun. BI values are expressed by the range between 0 and 1.0 from Eq. (2). The bright pixels on the image show high BI. Accordingly, the sun and the white cloud areas on the image should be shown by the lowest SI and the highest BI.

3. Sky Conditions discriminated by ESI

In this study, we defined four categories of clear sky, clouds mixture with sun, clouds mixture without sun, and perfect cloudy sky as the typical sky conditions. As for the clouds, its brightness and cloud cover were considered also. A large number of whole sky imagery has been accumulated so far, so that we selected the appropriated images corresponded to the typical sky conditions through the visual interpretation from among accumulated images which were taken at the around noon time. Thus the selected images were regard as the standard of each sky condition. Furthermore, we chose the sky items as the components of sky conditions in order to understand the relation with ESI. In this paragraph, the relationship between sky items and ESI and the ESI characteristics correspond to the defined four sky conditions are explained.

3.1 Relationship between Sky items and ESI

The sky items which were chosen from the imageries on typical sky conditions consists of the blue sky area in clear sky (DOY137), the blue sky area in the clouds mixture sky (DOY130), various clouds area in the clouds mixture sky

(DOY130), thick and dark cloud area in the perfect cloudy sky (DOY121) and thin cloud area in the perfect cloudy sky (DOY140). SI and BI were calculated from 10 to 17 sampling areas for each sky item on one whole sky image in order to examine the relationship between ESI and sky items as the components of sky conditions. Fig.2 shows the graph of SI and BI plots at five sky items.
As for two sky items of clear sky and sky in clouds mixture in fig.2, when SI value is getting higher, BI is lower with the exponential function especially at clear sky. Compared to sky in clouds mixture, SI values are distributed in the almost same range but BI values are lower than BI of clear sky. On the contrary, BI values of various clouds have wide range from 0.3 to 1 but the range of SI is narrow from 0 to 0.1. Both SI and BI are low in thick and dark cloud but in case of thin cloud, SI values are close to 0 and BI is higher than thick and dark cloud. From this result, ESI at various sky areas should be distributed between two exponential functions and ESI at the others clouds should be under the line of exponential function at various clouds on this graph.

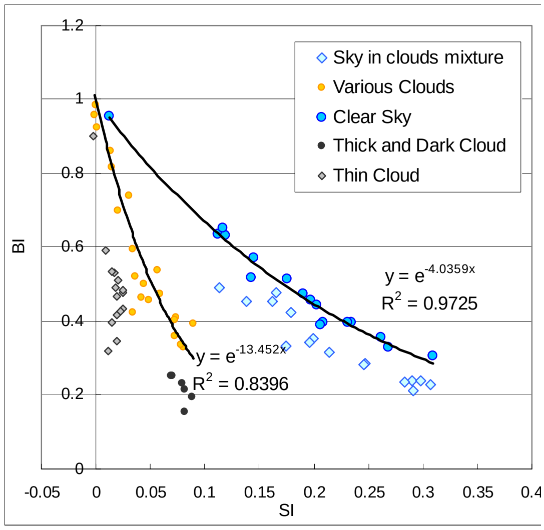

Fig. 2 Illustration of SI and BI plots at five sky items

3.2 ESI characteristics correspondent to sky conditions

In order to understand the characteristics of ESI correspondent to sky conditions, the BI mean and the histogram at each SI value's zone (0.0078 intervals) were examined for four sky conditions (Clear Sky, Cloudy Sky, Clouds mixture with sun, Clouds mixture without sun). We used the image area in the circle less than 60 degrees zenith angle for this analysis. These results are illustrated in fig.3 that shows graphs of the BI mean and the histogram at SI value on four sky conditions and used whole sky imageries.

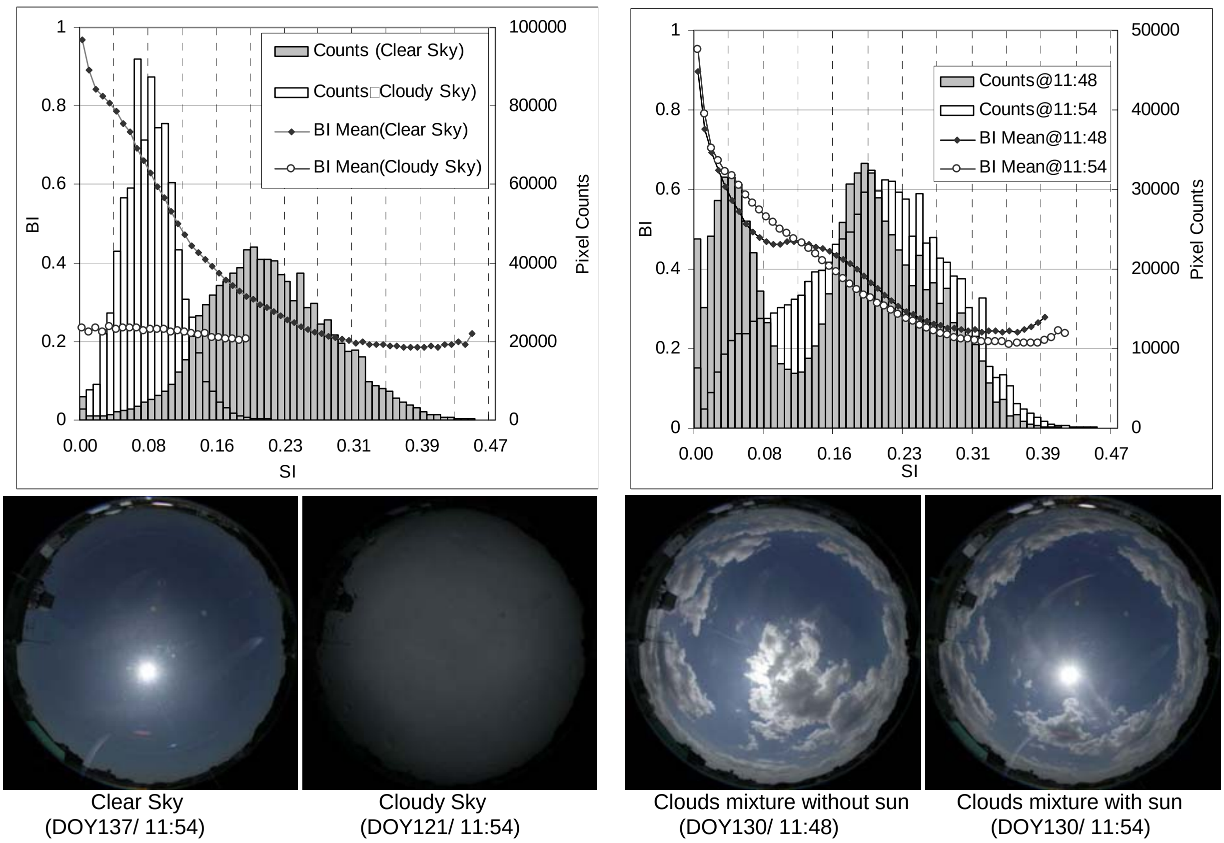

Fig. 3 Graphs of BI mean and histogram at SI value on four sky conditions and used whole sky imageries

According to the graph in the cases of clear sky and cloudy sky in fig.3, the histogram of clear sky has the peak around SI 0.2 and the wide distribution. In the case of cloudy sky, the SI distribution is narrow range and SI values show wholly low. As for the relation to BI, the value of BI mean is getting lower as SI value is higher on clear sky condition, but BI mean of cloudy sky has almost no change and low value about 0.23. On the other hand, the histogram has two peaks of cloud area and sky area on the sky condition of clouds mixture without sun. Furthermore, the cloud areas around the first peak at low SI value shows the drastic decrease of BI mean and the sky area in second peak have low BI mean and the gentle slope as compared with the cloud area. In the case of clouds mixture with sun, the sun area is shown by SI as 0 and the highest BI mean as same as the pattern of sun area in clear sky. These characteristics shown in ESI are similar pattern of the relationship between sky items and ESI. Therefore, ESI is effective for sky conditions monitoring and discrimination.

4. Comparison between Sky conditions and PAR

The solar radiations are affected by the existence of clouds. Here, we compared between sky conditions discriminated by ESI and the actual observed radiation. Table 1 lists six sky conditions and the ratio of observed PAR to estimated PAR on clear sky condition. Each sky condition was expressed by cloud cover, the brightness (BI mean) in cloud area and the sun appearance or disappearance in this study. Cloud cover was estimated by the method using SI threshold [1]. As for the radiation, we used Photosynthetically Active Radiation (PAR) because RGB corresponds to visible wavelength.

Table 1. Sky conditions discriminated by using ESI and comparison with the ratio of the observed PAR to the estimated PAR on clear sky condition by existing model

DOY/Time	Cloud Cover	BI Mean in Cloud Area	Sun	Ratio of Obs./Est. PAR
121 /11:54	100%	0.23	□	0.177
130 /11:48	36%	0.52	□	0.407
130 /11:54	21%	0.54	○	0.990
130 /12:08	35%	0.59	○	1.127
137 /11:54	**0%**	**0.00**	○	**1.015**
140 /11:54	100%	0.47	□	0.442

The estimated PAR on the clear sky condition was calculated by using existing model [3] and actual observed radiation and PAR. Therefore, in the case of observed PAR at clear sky condition, the ratio shows almost 1.0.
According to table 1, the cloudy sky condition on DOY121 shows low BI, which means dark cloud area, with 100% cloud cover, so that the ratio of observed PAR is the least. On the other hand, the cloudy sky condition on DOY140 has comparatively bright and thin cloud, and also the ratio of PAR is larger than DOY121. Regarding the clouds mixture sky on DOY130, when the sun covered with cloud at 11:48 the ratio of PAR is less than half, but the ratio of PAR in the largest at 12:08 when the BI mean in cloud area is the highest and the sun appears. That is the defuse radiation is increased by reflected sun light from the cloud around the sun in addition to the direct radiation. From this consideration, the cloud effects work mainly as two functions to decrease radiation (i.e., negative effect) and to increase radiations (i.e., positive effect).

5. Conclusion

Clouds have directly the strong impact to the solar radiation environment. Accordingly, understanding the various sky conditions is indispensable for estimating global radiation consists of direct and defuse radiations. We have accumulated whole sky imageries in order to monitor and discriminate sky conditions. In this study, the method how to discriminate the sky conditions, which are clear sky, existence of clouds with or without direct sun shine, perfect cloudy sky and so on, automatically using Enhanced Sky Indexes (ESI) calculated from whole sky imageries was examined.
Through this study, ESI could be identified as the useful index for automatic sky conditions discrimination and estimation of solar radiations.
As the future works, we have to consider much detail about ESI characteristics on sky conditions in the different time and season, and parameterize the clouds effects by using ESI and observed radiations data.

Acknowledgement

This study was performed with support of Grant-Aid for Science Research (No. 16310017)

References

[1] Yamashita M., Yoshimura M., Nakashizuka T. (2004), Cloud Cover Estimation using Multitemporal Hemisphere Imageries, International Archives of the Photogrammetry, Remote Sensing and Spatial Information Science, Vol. XXXV, Part B, pp826-829.

[2] URL: Phenological Eyes Network - Ground-based Measurement for Remote Sensing Studies -: http://www.pheno-eye.org/.

[3] Junsei KONDO. (2000), Atmospheric Science near the Ground Surface, University of Tokyo Press.