Final report on
Meteorological and biological influence on the carbon dioxide concentration and fluxes in the tropical secondary forest

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1. Introduction

Our knowledge of the sources and sinks of carbon dioxide CO_2 is not sufficient. Especially, there are few data in the tropical area where absorption of CO_2 by forests seem to be large. There are few observation of CO2 balances are reported in the mature tropical rain forest where sink and source of CO2 seems to be equivalent. However, there have been no observation is reported about CO2 balances in the secondary forests which occupy relatively large areas in the tropical rain-forest regions. Our purpose is to observe CO2 flux and estimate CO_2 balance in the growing secondary forests during long periods.

2. Site

The site (0°51'41"S,117°02'41"E, height; 60m above se level) lies in the gently undulating plains in the east part Kalimantan Island, Indonesia. An observation tower located in 5,000 ha Bukit Soeharto Educational Fores PPHT UNMUL. Heights of canopy of *Macaranga* speci were about 15~20 meters before fire caused by droug related with ENSO event. All *Macaranga* species fell dow by fire. In present, *Macaranga* species, especial *Macaranga Gigantea* becomes predominant, and in tl rapid growing stage. After 5 years from fire, canopy heigh become near 10 meters above the surface.

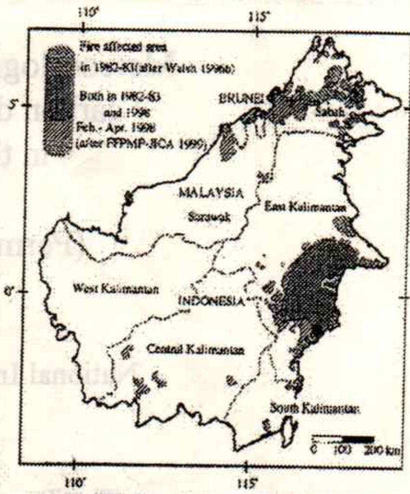


Fig.1 Area affected by the fires in 1982-83 and 1998. Black circle:Site in BKEF, UNMUL

3. Methodology

Plants produce organic matter from carbon dioxide and water by photosynthesis. While, plants emit CO_2 to the atmosphere by plant metabolism.

Considering balance of CO_2 from Figure 2, we get

$NEP=GPP-R_{ec}$. (1)

Here, NEP is net ecosystem production, which is sum of CO_2 absorption and emission of the community. Thus, if NEP is plus, ecosystem is sink, if NEP is minus, ecosystem is source. Ecological respiration R_{ec} is the total respiration of plant R_a and non-plant matters R_h. R_h shows respiration by non-plant activity, that is, respiration mainly by decomposition of soil organic matter. GPP is gross primary production, which shows amount of photosynthesis. The following expression is deriveed by Equation (1).

$NEP=NPP - R_h$. (2)

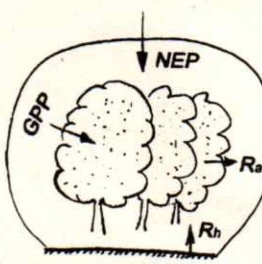
Here NPP is net primary production, which is expressed by $GPP-R_a$. NPP is also described as

$NPP=\Delta B+L+C$, (3)

where ΔB is growing rate of biomass, L, the litter production (litter fall), C the consumption by insects.

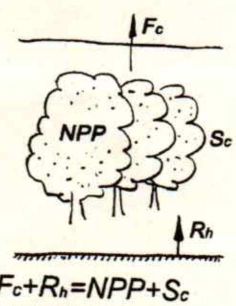
While, concept of CO_2 flux (that is, F_c) obtain by eddy correlation method above the canopy is shown in Figure 3. F_c is plus in the case when CO_2 flux is upward according to the custom. In this case,$(-F_c+R_h)$ which is incoming CO_2 to the canopy is balanced with $(NPP+S_c)$. Here, S_c is storage of CO_2 in the canopy. Thus, $-F_c+R_h = NPP+S_c$ is described. This equation is rewritten as,

$F_c+S_c =$ ~~$NPP+R_h$.~~ (4)



$NEP=GPP-(R_a+R_h)$
$=NPP-R_h$

Fig.2 Concept of CO2 balance



$-F_c+R_h=NPP+S_c$
$-NEP=F_c+S_c \equiv NEE$

Fig.3 Definition of NEE

S_c is obtained by time change of CO_2 profile under the CO_2 flux measuring height. Observed parameters F_c+S_c is defined as net ecosystem exchange NEE. From equations 2 and 3, the following expression is derived:

F_c+S_c=NEE=-NEP (5).

NEP is the concept in CO_2 balance in the closed canopy system. While NEE is the observed value whether canopy is closed system or canopy is open system. Thus, equation 5 holds in the horizontally homogeneous condition. Considering S_c becomes zero when S_c is over one day,

F_c=-NEP (6)

is expressed. This means net ecosystem production NEP can be derived only by F_c measured in the appropriate altitude above the canopy in the case when canopy system is closed.

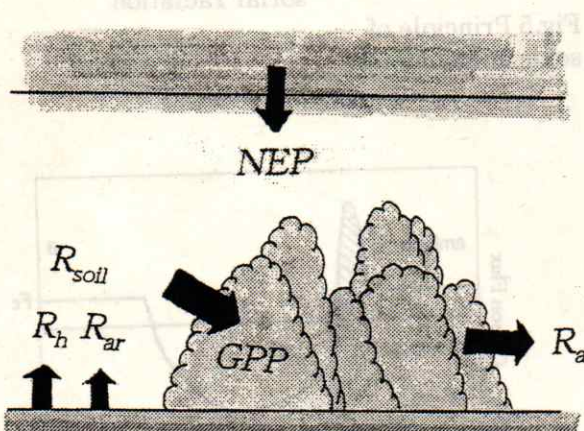


Fig. 4 Schematic of CO_2 balance for the community

NEP net ecosystem production
NEE =-NEP
GPP gross primary production
R_a autotorophic respiration
R_{aa} R_a above the surface
R_{ar} R_a below the surface (root)
R_h heterotrophic respiration
$R_{soil}=R_h+R_{ar}$ soil respiration
$R=R_a+R_h=R_{aa}+R_{soil}$ total respiration
NPP Net Primary Production

Now we will try estimate CO_2 balance in the ecological system of this site. We divide biomass increment ΔB and litter fall L into 'above the surface' and 'below the surface,such as: $\Delta B=\Delta B_a+\Delta B_r$, and $L=L_a+L_r$. Suffixes a and r show 'above the surface', and 'below the surface, respectively.

Observed values are NEP(NEP is assumed to be equal -NEE), ΔB_a ,L_a, and R_{soil}. R_{soil} is sum of R_h and R_{ar}. R_h or R_{ar} is not able to be measured, individualy.

For simplicity, we assume ratio of biomass increment $\Delta B_r/\Delta B_a$ to be the same with the ratio of biomass, such as the following expression,

$Br/\Delta B_a=\Delta B_r/\Delta B_a=\alpha$ (7).

And $L_r/L_a=\alpha$ is also assumed. Here, L_a is falling leaves and falling wigs, L_r shows dead roots. Thus, net primary production NPP becomes

$NPP=(1+\alpha)(\Delta B_a+L_a)$(8)

in the case of the consumption of insects C is neglected.

Autotorophic respiration, that is plant respiration R_a is divided into R_{aa} (above the surface) and R_{ar} (below the surface, that is respiration by root). R_{aa} during night is estimated from the condition that GPP is zero at night as follows:

$NEP+R_{aa}+R_{soil}=0$ (nighttime). Nighttime R_{aa} is assumed to be the R_{aa} at sunset, because temperature difference between at sunset and sunrise is only 2-3 degrees. Besides, R_{ar}/R_{aa} is also assumed to be equal to α.

Ecological parameters will be roughly estimated by the simple method as described above.

4. Measurements

CO_2 flux is measured by the eddy correlation (or eddy covariance) method. Fluctuations of wind are measured by a three-dimensional sonic anemometer (model Windmaster Gill) with path length of 0.145 m at 14 m height on a 30 m tower. Figure 5 shows how to measure the vertical wind velocity. Fluctuations of CO_2 and water vapor concentrations are measured by a closed-path type infrared gas analyzer (model Li-6262 LI-COR). Figure 6 shows CO_2 is detected at a wavelength of 4.3 μm where CO_2 is absorbed. (H_2O is absorbed at 4.3 μm.) The air inlet is fixed at near the sensor of the sonic anemometer. The distance between the inlet and the gas analyzer is several meters. The air is drawn through a Teflon tube, then it is pumped into a sample cell of Li-6262 at about 5 l/min. The gain of CO_2 of the analyzer is checked manually once a week by flowing two CO_2 standard gases of about 350 ppm and about 400ppm.

Soil respiration (R_{soil}) is measured by CO_2 analyzer (model LI-800 LI-COR) by chamber method. Measurements were made for 4 sites for soil, and two sites for dead falling logs of *Macaranga gigantia*。

All raw data were recorded at 5Hz in a small computer (Toshiba Libretto) using a data loggar (NR1000). Half-hour fluxes were calculated for CO_2,water vapor, and sensible heat. A three-dimensional coordinate rotation for the vertical wind velocity normal to the mean wind direction was applied. The time lag required to draw air to the CO_2 analyzer in the box was determined automatically by maximizing the correlation between the vertical wind velocity and CO_2 concentration.

The schematic daily patterns of F_c, S_c, NEE, and GPP are shown in Figure 7. There are big upward CO_2 flux F_c during 2 hours just after sunrise. While after sunrise S_c shows large negative value which shows upward release of CO_2 accumulated in the canopy during night. Steady increase of S_c during night is also characteristics of this site.

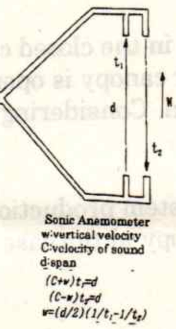


Fig.5 Principle of sonic anemometer

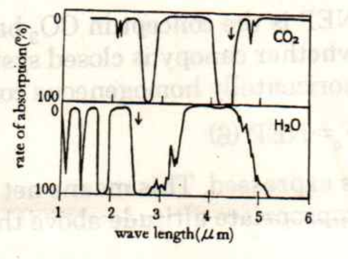


Fig.6 Absorption rate of sorlar radiation

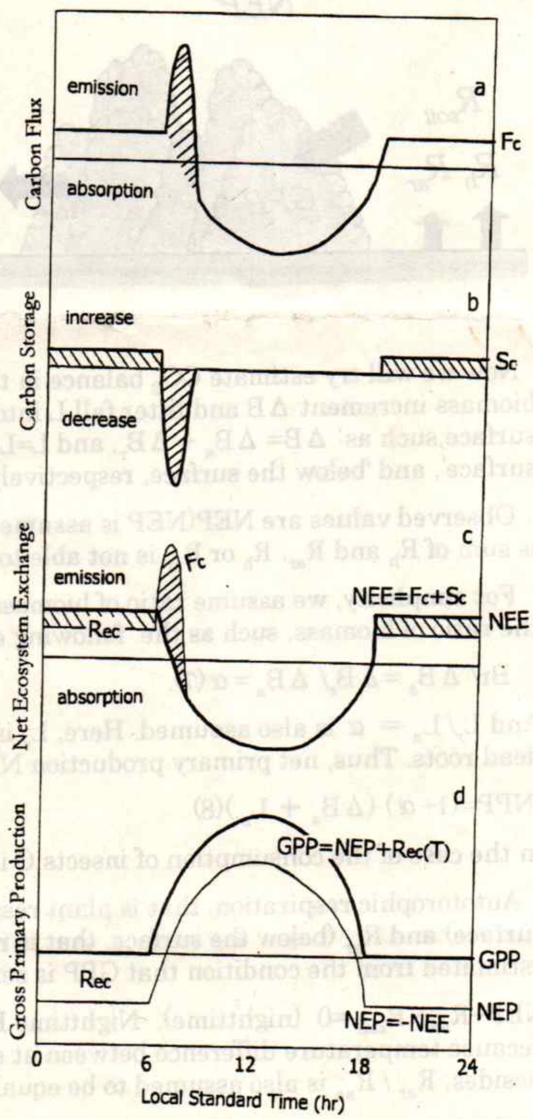


Fig.7 Schematic model of daily change of Fc, Sc, NEE, and GPP

5. Research Results obtained during this period

Meteolological observations have been started from 8th December 1999, and carried out continuously till present. While rate of acquisition of CO2 flux was low in the first stage, because there are many breakdown of instruments due to severe environment of high temperature and high humidity climate. After the appropriate counter measures, the rate of acquisition became higher. Now we can measure CO2 flux successively over 90%.

5.1 yearly accumulated NEE

Figure 8 shows time series of precipitation, soil wetness, and NEE (Net Ecosystem Exchange). Absorption is described as minus, source is described as plus in the figure. Zero shows no data of CO_2 flux. CO_2 is absorbed by photosynthesis in daytime. CO2 is emitted by respiration in the night. Daily total shows absorption is larger than emission in this community. We try to estimate yearly NEE by sum of observed daily NEE multiplied by (365days/(total observed days)). Yearly NEE was 7.0 Mg C/ha/year in 2001 when typical tropical rain forest climate was predominant. While NEE in 2002 when there were no rain terms by ElNino event was 5.3 Mg C/ha/year. Daily NEE is similar during year in 2001. While daily NEE in 2002 varied month to month. The reason why daily NEE was small from February to May in 2002 is not clear. Daily NEE was large in June and July in the beginning of dry season. However, NEE decreases rapidly after one month from start of dry season. This tendency appeared also during short dry season in 2000 and 2001. This shows photosynthesis is very active in the beginning of the dry season, maybe because of many leaves, ample sunshine, and small soil respiration. During dry season after one month from, photosynthesis becomes small maybe because of falling leaves, dryness of leaves, and small soil respiration.

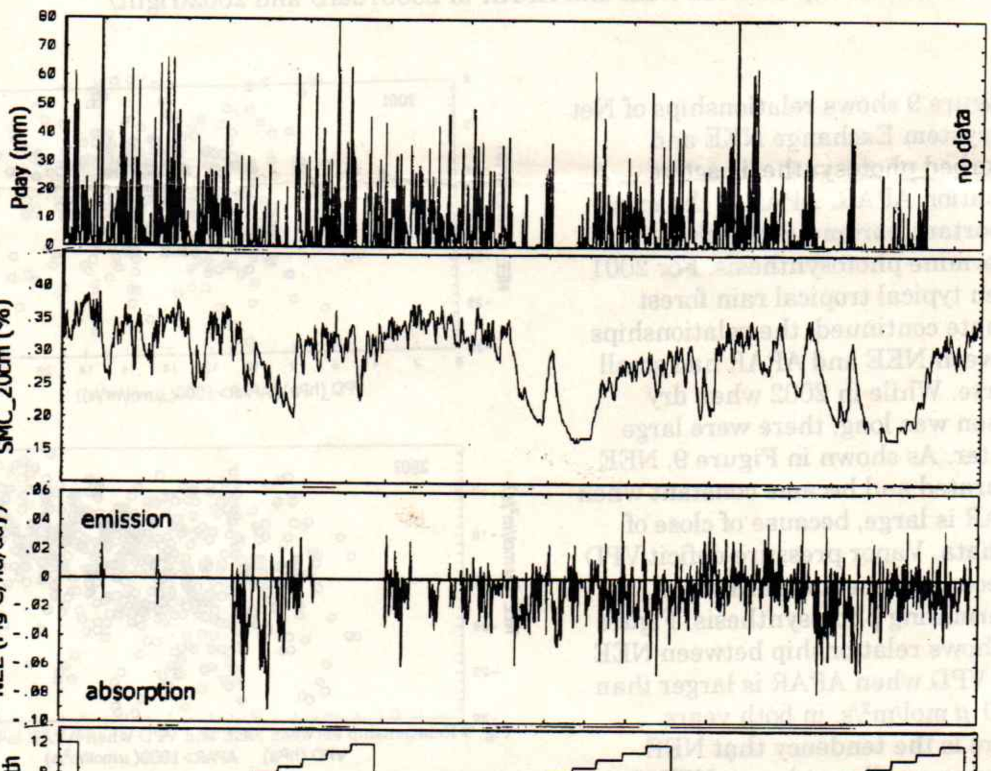


Fig.8 Bukit Soeharto Site (from top to down)

P_{day}:Daily Precipitation, SMC_20cm:Soil wetness (20cm deep), NEE:Net Ecosystem Exchange

5.2 Relations between NEE and meteorological parameters

We also measure the meteorological and biological elements which are related sensitively with photosynthesis of community. Our purpose is to present a way to parameterize the carbon balance in order to understand the role of the factors controlling the carbon budget of the tropical secondary forest ecosystem. Parameterization is also necessary to estimate CO_2 flux by meteorological data, because CO_2 flux is very difficult to measure continuously.

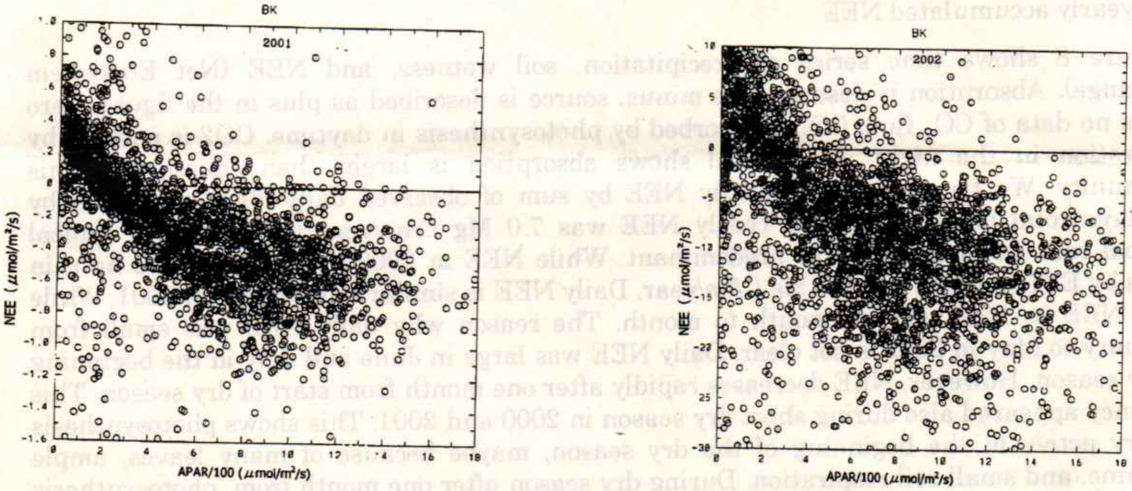


Fig. 9 Relationship between NEE and APAR in 20001(left) and 2002(right)

Figure 9 shows relationships of Net Ecosystem Exchange NEE and absorbed photosynthesis active radiation APAR. APAR is the most important parameter which determine photosynthesis. For 2001 when typical tropical rain forest climate continued, the relationships between NEE and APAR had small sparse. While in 2002 when dry season was long, there were large scatter. As shown in Figure 9, NEE saturated and became constant when APAR is large, because of close of stomata. Vapor pressure deficit VPD is second important parameter determining photosynthesis. Figure 10 shows relationship between NEE and VPD when APAR is larger than 1000 μmol/m^2/s. in both years. There is the tendency that NEE becomes smaller at larger VPD. It is also explained by close of stomata . There is wider range of VPD in 2002 than in 2001.

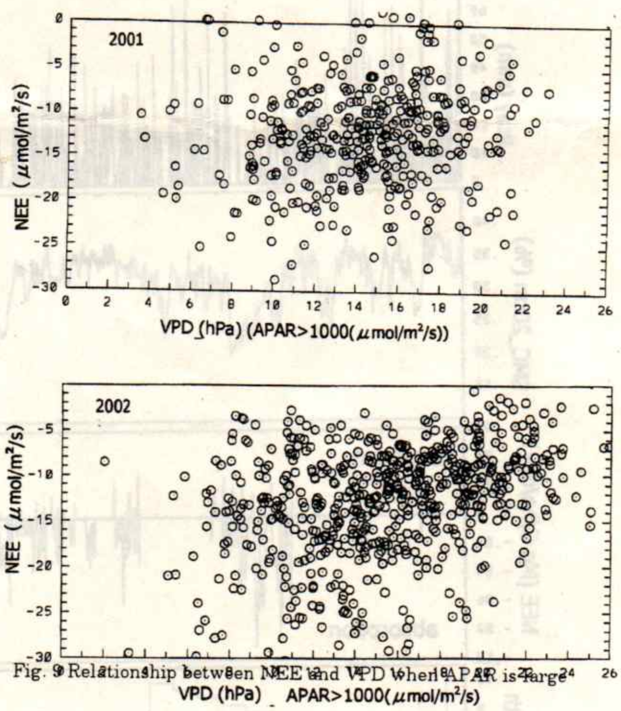


Fig. 10 Relationship between NEE and VPD when APAR is large in 2001(above) ad 2002(down)

6 Roughly estimation of CO_2 balance

CO_2 balance of this ecosystem is roughly estimated. CO_2 balance in the forest community is important to clarify the difference between forest types in the world. And yearly change of CO_2 balance shows what part of community is affected mostly by global climate change such as ElNino. In Bukit Soeharto, observed values are NEP, ΔB_a, L_a, and R_{soil} as shown in Table 1. In Equation 7, we assume α is 0.2, because the value of α is generally 0.2-0.25 in spite of the type of forest throughout the world. Thus, we assume

$\Delta B_r / \Delta B_a = 0.2$, $L_r/L_a = 0.2$, and $R_{ar}/R_{aa} = 0.2$.

R_{soil} at near sunrise when soil temperature was low, was about 0.05 mg $CO_2/m^2/s$ for 2000 and 2001. R_{soil} has dependency with soil temperature. In this site, difference of temperature from sunset to sunrise is between 2-3 deg C. Thus, we assume R_{soil} has constant value of 0.05 mg $CO_2/m^2/s$ throughout the night. While we we assume R_{soil} during daytime was 0.1 mg $CO_2/m^2/s$ from observation. Under these assumption, yearly R_{soil} was 6.5 ton C/ha/year. Therefore, the net primary production NPP is 8.9 ton C/ha/yearfrom Equation (8). From Equation (2), heterotrophic respiration R_h, that is respiration caused mainly by soil organic decomposition, is 4.1 ton C/ha/year.

Ecological parameters obtained by the above simple method are shown in Table 1 and Figure 11. From Equation 2 and 3, NEP+ $R_h = \Delta B + L + C$ is obtained. Decomposition is very rapid in the tropical regions. If we can assume all litter fall L is decomposed and changed to R_h in the time scale of one year, NEP coincidences with ΔB. Data seems to support this hypothesis in this site. If so, eddy correlation method estimates the biomass increasing which is the baseline of CDM (Clean Development Mechanism).

Table 1 Ecological parameters (unit in ton C / ha / year)

observed

NEP	ΔB_a	L_a	R_{soil}	C	ΔB_r	L_r	ΔB	L	NPP	R_h	R_{ar}	R_{aa}	R_a	R_{ec}	GPP
4.8	4.3	3.1	6.5	0	0.9	0.6	5.2	3.7	8.9	4.1	2.4	12.0	14.4	18.5	23.3

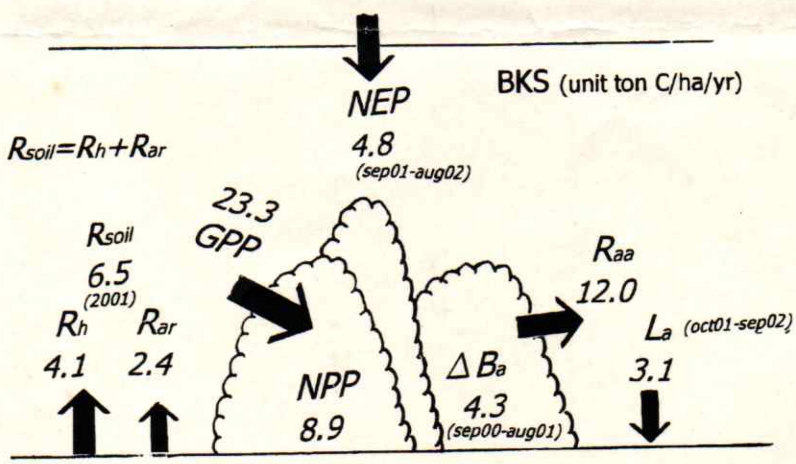


Fig.11 CO2 balance in the secondary forest in Bukit Soeharto

Observed data NEP, ΔB_a, L_a, R_{soil} (at sunset)

7 Conclusions

Analytical method was established in 2002, and acquisition rate of CO_2 flux became over 90% in 2002. Thus, analytical results became more precise. There was a long dry season related with ENSO in 2002. Net Ecosystem Production NEP in 2002 became smaller than that in 2001 of normal rain forest climate. Distribution of CO2 between elements consisting forest canopy is roughly estimated by simple assumption. Similar values between NEP and increment of biomass ΔB shows possibility that ΔB which is the baseline of CDM is estimated by NEP obtained by eddy correlation method.