# Energy consumption, solar energy and net primary production by vegetation in Kii peninsula, Japan.

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## Abstract

We would like to know the effect of human activity on the thermal energy budget. We consider that energy consumption is one index of human activity. In this study, we defined a forested area, Nara, Wakayama and Mie prefecture and area of high human activity, Osaka prefecture. For each prefecture, we estimated the green coverage and net primary production of vegetation using satellite data. We collected statistical data on energy consumption and calculated the amount of $CO_2$ exhaust using the data of energy consumption for each prefecture. In forested ares of Nara prefecture, the amount of $CO_2$ exhaust was 20 % of the amount of $CO_2$ absorption by forests. In Osaka prefecture, the amount of $CO_2$ exhaust was almost same of $CO_2$ absorption of the forested area in Kii peninsula. We calculate the percentage of the amount of energy exhaust to total solar energy incoming in each prefecture. The percentage was the smallest in Nara prefecture around 0.2 %, and the largest in Osaka prefecture around 8%.

## 1 Introduction

The thermal energy budget on terrestrial area depends on land cover types such as forested or city area. Human beings have changed the land cover. We would like to examine the effect of human activity on the thermal energy budget. In this study, we consider that one index of human activity is energy consumption. We evaluate a forested area and an area of high human activity. We estimated green coverage and net primary production of vegetation for each area using satellite data and collected statistical data on energy consumption for each prefecture. We compared the results using satellite data with the statistical data.

# 2 Experimental site

We selected Kii peninsula for an experimental site. The reason is that Kii peninsula has cities and forests. We defined the forested areas, Nara, Wakayama and Mie prefecture, and the area of high human activity, Osaka prefecture. The areas of Nara, Wakayama, Mie and Osaka prefecture were was 3691, 4725, 5776, and 1893 $km^2$, respectively and the population is 1.4, 1.1, 1.8 and 8.8 ($\times 10^6$), respectively, as shown in Figure 1.

# 3 Data used in this study

We used satellite data and statistical data.

For satellite data, we used Terra/MODIS data. The Terra satellite was launched by NASA on Dec. 18, 1999, and observes earth with 250m, 500m or 1 km spatial resolution and 36 spectral bands. Figure 2 shows the MODIS spectral bands that were used in this analysis. We used data measured on Jul. 4, Oct. 15, Nov. 11 and Dec. 2, 2001. From the data, we estimate the green cover and net primary production of vegetation using pattern decomposition method.

For statistical data, we collected the data of energy and water consumption for each prefecture.

# 4 Analysis method

## 4.1 Pattern decomposition method and vegetation index

We analyzed the spectral reflectance data measured on the ground, and satellite data using the pattern decomposition method [1,2]. The method is briefly explained in this section.

The pattern decomposition method was developed for analysis of multi-spectral satellite data. The method is based on spectral mixing analysis. The method is powerful for extracting signatures to obtain information about land cover objects for classification and for analysis of vegetation.

The set of spectral reflectance values $(A_1, A_2, \ldots, A_n)$ of n bands for a pixel is transformed into three coefficients such as water (Cw), vegetation (Cv) and soil (Cs) with three standard spectral shape patterns that correspond to typical ground objects, namely water, vegetation and soil as follows:

$$A_i \rightarrow C_w P_{iw} + C_v P_{iv} + C_s P_{is} \quad . \tag{1}$$

Here three standard spectral patterns are as follows:

$$\begin{aligned} \textbf{Water pattern} &= (P_{1w}, P_{2w}, \ldots, P_{6w}) \ , \\ \textbf{Vegetation pattern} &= (P_{1v}, P_{2v}, \ldots, P_{6v}) \ , \quad (2) \\ \textbf{Soil pattern} &= (P_{1s}, P_{2s}, \ldots, P_{6s}) \ , \\ \sum_{i=1}^{n} P_{ik} &= 1, \quad (k = w, v, s) \ . \quad (3) \end{aligned}$$

$C_w$, $C_v$, and $C_s$ are decomposition coefficients for a water shape pattern, vegetation shape pattern, and soil shape pattern, respectively. The coefficients are found using the least square method.

we defined vegetation index VIPD [3] as follows;

$$VIPD = \frac{C_v - C_s + C_w \times \sum_{i=1}^{n} A_i}{S_v + S_s}, \quad (4)$$

where $A_i$ is the value of reflectance of band $i$, and $S_v$ and $S_s$ is the sum of reflectance from band $i = 1$ to $n$ for a standard vegetation and soil sample, respectively.

### 4.2 Net primary production of vegetation

The estimation method of net primary production(NPP) of vegetation is developed by S. Furumi [4]. NPP is obtained by subtraction of the respiratory loss from gross primary production (GPP). GPP is estimated by the relationship between the vegetation index VIPD and the light-photosynthesis curve as follows:

$$GPP = z \times (1 + 0.05z^2) \times P_{standard}(PAR), \quad (5)$$

$$z = VIPD/VIPD_{standard}, \quad (6)$$

where $P_{standard}(PAR)$ is the standard sample's light-photosynthesis curve shown in Figure 3 and its value of vegetation index is $VIPD_{standard}$. Respiratory loss is estimated by the empirical method as follows:

$$\text{Respiratory loss} = (7.825 \times 1.145T)/100. \times GPP, \quad (7)$$

where $T$ is air temperature.

## 5 The results of satellite data analysis

### 5.1 Vegetation cover

Using the pattern decomposition coefficients, we identified the vegetation area as shown in Figure 4. The vegetation cover of Nara, Mie, Wakayama and Osaka was 86, 67, 85, and 38 (%), respectively.

### 5.2 Net primary production of vegetation

The image of NPP estimation is shown in Figure 5. The absolute value of NPP includes large error around 30%. we are now trying to estimate the NPP with higher accuracy and it's error. For validation and estimation of the error, we started the forest survey in Kawakami village in Nara from summer 2002. Measurement items are the tree's diameter at the basal height, height of tree, density and species of tree, and dry weight of litter. We do not have detailed results of the measurement yet. So we made a rough estimate of NPP of the forest was 5.1 $Kg\mathrm{CO}_2/year$, on the assumption that width of a growth ring of a tree was 2mm. The estimation results from satellite seems reasonable roughly speaking. In detail, we need the validation for the estimation results from satellite. At this stage, we consider that the relative value is sufficient to use this study.

The NPP was 17., 19., 21. and 4. ($10^9 KgCO_2/year$) for Nara, Mie, Wakayama and Osaka prefecture, respectively. The results of vegetation cover and NPP estimations are summarized in Table 1.

## 6 Energy and water consumption in each prefecture

We collected statistical data of energy consumption, such as electricity, city gas and fuel(crude) , as well as the water consumption of each prefecture. The results are summarized in Table 2. The consumption of electricity, city gas and water in Osaka is much larger than in Nara, Mie and Wakayama. Fuel consumption in Nara is quite small compared to the other prefectures. These reason for this difference is that Mie and Wakayama prefecture have a lot of factories as opposite to Nara. From these results, the characteristics of Nara are clear; most of the area is covered by forests and these is little energy consumption because there are no factories.

## 7 Discussion

### 7.1 CO2 exhaust and absorption

We calculated the total $\mathrm{CO}_2$ exhaust for each prefecture from the energy consumption values in Table 2. The total $\mathrm{CO}_2$ exhaust in Nara, Mie, Wakayama and Osaka was 4., 30. 21. and 56. ($10^9 kgCO_2/year$), respectively. The results are summarized with the amount of $\mathrm{CO}_2$ absorption of forests estimated using the satellite data in Table 3.

The amount of $\mathrm{CO}_2$ exhaust in Nara prefecture was 10 % of the amount of $\mathrm{CO}_2$ absorption of forests. The amount of $\mathrm{CO}_2$ exhaust in Mie and Wakayama prefecture was almost same as the amount of $\mathrm{CO}_2$ absorption of forests. In Osaka prefecture, $\mathrm{CO}_2$ exhaust was 10 times of $\mathrm{CO}_2$ absorption. Before the industrial revolution, $\mathrm{CO}_2$ exhaust and absorption were in balance. At that time, the $\mathrm{CO}_2$ absorbed by forest should be equal to the $\mathrm{CO}_2$ emission from life on earth. From Table 3, Osaka is exhausting almost half the amount of absorbs $CO_2$ as forests. If there were no forest, situation would be much worse.

### 7.2 Energy consumption and solar energy

We compare the amount of energy consumption and that of total solar energy incoming in each prefecture. The total solar energy receiving in Nara, Mie, Wakayama, and Osaka was 17.6, 27.6, 26.9 and 9.2 ($10^{12} MJ/year$), respectively. The percentage of energy consumption of the total solar energy in Nara, Mie, Wakayama and Osaka was 0.2, 1.5, 1.1 and 8.3 (%), respectively, as summarized in Table 4.

The percentage was the smallest in Nara prefecture, around 0.2 %, and the largest in Osaka prefecture, around 8%. We consider 8 % to be too high with respect to the rest of life on earth.

## 8 Conclusion

We selected Kii peninsula for an experimental site defined Nara, Wakayama and Mie prefecture as forested areas, and Osaka prefecture as area of high human activity. For each prefecture, we estimated the green coverage and net primary production of vegetation. We collected statistical data of energy consumptions, and calculated the amount of $CO_2$ exhaust using the energy consumption data.

For forested areas, for example Nara prefecture, the amount of $CO_2$ exhaust was 20 % of the amount of $CO_2$ absorption of forests. In Mie and Wakayama prefectures, the amount of $CO_2$ exhaust was almost the same as the amount of $CO_2$ absorption of forests. Osaka is exhausting almost same amount of absorbs $CO_2$ by forests in Kii peninsula. In Osaka prefecture,

We calculate the percentage of the amount of energy exhaust to the total solar energy accepting in each prefecture. The percentage was the smallest in Nara prefecture, around 0.2 %, and the largest in Osaka prefecture, around 8%. We consider 8 % to be too big in relation to the rest of life on Earth.

In the future, we would like to subdivide the prefecture units into factory, city and forested area.

## Acknowledgments

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| Prefecture | Green coverage (%) | NPP ($10^9 KgCO_2/year$ ) |
|---|---|---|
| Nara | 86 | 17. |
| Mie | 67 | 19. |
| Wakayama | 85 | 21. |
| Osaka | 38 | 4. |
| Total | | 61. |

Table 1: Green cover and net primary production of vegetation in Nara, Mie, Wakayama and Osaka prefecture.

| | Electricity ($10^9 MJ/y$) | City gas ($10^9 MJ/y$) | Fuel ($10^9 MJ/y$) | Water ($10^9 MJ/y$) |
|---|---|---|---|---|
| Nara | 27.5 | 9.6 | 7. | 5.4 |
| Mie | 54.8 | 8.1 | 348. | 8.5 |
| Wakayama | 23.0 | 8.2 | 269. | 5.2 |
| Osaka | 216.6 | 182.8 | 365. | 41.3 |
| Total | 321.9 | 208.7 | 989. | 60.4 |

Table 2: Energy and water consumption in Nara, Mie, Wakayama and Osaka prefecture.

| Prefecture | Exhaust ($10^9 kgCO_2/year$) | Absorption by Forest ($10^9 kgCO_2/year$) |
|---|---|---|
| Nara | 4. | 17. |
| Mie | 30. | 19. |
| Wakayama | 21. | 21. |
| Osaka | 56. | 4. |
| Total | 112. | 61. |

Table 3: $CO_2$ exhaust and absorption in Nara, Mie, Wakayama and Osaka prefecture.

| Prefecture | Consumption ($10^9 MJ/year$) | Solar radiation ($10^{12} MJ/year$) | Ratio (%) |
|---|---|---|---|
| Nara | 44. | 17.6 | 0.2 |
| Mie | 411. | 27.6 | 1.5 |
| Wakayama | 300. | 26.9 | 1.1 |
| Osaka | 765. | 9.2 | 8.3 |
| Total | 1520. | 81.3 | 1.9 |

Table 4: Energy consumption and solar energy accepting in Nara, Mie, Wakayama and Osaka prefecture.

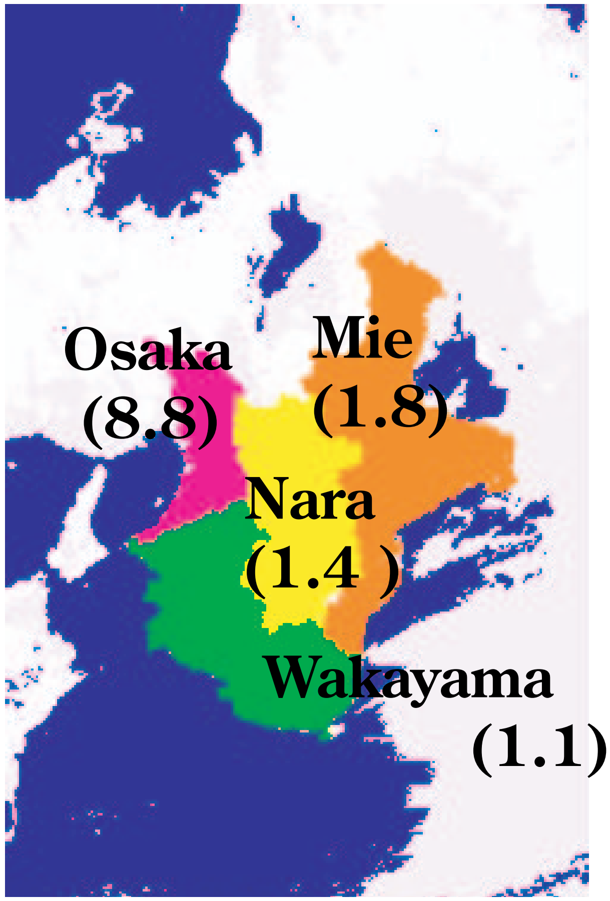


Figure 1: Kii peninsula and population($10^6$) of each prefecture in Kii peninsula.

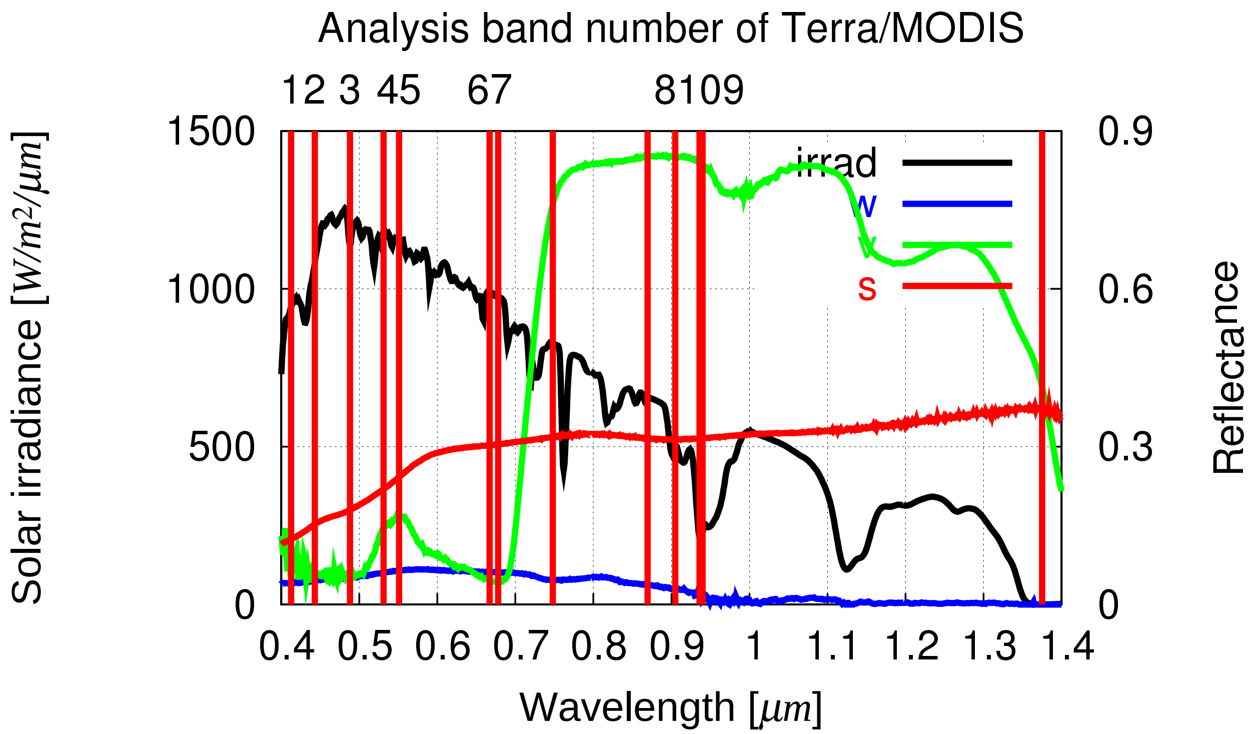


Figure 2: Spectral bands of Terra/MODIS data

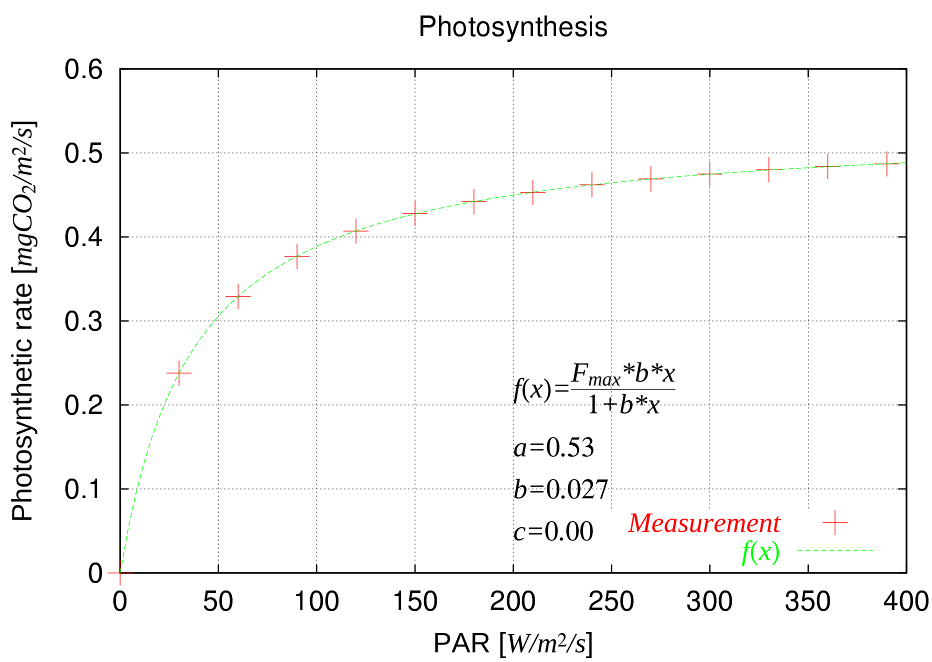


Figure 3: Light-photosynthesis curve

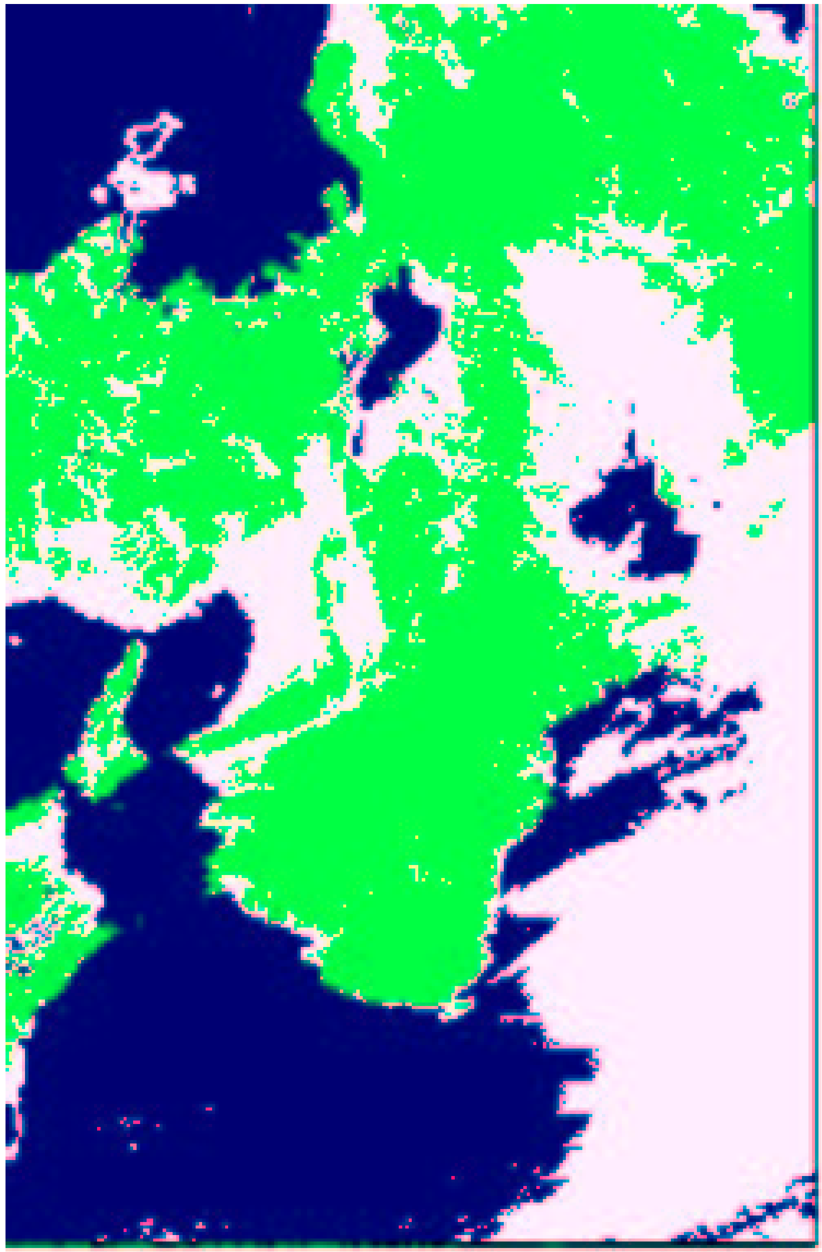

Figure 4: Vegetation cover: Green area is identified as vegetation area

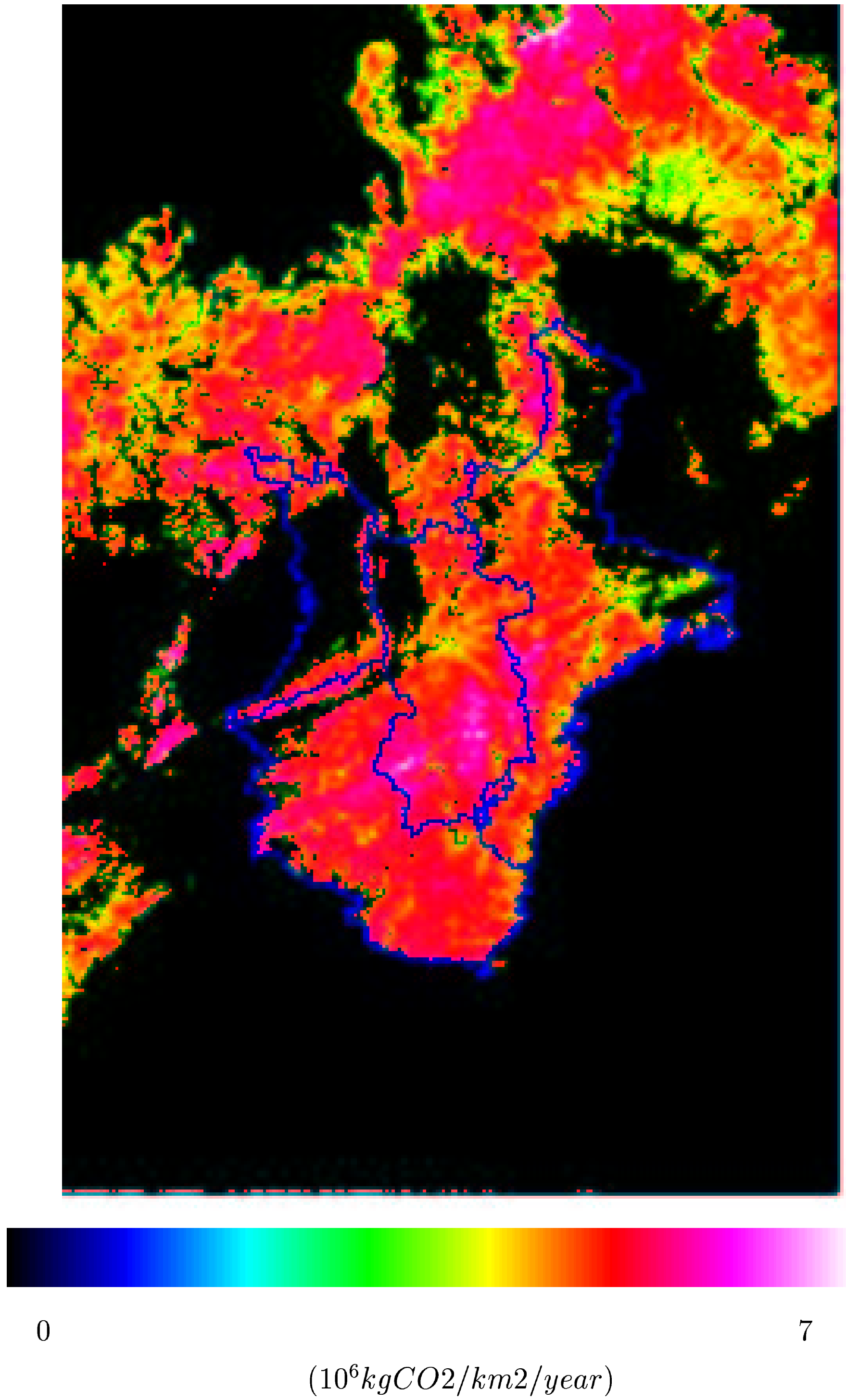


Figure 5: Net primary production of vegetation: white area is non vegetation area.