MODELING CO_2 EXCHANGES BETWEEN THE FOREST AND ATMOSPHERE

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INTRODUCTION

FOREST-ATMOSPHERIC INTERACTIONS

Net ecosystem exchange (NEE) of CO_2 between the forest ecosystem and atmosphere is determined by gross primary production (GPP) and ecosystem respiration (ER). CO_2 is sunk by the forest during the photosynthesis, which is called the gross primary productivity (GPP). However, CO_2 is released not only by the autotrophic respiration (AR) which consists of the respiration by leaf, stem, and root; but also by the heterotrophic respiration (HR) from microbial decomposition. The difference between the gross primary productivity (GPP) and the autotrophic respiration (AR) is the net primary productivity (NPP). Fig. 1 shows these components of forest-atmospheric interactions:

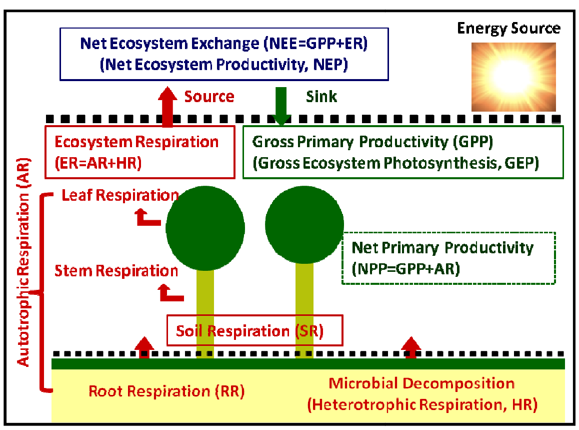

Figure 1: Components of CO_2 exchanges between the forest and atmosphere

RATIONALE OF THE STUDY

Gross primary productivity, one of the key ecosystem processes between the forest ecosystem and atmosphere, is more likely to be changed because of the global change issues. However, the assessment of global gross primary productivity (GPP) and determining the role of forest ecosystems in the global carbon cycle is particularly a difficult problem because of the high degree of spatial heterogeneity in the sinks and sources, and temporal dynamics of forest ecosystems across complex landscapes and regions. The recent growth of the worldwide networks of flux-tower stations has made it possible to analyze long-term trends in the CO_2 flux above ecosystems and to explain the relationship between the climatic variables and the forest carbon budget. However, because of the single point representation by this eddy covariance (EC) based method, and the requirement to assess the global GPP, the modeling with satellite based data have been expected. Nevertheless, because of the uncertainties associated with these satellites based models, it is necessary to validate these models based on site-specific study. Furthermore, it is essential to improve these satellites based models with combination to site-specific bottom-up study. The logical framework of this study has been shown in Fig. 2.

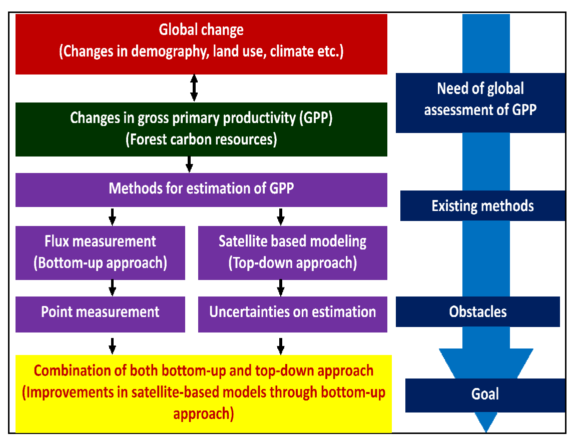

Figure 2: Logical framework of the study

OBJECTIVES

The general objective of this study was to improve the satellite based model with combination to site-specific flux studies. The specific objectives of this study were as follows:

1. Estimate the net ecosystem exchange (NEE) of CO_2 between the forest and atmosphere
2. Partition of net ecosystem exchange (NEE) into ecosystem respiration (ER), gross primary productivity (GPP), and net primary productivity (NPP)
3. Validate satellite based models of predicting gross primary productivity (GPP)
4. Develop a model for predicting gross primary productivity (GPP)

STUDY SITE AND MEASUREMENTS

The study site was Takayama deciduous broadleaf forest, located in Takayama city, in central Japan (36˚08'N, 137˚25'E, elevation 1420 m). The site consists of a temperate broadleaf deciduous forest, which is an important temperate forest in Japan. The eddy covariance method was applied to measure the carbon flux (Fc) above the forest canopy. The vertical flux of CO_2 in the turbulent surface layer is calculated as the covariance of the vertical wind velocity and CO_2 density. Flux (Fs) was calculated by integrating the change in CO_2 density with respect to time from ground level up to canopy level (25m). This study was carried out for the period of 2004 to 2005. The input data and the calculated outputs have been shown in Fig. 3.

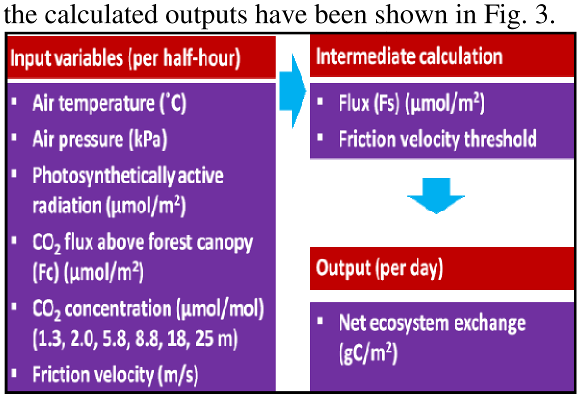

Figure 3: Input data and outputs for NEE estimation

Eight days composite product of surface reflectance data observed by NASA, MODIS sensor onboard the satellite was obtained for the period of 2004-2005 representing Takayama forest and the normalized difference vegetation index (NDVI), enhanced vegetation index (EVI), and land surface water index (LSWI) was calculated.

ANALYSIS AND RESULTS

ESTIMATION OF NEE AND ITS PARTITION

NEE was obtained by combining the Flux (Fc) and the Flux (Fs). By using the temperature response function of night time ecosystem respiration, day period NEE was separated into ER and GPP. Both functions of night period temperature response function of ER and day period temperature response function of GPP were used to correct the fluxes having less than

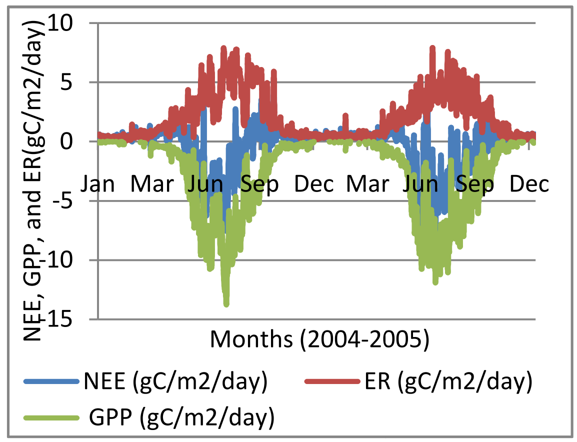

Figure 4: Estimation of NEE and its partition

0.2 m/s friction velocity, and to fill the gaps in the data. The estimated NEE and its partitioned components have been shown in Fig. 4 and in Table 1.

Table 1: Estimation of ecosystem components

S. N.	Ecosystem components	Quantity (tC/ha/yr)	Method
1	Ecosystem respiration (ER)	7.39	EC
2	Gross primary productivity (GPP)	9.48	EC
3	Soil respiration (SR)	6.8	Chamber
4	Root respiration (RR)	2.9	Trench
5	Heterotrophic respiration (HR)	3.9	SR-RR
6	Autotrophic respiration (AR)	3.49	ER-HR
7	Net primary productivity	5.99	GPP-AR

VALIDATION OF SATELLITE BASED MODELS

Two satellite based models namely MODIS-GPP and vegetation photosynthesis model (VPM) were taken for validation at Takayama deciduous broadleaf forest. The equations of these models are as follows:

MODIS, GPP=MLUE*T*VPD*fPAR*PAR
VPM, GPP=MLUE*T*LSWI*EVI*PAR

Validation of MODIS-GPP model

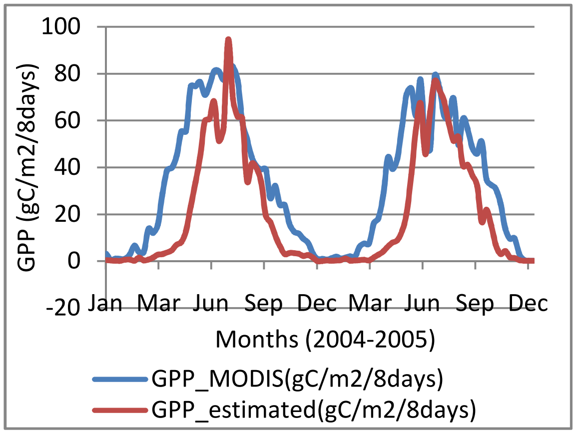

Figure 5: Validation of MODIS-GPP model

The results of validation for MODIS-GPP model has been shown in Fig. 5. The gross primary productivity (GPP) as given by MODIS-GPP team was compared with the observed gross primary productivity (GPP). MODIS-GPP estimation was 15.5 tC/ha/year. However, estimation from eddy covariance method was 9.5 t C/ha/year. This shows that satellite based model overestimated GPP by 6 t C/ha/year as compared to the observed GPP of 9.5 t C/ha/year.

Validation of VPM-GPP model

The observed gross primary production (GPP) as estimated by flux measurements were 9.5 t C/ha/year. However, the predicted gross primary production (GPP) by the vegetation photosynthesis (VPM) model was 7.0 tC/ ha/year. The result of validation with VPM model has been shown in Fig. 6. The prediction by this VPM model was better than the prediction by MODIS-GPP model.

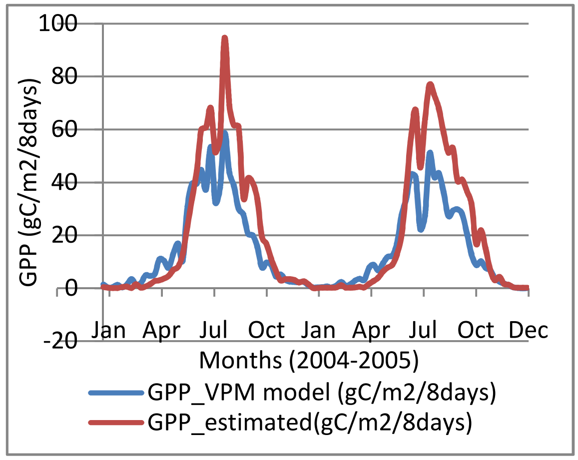

Figure 6: Validation of VPM-GPP model

However, neither MODIS-GPP nor VPM-GPP model could best estimate the gross primary production (GPP) at Takayama forest. Therefore, there were uncertainties associated with satellite based modeling. That's why; it was found that the potential causes of uncertainties should be understood and the satellite based model should be improved.

IMPROVEMENTS IN SATELLITE BASED MODELS

The combination of the following two hypotheses would best estimate gross primary productivity at Takayama forest:

1. Modeling with the absorbed PAR by the photosynthetically active portions of vegetation would better estimate the gross primary productivity, by changing light use efficiency as GPP/ABPAR.
2. The selection of the best independent variables of GPP and the modeling with these variables.

Selection of best parameters of GPP

While considering 11 variables (Table 2), only air temperature (AT) and absorbed PAR (ABPAR) could well explain GPP at Takayama forest.

At Takayama forest, neither soil water content (SWC) nor water vapor pressure deficit (VPD) could explain the variation of GPP. These variables were considered as an important stress factors in MODIS-GPP and VPM-GPP model. Because of the humid temperate forest, and the forest located in hills and valleys, SWC and VPD were not the stress factors.

Table 2: Regression analysis with GPP (linear and non-linear)

S.N.	Independent variables	GPP
1	Incident Photosynthetically active radiation (IPAR)	$R2=0.15$
2	Air temperature (AT)	$R2=0.81$
3	Soil temperature (ST)	$R2=0.77$
4	Water vapor pressure deficit (VPD)	$R2=0.09$
5	Soil water content (SWC)	$R2=0.35$
6	Land surface water index (LSWI)	$R2=0.0009$
7	Day length (DL)	$R2=0.41$
8	Enhanced vegetation index (EVI)	$R2=0.85$
9	Absorbed PAR by canopy (APAR)	$R2=0.58$
10	Absorbed PAR by photosynthetically active canopy (ABPAR)	$R2=0.87$
11	Atmospheric CO2 concentration (CO2)	$R2=0.26$

These were the reason why previous models either over estimated or under estimated the GPP.

NEW MODEL FOR TAKAYAMA FOREST

With consideration to only those independent variables which showed a good relationship with gross primary productivity (GPP), the following equation was derived:

$$GPP= MLUE *ABPAR*ATs$$

Where,
GPP=Gross primary productivity ($gC/m^2/8days$)
MLUE = Maximum light use efficiency observed at Takayama forest (5.6 g C per mol of ABPAR)
ABPAR= Absorbed PAR by photosynthetically active portions of canopy
ATs=Air temperature in the fraction of 1.0

VALIDATION OF NEW MODEL

The predicted gross primary productivity at Takayama forest from 2004 to 2005 by the new model was compared with the observed gross primary productivity (GPP) through flux measurements (Fig. 7).

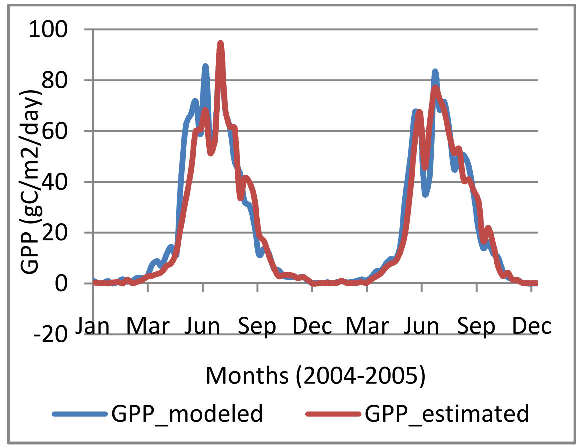

Figure 7: Validation of new model at Takayama forest

The model predicted gross primary productivity was 10 tC/ha/year, and the observed GPP by eddy covariance method was 9.5 tC/ha/year. By selecting only the best independent variables and by applying the relationship of absorbed PAR by the only photosynthetically active portions of tree canopy (ABPAR), there was a significant improvement in the prediction of gross primary productivity (GPP) at Takayama forest.

CONCLUSION

First, this study accomplished a comprehensive study on the estimation of gross primary productivity (GPP), ecosystem respiration (ER), and net primary productivity (NPP). While comparing the satellite based prediction of GPP with the observed GPP, this study identified the uncertainties associated with satellite based modeling. After analyzing the observed relationship between the GPP and its independent variables, only two variables namely, the AT and the ABPAR could show a good relationship with GPP. Thus, the causes of uncertainties in satellite based models were identified. Therefore, the new model was derived selecting the best independent variables of GPP. This new model could better predict the GPP at Takayama forest. Therefore, this study highlighted the importance of site-specific and bottom-up approach in order to improve the satellite based models.