Estimation and Validation of Net Primary Production of Vegetation using ADEOS-II/GLI data.

K. Muramatsu[1], L. Chen[2], Y. Xiong[1], Y. Omura[2], S. Furumi[1], M. Daigo[3] and N.Fujiwara[4]

[1]*KYOUSEI* Science Center for Life and Nature, Nara Women's University, Kitauoya Nishimachi, Nara 630-8506, Japan

[2]Dept. of Information and Computer Sciences, Nara Women's University, Japan

[3]Doshisha University, Japan

[4]Nara Sangyo University, Japan

E-mail:muramatu@ics.nara-wu.ac.jp

Abstract It is important to estimate net primary production of vegetation with high accuracy to study the carbon cycle and the biotic response to climatic warming. We have developed " Pattern decomposition methods (PDM or UPDM) " for multi-spectral sensor data, vegetation index based on these methods VIPD (Vegetation index based on pattern decomposition method) and MVIUPD (Modified vegetation index based on universal pattern decomposition method), and an algorithm for estimating net primary production using these indeces. Purpose of this study is to estimate the net primary production of vegetation using ADEOS-II/GLI data with the indeces and to validate the results.

To get the validation data of the amount of tree's growth, we started the forest survey from 2002 in Kawakami village in Nara in cooperation with Nara prefecture. It consists cedar and Japanese cypress and it's area is 80mx80m. Measurement items are the tree's diameter at the basal height, height of tree, density and species of tree, and dry weight of liter. The average growth ratio is 4% during two years.

Spatial resolution of GLI is 250m for six channels and 1 km for 30 channels. To validate the results from GLI sensor, it is difficult to compare the results to those of forest survey, directly. Because it is needed that a uniform area larger than 4 times of spatial resolution. Since Landsat-7/ETM+ data is used for estimation of NPP. These results are compared with the results from GLI 250m and 1km spatial resolution data. They are agree with each other within estimation error. Finally, annual global net primary production is estimated from GLI Mosaic data, and it is 66.5 +- 17.3 (PgC/year). This value showed the same tendency of IPCC report.

Keywords Forest survey, cedar forest, global net primary production

1 Introduction

It is important to estimate net primary production (NPP) of vegetation with high accuracy to study the carbon cycle and the biotic response to climatic warming.

The amount of the growth of vegetation had been measured in worldwide from 1960"s to 1980"s by the International Biological Program (IBP). Using the data of Biomass and NPP, climatic model (Leith, 1973, Uchijima and Seino 1985) for NPP estimation has been successfully developed. The vegetation information such as distribution and vigor is not included in climatic model. Recently, global vegetation can also be monitored using satellite sensor. Including the vegetation information for the estimation, light-use efficiency (LUE) model has been developed. I]n LUE model, gross primary production is estimated as the product of light use efficiency, absorption ratio of photosynthetically active radiation, by photosynthetically active radiation. Absorption ratio of photosynthetically active radiation is estimated by the normalized difference vegetation index (Kriegler 1969, Rouse 1973) obtained from satellite sensor data of spectral reflectance of red and near infrared region, and gross primary production is determined with linear relationship to photosynthetically active radiation. Global net primary production has been estimated using LUE model and NDVI (Goetx et al., 1999, Haxeltine et al., 1996, Monteith , 1981), and environmental stresses such as the vapor pressure, surface soil moisture and air temperature are considerd for the estimation (Goetx et al, 1999, Heinsch et al., Potter et al., 1993, Awaya et al., 2004) .

The estimation algorithm of gross photosynthesis has been developed (S. Furumi et al, 2005). The main characteristics of this model are 1) it is included the non-linear relationship between gross photosynthesis and photosynthetically active radiation, 2) it is used the vegetation index which is developed for multi-spectral sensor data. In this model, only one set of the parameters of the non-linear photosynthetic curve is used. But this model has potentiality to include the various types of photosynthetic curve, when the ecological parameters of photosynthetic curve are determined for each vegetation species. Using this algorithm, the method of integration of gross photosynthesis to estimate gross primary production using satellite sensor data was developed (Yuu, 2005).

Purpose of this study is the validation of the estimation of the net primary production of vegetation using the method.

2 ADEOS-II/GLI data and Landsat/ETM+ data

The second Advanced Earth Observing Satellite (ADEOS-II) was launched on 14 December 2002 by Japan Aerospace Exploration Agency (JAXA). Unfortunately the satellite ceased operation on 25 October 2003. The data during 7 months (from April to October) is avairable. The satellite had a polar, circular, and sun-synchronous orbit with a 4-day repeat cycle.

The GLI sensor is onboard ADEOS-II satellite. It has 23 bands in visible and near infrared (VNIR), 6 bands in short wave infrared (SWIR), and 7 bands in middle and thermal infrared (MTIR) region with 1km or 250m spatial resolution. In this study, six band data with 250 m spatial resolution and global mosaic data with 1km spatial resolution are used. Global mosaic data are composite over 16 days for reducing the effects of clouds. The center wavelength of 250 m spatial resolution data is 460, 545, 660, 825, 1640, and 2210 nm. They are same as Landsat/TM or ETM+ sensor. Nine bands of global mosaic data of v180 are used in this analysis. It's center wavelength is 460, 545, 678, 710, 865, 1050, 1240, 1640 and 2210 nm. The reflectance at satellite level is calculated and Rayleigh scattering is subtracted (Yuu 2005).

In this study, Landsat-7/ETM+ data is also used, because the spatial resolution is higher than GLI data. The spatial resolution is 30 m and the spectral region is 450-520, 520-600, 630-690, 760-900, 1550-1750, 2080-2350 nm. The reflectance at satellite level is calculated and Rayleigh scattering is subtracted (Muramatsu 2000).

3 Algorithm of estimation NPP

Net primary production (NPP, gCO_2/m^2/year) is calculated by subtracting autotrophic respiration (R_p) from the gross primary production (GPP),

$$NPP = GPP - Rp. \tag{1}$$

The gross primary production is calculated by the integration of gross photosynthesis with time, and the gross photosynthesis is estimated as a function of photosynthetically active radiation (PAR) and vegetation index(VI: VIPD or MVIUDP) as follows:

$$GPP = \int P(PAR(t), VI(t))dt, \simeq \int \frac{VI(t)}{VI_{std}} \times P_{std}(PAR(t)). \tag{2}$$

where t is time, and $PAR(t)$[W/m^2], $VI(t)$, $P(PAR(t), VI(t))$[mgCO$_2$/(m$^2 \cdot$ s)] are PAR, vegetation index, and gross photosynthesis at time t, respectively. Here, VI_{std} is calculated from ground measurement reflectance data, it is a constant for optical sensor data as $VIPD_{std}$= 0.56, and $MVIUPD_{std}$ = 0.77. $P_{std}(PAR(t))$ ([mgCO$_2$/(m$^2 \cdot$ s)]) is the light-photosynthetic curve as follows,

$$P_{std}(PAR(t)) = \frac{P_{std\_max} \times b \times PAR(t)}{1 + b \times PAR(t)}, \tag{3}$$

where P_{std_max} is 0.52 [mgCO$_2$/(m$^2 \cdot$ s)] and the b is 0.028 [m^2/W] in this study.

Vegetation index VIPD and MVIUPD are defined as,

$$VIPD = \frac{C_v - C_s - \frac{S_s}{\sum_{i=1}^{n} \rho_i} C_w + S_s}{S_v + S_s}, \tag{4}$$

$$MVIUPD = \frac{uC_v - uC_w - 0.2 \times uC_s - uC_4}{uC_w + uC_v + uC_s}. \tag{5}$$

Here, C_w, C_v and C_s are pattern decomposition coefficients for water, vegetation and soil spectral shape patterns (Fujiwara et al., 1996 , Muramatsu et al, 2000, Daigo el al., 2003) and uC_w, uC_v, uC_s and uC_4 are coefficients of universal pattern decomposition method for water, vegetation and soil spectral shape patterns, and remainder shape pattern of yellow leaf (L.F.Zhang et al., 2004). The universal pattern decomposition method (UPDM) , which is based on the pattern decomposition method (PDM)(Fujiwara 1996, Muramatsu 2000, Daigo 2003). In the PDM framework, the normalization of standard patterns depends on how many bands and which wavelengths the sensor detects. As a result, the obtained pattern decomposition coefficients might differ between sensors such as TM and GLI, even when observing the same sample. However, with UPDM the same normalized spectral patterns are used for all sensors, and therefore, the same coefficient values are obtained even when using different sensor.

Reflectance observed by satellite sensor include the mixed information on vegetation vigor and coverage. Vegetation vigor and coverage are reflected in the vegetation index by multiplication (Hayashi et al., 1998, Furumi et al., 1998). To estimate NPP accurately using satellite sensor data, the vegetation index should have a linear relation with vegetation vigor and coverage. Both of vegetation indeces, VIPD and MVIUPD have linear relationship to vegetation coverage. The MVIUPD's linearity to vegetation vigor such as photosynthesis was improved (Yuu 2005) .

The autotrophic respiration Rp [kgCO$_2$/(m$^2 \cdot$ month)] can be estimated as following empirical equation [3],

$$Rp = \frac{7.825 + 1.145T[°C]}{100} \times GPP. \tag{6}$$

where T[°C] is air temperature.

Annual GPP is calculated as follows (Yuu 2005) :

$$GPP_{annual} = \sum_{month=1}^{month=12} GPP_{month}, \tag{7}$$

and

$$GPP_{month} \sim \sum_{day}\{\frac{VIPD_{day}}{VIPD_{std}}P_{std}(PAR_h)\Delta t \times h\}, \tag{8}$$

where h is the effective integral time (hours) of the period from sunrise to sunset, minus 2 hours, PAR_h (W/m^2) is photosynthetically active radiation averaged by the time h, Δt is 3600 sec. The photosynthetically active radiation PAR_h (W/m^2) is calculated using global solar exposure S of a day ($J/m^2/day$) as follows:

$$PAR_h = \frac{0.48 \times S}{h \times \Delta t}. \tag{9}$$

The estimation error of NPP is around 26 % (Yuu 2005), which is from the gross photosynthesis estimation and effective integral time of photosynthesis.

4 Forest sruvey

4.1 Ground measurement

Validation data of estimation of NPP is taken in Japanese cedar and cypress forest of 80m × 80m area in Nara, Japan. In the area, there is 1108 trees and the ratio of Japanese cedar and cypress is 7:2, respectively. From 1108 trees, 83 trees are sampled for measurement of diameter at breast height (D.B.H.), and tree heigh. This survey was started in July 2002, and D.B.H. is observed every month.

Figure 1 shows the seasonal change of D.B.H. The ratio of diameters to the diameter observed at Oct. 2002. Diameters are increased from Apr. to July.

The average of sampling trees' diameter is 18.8, 19.0 and 19.5 cm in Oct. 2002, Oct. 2003, and Oct. 2004, respectively. It's average rate of increase is 1.9%/year. The height of tree is measured using hand level. It takes two years to measure all of the samples. The average height of samples is 11.4m. To calculate the dry weight of trees from volume, volume density is measured using timber of thinning. The trunk of tree is cut every length of 60cm. From each 60cm length of trunk, the part of length 10cm is sampled, and measured volume and dry weight. In the field, samples are divided into a trunk, a branch and a leaf. The measurement results are as follows: 1) height : 14.6m, 2) B. H. D.: 23.6cm. 3) dry weight: trunk: 94.0kg, branch: 4.4kg, leaf: 12.1kg, 4) trunk volume : 0.32 m^3, 5) volume density: 293.8 kg/m^3. For timber of thinning, the trunk volume can directly calculate using the data. For other tree samples, a trunk volume can be approximately estimated by a corn shape. To increase the accuracy of the estimation, the relationship between the volume of a corn and measured volume is studied. The result is shown as " Ikari" in Figure 2 (a) with the results of Japanese cedar forest by Andou et al.(1968). The relationship is determined as

$$V = V_{cone} \times 1.285, \tag{10}$$

where V is the measured volume and V_{corn} is the volume with a corn approximation. If a corn volume of trunk can calculate, the dry weight of trunk can calculate from a corn volume and volume density.

Next, the relationship between dry weight (W_{stem}) of trunk and that of above ground (W_{above_ground}). Figure 2 (b) shows the relationship. In the Figure, "ikari" means the result of this study, and others are the results of Japanese cedar forest by Andou et al.([Andou et al., 1968]). The relationship is

$$W_{above\_groud} = W_{stem} \times 1.224. \tag{11}$$

Using the survey data, Equation (10), Equation (11), and volume density, the dry weight of above ground can be evaluated. The dry weight of under ground is estimated as 29% of above ground [Andou et al., 1968]. In this study, the growth of the height of tree can not measured directly. It is assumed that the rate of tree height growth is the same as that of B. H.D.

From these data, the growth of the forest is estimated as 0.92 kg/m^2/year. It is converted to 1.50kg CO_2/m^2/year. In this study, there is uncertainty of the growth of tree height. if the tree height growth is changed $\pm$ 0.1 m/year, the total growth is different about 50%. This error is too large. In this study, the volume density is observed as 293.8 kg/m^3. In has been reported that it is observed for Japanese cedar forest as 350 kg/m^3. Our result has a tendency that it's value is smaller than previous study. If the value of 350 kg/m^3 is used, the growth is different about 20%. From these results, this observation has around 50 % error. The growth of the forest is

$$1.50 \pm 0.75 (kgCO_2/m^2/year). \tag{12}$$

The precision of the growth of height and volume density should be improved.

5 Results and discussion

5.1 NPP estimation using Landsat/ETM+ data

The spatial resolution of GLI data is 250m or 1km. It is too large to compare directory with the ground truth data. At first, LANDSAT-7/ETM+ data with spatial resolution is 30m is used. The data observed at July 7 2001, Apr. 2 2002 and Aug. 8 2002 is used. The vegetation index calculated with Equation (**??**) . Using the index VIPD, the net primary production of each month is calculated. In the experimental area, the season of the average air temperature being higher than 10°C is from May to Sep. The photosynthetically active radiation is calculated from 0.39 $\times$ global solar radiation. The net primary production in one year is calculated by integrating the monthly production (0.40, 0.38, 0.37, 0.41 and 0.42) during May to Sep. as follows:

$$1.98 \pm 0.50 (kgCO_2/m^2/year). \tag{13}$$

It is agree with the forest survey result within error.

5.2 NPP estimation using ADEOS-II/GLI data

In GLI sensor, the data with spatial resolution 250m is available and it is useful for regional study. The GLI data with 250m spatial resolution observed at Feb. 7 2003 and June 3 2003 is used. The vegetation index VIPD from GLI data and Landsat-7/ETM+ data is compared for the evergreen forest in Nara Prefecture in Japan as shown in Figure **??**. The vegetation index of the experimental area observed by ETM+ data is also shown in the Figure. The value of VIPD observed by ETM+ sensor and GLI sensor is almost same, and the sesonal change of VIPD measured by ETM+ sensor and GLI sensor has the similar tendency. The vegetation index VIPD observed by GLI sensor is validated.

Using the vegetation index, the net primary production of one year is estimated during the season from May to Sep. We have only two month data such as vegetation active season in June and non active season Feb. For the season of vegetation's vigor being high such as from June to Aug., the same VIPD value of June is used. The value of May and Sep. is interpolated using the VIPD value of Feb. and June.

The net primary production around the experimental area is

$$1.73 \pm 0.45 (KgCO_2/m^2/year). \tag{14}$$

This value agrees with that from ETM+ data within error. The tendency of smaller value of NPP is considered that GLI data's spatial resolution is large and the influence from path through a road causes the smaller NPP.

The global NPP used ADEOS-II GLI global mosaic data is analyzed (Yuu 2005). For discussion, only the results of the analysis are shown. In this analysis, one scene data with less cloud is made to select the pixel with the higher value of MVIUPD from the two scene data observed in the same month. To estimate annual net primary production, annual data is needed. Since the vegetation index MVIUPD is extrapolated for the lack data of Jan. Feb. Mar. Nov. and Dec. Global solar radiation data in 2003 is provided by National Center for Atmospheric Research (NCEP). Air temperature with altitude 2m is provided by European Centre for Medium-Range Weather Forecasts (ECMWF). To calculate annual net primary production, integration of monthly npp with the condition air temperature being warmer than 10 °C. The result is shown in Figure 4.

This result is compared with the ground measurement data ([Esser, 1998], [Esser et.al, 1994]). The data has been taken from 1960's to 1980's. From the data, we can not know the uniformity of the experimental area. This data is too old to compare with high precision, but we can check the tendency for each climate zone. The result of comparison is shown in Figure 5. The comparison with the forest survey in this study is also shown in the Figure. The area number 7, 11, 15, 20 and 26 shown in the Figure is (30° N $\sim$ 60° N, 90°W $\sim$ 120°W), (30° N $\sim$ 60° N, 0°E $\sim$ 30°E) , (30° N $\sim$ 60° N, 120°E $\sim$ 150°E), (0° N $\sim$ 30° N, 60°W $\sim$ 90°W), and (0° N $\sim$ 30° N, 90°W $\sim$ 120°W), respectively. The value of NPP estimated using GLI data is larger than that of the forest survey. It is because the higher air temperature of ECMWF data with mountainous area (heighter altitude) than that in reality cause the longer integration month for photosynthesis. If the integration month is determined with the air temperature in reality, the both values of NPP agree with each other within error. Although there is tendency that the estimation value of NPP is larger than observation, both values have linear relationship.

The estimation results is compared with the results from climatic model [Seino and Uchijima, 1992] [Uchijima a and NOAA/AVHRR data [Awaya et al., 2004] based on LUE model, and Terra/MODIS data [Heinsch et al., 2003]. The pattern of our results' distribution is similar to that of other study's, our result is higher than the result from NOAA/AVHRR data, and lower than from Terra/MODIS data.

Annual global net primary production is 66.5 ± 17.3 (PgC/year). This value showed the same tendency of IPCC report.

6 Conclusion

In this study, the net primary production of vegetation is estimated using ADEOS-II/GLI data and validated it.

To get the validation data of the amount of tree's growth, we started the forest survey from 2002 in Kawakami village in Nara in cooperation with Nara prefecture. It consists cedar and Japanese cypress and it's area is 80mx80m. Measurement items are the tree's diameter at the basal height, height of tree, density and species of tree, and dry weight of liter. The average growth ratio is 4% during two years. The precision of the height of tree is not enough to use the data as validation and it should be improved. Spatial resolution of GLI is 250m for six channels and 1 km for 30 channels. To validate the results from GLI sensor, it is difficult to compare the results to those of forest survey, directly. Because it is needed that a uniform area larger than 4 times of spatial resolution. Since Landsat-7/ETM+ data is used for estimation of NPP. These results are compared with the results from GLI 250m spatial resolution data. They are agree with each other within estimation error.

Finally, annual global net primary production is estimated from GLI Mosaic data, the result was compared with ground survey data in prefectural forest, ground measurement data from 1960's to 1980's, estimation results using climatic model, AVHRR data and Terra/MODIS data based on LUE model. The pattern of our results' distribution was similar to that of other study's. Annual global net primary production was 66.5 ± 17.3 (PgC/year). This value showed the same tendency of IPCC report.

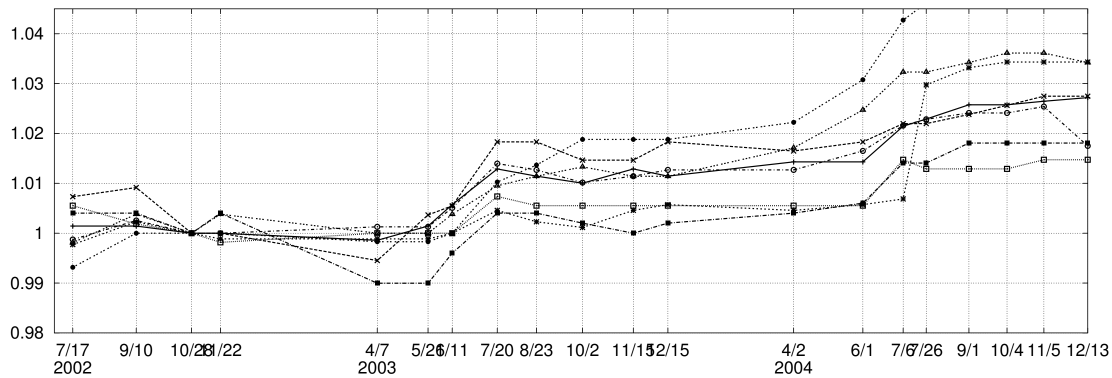

Figure 1: Seasonal changes of B. H. D. It is shown the ratio to the value of B. H. D. at Oct. 2002.

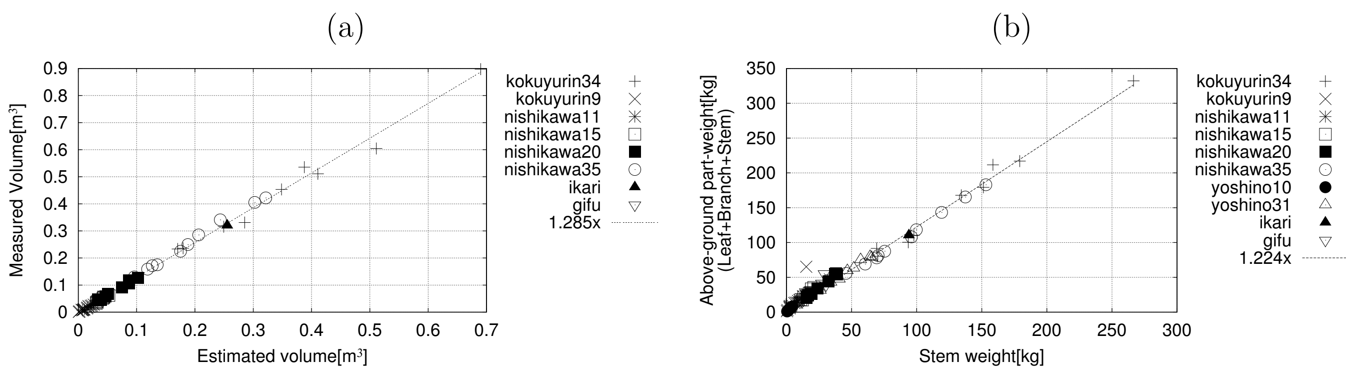

Figure 2: (a)The relationship between the trunk volume measured and calculated on the assumption that the shape of trunk is a corn. (b) The relationship between dry weight of trunk and that of above ground

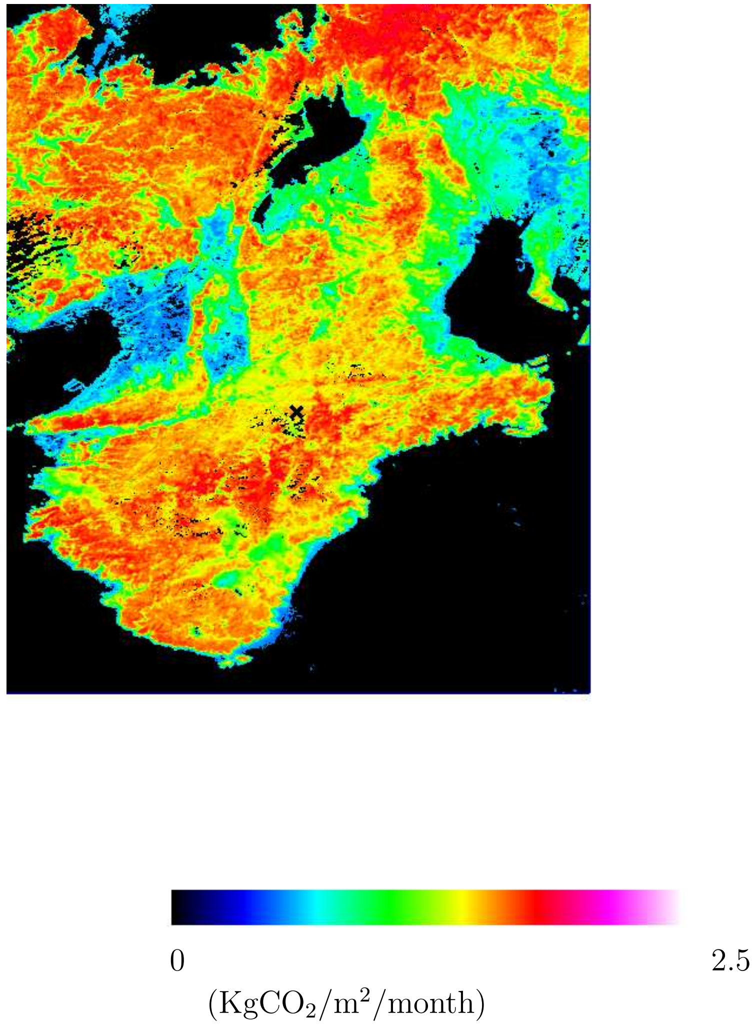

Figure 3: Annual NPP estimated from GLI 250m data($KgCO_2/m^2/month$)

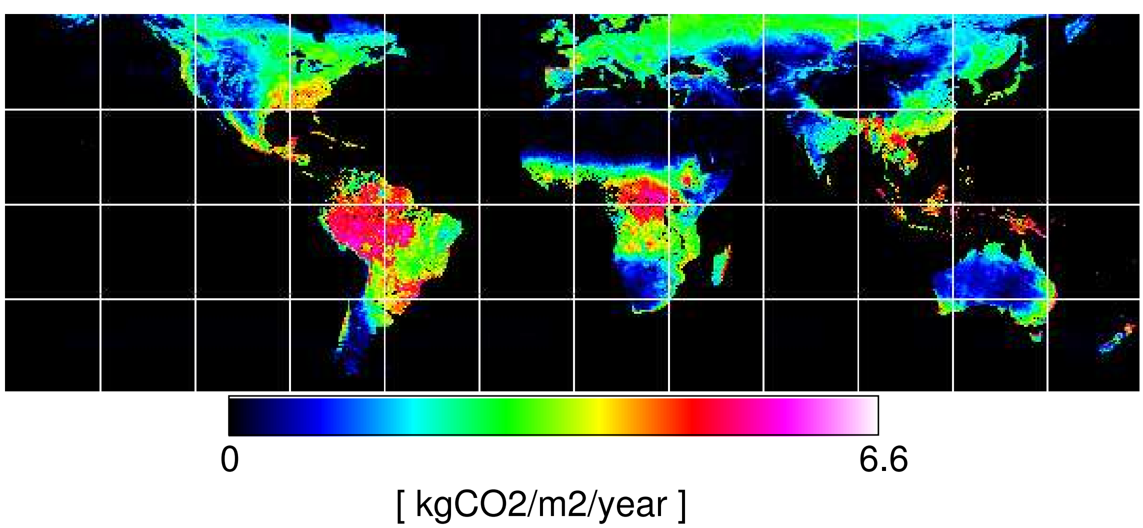

Figure 4: Annual net primary production

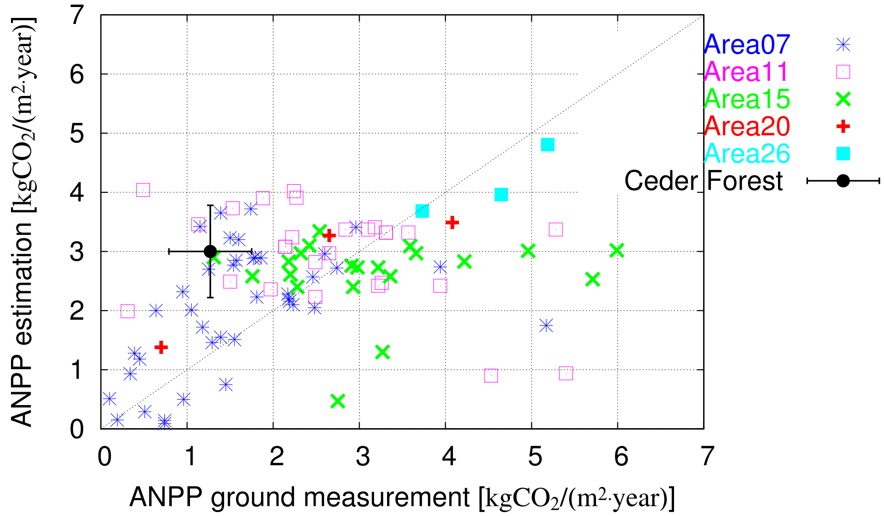

Figure 5: The relationship between annual NPP estimated from GLI mosaic data and field survey data measured in 1960's to 1980's, and forest survey data in Nara

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