B-1.8 Research on the Modeling of the Carbon Budget of Temperate Forest by the Field Measurements of CO_2 Flux(Final Report)

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Total Budget for FY1993-FY1995 41,117,000Yen (FY1995;13,749,000Yen)

Abstract The fluxes of CO_2 between air and temperate forest were estimated by the field measurement of CO_2 concentration and meteorological conditions using a tower sited in the temperate forest. The fluxies of CO_2 were calculated according to the eddy correlation and aerodynamic methods, and diffusion coefficient was determined from the comparison of their results. The seasonal variation of fluxes and the relation between them and meteorological conditions were investigated. The uptake rate of CO_2 in this temperate forest was positive (uptake by vegetation) from May to September and negative(release to the air) from October to April. Annual net uptake was 460 gCO_2/m^2 from October '93 to September '94 and 210 gCO_2/m^2 from October '94 to September '95.

Key Words Temperate Forest, CO_2 Flux, Photosynthesis, Tower Measurement, Carbon Cycle

1.Introduction

Carbon dioxide, a very important greenhouse gas, contributes approximately 55 % to global warming. Our knowledge of the sources and sinks of carbon on a global basis is not sufficient. IPCC(1994)(1) suggested that unknown 1.5-2.0 GtC/year may be sunk in terrestrial ecosystem, in particular, in the Northern Hemisphere. Clear evidence for this has not been shown by IPCC(1994). However, based on the gradient of CO_2, as a function of latitude, the main CO_2 sink may be considered the terrestrial biosphere from middle to high latitudes of the Northern Hemisphere. Recent estimation of carbon flux in the terrestrial biosphere has a high degree of uncertainty in the magnitude(for example Keeling et al.(2), Dixon et al.(3)). From this view, more investigation of the role of temperate forests on the CO_2 balance is inevitable. We intend to elucidate the seasonal variation of CO_2 flux between air and biosphere in temperate forest in Japan.

2.Research Objective

Our objective of this research was to elucidate the seasonal variation of CO_2 flux between air and biosphere in temperate deciduous forest in Japan. The fluxes of CO_2 between air and temperate forest were estimated by the field measurement of CO_2 concentration and meteorological conditions using a tower sited in the temperate forest. The seasonal variation of fluxes and the relation between them and meteorological conditions were investigated.

3.Measurements

The measurements of the atmospheric concentration of CO_2 and meteorological conditions using a tower (height=27m) in the temperate forest were started from September,1993. The tower was sited in a mountaineous area at an elevation of 1420m, in the middle of Japan as shown in Figure 1. The main species of trees in the site were

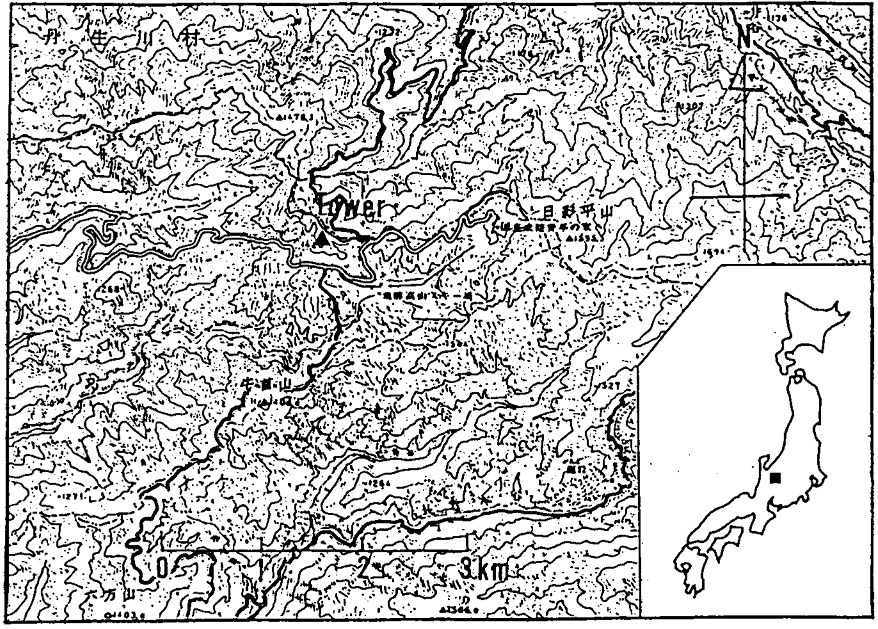

Figure 1. Map of the observation site.

Table 1. Observational items and measurement heights.

Observation Items		Observation Heights
Continuous Measurement	CO_2(mean value)	27, 18, 8.8, 5.8m
	Insolation	25.5m
	Wind Speed(mean)	26, 9.5m
	Wind Direction(mean)	26, 9.5m
	Temperature(mean)	25.5, 9m
	Humidity(mean)	25.5, 9m
Intensive Period	CO_2(fluctuation)	24.5, 11m
	Temp(fluctuation)	25, 10m
	Humid(fluctuation)	24.5, 11m
	Wind(turbulence)	25, 10m

deciduous such as birch (Betula ermanii, Betula platyphylla) and oak (Quercus mongolica), and average height of the trees (canopy height) was about 17m. The observational items were the mean values of CO_2, insolation, temperature, humidity, wind speed and wind direction as listed in Table 1. Moreover, in the intensive observation period, fluctuations of CO_2 concentration and temperature, and turbulence of vertical wind were measured by high-response CO_2 sensors and sonic anemometer & thermometer.

4.Analytical Method for CO_2 Flux

The flux of CO_2 was calculated according to the eddy correlation and aerodynamic methods.

(1) Eddy correlation method

Using data of CO_2 fluctuation (c') and turbulence of vertical wind (w') in the intense observation period, CO_2 flux (Fc) can be computed directly from the equation, $Fc = w'c'$. In this method, there is no need for hypothetical parameter, but measurement of fluctuation in CO_2 through whole a year is difficult practically.

(2) Aerodynamic method

CO_2 flux was determined based on the vertical gradient of the CO_2 concentration and diffusion coefficient (K), $Fc= Kdc/dz$. The value of K was calculated from the mixing length theory, $K=l^2du/dz$, where l is mixing length (l=2.69 m in daytime and 2.28 m in night were used in this research for the value of deciduous forest in Watanabe et al.(4)), and du/dz is the gradient of mean wind speed. Also, K could also be determined from a comparison with the flux calculated by eddy correlation method. The merit of this method is that the flux of CO_2 throughout the year can be calculated from mean values of CO_2 concentration and wind speed.

5. Results and Discussion

Figure 2 shows seasonal variation of daily average CO_2 measured at a height of 27m from September,1993 to August,1995. Though the data are scattered, the concentration of CO_2 takes maximum value (about 367 ppmv) in April and minimum value (about 355 ppmv) in September. Such seasonal variation is typical one at the site in the middle latitude of the Northern Hemisphere.

Figure 3 is an example of the time variation of CO_2 fluxes calculated by the eddy correlation (FCO2EC) and aerodynamic (FCO2AD) methods on July 29 and 30 in 1994. The fitting of fluxes by two methods is good in daytime and flux has positive (uptake of CO_2 by vegetation) value. On the contrary, in night, fitting of them is not good and flux has negative (release of CO_2 to the air) and small value.

Figure 4 shows the correlation of eddy correlation and the aerodynamic methods. The correlation coefficient of them is 0.91. The relationship between FCO2EC and insolation is shown in Figure 5. Though the scattering of data is large, it can be approximated in lower insolation range than 0.6 kW/m^2 by the following equation;

$$FCO2EC = 6.2Is/(1+0.68Is) - 0.28, \qquad (1)$$

where FCO2EC is flux of CO_2 in $gCO_2/m^2/hr$ and Is is insolation in kW/m^2. The CO_2 flux in this is 2.03 $gCO_2/m^2/hr$ at Is = 0.5 kW/m^2 at temperate forest in summer. This value is a little smaller than the value 2.41 in the tropical forest in Amazon (5) and 2.44 in subtropical forest in Iriomote, Japan (6). And, this value is comparable to the flux measured at temperate forests in Massachusetts,U.S.A. (7).

Figure 6 shows the relation between FCO2AD in night and air temperature. The release of CO_2 in night time relate to the respiration of vegetation and decomposition of organic matter. It depends on the temperature and humidity of air and soil. Therefore,

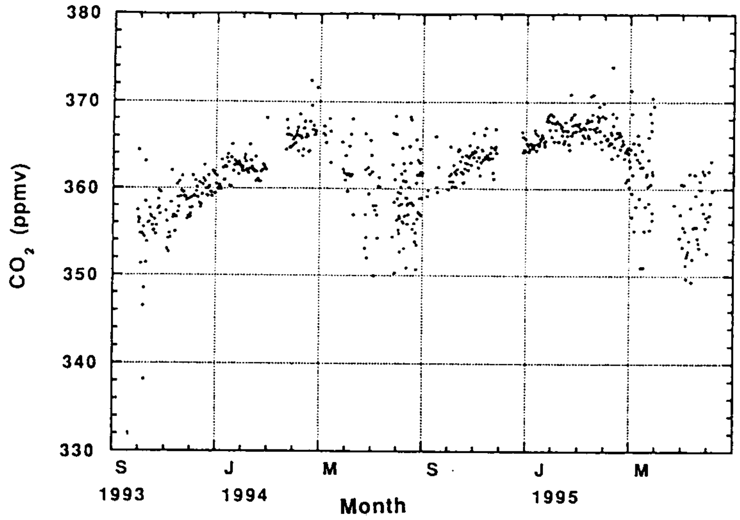

Figure 2. Seasonal variation of CO_2 concentration at the height,27m.

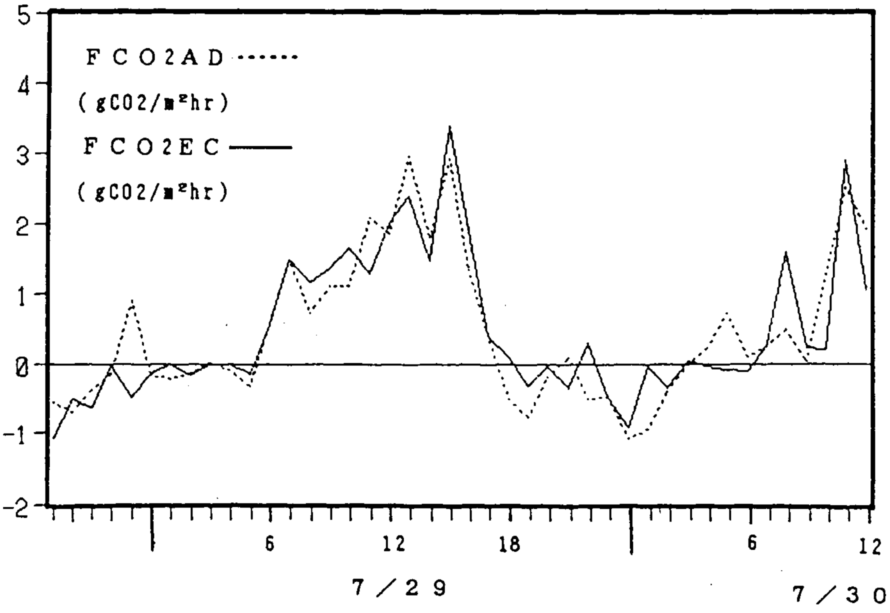

Figure 3. An example of the time variation of CO_2 fluxes according to the eddy correlation (FCO2EC) and aerodynamic (FCO2AD) methods.

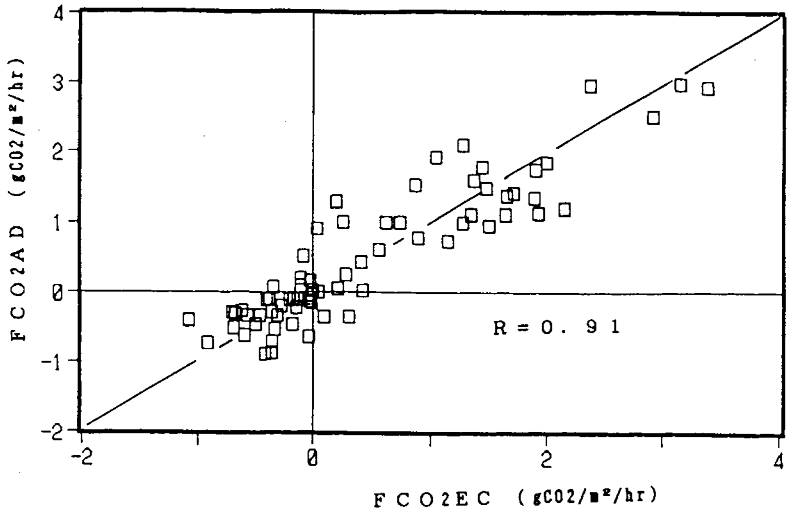

Figure 4. Comparison of the eddy correlation (FCO2EC) and aerodynamic (FCO2AD) methods.

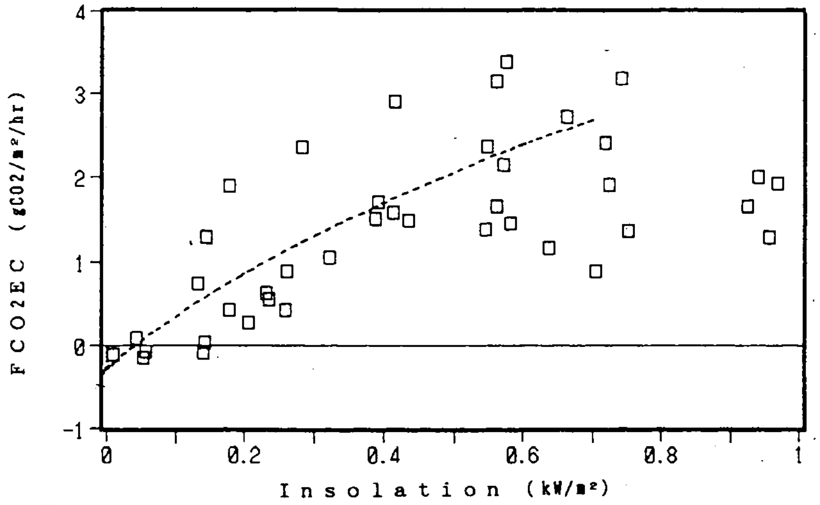

Figure 5. Relationship between FCO2EC and insolation in daytime.

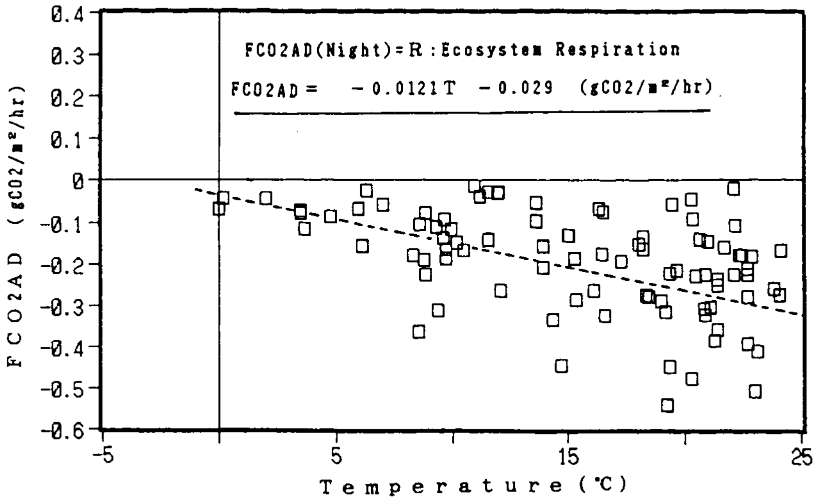

Figure 6. Relationship between FCO2AD and air temperature in night.

the data scatter in wide range, but its relation can be approximated by linear equation;

$$FCO2AD = -0.0121T - 0.029, \qquad (2)$$

where FCO2AD is CO$_2$ flux in gCO$_2$/m^2/hr and T is air temperature in deg C. This relation is roughly coincident with the result of Raich et al.(8).

Figure 7 shows seasonal variations of integrated uptake rate of CO$_2$ for daytime, night and whole day in each month from October '93 to September '94 and from October '94 to September '95. This site is covered by snow from November to April, and the beginning of October is deciduous period of leaves. Net of uptake rate of CO$_2$ in this site was positive (uptake by vegetation) from May to September and negative (release to the air) from October to April. Release rate of CO$_2$ in summer is larger than the other seasons due to high temperature.

Uptake rate of CO$_2$ in May-July,1995 was smaller than the value in May-July,1994(70 % of the value in 1994). And release rate of CO$_2$ in summer,1995 was 80 % of the value in 1994. These differences between two years were related to the deferences of insolation and air temperature in May-July. Figure 8 shows the time Variation of insolation (monthly mean of insolation in daytime) from Oct.1993 to Sept.1994 and from Oct.1994 to Sept.1995 at observation site. Figure 9 shows the time variation of maximum temperature (monthly mean of daily maximum) from Oct.1993 to Sept.1994 and from Oct.1994 to Sept.1995.

Table 2 is summary of the uptake amounts of CO$_2$ integrated in whole year (from Oct.'93 to Sept.'94:left column / from Oct.'94 to Sept'95:right column) and in seasonal periods (Oct-Dec & Sept,Jan-Apr and May-Aug in each year) for whole day, daytime and night. Annual net uptake was 460 gCO$_2$/m^2 from October '93 to September '94 and 210 gCO$_2$/m^2 from October '94 to September '95.

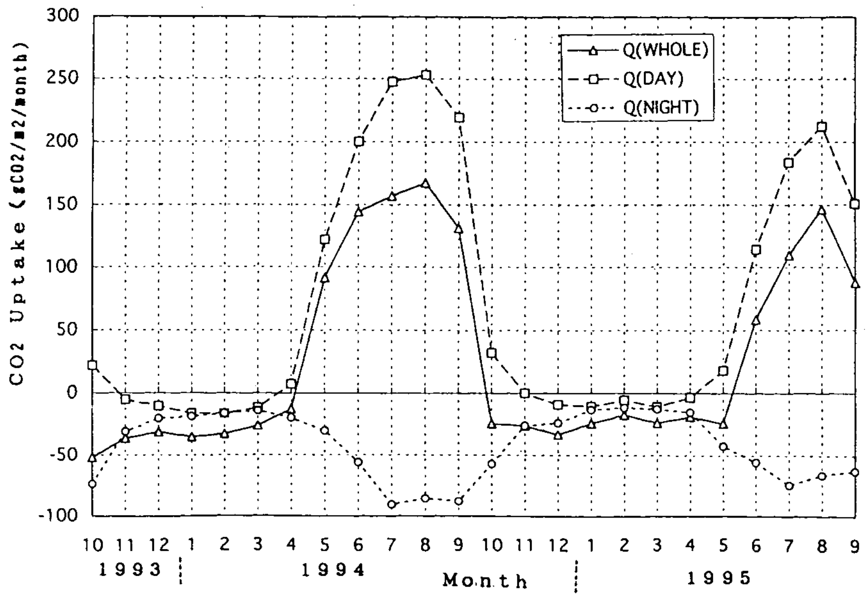

Figure 7. Seasonal variations of integrated uptake rate of CO$_2$ for daytime, night and whole day in each month from Oct.,1993 to Sept.,1995).

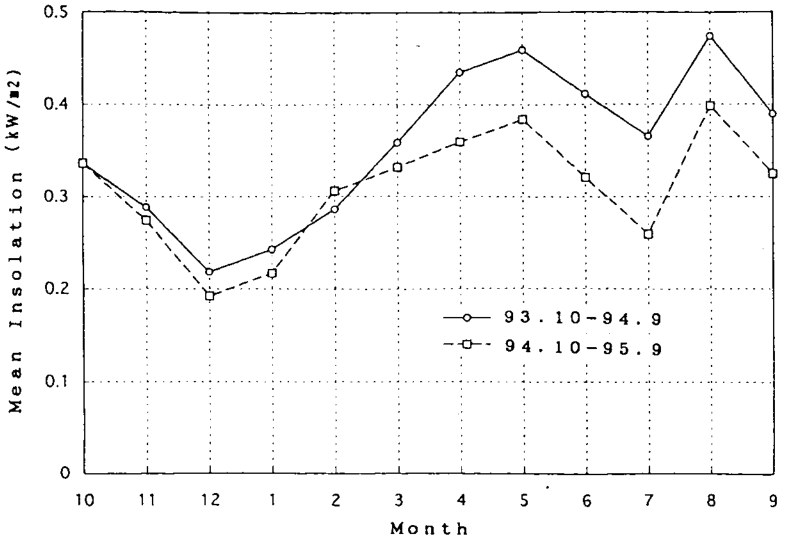

Figure 8.Time Variation of insolation (monthly mean of insolation in daytime) from Oct.1993 to Sept.1994 (solid line) and from Oct.1994 to Sept.1995 (dashed line) at observation site.

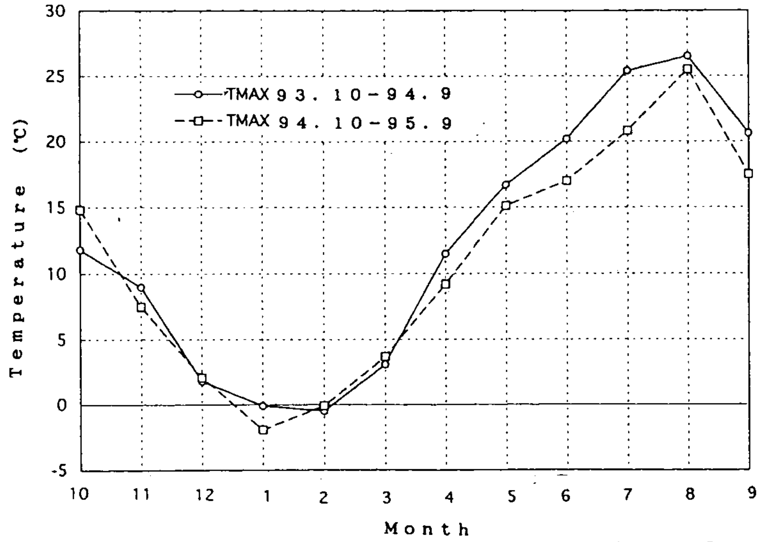

Figure 9.Time Variation of maximum temperature (monthly mean of daily maximum) from Oct.1993 to Sept.1994 (solid line) and from Oct.1994 to Sept.1995 (dashed line) at observation site.

Table 2. Uptake amounts of CO_2 integrated in whole year (from October '93 to September '94) and in seasonal periods (Oct-Dec & Sept, Jan-Apr and May-Aug) for whole day, daytime and night.

PERIOD	DAY		日中		NIGHT	
SEP-DEC	11	3	225	173	-214	-171
JAN-APR	-108	-85	-38	-31	-70	-54
MAY-AUG	559	289	822	528	-263	-238
YEAR	462	208	1009	671	-547	-463

6.Conclusion

The values of CO_2 flux depend on the activities of vegetation including photosynthesis, respiration and the decomposition of organic matter which relate to the meteorological conditions such as insolation, temperature and wind speed. In this paper, The fluxes of CO_2 between air and temperate deciduous forest were estimated by the field measurement of CO_2 concentration and meteorological conditions using a tower. The fluxes of CO_2 were calculated according to the eddy correlation and aerodynamic methods. The seasonal variation of fluxes and the relation between them and meteorological conditions were investigated.

The main results of this study are as follows;

(1) CO_2 fluxes were calculated by the correlation and aerodynamic methods, and diffusion coefficient (K) was determined from the comparison of their results.

(2) Relations between CO_2 flux (daytime) and insolation (kW/m^2) and between CO_2 flux (night) and air temperature are roughly approximated by equations (1) and (2).

(3) Uptake rate of CO_2 in this temperate forest was positive (uptake by vegetation) from May to September and negative (release to the air) from October to April.

(4) Annual net uptake was 460 gCO_2/m^2 from October '93 to September '94 and 210 gCO_2/m^2 from October '94 to September '95.September '94.

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