Evaluation of Modified Soil-Plant-Atmosphere Model (mSPA) to Simulate Net Ecosystem Carbon Exchange Over a Deciduous Forest at Gwangneung in 2006

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2006년 광릉 활엽수림에서 순 생태계 탄소 교환량의 모의에 대한 modified Soil-Plant-Atmosphere (mSPA) 모델의 평가

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ABSTRACT

We evaluated modified Soil-Plant-Atmosphere model's performance to simulate the seasonal variation of net ecosystem exchange (NEE) of carbon and examined the critical controlling mechanism on carbon exchange using the model over a deciduous forest at Gwangneung in 2006. The modified Soil-Plant-Atmosphere (mSPA) model was calibrated to capture the mean NEE during the daytime (1000-1400 LST) and used to simulate gross primary productivity (GPP). Ecosystem respiration (R_e) has been estimated using an empirical formula developed at this site. The simulation results indicated that the daytime mean stomatal conductance was highly correlated with daily insolation in the summer. Low stomatal conductance in high insolation occurred on the days with low temperature rather than with high vapor pressure deficit. It suggests that the forest rarely experienced water stress in the summer of 2006. The model captured the observed bimodal seasonal variation with a mid-season depression of carbon uptake. The model estimates of annual GPP, R_e and NEE were $964 \text{ gC m}^{-2} \text{ yr}^{-1}$, $733 \text{ gC m}^{-2} \text{ yr}^{-1}$, and $-231 \text{ gC m}^{-2} \text{ yr}^{-1}$, respectively. Compared to the observed annual NEE, the modeled estimates showed more carbon uptake by about $140 \text{ gC m}^{-2} \text{ yr}^{-1}$. The uncertainty of the estimate of annual NEE in a complex terrain is discussed.

Key words : Complex terrain, Deciduous forest, mSPA model, Net ecosystem carbon exchange

I. INTRODUCTION

The need to understand and quantify biogeochemical cycles has lead to a proliferation of long-term eddy flux measurements of carbon dioxide (Baldocchi *et al.*, 2001) and the development of many land-surface models (Williams *et al.*, 1996; Baldocchi, 1997). The forest

ecosystems play an important role in global carbon cycle as large carbon stock (Kondratyev *et al.*, 2003) and hence, it is important to quantify carbon dioxide (CO_2) flux from various forest ecosystems to understand biogeochemical cycle. The Gwangneung forest site is one of KoFlux sites, which was established to quantify CO_2 exchange over forested areas in Korea.

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The study site is located in a complex terrain, which is very typical in Korean forested areas. In the complex terrain, local wind system develops very often, which complicates energy and carbon budgets. Hong *et al.* (2008) investigated the budget equations of H₂O and CO₂ exchanges at this site and showed that the vertical and horizontal advections canceled each other out and therefore at 40m, the turbulent eddy flux alone can be used for net ecosystem exchange within 10% uncertainty. Kwon *et al.* (2009) examined seasonality of net ecosystem exchange (NEE), gross primary productivity (GPP), and ecosystem respiration (R_e) using the gap-filled data which have been processed by the standardized method and reported annual net ecosystem exchange at this site for 2006.

In this study, we used the same dataset for modeling approach. In modeling approach, the model parameters are calibrated with observation data and the calibrated model is used to examine water and carbon exchange process and estimate annual NEE. The modeling approach is useful in that the calibrated model can be used for up-scaling of flux from plot scale to regional scale. We calibrated a model using the observation data for use as a scaling tool. The used model is modified Soil-Plant-Atmosphere model (mSPA model), which is a process based model with two canopy layers (Lee and Mahrt, 2004). The model considers the plant water transport explicitly and therefore it is useful to examine how plant water controls photosynthesis. The model has been tested for Boreal deciduous forest (Lee and Mahrt, 2004), pine forest in water stress conditions (Lee and Park, 2007), and rice paddy field (Lee *et al.*, 2008).

The objectives of this study are to evaluate model's performance to simulate the seasonality of NEE by calibrating model parameters with observations, and to examine the critical controlling mechanism on carbon exchange at this site in 2006.

II. MATERIALS AND METHODS

2.1. Site description

The study site is located in the Gwangneung forest at a west-central part of Korean peninsula (37° 45' N, 127° 9' E, 340m), which is one of KoFlux sites. The terrain has a valley-like topography with a 10° slope with the aspect of east dominantly. The mean canopy height is approximately 18m and maximum plant area index (PAI) was about 5.8 during the study period. The

tree age ranges from 80 to 200 years (Lee *et al.*, 2007). The forest is dominated by serrata oak (*Quercus serrata*). More detail information on the study site can be found in Lim *et al.* (2003) and Kwon *et al.* (2009).

2.2. Field measurements

Turbulent fluxes have been measured with two eddy covariance systems installed at 40m and 20m on the tower. The main system consists of a three dimensional sonic anemometer (CSAT3, Campbell Scientific Inc., Logan, UT) and an open-path H₂O/CO₂ gas analyzer (LI7500, LICOR, Lincoln NE). Sampling rate was 10Hz. Turbulent fluxes were computed from 30min records. A radiometer (CNR1, Kipp & Zonnen, The Netherlands) was installed at 40m above the ground to measure downward and upward components of shortwave and longwave radiation. The soil temperature was measured using soil temperature probes (Model TCAV, Campbell Scientific Inc.) The measurements of PAI were made at several points around tower during the period from DOY 82 to DOY 314 using LAI-2000 plant canopy analyzer (Li-Cor, Lincoln, Nebraska) (Park *et al.*, 2006). The half hourly mean meteorological fields and radiation data have been used to drive a model in an offline mode. In this study, we used the data measured in 2006 when the number of missing record was relatively small during the growing season.

2.3. Quality control and Gap filling method

We used the eddy covariance data processed by the FluxNet standardized method (Papale *et al.*, 2006; Kwon *et al.*, 2009). The processing includes storage correction, spike detection, friction velocity threshold, and gap-filling method. Marginal distribution sample (MDS), which is a modified look-up table method, was used to fill the missing CO₂ flux data (Reichstein *et al.*, 2005). The intervals for MDS were 40 W m⁻² for net radiation, 2.5°C for air temperature, and 0.5 kPa for vapor pressure deficit, respectively. In order to minimize the confounding effects introduced into a temperature dependent function for ecosystem respiration, the nighttime CO₂ fluxes were estimated using temperature sensitivity both from short-term data (15days window with 10days overlap) and seasonal data. Consequently, the gap-filled nighttime CO₂ fluxes considered short- and long-term response of ecosystem respiration to temperature. Friction velocity correction was also applied for compensating the loss of CO₂ fluxes in the nighttime conditions. More information can be found on a FLUXNET website

Table 1. The correlation of input variables between Gwangneung and Dongduchon

	The ratio of gap-filled data with Dongduchon data	Correlation coefficient between two sites
Temperature	10%	0.98
Mixing ratio	22%	0.99
Solar radiation	4%	0.96
Wind speed	10%	0.57

(<http://www.fluxdata.org/default.aspx>) and Kwon *et al.* (2009).

The missing data in meteorological fields and radiation data were filled as follows. Short gaps less than 3 hours were filled by linear interpolation. Longer gaps of mixing ratio and radiation data were filled using meteorological data at Dongduchon station of Korean Meteorological Administration which is nearest station (37° 54' N, 127° 4' E, 112.5m) from Gwangneung site. For CO₂ concentration, the missing value for a certain 0.5-h was replaced with the monthly averaged value at that time of day. For air temperature and wind speed, the missing value was replaced with corresponding data at Dongduchon station corrected with ratio of seasonal mean at that time between two sites. Table 1 shows the ratio of gap-filled data with data at Dongduchon station and correlation coefficient of variables between two sites. Except for mixing ratio, the ratio of gap-filled data is less than 10% and correlation coefficients between two sites are very high for the variables except for wind speed. The observed soil temperature at 10cm depth has been used to calculate ecosystem respiration estimate. When the observed soil temperature was not available, we used daily mean soil temperature estimate using the empirical formula of Kang *et al.* (2000). The missing rate of soil temperature was about 2% and most of them occurred during winter in which diurnal variation of soil temperature was relatively small.

2.4. Estimation of GPP and R_e

NEE is defined as the difference between gross primary productivity (GPP) and ecosystem respiration (R_e) given by

$$NEE = R_e - GPP \quad (1)$$

GPP is estimated using the mSPA model. The mSPA model is a two-layer canopy model, which is based on

the canopy model of Williams *et al.* (1996), coupled to a multi-layer soil model with snow and frozen soil physics (Koren *et al.*, 1999). In the canopy model, layer stomatal conductances for sunlit and shaded leaves are calculated iteratively by incrementing layer stomatal conductance until either this results in no appreciable increases in net photosynthesis or minimum leaf water potential has been reached (Williams *et al.*, 1996). The photosynthesis V_c is based on the model of Farquhar and Von Caemmerer (1982) given by

$$V_c = \min\{W_c, J'\} \quad (2)$$

where J' is the maximum rate of carboxylation allowed by the electron transport and $\min\{\}$ denotes 'minimum of' and W_c is related to V_{cmax} as follows

$$W_c = V_{cmax} \frac{C}{C + K_c(1 + O/K_o)} \quad (3)$$

where V_{cmax} is maximum carboxylation capacity and C and O are the partial pressures of CO₂ and O₂ and K_c and K_o are the Michaelis-Menten constants for CO₂ and O₂, respectively. The modeled GPP is calculated by integrating the photosynthesis of leaf over the whole canopy. The photosynthesis is calculated on the sunlit and shaded leaf separately at each layer and the corresponding leaf area index (LAI) is used for the integration.

The radiation routines include the incidence, interception, absorption and reflectance of photosynthetically active radiation (PAR), near infrared radiation (NIR) and longwave radiation in each canopy layer (Amthor, 1994; Amthor *et al.*, 1994). A spherical leaf angle distribution is assumed and the clumping factor was considered as 0.9 in the radiation routine.

For estimation of R_e , we developed an empirical formula using gap-filled NEE data during the nighttime from 2000 LST to 0500 LST. For this estimation, we divided data into two periods and developed empirical formula for each period separately. The features of nighttime respiration have been discussed in section 3.2. Ecosystem respiration rate is calculated by using a temperature-based exponential model:

$$R_e = A \exp(BT_s) \quad (4)$$

where A and B are constants and T_s is soil temperature (°C) at 10cm depth, and R_e is given in mmol m⁻² s⁻¹.

We developed two empirical formulas for R_e (Table 3). In Resp 0, to consider seasonal variation of nighttime NEE, we divided data into two periods of before

Table 2. The used key parameter values for mSPA model at study site

Parameter Description	Units	Values
Minimum leaf water potential prior to cavitation	MPa	-1.3
Maximum carboxylation capacity (V_{cmax})	$\mu\text{mol m}^{-2} \text{s}^{-1}$	24.3
Maximum electron transport rate (J_{max})	$\mu\text{mol m}^{-2} \text{s}^{-1}$	49
Maximum leaf area index (LAI)	$\text{m}^{-2} \text{m}^{-2}$	4.8
Plant hydraulic conductivity	$\text{mmol m}^{-1} \text{s}^{-1} \text{MPa}^{-1}$	10
Root resistivity	$\text{MPa s}^{-1} \text{g mmol}^{-1}$	3
Rooting depth	M	1.0
Total fine root biomass	g m^{-2}	600

Table 3. Temperature dependent Q_{10} formula for ecosystem respiration at study site in 2006.

	Period	Formula	R ²	Correlation coefficient between regression model and observation
Resp 0	From January to July	$R_e = 0.6575 * \exp(0.104T_s)$	0.95	0.84
	From August to December	$R_e = 0.7468 * \exp(0.058T_s)$	0.81	
Resp 1	From January to December	$R_e = 0.7628 * \exp(0.078T_s)$	0.94	0.70

and after around July, and developed empirical formula for each period. The first period ranged from January to July and the second period included the other months. In developing empirical formula in period 2, we excluded unrealistic large R_e during the days from DOY 348 to DOY 351. In Resp 1, we developed one empirical formula by fitting Eq. (2) to observations for the whole year.

2.5. Model calibration

We calibrated the model parameters as follows. The ratio of J_{max} to V_{cmax} was fixed as 2 following Wullschleger (1993). Minimum leaf water potential was set up to -1.3 MPa according to Saito *et al.* (2003). The value of V_{cmax} was calibrated by minimizing the bias of the selected variable between the observation and the model. In this study, for the model calibration, we used the mean NEE data during the hours between 1000 LST and 1400 LST of 243 days, which are in strong turbulent conditions. We excluded the gap-filled data and selected days with less missing rate (<25%) during those hours.

The optical parameters of plant were calibrated to match the observed mean albedo at this site. Table 2 shows the used key parameters of the calibrated model at the study site. Wullschleger (1993) reported V_{cmax} estimate as $47 \pm 33 \mu\text{mol m}^{-2} \text{s}^{-1}$ for temperate hardwood forest. Current estimate of V_{cmax} at this site is within the range but shows a relatively low value. Kosugi and Matsuo (2006) indicated that in the decid-

uous oak, declines in V_{cmax} were observed after summer, along with changes in V_{cmax} during the leaf out and leaf fall period. To consider the seasonal variation of V_{cmax} , the value of V_{cmax} was set to decrease linearly from DOY 243 to DOY 303 and reach a half of summer V_{cmax} on DOY 303.

III. RESULTS

3.1. The characteristics of meteorological fields and PAI in 2006

Fig. 1 shows monthly averaged meteorological fields in 2006. The annual average air temperature and precipitation are 11.3°C and 1365 mm (Lim *et al.*, 2003), respectively at this site. The year of 2006 has a little larger rainfall (1625 mm) than annual average and has normal temperature. Most of rain is concentrated during summer, which is typical in monsoon regions. Insolation is reduced due to frequent rain in July. Vapor pressure deficit is not high showing values around 1 kPa during growing season. The low vapor pressure deficit in July is due to a large amount of rainfall. Fig. 2 shows seasonal variation of PAI used in this study. We used mean measured PAI during the measurement period and assumed that PAI measured in early spring is applied throughout the remaining period. We assumed stem area index (SAI) as 1.28 during whole year. Maximum leaf area index (LAI) is about 4.5 and occurred on DOY 158.

Fig. 1. The seasonal variation of monthly (a) mean air temperature at 40m (b) mean vapor pressure deficit at 40m (c) monthly precipitation amount and (d) monthly insolation in 2006.

Fig. 2. The seasonal variation of PAI used in this study.

3.2. Ecosystem respiration and soil temperature

Fig. 3 shows the seasonal variation of mean nighttime NEE and soil temperature during the hours between 2000 LST and 0500 LST. The soil tempera-

ture showed a maximum in August while the nighttime NEE showed a maximum in July. After a large amount of rainfall in July, nighttime NEE was reduced. Fig. 4 shows the scatter plot between soil temperature at 10 cm depth and mean nighttime ecosystem respiration at

Fig. 3. The time series of mean (a) ecosystem respiration ($\mu\text{mol m}^{-2} \text{s}^{-1}$) and (b) soil temperature ($^{\circ}\text{C}$) during the nighttime (2000 LST-0500 LST).

soil temperature bin for each period and whole period. The soil temperature explains about 95% of variation in R_e in period 1 while it explains about 81% of variation in R_e in period 2. In a given temperature, nighttime ecosystem respiration is higher during period 1 than period 2.

One possible cause for such difference is higher foliar respiration for foliage expanding because of its large contribution to growth respiration (Ryan *et al.*, 1997; Reichstein *et al.*, 2005) and higher maintenance respiration due to larger LAI in period 1 than in period 2 (Fig. 2). Another possible cause is removal of surface litter layer due to the concentrated rainfall in July, which resulted in reduction of heterotrophic respiration in period 2. Chae (2008) examined soil respiration rate at Gwangneung and indicated that a large amount of rainfall restrained soil respiration rate and its impact lasted for almost three weeks. The calculated nighttime respirations using the regression model are plotted in Fig. 3. The empirical formula of Resp 1 does not capture the observed seasonal variation, showing less correlation coefficient (0.70) between observation and regression for mean nighttime respiration during the hours between 2000 LST and 0500 LST compared to that (0.85) in Resp 0. In the following sections, we used

Fig. 4. The relationship between soil temperature and ecosystem respiration rate during the nighttime for each period. The curve is nonlinear regression fitted to the mean.

empirical formula of Resp 0 accordingly.

3.3. Comparison between model and observation

Fig. 5a shows the comparison of simulated mean NEE during the hours between 1000 LST and 1400 LST with observations. Here, the simulated mean NEE was calculated as R_e estimate minus simulated GPP. Although the simulated NEE showed less variability

Fig. 5. (a) The time series of simulated mean NEE with observations and (b) simulated mean stomatal conductance during the hours between 1000 LST and 1400 LST.

Fig. 6. The scatter plot of daily insolation and simulated mean stomatal conductance during the hours between 0600 LST and 1800 LST in summer.

compared to observations during the summer, it captured the bimodal seasonal variation of NEE reason-

ably. The root mean square error (RMSE) is $2.27 \mu\text{mol m}^{-2} \text{s}^{-1}$. Fig. 5b shows the simulated mean stomatal

Fig. 7. The diurnal variation of (a) insolation (b) friction velocity and (c) vapor pressure deficit for selected 10 days.

conductance during the hours between 1000 LST and 1400 LST. During the non-growing season (January–March and November–December), LAI was very low (about 0.03) and hence both upper and lower canopy got enough solar radiation and show similar conductance. As LAI increased, lower canopy got less solar radiation than upper canopy and the difference of stomatal conductance between upper and lower canopy increases. The simulated stomatal conductance of upper canopy showed broad maximum during summer and shows sudden reduction on rainy days.

Fig. 6 shows scatter plot of daily insolation and simulated mean stomatal conductance during the hours between 0600 LST and 1800 LST in the summer. The stomatal conductance is linearly correlated with daily insolation when daily insolation was less than $18 \text{ MJ m}^{-2} \text{ d}^{-1}$. In high insolation ($>18 \text{ MJ m}^{-2} \text{ d}^{-1}$), low stomatal conductance occurred on the days with low temperature. During the growing season (April to October), rooting zone soil water provided enough water for plant activities and most of days had moderate vapor pressure deficit. The simulated daily mean leaf water potential did not fall below -0.2 MPa during the growing season, indicating that plant water stress was not significant at this site during the growing season in study year.

To examine the model's ability to simulate diurnal variation of NEE, we selected 10 days where the data missing rate is low in summer. Compared to other seasons in which leaf out or leaf fall occurred, heterogeneity of LAI was expected to be relatively small in the summer and hence the observed NEE was expected to show relatively small directional dependence. Fig. 7 shows the diurnal variation of meteorological fields for selected 10 days. The selected days had no rain and have moderate vapor pressure deficit ($<2 \text{ kPa}$) except for DOY 153 and DOY 216. Relatively low insolation was shown on DOY 189 and DOY 218. Fig. 8 shows the comparison of the model results with the observed NEE. The observations showed large fluctuations of NEE compared to the model results. Although even in well watered condition, upper canopy could experience stomatal closure in the afternoon with high evaporation demand, reduction of carbon uptake was not very large in well watered condition, resulting in slightly asymmetry pattern around noon (Williams *et al.*, 1996; Baldocchi, 1997). Therefore, the observed reduction of carbon uptake in the afternoon on DOY 169 and 189 seemed to be due to other factors such as local wind due to terrain effect which are not considered in the model rather than physiological control. On both days, vapor pressure deficits are not high enough to cause

Fig. 8. The comparison between model and observation for NEE of selected 10 days.

Fig. 9. The seasonal variation of daily-integrated (a) simulated GPP and R_e and (b) simulated NEE with gap-filled NEE in 2006.

stomatal closure in the afternoon (Fig. 7).

3.4. Seasonal variation of simulated GPP, R_e and NEE

In this section, we examined the simulated seasonal

variation of GPP, R_e and NEE. The GPP has been calculated using the calibrated model and R_e has been estimated using empirical formula of Resp 0 in Table 3. Fig. 9 shows the simulated time series of daily-integrated GPP, R_e and NEE with gap-filled NEE data in

2006. In spring, the GPP rapidly increased in magnitude. This is consistent with the quick increase in LAI. The gentle decrease of GPP during the summer resulted from the slow decrease of LAI and insolation. Some large reductions of GPP occurred due to very low insolation during the intensive rainy spell in the summer. In the autumn, the decrease of V_{cmax} also contributed to reduction of the simulated GPP. R_e showed peak in late July. Therefore, the simulated largest carbon uptake occurred in early June when GPP was large but R_e was not large yet.

The model captured the observed bimodal seasonal variation of NEE with a mid-season depression (Kwon *et al.*, 2009) reasonably with not serious overestimation. Relatively large difference was found during the leaf out period from DOY 110 to DOY 140 and in August. Kwon *et al.*, (2009) estimated seasonal variation of GPP using gap-filled NEE and empirically derived R_e and showed large reduction of GPP in August although insolation was not low in August. On the other hand, the simulated GPP showed only slight reduction in August due to slightly decreased LAI and insolation. The mechanism of GPP reduction in August needs to be examined. The difference during leaf out period might be due to large growth respiration during the period. Compared to other studies (Zhang *et al.*, 2006; Saigusa *et al.*, 2005), the reduction in carbon uptake was larger in mid-summer at this site due to lower insolation during the summer monsoon at this site in study year and decreasing LAI in the summer compared to constant LAI in other sites (Kwon *et al.*, 2009).

IV. DISCUSSION

In this section, we discussed uncertainty of the estimated annual NEE at this site in relation to complex terrain. In complex terrain, drainage flow develops very often during night, which results in difference between ecosystem respiration and turbulent flux at reference level. To examine the uncertainty of the estimated annual NEE in relation to complex terrain, we

made one hypothesis about R_e estimate and calculated annual NEE. We designated current estimate of NEE as Case 0 where current processed NEE data are assumed to represent R_e during the night.

Ecosystem respiration is sum of above ground respiration and the soil respiration. Above ground respiration data are not available at this site. The empirical formulas for soil respiration have been, however, developed at this site independently from chamber measurement. In Case 1, we used an empirical soil respiration formula developed at this site and assumed that soil respiration consists of 70% of R_e (Raich and Schlesinger, 1992). Chae (2008) has measured soil respiration at this site by the chamber method during Oct 2001 to Sept 2004 and developed empirical formula for each year. The year of 2004 shows similarity to this study year in that large precipitation was concentrated in July. And the soil respiration estimate in 2004 was lower than the observed nighttime NEE this year while soil respiration rates in 2002 and 2003 exceeded the observed NEE this year. Therefore, we used empirical formula of soil respiration in 2004 given by

$$R_s = 0.43 \exp(0.11 T_s) \quad (6)$$

where R_s is soil respiration rate ($\mu\text{mol m}^{-2} \text{s}^{-1}$) and T_s is soil temperature ($^{\circ}\text{C}$) at 10 cm depth.

The model parameter V_{cmax} has been calibrated to capture the mean NEE during the hours between 1000 LST and 1400 LST for selected days. The value of V_{cmax} increased from $24.3 \mu\text{mol m}^{-2} \text{s}^{-1}$ in case 0 to $27.8 \mu\text{mol m}^{-2} \text{s}^{-1}$ in Case 1. The estimated annual GPP, R_e and NEE are shown in Table 4 in comparison with gap-filled ones (Kwon *et al.*, 2009). Baldocchi (2008) reported that the ratio of annual R_e to GPP in undisturbed ecosystems was 0.77 while the ratio in disturbed ecosystem was 0.94. The ratio of Case 0 is 0.76 which is close to 0.77 in undisturbed forest, while that of Case 1 is 0.98, which is much higher than 0.77, implying that the ecosystem respiration estimate by Case 1 was overestimated. Using the FluxNet standardization, Kwon *et al.* (2009) reported that annual GPP, R_e and NEE are $835 \text{ gC m}^{-2} \text{yr}^{-1}$, $746 \text{ gC m}^{-2} \text{yr}^{-1}$ and $-87 \text{ gC m}^{-2} \text{yr}^{-1}$,

Table 4. The comparison of simulated annual GPP, ecosystem respiration and NEE with gap-filled ones in 2006

	GPP ($\text{gC m}^{-2} \text{yr}^{-1}$)	R_e ($\text{gC m}^{-2} \text{yr}^{-1}$)	NEE ($\text{gC m}^{-2} \text{yr}^{-1}$)	R_e/GPP
Case0	964	733	-231	0.76
Case1	1033	1001	-32	0.98
Kwon <i>et al.</i> (2009)	835	746	-87	0.89

respectively. Annual ecosystem respiration estimates are similar between two studies because both studies used same data set. The difference of annual GPP accounts for most of difference of NEE between the two studies. The difference between model estimate of annual NEE and gap-filled annual NEE is about $140 \text{ gC m}^{-2} \text{ yr}^{-1}$

V. SUMMARY

We have calibrated the mSPA model using the tower flux data to capture mean NEE during the hours between 1000 LST and 1400 LST and used to simulate GPP, and then evaluated the model's performance to simulate the seasonal variation of NEE. We also examined the critical controlling mechanism on the simulated carbon exchange over deciduous forest at Gwangnong in 2006. For the simulation of ecosystem respiration, the empirical formula was developed at this site. This study provides the calibrated model which could be served as a tool for up-scaling of fluxes from plot to regional scale.

The simulated GPP showed peak in early June and then decreased slowly in summer, which is consistent with the seasonal pattern of PAI. The simulation results indicated that daytime mean stomatal conductance was highly correlated with daily insolation in the summer and low stomatal conductance in high insolation occurred on the days with low temperature rather than high vapor pressure deficit. It suggests that plant rarely experienced water stress in the summer in 2006. The model captured the observed bimodal seasonal variation of NEE with a mid-season depression. The model estimates of annual GPP, R_e and NEE are $964 \text{ gC m}^{-2} \text{ yr}^{-1}$, $733 \text{ gC m}^{-2} \text{ yr}^{-1}$ and $-231 \text{ gC m}^{-2} \text{ yr}^{-1}$. Compared to observation based annual NEE, the model estimate showed more carbon uptake by about $140 \text{ gC m}^{-2} \text{ yr}^{-1}$. The main difference occurred during leaf-out period and in August.

적 요

2006년 광릉 활엽수림지역에서 관측된 자료를 활용하여 수정된 토양-식생-대기 모델을 보정하고 연간 순 생태 교환량의 계절변동성에 대한 모델의 모의 능력을 평가하고 탄소교환을 조절하는 주요 인자에 대하여 조사하였다. 수정된 토양-식생-대기 모델(mSPA model)을 1000 LST부터 1400 LST까지 관측된 낮 시간의

평균 순 생태 교환량(Net ecosystem exchange)을 모의하도록 보정한 후 총 일차 생산량(Gross primary productivity)을 계산하는데 사용하였고 생태 호흡량(Ecosystem respiration)은 관측지에서 개발된 경험식을 사용하여 추정하였다. 모델 결과는 여름철에 낮 시간의 평균 기공 전도도는 일사량과 매우 높은 상관성이 있음을 나타내었고 수증기 포치는 기공전도도의 변화에 큰 영향을 미치지 않는 것을 보였다. 모델은 성장기간에 두 개의 극대값을 갖는 관측된 순 생태교환량의 계절 변동성을 모의하였다. 모델에서 계산된 연간 총 생산량과 생태호흡량, 그리고 순 생태 교환량은 각각 $964 \text{ gC m}^{-2} \text{ yr}^{-1}$, $733 \text{ gC m}^{-2} \text{ yr}^{-1}$ 그리고 $-231 \text{ gC m}^{-2} \text{ yr}^{-1}$ 이었다. 관측값에 기반하여 산정된 연구결과와 비교할 때 모델 추정값이 약 $140 \text{ gC m}^{-2} \text{ yr}^{-1}$ 더 많은 탄소 흡수를 보였다. 복잡한 지형에서 연간 생태 교환량 추정의 불확실성에 대하여 논의하였다.

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