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Characteristics of CO_2 Fluxes in Cool-Temperate Coniferous and Deciduous Broadleaf Forests in Japan

By

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Summary

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Long-term CO_2 flux monitoring in coniferous and deciduous forests was conducted in Fujiyoshida and Takayama sites, Japan. Both forests observed are representatives of naturally regenerated secondary coniferous and broadleaved deciduous forests in cool-temperate regions of Japan. In this report, we compared net ecosystem production in both sites by eddy covariance method, and analyzed the climatic factors that affect the seasonal and inter-annual changes in NEP in relation to forest type. The observed NEP showed that the maximum NEP was about 1.5 times larger in the Takayama site, although the growing period was about 2 times longer in the Fujiyoshida site. The monthly NEP in the Fujiyoshida site had large inter-annual variation throughout the season, but the variation was only appeared from April to October in the Takayama site. The difference in the inter-annual variation in monthly NEP between forest types might be explained as follows. The coniferous forest maintains canopy needles throughout the year, that is, the forest is ready to assimilate if climatic conditions are favorable, and can be continuously affected by changes in *Sd* and *Ta*. In contrast, the deciduous broadleaved forest experiences leaf-expansion and leaf-fall events, therefore, the period affected by climatic changes is limited only to the growing season. Respiration is relatively more consistent than assimilation, because the *Ta* behaves similarly among years in summer, and the forests are snow covered in winter when the inter-annual variation of *Ta* becomes large. Consequently, in the cool-temperate coniferous forest, the balance of assimilation and respiration induced by seasonal changes in solar radiation and air temperature is an important factor, while in the cool-temperate deciduous broadleaved forest, solar

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radiation and the duration of the growing season are important factors with regards to annual NEP.

Introduction

Recent studies showing the results of FLUXNET (i.e. BALDOCCHI & al. 2001, FALGE & al. 2002) have discussed the seasonal patterns of gross primary production and ecosystem respiration based on the net ecosystem production (NEP) observed by flux measurements. Some studies have suggested that the forest carbon budget is highly sensitive to temperature (FAN & al. 1995, LINDROTH & al. 1998).

We conducted long-term CO_2 flux monitoring in cool-temperate coniferous and deciduous forests in Fujiyoshida and Takayama, Japan, respectively. In this report, we compared net ecosystem production in both sites by eddy covariance method, and analyzed the climatic factors that affect the seasonal and inter-annual changes in NEP in relation to forest type. Temperate coniferous and broadleaved forests cover approximately 40 and 45%, respectively, of the total forested area of Japan (MAFF 2003). Both forests observed are representatives of natural or naturally regenerated secondary forests in cool-temperate regions of Japan.

Site and Methods

Study sites

Fujiyoshida site (cool-temperate coniferous forest, 35° 27' N, 138° 46' E, 1030 m in elevation) is located on a gentle volcanic slope in a cool-temperate region of central Japan. This area has a mean annual temperature and precipitation of about 9.5 °C and 2018 mm, respectively. The dominant tree species are Japanese red pine (*Pinus densiflora*) and Japanese holly (*Ilex pedunculosa*), which occupy the upper and lower canopy, respectively. The mean upper canopy height and diameter of pine trees about 90 yr old were approximately 20 and 0.3m, respectively (OHTSUKA & al. 2001). The forest soil is immature, composed of volcanic lava covered partially with litter and organic matter. During the study period, the site experienced little soil moisture loss because precipitation regularly occurred during the growing season.

Takayama site (cool-temperate deciduous broadleaved forest, 36° 08' N, 137° 25' E, 1420 m in elevation) is located on complex terrain also in a cool-temperate region of central Japan. It has a mean annual temperature and precipitation of about 7.3 °C and 2300 mm. The vegetation consists mainly of approximately 50-yr-old secondary deciduous forest, primarily dominated by oak (*Quercus crispula*) and birch (*Betula ermanii*; *Betula platyphylla var. japonica*) (JIA & al. 2002, MURAOKA & al. 2003, OHTSUKA 2003). Dense evergreen dwarf bamboo (*Sasa senanensis*) covers the understory. The Asian monsoon provides sufficient water to most ecosystems during the growing season. Further descriptions of Takayama site can be found in YAMAMOTO & al. 1999 and MURAYAMA & al. 2003. The climate at both study sites is characterized by abundant precipitation and apparent seasonal changes, which are affected by the East-Asian monsoon.

Estimation of leaf area index

Leaf area index (LAI) was estimated by the attenuation of photosynthetic active radiation (PAR) in the canopy using the following equation:

$$\mathrm{LAI} = -\frac{1}{K_p} \ln \frac{\mathrm{PAR_u}}{\mathrm{PAR_a}} \quad . \qquad (1)$$

where K_p is an extinction coefficient, PAR_a and PAR_u are the downward PAR above and under the canopy, respectively. PAR was measured by quantum sensors using LI190SA (LI-COR) in Fujiyoshida and IKS27 (KOITO) in Takayama. We conducted measurements on cloudy days only to minimize estimation errors caused by seasonal change in the incident angle of direct solar radiation. In Fujiyoshida, LAI was determined by comparing the measured LAI values obtained in 2002 with a plant canopy analyzer (LAI-2000/LI-COR), then Kp was adjusted to give the final LAI. In Takayama, rather a K_p of 0.83 was assumed. (SAIGUSA & al. 2002). In this report, LAI includes the effect of stems and branches, namely, the plant area index.

Carbon dioxide flux measurements and data processing

In Fujiyoshida site, continuous CO_2 flux monitoring started in May 1999 from a 32 m high tower constructed in the forest. A three-dimensional sonic anemometer (SAT; DA600/KAIJO) and infrared gas analyzer (IRGA; Li6262/LI-COR) were used to measure the flux by eddy covariance. The SAT was set at a height of 26m on the tower, which is about 6m above the mean canopy height (OHTANI & al. 2005). In Takayama site, CO_2 flux has been continuously measured by eddy covariance since July 1998 from a height of 25m on a 27 m high tower located in a hilly area, using a SAT and an IRGA (SAIGUSA & al. 2002).

The net ecosystem CO_2 production (NEP) was calculated every 30 minutes, taking into account CO_2 storage changes in the canopy. Data quality control was performed, and data gaps were filled by estimations using parameterization of ecosystem respiration and gross primary production (OHTANI & al. 2005, SAIGUSA & al. 2002).

Results and Discussion

Seasonal changes in leaf area index

Fig. 1 shows the seasonal changes in LAI in the Fujiyoshida and Takayama sites calculated using Eq. (1). In Fujiyoshida site (Fig. 1a), LAI ranged from 3 to 5, and changed seasonally. The needle longevity of Japanese red pine is 2~3 years, thus 1/2~1/3 of all pine needles are replaced annually. Needle-fall and needle-expansion mainly occurred in November and May, respectively. The LAI increased rapidly in early May, showed a maximum in mid summer, then decreased from September to November. The timing of the LAI increase and decrease differed in 2001 and 2002, and the period of higher LAI was around 20 days longer in 2002. A gradual decrease in LAI from January to late April was revealed from changes in leaf inclination of evergreen broadleaved trees in the lower canopy, which was initially horizontal and then inclined with low temperatures.

In Takayama site (Fig. 1b), LAI ranged from 0.5 to 4, and changed seasonally much more obviously than in the coniferous forest. The site was covered with snow from November to early April, at which time few leaves remained, however, from May to June, most leaves were fully expanded. This rapid increase in LAI might be influenced by the duration of the snow cover, which differed by 2~3 weeks from year to year. SAIGUSA & al. (in press) reported that the beginning of leaf-expansion differed by about 30 days from 1994 to 2002. A rapid decrease in LAI occurred from September to October with leaf-fall, which was mainly brought about by a temperature decrease, but sometimes by windy storms causing unexpected early leaf-fall. Fig. 1b shows the clear shift of the growing period among years caused by climatic conditions.

Changes in the seasonal LAI pattern seems to be potentially important if we consider the seasonal and inter-annual changes in NEP. In winter, needles are maintained to some extent in coniferous forests, but few leaves remain in deciduous broadleaved forests. This difference might affect the behavior of CO_2 assimilation processes in coniferous and deciduous forests from late autumn to early spring.

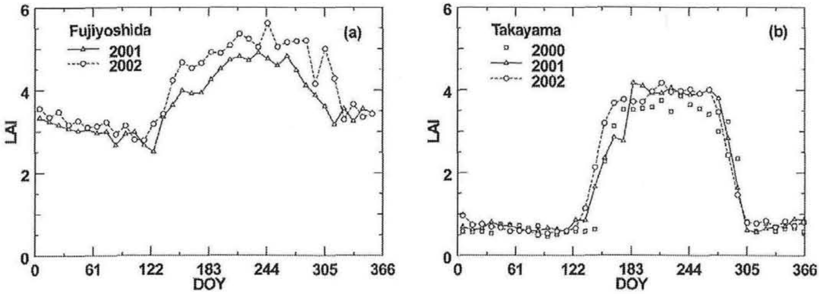

Fig. 1. Seasonal changes in leaf area index in (a) the Fujiyoshida and (b) Takayama sites.

Seasonal changes in solar radiation, air temperature and NEP

Fig. 2 shows the seasonal changes in global solar radiation, air temperature and net ecosystem production (NEP) in 2001 in the Fujiyoshida and Takayama sites. In Fujiyoshida site, global solar radiation (*Sd*) varied from 5 to 28 $MJm^{-2}d^{-1}$, showing a minimum in October and maximum in July. Potential incident solar radiation showed a minimum in December and maximum in June, and the strong reductions of *Sd* that appeared in June and September were caused by a stationary front under the influence of the East-Asian monsoon. Air temperature (*Ta*) varied from 3 to 25°C, showing a minimum in January and maximum in July. Although it presented some fluctuations, the seasonal pattern seemed more regular than that of *Sd* (Fig. 2a). After a continuous weak negative NEP from January to February, NEP increased, showing a maximum in May then gradually decreasing towards December. In the seasonal course, the NEP was accompanied by large fluctuations; it was particularly diminished in September (Fig. 2b). These decreases in NEP can also occur in June, but they are remarkable in September because the *Ta* is higher and thus ecosystem respiration might be larger than that in June.

In Takayama site, *Sd* varied from 1 to 28 $MJm^{-2}d^{-1}$, showing a minimum in January and maximum in May. A reduction of *Sd* also appeared in June and September as previously explained. Furthermore, the winter monsoon highly affected the winter weather in this site, resulting in a reduction of *Sd* and abundant precipitation from snow. *Ta* varied from -13 to 22°C, showing a minimum in January and maximum in July (Fig. 2c). The negative NEP continued from the winter dormant season in late October to the following May. Along with leaf-expansion, NEP rapidly increased, showing a maximum in July then a gradual decreased until early October. The positive NEP ended with leaf-fall. The NEP was also accompanied by large fluctuations; it was particularly diminished in June and

September (Fig. 2d). The decrease of NEP in the growing season was highly affected by the diminution of *Sd*.

The maximum NEP was 4.9 $gCm^{-2}d^{-1}$ in the Fujiyoshida and 6.0 $gCm^{-2}d^{-1}$ in Takayama sites. The period of positive NEP (the growing period) lasted approximately 260 and 140 days in Fujiyoshida and Takayama, respectively. The maximum NEP was about 1.5 times larger in the Takayama site, although the growing period was about 2 times longer in the Fujiyoshida site.

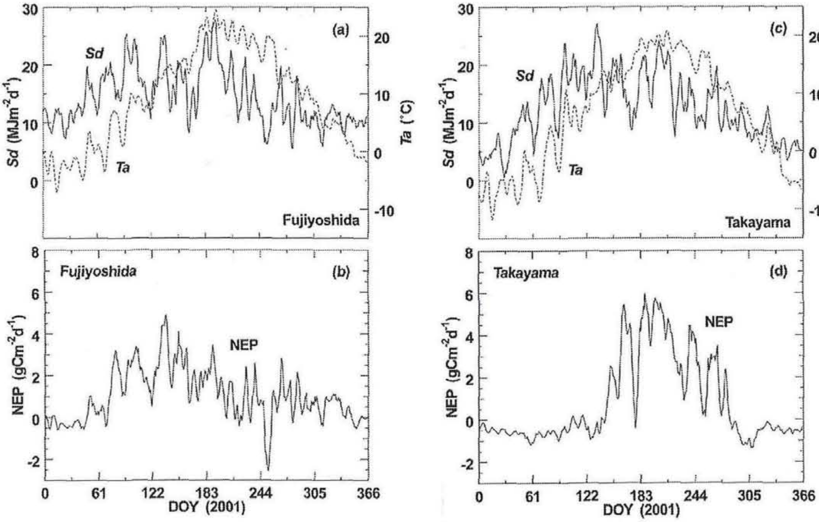

Fig. 2. Seasonal changes in (a) global solar radiation (*Sd*), air temperature (*Ta*) and (b) net ecosystem production (NEP) in Fujiyoshida site. (c) *Sd*, *Ta* and (d) NEP in Takayama site. Data are averaged over 5 days.

Seasonal and inter-annual changes in solar radiation, air temperature and NEP

Fig. 3 shows the seasonal and inter-annual changes in solar radiation, air temperature and NEP from 2000 to 2003 according to monthly data obtained in the Fujiyoshida and Takayama sites. In Fujiyoshida site, the monthly *Sd* had large year-to-year variation in almost all months. The monthly *Ta* also showed year-to-year variation, but was relatively low from May to October. The year-to-year variations in *Sd* and *Ta* occurred in almost the same manner in the Takayama site, except that the *Sd* in September was nearly constant from year-to-year. The monthly NEP in the Fujiyoshida site had large inter-annual variation throughout the year, but the variation was only seen from April to October in the Takayama site.

The difference in the inter-annual variation in monthly NEP between forest types should be discussed based on gross ecosystem production and ecosystem respiration, but might be easily explained as follows. The difference in the seasonal

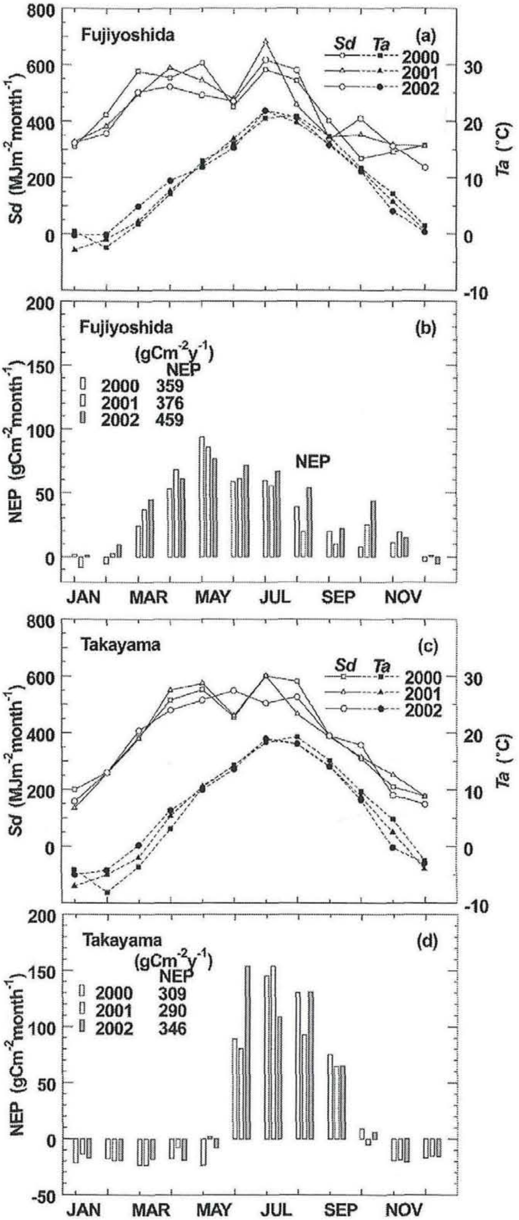

Fig. 3. Seasonal and inter annual changes in monthly mean (a) global solar radiation (*Sd*), air temperature (*Ta*) and (b) net ecosystem production (NEP) in Fujiyoshida site. (c) *Sd*, *Ta* and (d) NEP in Takayama site.

changes in LAI is the most important factor affecting the changes in NEP. The coniferous forest maintains canopy needles throughout the year, that is, the forest is ready to assimilate if climatic conditions are favorable, and can be continuously affected by changes in *Sd* and *Ta*. In contrast, the deciduous broadleaved forest experiences leaf-expansion and leaf-fall events, therefore, the period affected by climatic changes is limited only to the growing season. Respiration is relatively more consistent than assimilation, because the *Ta* behaves similarly among years in summer, and the forests are snow covered in winter when the inter-annual variation of *Ta* becomes large. Consequently, in the cool-temperate coniferous forest, the balance of assimilation and respiration induced by seasonal changes in solar radiation and air temperature is an important factor, while in the cool-temperate deciduous broadleaved forest, solar radiation and the duration of the growing season are important factors with regards to annual NEP.

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