Validation of Photosynthetically Available Radiation Estimated from Satellite Data for Primary Productivity Model

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Abstract

A vertically resolved primary productivity model was proposed for a satellite remote sensing using a ocean color sensor and an infrared thermal sensor. A photosynthetically available radiation (PAR) was estimated from a satellite data and a radiative transfer model. A basic function for the PAR is given as a function of cloud distribution from satellite observations. A weekly composite of chlorophyll-a distribution by SeaWiFS was used to estimate a cloud distribution. The radiative transfer model, MODTRAN 4.3, was operated to compute the solar irradiation on the sea surface under the ideal atmospheric condition for 24 hours and for each month. A vertical distribution of PAR along the water column is given by an empirical equation as a function of chlorophyll-a concentration in the surface. A vertical distribution of chlorophyll-a concentration is given by an empirical equation as a function of chlorophyll-a and PAR in percentage. Then a primary productivity is computed based on the chlorophyll-a and sea surface temperature distribution with the PAR and related parameter along the water column. The current model indicated a good agreement with in-situ measurements.

1. Vertically resolved primary productivity model

We have proposed a depth resolved primary productivity model to estimate a primary productivity from a satellite measurement. A concept of this model is given as follows;

$$PP_{eu}=\int_t\int_z P_b(z,PAR(z,t),T)C(z,E\%(z))dz\,dt \quad .....(1)$$

,where PP_{eu} is the primary productivity (mgC.m-2.day-1), P_b *is the* carbon fixation rate (mgC.mgChl-a^{-1}.m^{3}.hour-1), ***PAR*** *is the* photosynthetically available radiation (Ein.m-2.hour-1), ***C*** *is the* chlorophyll-a concentration (mg.m-3), ***T*** *is the water* temperature (deg-C) and ***t*** is the time for 24 hours. We proposed the carbon fixation rate, ***Pb***, as a function of PAR, temperature and depth from the in-situ measurement along the Equator and the middle latitude in the Pacific. The carbon fixation rate is given as follows;

$$Pb(z,PAR(z,t),T)=16\,[1-exp\{-0.5a*PAR\%(z)*0.01\}]\,exp\{-0.3b*PAR\%(z)*0.01\} \quad .....(2)$$

,and $a=0.1*s*PAR(0)+i$

$s=-0.00011T**3+0.0039*T**2-0.0007T+0.2557$

*i=0.000215T**3-0.0106T**2 +0.0868T-0.1042*

*b=0.00048T**3-0.018T**2 +0.1134T+3.1214*

We empirically defined a vertical distribution of photosynthetically available radiation along the depth in percentage, PAR%(z,C_0), as a function of a chlorophyll-a concentration in the surface as follows;

$$Log(PAR\%(z,C_0))=(aC_0+b)Z+2 \quad \ldots(3)$$

,where C_0 is a chlorophyll-a concentration in the surface, which could be replaced by a satellite observation, Z is the depth, and a and b is empirical constants.

A vertical distribution of chlorophyll-a concentration is proposed by the following function as a function of a vertical distribution of PAR and a chlorophyll-a concentration in the surface.

$$C(z)=[1-c\cdot exp\{-a\cdot PAR\%(z,C_0)\}]\cdot exp\{-b\cdot PAR\%(z,C_0)\}+C_0 \quad \ldots..(4)$$

,where a, b, and c are empirical constants.

2. Photosynthetically Available Radiation

A determination of the PAR on the surface is another key issue to estimate the primary productivity. Frouin et al. (.http://orca.gsfc.nasa.gov/seawifs/par/doc/seawifs_par_wfigs.pdf, 2000) proposed a research product for the PAR from SeaWiFS measurement. The PAR at the surface for the day, ***PARday***, is computed with a remote sensing reflectance ***R i(t)*** from SeaWiFS measurement as follows:

$$PARday = PARext \iint f(Ri(t),\ Td,\ Tg,\ Sa)dt\ d\lambda \ldots..(5)$$

,where ***PARext*** is the incoming solar flux at the top of the atmosphere, ***Td*** is the clear sky diffuse transmittance, ***Tg*** is the gaseous transmittance, ***Sa*** is the spherical albedo. They computed the PAR at the sea surface at the time for a single path from the top of the atmosphere to the sea surface without considering the total sky radiance.

In our study, ***PAR(t)*** at the sea surface is computed by MODTRAN-4.3 for the ideal atmospheric condition as a function of the time, ***t***, date of the year, and the latitude with considering the total sky radiance. In this computation, the aerosol model is selected for the maritime extinction with 23 km visibility under the model for the mid-latitude summer atmosphere. Then, a cloud distribution is estimated from the SeaWiFS chlorophyll-a distribution, where missing data is considered as the presence of cloud. The weekly composite data is selected to estimate a cloud distribution. Although there remains a possibility of the sun glint region in the missing data as discussed by Frouin et al.(2000), we took a lower possibility of the sun glint region than a daily composite chlorophyll-a distribution. The averaged ***PAR(t)*** for the hour and for one month is computed by MODTRAN-4.3. Fig.1 shows an example of ***PAR(t)*** distribution for Jun, where a higher irradiation is expected in the northern higher latitude. Then, the daily integrated ***PARday*** for one month is given as follows:

$$PARday = (0.9 - 0.05\ \Sigma Cloud) \int PAR(t)\ dt \quad \ldots..(6)$$

,where ***Cloud*** is given as 1.0 from the missing chlorophyll-a data. The cloud distribution is integrated four weeks and the PAR is integrated for 24 hours.

Fig.2-a shows a monthly mean PAR determined in this study and Fig. 2-b shows a monthly mean PAR proposed by Frouin et al.(2000), indicated as GSFC. Fig.3 shows a comparison of the PAR along the date line in December 1997 between this research and GSFC.

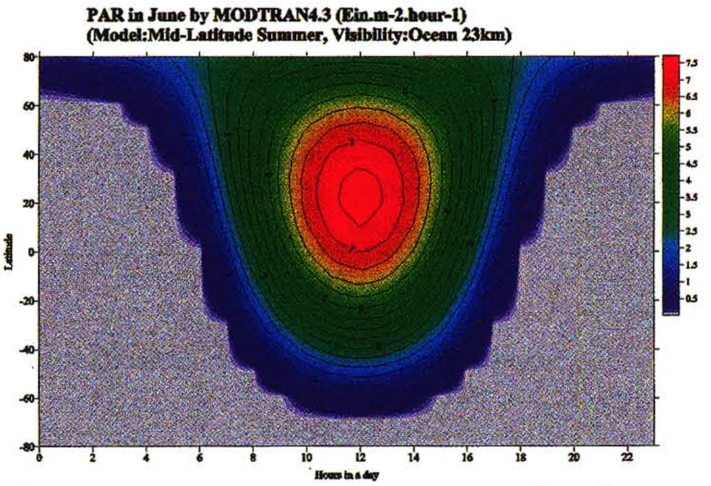

Fig. 1 Monthly mean PAR in June computed by MODTRAN4.3 in Ein.m^{-2}.$hour^{-1}$. X axis shows hours for the day and Y axis shows latitude.

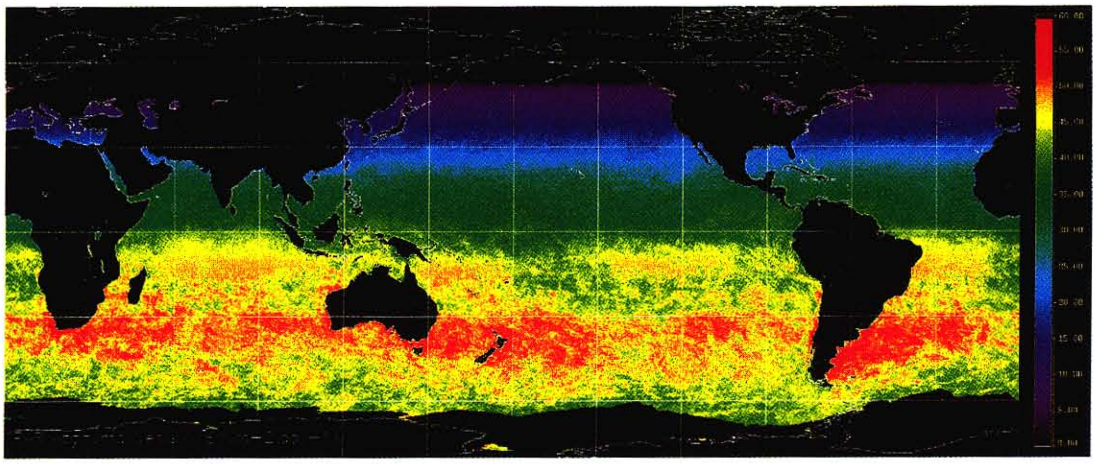

Fig. 2-a Monthly mean PAR for December 1997.

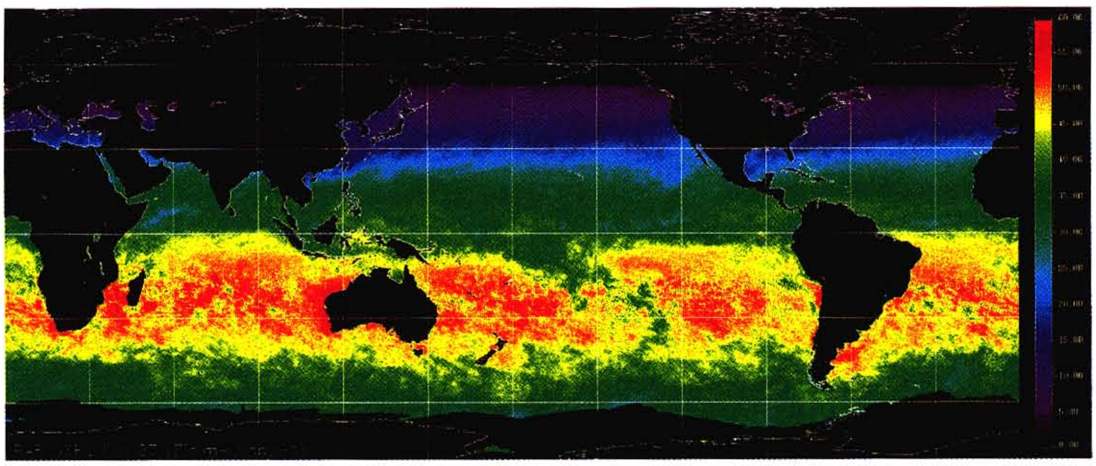

Fig. 2-b Monthly mean PAR for December 1997 by Frouin et al. (2000).

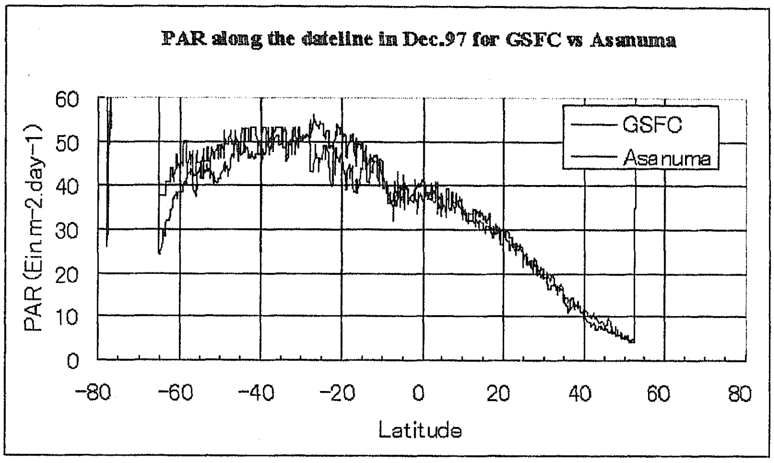

Fig.3 PAR along the dateline in December 1997 for GSFC and this research.

3. Discussion

This research and GSFC showed a different PAR in the southern higher latitude for December 1997 in Fig. 2-a and 2-b. According to the profile along the date line in Fig.3, two profiles show a good agreement for the northern sphere and to 10 deg-S. In contrast, GSFC showed a higher PAR around 20 deg-S and a lower PAR between 40 to 60 deg-S. Around 20 deg-S, the sun glint region, which was not eliminated through weekly composite and was recognized as a missing data, has a possibility to reduce the PAR in our research. The difference between this research and GSFC goes to 5 to 10 $Ein.m^{-2}.day^{-1}$ around 20 deg-S. In 40 to 60 deg-S, the difference between two algorithms may go to the difference of definition of PAR. Frouin et al.(2000) computed the PAR on the surface as the transmitted ***PARext*** through the atmosphere. This research computed the PAR on the surface by MODTRAN4.3 with including all possible sky radiance to the sea surface. The difference may increase for the higher latitude, especially for the longer daytime. The maximum difference between two PARs is around 25 %, which may cause a significant difference in the primary productivity. Unfortunately, we are missing PAR data on the higher latitude and it will be an important target for the in-situ measurement.

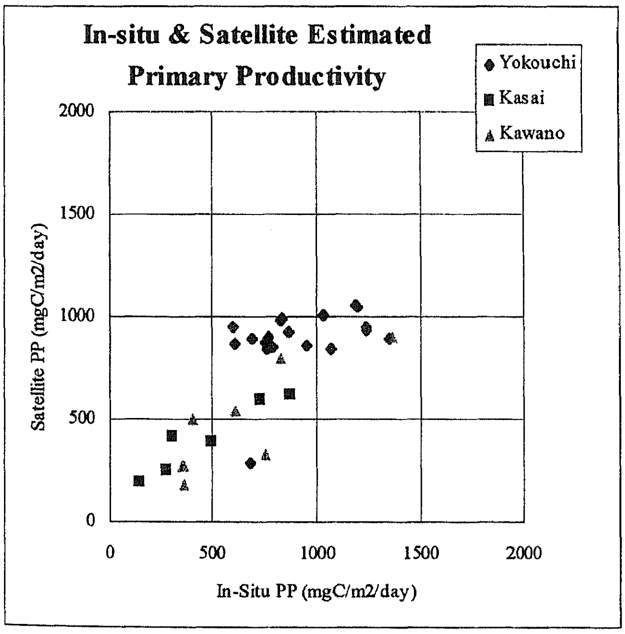

Fig. 4 In-situ and satellite estimated PP.

Currently, our primary productivity model is running very well. Fig.4 shows a scatter diagram between the computed primary productivity and in-situ measurements along the Equator and the mid-latitude around Japan. As described for the PAR in-situ measurement, the in-situ measurement in the higher latitude may keep a key for this study.