Study on net primary production of vegetation in the Mongolian plateau using satellite data

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Abstract: Advanced Earth Observing Satellite-II (ADEOS-II) will be launched by National Space Development Agency (NASDA) on December 2002. We want to estimate the net global primary production (NPP) of vegetation as a part of carbon cycle by using ADEOS-II/GLI data, which plays an important role in global warming. As a preliminary study, We try the NPP estimation by vegetation index based on pattern decomposition (VIPD) method using LANDSAT/ETM data. We have obtained the NPP estimation at the area of higher vegetation density in the Kii Peninsula of Japan. We also need to prove the NPP estimation in the area of lower vegetation density, for example, the plateau in Mongolia. In this study, we estimate NPP in Mongolia and compared with the measurement data.

Keywords: reflectance, photosynthesis, canopy structure, Mongolian plateau.

1. Introduction

The effects of global warming on vegetation in ecosystems were investigated by many studies, from these studies we know the effects of climate changes on geographical distribution of the net primary production (NPP) of natural vegetation in the world. We are developing the algorithm to estimate NPP by using satellite data now. Satellite ADEOS-II will be launched on December 2002 in Japan. ADEOS-II carries 5 sensors, one of them is hyper spectral sensor named global imager (GLI). Use of GLI hyper spectral data to estimate the NPP is our objective. As a preliminary study, we have estimated the NPP with pattern decomposition method (PDM)[2] by using LANDSAT/TM data. We obtained the NPP estimation at the area of higher vegetation density in the Kii Peninsula of Japan, and compared with ground measurement data. We also need to validate the NPP estimation in the area of lower vegetation density, for example in the Mongolian plateau.

2. Pattern decomposition method

Pattern decomposition method was developed by our study group. The spectral albedo (A_i) in any pixel can be decomposed by three normalized basic spectral patterns shown in equation (1), they are water, vegetation and soil.

$$A_i = C_w P_{iw} + C_v P_{iv} + C_s P_{is} + R_i \tag{1}$$

where i corresponds to wavelength. P_{iw}, P_{iv} and P_{is} are the normalized basic spectral patterns of water, vegetation and soil. C_w, C_v and C_s are the decomposition coefficients of water, vegetation and soil respectively. The sum of standard pattern over every band is equal to 1 for standardization in equation (2).

$$\Sigma_{i=1}^{6} P_{il} = 1 \qquad (l = w, v, s) \tag{2}$$

In this study, we use a vegetation index based on pattern decomposition (VIPD) shown in equation (3).[3]

$$VIPD = \frac{C_v - C_s - \frac{S_s}{\Sigma_{i=1}^{6} A_i} C_w + S_s}{S_v + S_s} \tag{3}$$

where S_v and S_s are constant, they are the sum of albedo over all bands of typical samples used for standard pattern vegetation and soil respectively. $\Sigma_{i=1}^{6} A_i$ is the sum of albedo values over all bands, For LANDSAT/ETM data, i is from band 1 to band

5, and band 7. VIPD will be near 1 when vegetation is active, by contraries VIPD will be near 0 when vegetation is dead. And VIPD should be about 0 for water and soil.

3. The algorithm to estimate NPP

Carbon dioxide in the atmosphere can be fixed inside to the vegetation due to the photosynthesis activities. It is called gross primary production (GPP). Net primary production (NPP) is the value that the loss of vegetation respiration (R_d) was reduced from gross primary production. Net primary production (NPP) can be obtained by equation (4).

$$NPP = GPP - R_d \;, \qquad (4)$$

where GPP can be obtained from equation (5).[4]

$$GPP = Co \cdot \int_0^T [\, R_v(t) \cdot QE(t) \cdot R_s(t) \,]\, dt \qquad (5)$$

where T is a term of NPP estimating, T is a month in this study. $R_v(t)$ is vegetation area ratio of a pixel. QE is quantum efficiency $[mgCO_2/J]$. $R_s(t)$ is photosynthetic active radiation (PAR) $[W/m^2]$.

In equation (4), R_d is the reduced value by vegetation respiration. R_d can be obtained by air temperature using empirical relationship (6).

$$R_d = \frac{7.825 + 1.145T\ [^\circ C]}{100} \cdot GPP \qquad (6)$$

The relationship between quantum efficiency (QE) and vegetation index based on pattern decomposition method ($VIPD$) is as following equation (7).

$$R_v \cdot QE = 0.017 \cdot VIPD[mgCO_2/J] \qquad (7)$$

It was a consequence of our investigation. The relationship equation (7) of quantum efficiency (QE) and vegetation index based on pattern decomposition method ($VIPD$) is the consequence basing on a simple leaf. Nevertheless, satellite just can observes the vegetation colony only, it means just the gathering of leaves can be observed by satellite. Then, parameter Co expresses the effect of vegetation canopy structure, that is not included in equation (7).

Photosynthesis curve can be approximate to a straight line when photosynthetic active solar radiation (R_s) is low as shown in figure 1.

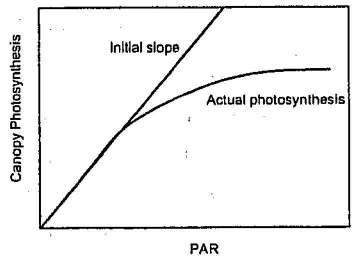

Fig.1 The initial slope of actual photosynthesis.

Therefore, photosynthesis can be obtained, if photosynthetic active radiation and quantum efficiency can be observed in low PAR region.

But there is the saturation of vegetation photosynthesis for high PAR. Vegetation can not do any more photosynthesis over the saturation point even in stronger photosynthetic active radiation. For this reason, the effect of the photosynthesis saturation is included in the parameter Co in equation (5).

The important point in our study is to evaluate the parameter Co. We estimate the parameter Co by using radiative transfer model[1] and photosynthesis model[1]. The radiative transfer model we used in this study is two-stream approximation model.

For estimating Co in Mongolian plateau, we measured reflectance and transmittance of a simple leaf, and soil reflectance as a background reflectance shown in figure 2.

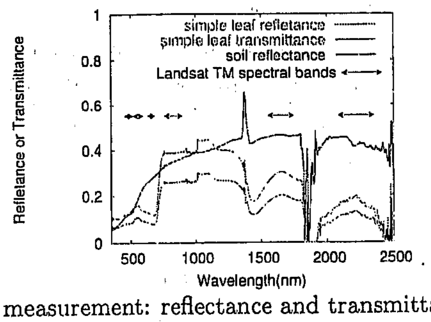

Fig.2 measurement: reflectance and transmittance.

We also measured the photosynthesis of a simple leaf in Mongolia plateau shown in figure 3.

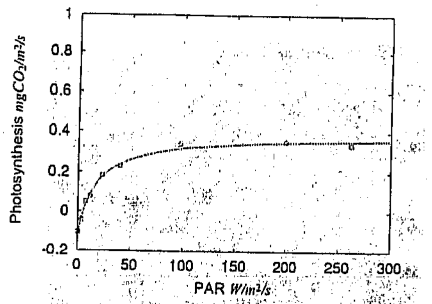

Fig.3 measurement: a simple leaf photosynthesis.

In figure 4, we discussed the relationship between leaf area index (LAI) and the parameter Co of canopy structure in case of shrubbery caragana. We also estimated the parameter Co for general grass without canopy structure. The average value of Co for general grass is 0.41, closely resemble to that when LAI equals 3 or 4 for shrubbery caragana in figure 4.

The value of parameter Co varies according to PAR, because Co contains the effect of the saturation in high PAR. So, parameter Co was estimated at the average value of PAR.

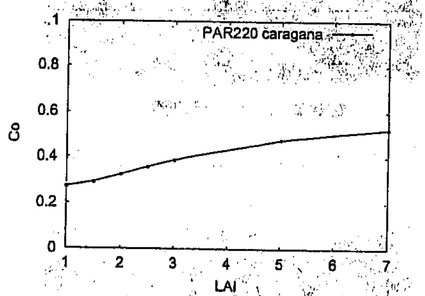

Fig.4 Relationship between LAI and Co of caragana.

4. Satellite data analysis

We estimated the NPP in the Mongolian plateau study area using LANDSAT/ETM data in this study, the ETM data was acquired on 12 June,2001. Of course, we would like to use the data of satellite ADEOS-II after it launched in this year.

For estimating the NPP and verifying the estimated NPP, we measured the solar radiation, solar spectral irradiance, air temperature and leaf area index in the study area as shown in table 1.

parameter	PAR[W/m^2]	LAI	T[$^\circ C$]	Co
value	220	3.5	20	0.43

Tabel.1 parameter used for NPP estimating.

We measured the solar radiation and solar spectral irradiance in clear day. We made a rough monthly average estimate for the photosynthetic active radiation, the average PAR in June,2001 is about 220 W/m^2 including rainy, cloudy weather, and fine days. The leaf area index is also the average value calculated from the measurement. The parameter Co is estimated by PAR equals 220 W/m^2 and LAI equals 3.5. The average temperature in a month is calculated from the temperature of daytime.

The estimating results are shown in the following figures. Figure 5 is the real image of study area in Mongolia using LANDSAT/ETM data on 12 June,2001. We calculated the vegetation index VIPD using pattern decomposition method, showing it in figure 6 and then estimated the net primary production of vegetation in Mongolian plateau showing in figure 7.

5. Validation of NPP estimated

To confirm the estimated net primary production of vegetation, we measured the practical net primary production of vegetation at the study area in Mongolian plateau in 2001 and 2002. We used the measurement data in 2001 here, to correspond to satellite data.

The average NPP at area of grass or shrubbery caragana with grass is estimated to be about 0.5 $tDM/ha/month$ from the satellite data in previous section. On the other hand, the average value measured in five areas is about 0.2 $tDM/ha/month$. It is considered that the difference from some factors such as water stress, because of low soil moisture in Mongolian plateau, the water stress constrains the photosynthesis of vegetation. The NPP value from satellite data does not take into account the limitation. And the measured NPP is that for the above ground, not including roots growth.

6. Conclusions

We measured the solar radiation, air temperature and leaf area index etc. in the Mongolian plateau. From these measurements, we estimated NPP of the area at lower vegetation density in Mongolia using LANDSAT/ETM data. The estimated NPP of vegetation using satellite data is higher than the value that we measured in Mongolian plateau.

Acknowledgment

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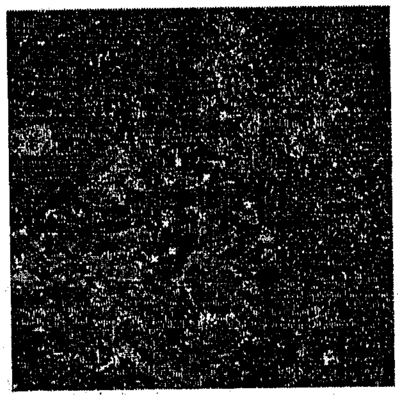

Fig.4 Gobi,Mongolia.Landsat/ETM on June 12,2001.

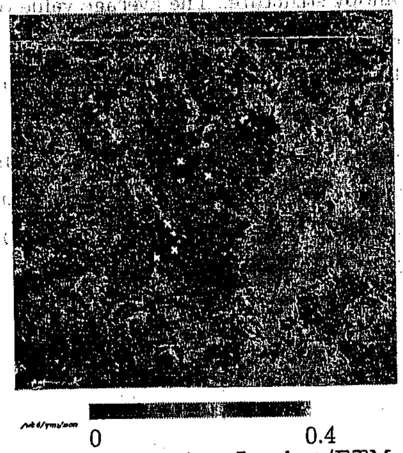

Fig.5 VIPD estimation. Landsat/ETM June 12,2001.

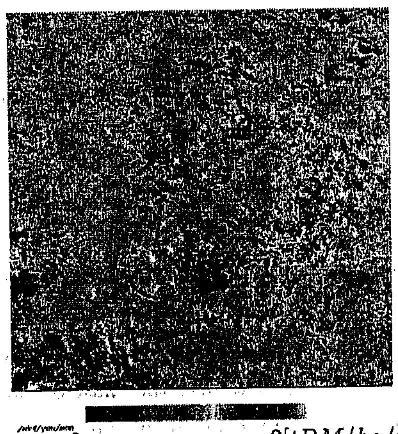

Fig.6 NPP estimation. Landsat/ETM on June 12,2001.