Ratio of photosynthetically active radiation to global solar irradiance.

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Abstract

Solar irradiance and photosynthetically active radiation was measured on the rooftop of Nara Women's Univ. in Nara, Japan, from Oct. 2003 to Sep. 2004. PAR was measured with two types of quantum sensors. One is LI-COR, inc.'s photon sensor LI-190SB, and another is EKO Instruments trading Co.'s ML-020P. Both sensor's daily PAR were the same as each other. Global solar irradiance was measured by pyranometers (MS-601,EKO Co.), and also measured with precision pyranometer CM-21 from December 15 2003 to January 18 2004. Using the data, ratio of photosynthetically active radiation to global solar irradiance was calculated. For clear sky day, it is from 0.40 to 0.41 in winter, and from 0.46 to 0.47 in summer. For cloud day, it is larger than that of clear sky day, and maximum it's value is 0.5. Our results have a tendency to be smaller than 1980's study. Precise measurements should be continue to make the ratio clear.

1 Introduction

Solar radiation is one of important resources for all life on earth. Plants utilize solar radiation in visible ranges for photosynthetic process. For biotic response and food security to climatic warming, it is necessary to estimate the net primary production of vegetation.

In order to estimate the net primary production using satellite data, incident value of photosynthetically active radiation (PAR) is one of variables. One method for acquisition of PAR is using the data of global solar irradiance and the ratio of PAR to the solar irradiance.

Many studies have been done for the ratio of PAR to the global solar irraiance in 1980s (Jitts et al. 1976 [1], J. Ross, 1981 [3], Z. Uchijima 1981 [4], K.J. McCree 1981 [5], Baker and Frouin, 1987 [6]) and by Tugjsuren (2001, [8]). And they were studied using spectral pyranometers with spherical shell filters. In Japan, the ratio with PAR's spectral region from 395nm to 715nm is reported as between 0.45 in winter season and to 0.52 in summer season (Z. Uchijima 1981 [4]). The quantity of water vapor in the atmosphere cause the seasonal change of the value. Since the filter has an aged deterioration, long-term observation is impossible using spectral pyranometers with the filters. Recently, PAR is measured by photon sensors. The spectral region of photon sensor is from 400nm to 700nm. Gaastra(1986 [2]) pointed out that the irradiance in the waveband 400nm to 700nm is an adequate measure as photosynthetic irradiance and the spectral difference should be modified. The effect of the spectral region difference of PAR measurement was reported as around 5-7 % (Tooming & Gulayav, 1967).

In this study, PAR with the spectral region from 400nm to 700nm and solar irradiance are measured and ratio of photosynthetically active radiation to global solar irradiance is studied using the measured data.

2 Measurements of PAR and Solar irradiance

Photosynthetically active radiation (PAR) and global solar irradiance were measured on the rooftop of Nara Women's University, Nara, in Japan.

PAR was measured with two types of quantum sensors. One is LI-COR Inc.'s photon sensor LI-190SB and another is EKO INSTRUMENTS Trading Co.'s ML-020P. The spectral range is almost same as each other, it is from 400nm to 700nm. The difference of these sensors is the top of the sensor, where light is condensed. LI-190SB PAR sensor has the flat and milky-white plastic one, and ML-020P has the half sphere transparent glass one. With the LI-190SB sensor, PAR was measured from October 2 to 7 2003, November 19 2003 to January 18 2004, July 14 to 28 2004, and September 15. With the ML-020P sensor, PAR was measured from July 14 to 28 2004, and September 15. LI-190SB sensor was calibrated on June 18 2002, and September 1, 2004 using the standard lamp at the Meiwa Co.. The output voltage was decreased 11.1% during two years and two months. ML-020P sensor was calibrated end of June, 2004.

Global solar irradiance was measured pyranometers (MS-601) from October 2 to 7 2003, November 19 2003 to January 18 2004, July 14 to 28 2004, and September 15. Global solar irradiacne was also measured with precision pyranometer CM-21 from December 15 2003 to January 18 2004. All sensors were finely adjusted in horizontal. But the precision of the level was different each other. The highest precision of the level is CM-21. PAR sensors and pyranometers were connected with the data logger DATAMARK (HAKUSAN Co.). The output from the sensors were sampled 10 seconds or 1 minute, and added value was recorded every 10 minutes. The voltage resolution of the data logger is 0.01mV. It is enough of the measurements.

2.1 Global solar irradiance measurement and calibration

The output of the two MS-601's was compared with the precision pyranometer CM-21. The relationship between the solar irradiance measured by CM-21 and that by MS-601 is shown in Fig. 1. The gain of MS-601 is less than CM-21 around 1.9 % and it was adjusted to CM-21's gain using the relationship shown in Fig. 1. Fig. 2 shows the daily average solar irradiance (W/m^2). X axis show the day number, and one is on Jan. 1 2003.

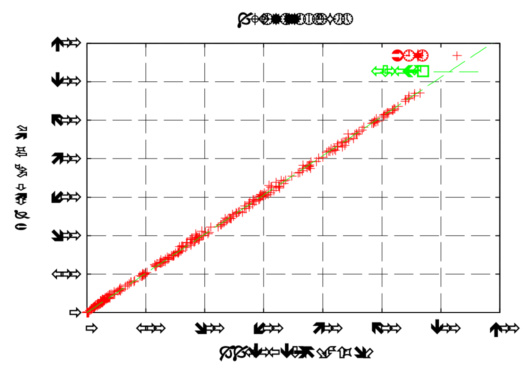

Figure 1: Relationship of the solar irradiance measured by CM-21 and MS-601.

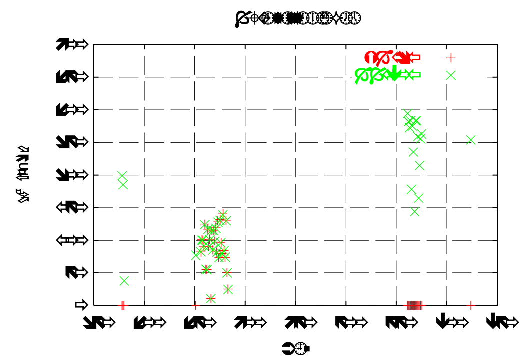

Figure 2: Solar irradiance measured by CM-21, MS-601 from Oct 2003 to Sep 2004.

2.2 PAR measurement and calibration

PAR measurement with EKO ML-020P was started after July 2004. PAR sensor of LI-190SB was calibrated on June 18 2002 by LI-COR inc., and recalibrated Sep. 1 2004 by Meiwa Shoji. Co.. Firstly the output of the ML-020P and LI-190SB after recalibration was compared. Hourly averaged PAR measured on Sep. 15 2004 was shown in Fig. 3. Y axis shows PAR as a unit of W/m^2. A mol of photons is converted into 0.22 radiant flux (W/m^2). There is tendency that the value of LI-190SB PAR sensor is smaller than that of ML-020P during sun's low angle of elevation, and that of LI-190SB is larger than that of ML-020P during sun's high angle of elevation. Fig. 4 shows the difference of outputs from two sensors. The value of ML-020P sensor minus that of LI-190SB is shown. The difference is around $\pm$ 10 (W/m^2). We can consider that the response of the incident light's angle or temperature is different each other. The daily average PAR measured by ML-020P is 119.2 (W/m^2) and that by LI-190SB is 119.8 (W/m^2). We consider that the daily average value from two sensors is the same as each other, but we should be careful to use the hourly average value.

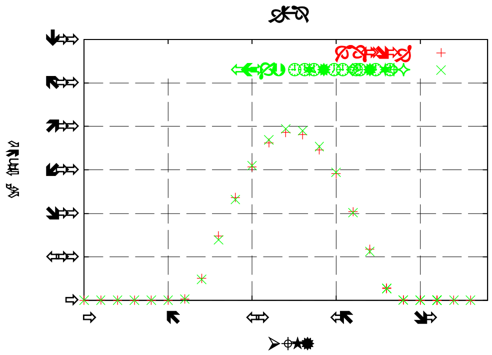

Figure 3: PAR measured by ML-020P and LI-190SB on Sep 15 2004.

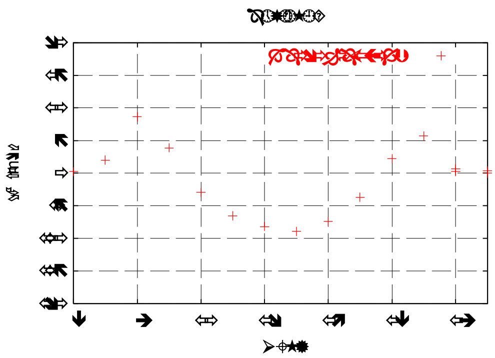

Figure 4: The difference of the output from ML-020P and LI-190SB measured on Sep 15 2004. The value measured by ML-020P minus that by LI-190SB.

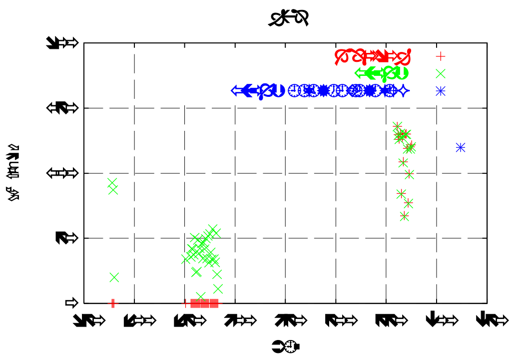

Figure 5: PAR measured by ML-202P and LI-190SB from Oct 2003 to Sep 2004. ML-202P sensor is available after July 2004.

The data measured by LI-190SB is available from Oct. 2003. But this PAR sensor was calibrated on two years ago, and it was recalibrated on Sep 2004. It was found that the output voltage was decreased 11.1% during two years. Since, the output voltage before recalibration was corrected with the assumption of the linear decrease as a function of day. The measurement and corrected result of daily average PAR was shown in Fig. 5. X axis show the day number, and one is on Jan. 1 2003.

3 Results of the ratio of PAR to global solar irradiance and Discussion

Using the data shown in Section 2, the ratio of PAR to global solar irradiance was calculated . The results from Oct. 2003 to Sep. 15 2004 are shown in Fig. 6. For clear sky day, it is from 0.40 to 0.41 in winter, and from 0.46 to 0.47 in summer. For cloud day, it is larger than that of clear sky day.

The ratio summarized by Z. Uchijima in 1981 was 0.45 in winter season, and 0.52 in summer season with PAR's spectral region from 395nm to 715nm. The ratio by Z. Uchijima with the spectral region was converted into that with the spectral region of photon sensor from 400nm to 700nm using the reduced factor 5 $\sim$ 7%. The ratio by Z. Uchijima was converted into from 0.42 $\sim$ 0.43 in winter, and from 0.48 $\sim$ 0.49 in summer. Fig. 7 shows the monthly ratio of Uchijima's measurement result [4] at Nishigahara and Kannodai from 1978 Oct. to 1980 Dec. The result of the Kannodai in 1980 have clear seasonal change, and that of Nishigahara have the scattering. The summarized value of 0.45 in winter season and 0.52 in summer season was considered to be determined using Kannodai's results.

The line in In Fig. 7 shows the value multiplied 0.95 or 0.93 to estimate the ratio with the spectral region from 400nm to 700nm. Our results are compared with the converted values shown in lines in Fig. 7. Our results have a tendency to be smaller than Kannodai's measurements in clear days. The ratio was very sensitive both of PAR and solar irradiance measurement, although we tried to reduce the measurement error. Precise measurements should be continue to obtain the clear result of the ratio.

In the next step, we will make simulation to explain the atmospheric condition of measured data.

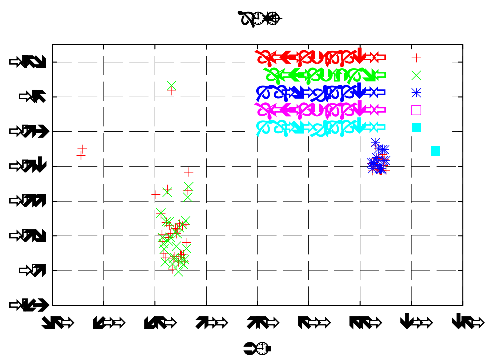

Figure 6: Ratio of PAR to global solar irradiance from Oct 2003 to Sep 2004.

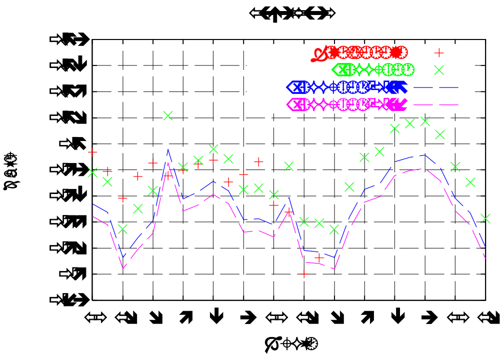

Figure 7: Ratio of PAR to global solar irradiance measured by Uchijima from Oct. 1978 to 1980 Dec.at Nishigahara and Kannondai, Japan

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