《**Note**》

Improvement accuracy of terrestrial NPP estimation using ADEOS-II/GLI data

(Part 1 : Study on photosynthesis activity by using FluxNet tower sites data)

Juthasinee Thanyapraneedkul
(Department of Advanced Information and Computer sciences, School of Interdisciplinary Scientific Phenomena and Information, Nara Women's University)

Kanako Muramatsu
(Kyousei Science Center for Life and Nature, Nara)

Motomasa Daigo
(Doshisha University)

Abstract

Ecosystem process model and remote sensing is useful for estimate Net Primary Production (NPP). This research will study to improve accuracy of terrestrial NPP estimation using ADEOS-II/GLI data as input towards Global Climate Observation Mission and carry Second generation Global Imager (GCOM-C/SGLI) that will be launched in near future. Fluxes data from FluxNet network[1] were used to improve NPP estimation algorithms from stand scale up to regional and global estimates. Firstly, Gross Primary Production (GPP) was estimated from flux Net Ecosystem Exchange (NEE) data by analyze GPP and PAR relationship. GPP is expected to be a function of PAR. In this study the relation ship is exponential (rectangular hyperbola) the maximum GPP (Pmax) at light saturation and slope to understand the photosynthesis capability be found. In next step, ADEOS-II/GLI data vegetation condition and meteorological variable will be utilized for NPP estimation as well.

Key words : NEP, GPP, PAR, CO_2 flux, VPD, Air temp, Flux Net

1. Introduction

Net primary production (NPP) is defined as the net production of organic matter by vegetation, the balance between the Gross Primary Production (GPP) by photosynthesis and the respiration of vegetation. GPP can be obtained from the integral of photosynthesis over Photosynthetically active radiation (PAR) from flux sites and satellite Vegetation Index (VI). To estimate GPP, PAR data with the diurnal variations is required. It's very useful to understand relationship of GPP and photosynthesis activity for potential estimation of NPP from satellite data. Therefore, light photosynthesis curve play an important role in GPP estimation. Fluxes data can be used to improve algorithms used to scale up from stand to regional estimates of net ecosystem productivity (NEP). Mostly of flux data measure net ecosystem exchange (NEE) with an eddy covariance (EC) system and record meteorological data regularly. The EC method forms provides a direct measurement of the net exchange of CO_2, water vapor and sensible heat between a vegetated surface and the atmosphere.[1] EC measurements can reliable estimates of long-term C sequestration to correct nighttime fluxes. Soil and vegetation gas exchange measurements are highly desirable because they can be scaled up to give an independent short-term measurement of NEP as well as provide insight into CO_2 exchange processes within the ecosystem. Later, we can also estimate GPP from NEE flux data by using ecosystem respiration. The objective of this study are firstly find relationship between NEP and PAR by using FluxNet tower data sites in each IGBP (The International Geosphere-Biosphere Programme) land covers classes. Secondly, in near future, study environmental factors (seasonal variation ; vegetation index and short term variation ; meteorological parameters) that have effect to light photosynthesis curve.[2] Furthermore, the final goal of this research is to improve accuracy of terrestrial NPP estimation using ADEOS-II/GLI data as input towards Global Climate Observation Mission and carry Second generation Global Imager (GCOM-C/SGLI) that will be launched in early 2014.

2. Study sites and Methodology

Selected sites from FLUXNET website[3] will be used in this study. FLUXNET ; a "network of regional networks," coordinates regional and global analysis of observations from micrometeorological tower sites. The flux tower sites use eddy covariance methods to measure the exchanges of carbon dioxide (CO_2), water vapor, and energy between terrestrial ecosystems and the atmosphere. At present, over 500 tower sites are operating on a long-term and continuous basis. Researchers also collect data on site vegetation, soil, hydrologic, and meteorological characteristics at the tower sites.

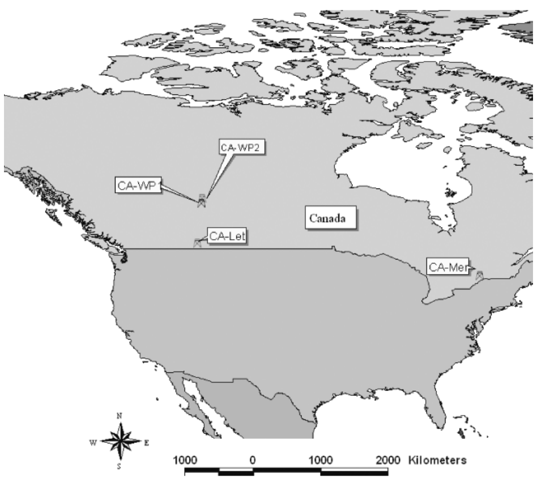

Fig. 1 Study sites

2. 1) Study sites

FluxNet Canada Sites are show in Table 1 and figure 1. Sites were selected

Table 1　Study sites

Site	Data Availability		Vegetation type	Lat	Lon
	From	To			
CA-Let	Jun 98	Apr 08	Mixed Grass Prairie	49.7093	−112.94
CA-WP 2	May 04	Oct 05	Wet land (Sphagnum moss)	55.5375	−112.334
CA-WP 1	Aug 03	Dec 05	Mixed Forests	54.9538	−112.467
CA-Mer	Jun 98	Dec 04	Peat land ecosystems	45.4094	−75.5186

base on IGBP land cover class then in Table 1 are representative sites in four kind of land cover class. Mostly of flux and meteorological data are comma delimited text files. The first row of each data file has a header with the parameter names listed below. The first seven columns of data file represent the time the data was collected (or time stamp). With the exception of the precipitation data, which represents a half-hour total, the other values in the data files represent 30 minute averages for the time period ending at the noted time stamp. The units and description for the parameter names are listed below.

Site Description : CA-Let[4]

Located at Lethbridge, Alberta, Canada (altitude 951 meters above mean sea level), approximately 145 kilometers east of the Canadian Rockies and 95 kilometers north of the United States (Montana) border. Mixed Grass Prairie. Maximum canopy height is approximately 50 cm.

Eddy Covariance and Energy Balance and Basic Micrometeorological Instruments are Infrared Gas Analyzers (CO_2 and H_2O) : LiCor LI-6262, Photosynthetically Active Radiation : LiCor Quantum Sensor : LI-190 SA, Air Temperature and Relative Humidity : Campbell Scientific 207 probe.

Parameter	**Units**	**Description**
Year	Year	Year
Month	Month	Number for Month of Year
Date	Day	Number for Day of Month
Day	Day	Day of Week
Julian Day	Day	Julian Day
hour	Hours	Hour of Day
minute	minutes	Minute of the Hour
SonicH	W m^{-2}	Sensible Heat Flux
LE	W m^{-2}	Latent Heat Flux
E	mmol m^{-2} s^{-1}	Evapotranspiration
C	μmol m^{-2} s^{-1}	Net Ecosystem Exchange
MomtmFlux	m^2 s^{-2}	Momentum Flux
U*	m s^{-1}	Friction Velocity
M-O length	m	Monin － Obukov length
av c	μmol mol^{-1}	Mean CO_2 concentration

av h	mmol mol^{-1}	Mean H_2O concentration
windspeed	m s^{-1}	Mean wind speed
wind dir	degrees	Wind direction (compass direction)
PPFD	μmol $m^{-2}s^{-1}$	Photosynthetic Photon Flux Density
Net Rad	W m^{-2}	Net radiation
207 Temp	^{0}C	Air Temperature 207 probe 2 m above ground
RH	%	Relative Humidity 207 probe 2 m above ground
Soil Heat Flx 1	W m^{-2}	Soil Heat Flux 2 cm below surface
Soil Heat Flx 2	W m^{-2}	Soil Heat Flux 2 cm below surface
Air 5 m	^{0}C	Air temp, aspirated thermocouple 5 m above ground
Air 1 m	^{0}C	Air temp, aspirated thermocouple 1 m above ground
Soil 2 cm	^{0}C	Soil temp 2 cm depth thermocouple
Soil 4 cm	^{0}C	Soil temp 4 cm depth thermocouple
Soil 8 cm	^{0}C	Soil temp 8 cm depth thermocouple
Soil 16 cm	^{0}C	Soil temp 16 cm depth thermocouple
Precip	mm	Total Precipitation

Site Description : CA-WP 1

Site located approximately 200 km north-east of Edmonton, Alberta close to the confluence of the La Biche and Athabasca Rivers (35 km north of the town of Grassland, Alberta). Mean annual precipitation is 503.7 mm, mean annual temperature is 2.1°C, and elevation is 626 m. The May Tower site is a poor fen dominated by *Sphagnum* moss. Tony's Fen is a rich fen dominated by *Carex,* with a ground layer of 'brown mosses'.

Eddy Covariance and Energy Balance and Basic Micrometeorological Instruments are Infrared Gas Analyzer (CO_2 and H_2O) : LiCor LI-7500 (Open-path), Photosynthetically Active Radiation : LiCor Quantum Sensor LI-190 SA. The meteorological equipment mast is 3 m tall. A separate mast (3 m tall) is used for the eddy covariance system.

Parameter	**Units**	**Description**
DataType	n/a	Flx 2 Met 2
Site	n/a	AB-May
SubSite	n/a	FlxTwr
Year	Year	Year UTC
Day	Day	Julian Day UTC
End_Time	HMin	Hour Minute UTC (e.g. 730 : 30 minutes after the hour 7)
CO_2MixingRatio_AbvCnpy_3 m	μmol mol^{-1}	Mean CO_2 mixing ratio (dry air) LiCor LI-7500
H_2OMixingRatio_AbvCnpy_3 m	mmol mol^{-1}	Mean H_2O mixing ratio (dry air) LiCor LI-7500
CO_2Flux_AbvCnpy_3 m	μmol $m^{-2}s^{-1}$	Net Ecosystem Exchange via Eddy Covariance at 3 m (CO_2 storage term not included)
NEE_AbvCnpy_3 m	μmol $m^{-2}s^{-1}$	Net Ecosystem Exchange via Eddy Covariance at 3 m (CO_2 storage term included)
LatentHeatFlux_AbvCnpy_3 m	W m^{-2}	Latent Heat Flux via Eddy Covariance at 3 m
SensibleHeatFlux_AbvCnpy_3 m	W m^{-2}	Sensible Heat Flux via Eddy Covariance at 3 m
FrictionVelocity_AbvCnpy_3 m	m s^{-1}	Friction Velocity at 3 m

HMP_AirTemp_2 m	℃	Vaisala HMP 45 C in an aspirated shield at 2 m
HMP_RelHum_2 m	%	Vaisala HMP 45 C in an aspirated shield at 2 m
Atm_Pressure	kPa	Atmospheric Pressure Vaisala PTB 101 B
NrL_NetRad_ AbvCnpy_3 m	W m^{-2}	Net radiation, Kip & Zonen NR Lite at 3 m
LI_DownPAR_AbvCnpy_3 m	μmol $m^{-2}s^{-1}$	Photon Flux Density (400−700 nm) LI-190 SA at 3 m
LI_UpPAR_3 m	μmol $m^{-2}s^{-1}$	Photon Flux Density (400−700 nm) LI-190 S
A at 3 m WaterTableDepth	cm	Water table level relative to average Hummock surface (negative values represent water below hummock surface)
RMY_WindSpd_AbvCnpy_3 m	m s^{-1}	Average wind speed R. M. Young 05103−10 at 3 m
RMY_WindDir_AbvCnpy_3 m	degrees	Compass direction of wind R. M. Young 05103−10 at 3 m

Site Description : CA-WP 2[5]

The main flux site (La Biche River, Western Peatland) is located approximately 200 km north-east of Edmonton, Alberta close to the confluence of the La Biche and Athabasca Rivers (35 km north of the town of Grassland, Alberta). At the nearby town of Athabasca, mean annual precipitation is 503.7 mm, mean annual temperature is 2.1℃, and elevation is 626 m. The peatland site is currently dominated by stunted trees of *Larix laricina* and *Picea mariana,* with *Betula pumila, Ledum groenlandicum* and *Salix* sp. (shrubs) and a wide range of moss species.

Eddy Covariance and Energy Balance and Basic Micrometeorological Instruments are Infrared are Gas Analyzer (CO_2 and H_2O) : LiCor LI-7000, Photosynthetically Active Radiation : LiCor Quantum Sensor LI-190 SA. The main equipment mast is 9.3 m tall, with instruments installed at various heights as noted below. The infrared gas analyzer is enclosed in temperature controlled housing and maintained at a temperature of 37±1℃. The infrared gas analyzer and housing are mounted on a 4.5 m tall scaffold below the Ultrasonic anemometer.

Parameter	**Units**	**Description**
DataType	n/a	Flx 2 Met 2
Site	n/a	AB-WPL
SubSite	n/a	FlxTwr
Year	Year	Year UTC
Day	Day	Julian Day UTC
End_Time	HMin	Hour Minute UTC (e.g. 730 : 30 minutes after the hour 7)
CO_2MixingRatio_AbvCnpy_9 m	μmol mol^{-1}	Mean CO_2 mixing ratio (dry air) LiCor LI-7000
H_2OMixingRatio_AbvCnpy_9 m	mmol mol^{-1}	Mean H_2O mixing ratio (dry air) LiCor LI-7000
CO_2Flux_AbvCnpy_9 m	μmol m^{-2} s^{-1}	Net Ecosystem Exchange via Eddy Covariance at 9.3 m (CO_2 storage term not included)
NEE_AbvCnpy_9 m	μmol m^{-2} s^{-1}	Net Ecosystem Exchange via Eddy Covariance at 9.3 m (CO_2 storage term included)
LatentHeatFlux_AbvCnpy_9 m	W m^{-2}	Latent Heat Flux via Eddy Covariance at 9.3 m
SensibleHeatFlux_AbvCnpy_9 m	W m^{-2}	Sensible Heat Flux via Eddy Covariance at 9.3 m
FrictionVelocity_AbvCnpy_9 m	m s^{-1}	Friction Velocity at 9.3 m
PRT_AirTemp_5 m	℃	Omega TX-92 A RTD in an aspirated shield at 4.5 m

HMP_AirTemp_5 m	˚C	Vaisala HMP 45 C in an aspirated shield at 4.5 m
HMP_RelHum_5 m	%	Vaisala HMP 45 C in an aspirated shield at 4.5 m
CS 105_Atm_Pressure	kPa	Atmospheric Pressure Vaisala PTB 101 B
CNR_ShortWaveIn_6 m	W m^{-2}	Short wave Solar radiation, Kip & Zonen CNR 1 at 6.15 m
CNR_ShortWaveOut_6 m	W m^{-2}	Short wave Solar radiation, Kip & Zonen CNR 1 at 6.15 m
CNR_LongWaveIn_6 m	W m^{-2}	Long wave radiation, Kip & Zonen CNR 1 at 6.15 m
CNR_LongWaveOut_6 m	W m^{-2}	Long wave radiation, Kip & Zonen CNR 1 at 6.15 m
CNR_NetRad_6 m	W m^{-2}	Net radiation, Kip & Zonen CNR 1 at 6.15 m
LI_DownPAR_AbvCnpy_9 m	μmol m^{-2} s^{-1}	Photon Flux Density (400–700 nm) LI-190 SA at 9.3 m
LI_UpPAR_6 m	μmol m^{-2} s^{-1}	Photon Flux Density (400–700 nm) LI-190 SA at 6.15 m
BF 3_DownTotalPAR_9 m	μmol m^{-2} s^{-1}	Photon Flux Density (400–700 nm) Delta-T-Devices BF 3 at 9.3 m
BF 3_DownDiffusePAR_9 m	μmol m^{-2} s^{-1}	Photon Flux Density (400–700 nm) Delta-T-Devices BF 3 at 9.3 m
BF 3_DownDirectPAR_9 m	μmol m^{-2} s^{-1}	Photon Flux Density (400–700 nm) Delta-T-Devices BF 3 at 9.3 m

Site Description : CA-Mer

Located just east of Ottawa, Ontario, Canada. Mer Bleue is an ombrotrophic (rain fed) bog covering 2800 ha in area. The bog is roughly oval shaped, with an east-west orientation. The western end is dissected by two longitudinal gravel deposits. The bog surface is dominated by a hummock-hollow microtopography that has an average relief of 25 m between hummocks and hollows. Hummocks compose 70% of the surface and have a median diameter of about 1 m. Overstorey vegetation is dominated by a shrub canopy that is between 0.2–0.3 m in height.

Fluxes of carbon dioxide, latent and sensible heat have been continuously measured using the eddy covariance (EC) technique since June 1998. A correction factor of 1.25 has been applied to all F_c (CO_2 flux) measurements prior to Jan 1, 2004. This correction was required to match F_c measured with the old EC system and new EC systems. This likely reflects the average proportion of flux lost with damping of high-frequency fluctuations due to lower flow rates in the sampling tube, lower sampling rates and lower IRGA response rates (LI-COR model 6252 vs. 7000). Eddy-covariance sensors were mounted at the 3-m level on a 1 m boom extending from the tower to the North.

Label	**Units**
DataType	(n/a)
Site	(n/a)
SubSite	(n/a)
Year	(UTC)
Day	(UTC)
End_Time	(UTC)
NEP	(umol/m^2/s)
R	(umol/m^2/s)
GEP	(umol/m^2/s)
GapFilledNEP	(umol/m^2/s)
GapFilledR	(umol/m^2/s)
GapFilledGEP	(umol/m^2/s)

ModelledNEP	(umol/m^2/s)
ModelledR	(umol/m^2/s)
ModelledGEP	(umol/m^2/s)
EClosureNEP	(umol/m^2/s)
EClosureR	(umol/m^2/s)
EClosureGEP	(umol/m^2/s)
GapFilledEClosureNEP	(umol/m^2/s)
GapFilledEClosureR	(umol/m^2/s)
GapFilledEClosureGEP	(umol/m^2/s)
ModelledEClosureNEP	(umol/m^2/s)
ModelledEClosureR	(umol/m^2/s)
ModelledEClosureGEP	(umol/m^2/s)

2. 2) Methodology

In FluxNet Canada NEE means (*Parameter's name : NEE_AbvCnpy_3 m or 9 m and F_s included*) was calculated as[3]

$$\mathrm{NEE} = \mathrm{F\_c} + \mathrm{F\_s} \quad (1)$$

Where F_c is the CO_2 flux at 3 m (site CA-WP 1) and at 9 m (site WP 2) and F_s is CO_2 storage (the 30 min change in CO_2 stored within the air column below the EC instrumentation). F_s was computed using the CO_2 concentration measured by the IRGA at 3 or 9 m.[6] With this definition, positive values of NEE correspond to C losses from the ecosystem (release) and negative for uptake. F_s or CO_2 storage will stored CO_2 in canopy at night and stored CO_2 is transported to the atmosphere after sunrise with increasing radiation and boundary layer growth.[7] The flux of CO_2 was determined as follows (*Parameter's name : CO_2Flux_AbvCnpy_3 m or 9 m and F_s not included*)

$$\mathrm{F\_c} = \rho_a \, \mathrm{cov}(w \; s\_c) \quad (2)$$

where cov(w s_c) is the covariance of the vertical wind speed (w) and the mixing ratio of CO_2 (s_c) over the averaging interval, usually 30 minute. Measurements were performed at 3 m (site CA-WP 1) and at 9 m (site WP 2) level. ρ_a is the density of dry air is given by $\rho_a = P/(R*T)$ where ρ_a is the air density in kg/m^3, P is pressure in Pa, R is the specific gas constant ; 287.05 J/kg^{-1}K^{-1} for dry air, and T is temperature in kelvins.

The rate of change in CO_2 storage (the "storage flux" ; F_s) in the air column below the EC measurement level was calculated from the mole fraction measurements of the LI-6252 IRGA sampling the eight profile levels using

$$F\_s = summation\_over\_j\ (dh(i, j)\ \rho\ (i, j)\ (dchi\_c(i, j)/dt)) \tag{3}$$

where dh is the thickness of the j-th air layer centered around each measurement height, and rho is the mean molar air density in the layer. Then, dchi_c(i, j)/dt was calculated for half-hour i using dchi _c(i, j)/dt=(chi(i+1, j)−chi(i−1, j))/dt where dt=3600s. When mixing ratio s_c was available from the LI-6262 it was used instead of mole fraction chi_c and mean air density ρ was replaced by mean dry air density ρ_a in the equation above.

In this study, FluxNet NEE (umol/m^2/s) from eddy covariance method, downPAR (μmol/mol), CO_2 concentration (μmol/mol), CO_2Flux (umol/m^2/s) and Air Temp (Celsius) from CA-Let site, CA-WP 2 site, CA-WP 1 site and CA-Mer were used. Half-hour fluxes data were calculated for average and group in each month of available years. The calculation separated growing season data (Apr to Sep) from other months and only used growing season data for fitting the GPP and PAR relationship curve. Analyze the relationship between GPP and PAR of each Land cover class. Using[8] NEE FluxNet data and equation (1), (2) and (3) for GPP calculation

$$NEE = -NEP \ (4)$$

$$GPP = NEP + Rec \ (5)$$

$$Rec = (A_1)\ Q^{(T1-T\ mon)/10} \ (6)$$

Here, Q=2.0 and A_1 is night time NEP ($mgCO_2/m^2/s$) at air temperature (T_1) in the neutral night (friction velocity ; u* more than 0.2 m/s) only, Tmon is Average air temperature in that month. And then plot the graph between GPP and PAR relationship to find maximum GPP level at light saturation. The relation ship between GPP and PAR is expected to exponential function (rectangular hyperbola) then find a and b by using[9]

$$GPP = b\ {*a}\ PAR/(1 + a\ PAR) \ (7)$$

Here, a is initial slope to photosynthesis capability, b (Pmax) expresses the maximum level of GPP at light saturation (PAR is highest).

3. Results and Discussion

If there is a linear relationship between PAR and photosynthesis, it can use daily average PAR values estimated from the integrated daily or monthly PAR data instead of using light photosynthesis

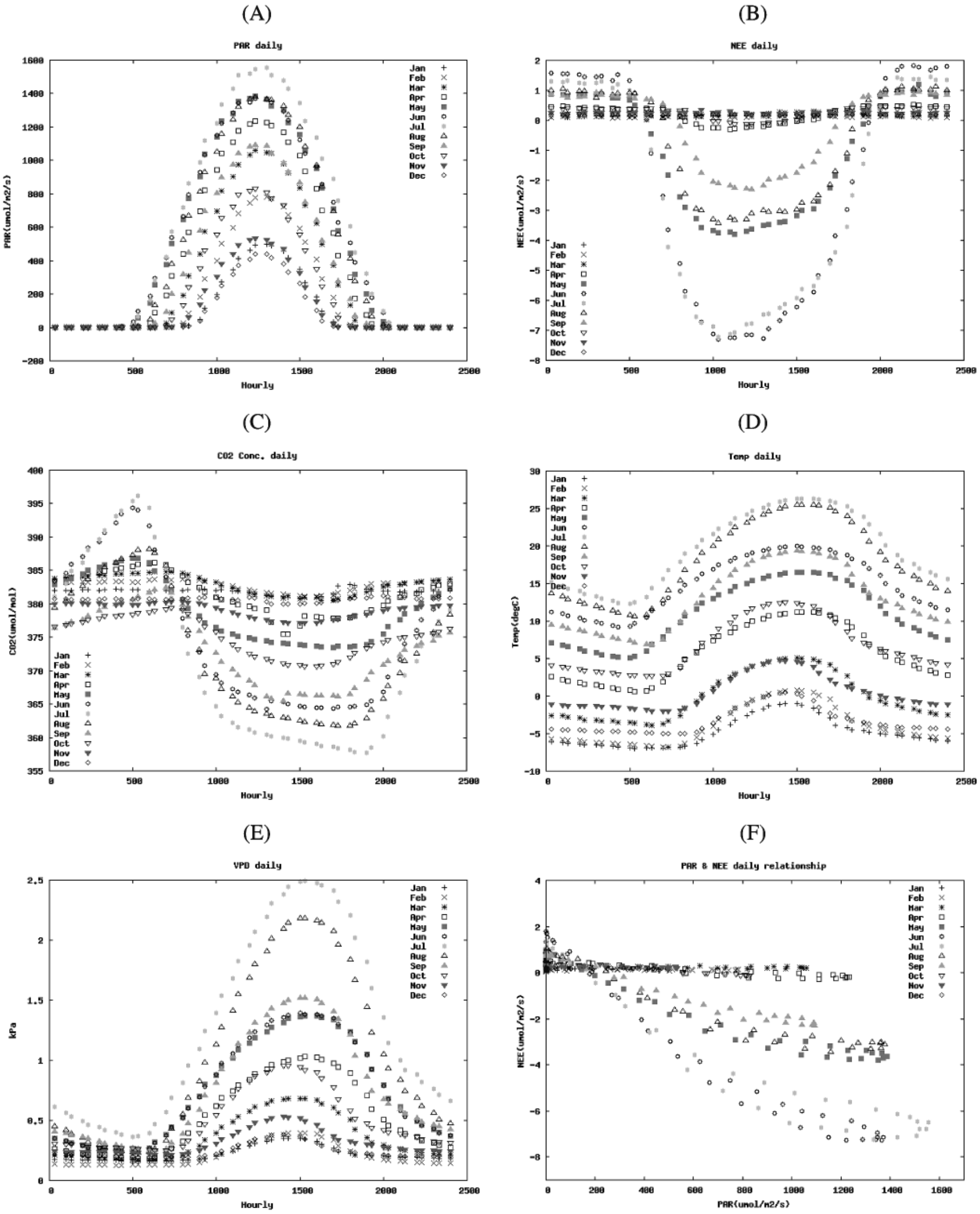

Fig. 1 A-F　show CA-Let site's diurnal data of PAR (A), NEE (B), CO_2 Concentration (C), Air temperature (D), Vapor Pressure Deficit (E) and NEE and PAR relationship (F)

10

curve that have diurnal variation (seasonal and meteorological) over time. Figure 1 A-F show diurnal data of CA-Let site that show PAR, NEE, CO_2 Concentration, Air temperature, Vapor Pressure Deficit and NEE and PAR relationship, respectively.

Fig. 2, A-D graph show relationship between NEE and PAR of CA-Let site, CA-WP 2 site, CA-WP 1 site and CA-Mer, respectively. Fig. 3 shows GPP and PAR relationship of CA-WP 2 site. This

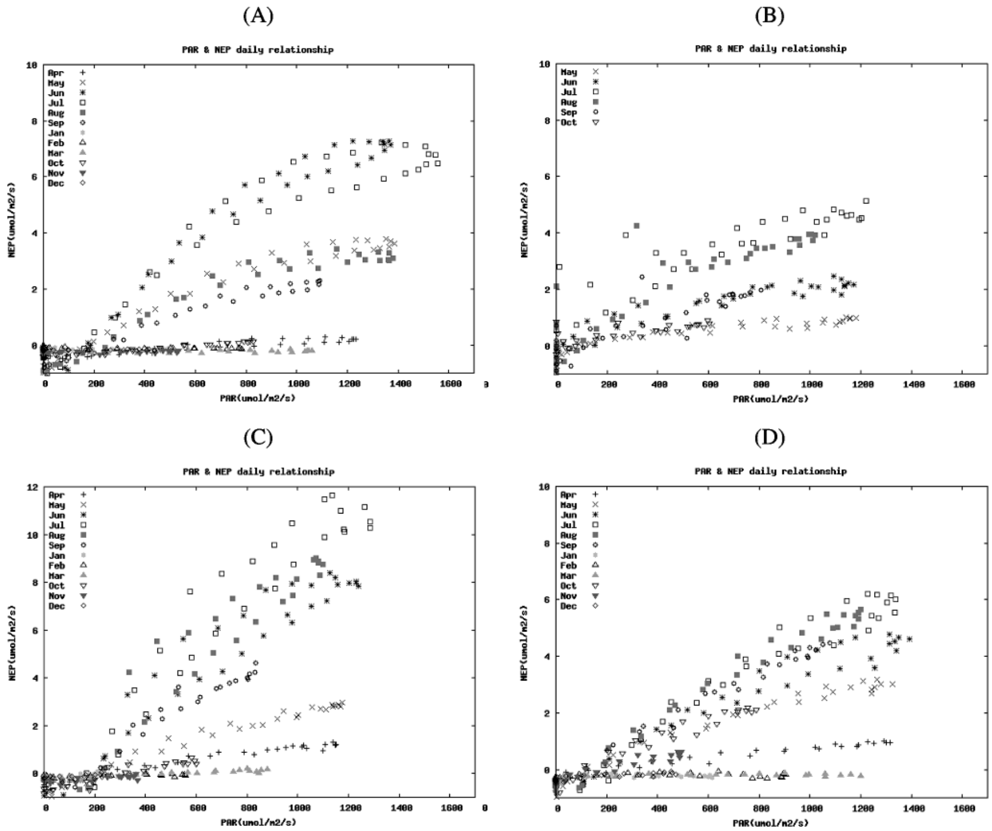

Fig. 2 A-D graph show relationship between NEP and PAR of CA-Let site (A), CA-WP 2 site(B), CA-WP 1 site(C) and CA-Mer(D), respectively.

Table 2 show NEE & PAR relationship (R^2)

IGBP Land cover type	GRA : Grassland	WET : Permanent Wetlands	MF : Mixed Forests	OSH : Open Shrublands
SiteName	CA-Let	CA-WP 2	CA-WP 1	CA-Mer
Jan-Dec	0.6546	N/A	0.6575	0.6524
Apr-Sep (Only growing season)	0.7308	0.6318 (May-Sep)	0.7252	0.8323
Apr	0.9255	N/A	0.9721	0.9702
May	0.9931	0.9207	0.9897	0.9837
Jun	0.9952	0.9031	0.967	0.989
Jul	0.988	0.8636	0.9785	0.9837
Aug	0.9909	0.7866	0.9787	0.9848
Sep	0.9929	0.7376	0.9811	0.9778

relationship tended to saturate at peak PAR values. Reveal that GPP and PAR have non-linear relationship. NEE are high in mixed forest ; CA-WP 1, grassland ; CA-Let ; open Shrub lands ; CA-Mer and wet land ; CA-WP 2, respectively.

From Table 2 Grassland is the best representative for study NEP and PAR relationship. The best NEP and PAR relationship is CA-Let site ; grassland (R^2=0.9952) in June and CA-WP 1 ; Mixed

Forests (R^2＝0.9897) in May. After PAR reach 1200−1400 (μmol/m^2/s), NEP seem to be constant at around 6−12(μmol/m^2/s). In summer (April September), NEP and PAR was higher than other months.

4. Future Tasks

Calculate light photosynthesis curve in other flux sites. Night time NEP and Wind velocity will use for ecosystem respiration calculation then GPP will calculated and fit to rectangular hyperbola equation by GPP＝b *a PAR/ (1＋a PAR) equation. Soil respiration and temperature will be examined. For develop accuracy of NPP calculation model, ADEOS-II/GLI satellite vegetation index and some significant meteorological variables (short term variation) such as Air temperature, Vapor Pressure Deficit (VPD), CO_2 flux and Humidity will be analyzed to see pattern that may be have significant relation to light photosynthesis curve as well.

Acknowledgement

This research was supported by Academic Frontier project (1999−2010).

References

1 The Fluxnet Canada Data Information System (DIS), http : //www.fluxnet-canada.ca (Download on July, 2008)

2 Reiko Ide, et al, 2008 "Estimating forest photosynthetic capacity by using spectral vegetation indices : Comparison among three larch forests in Japan, *SATECO proceeding,* pp. 87.

3 Fluxnet website http : //daac.ornl.gov/FLUXNET/

4 Flanagan, L. B., B. G. Johnson, 2005. Interacting effects of temperature, soil moisture and plant biomass production on ecosystem respiration in a northern temperate grassland. Agricultural and Forest Meteorology 130, 237−253

5 Barr, A. G., Black, T. A., Hogg, E. H., Kljun, N., Morgenstern, K., Nesic, Z., 2004. Inter-annual variability in the leaf area index of a boreal aspen-hazelnut forest in relaion to net ecosystem production. Agricultural and Forest Meteorology 126 : 237−255.

6 Humphreys, E. R. and Black, T. A. and Morgenstern, K. and Li, Z. and Nesic, Z., 2005, "Net ecosystem production of a Douglas-fir stand for three years following clear cut harvesting", *Global Change Biology,* In press.

7 Nobugo Saigusa, et al, 2002 "Gross primary production and net ecosystem exchang of a cool-temperate deciduous forest estimated by the eddy covariance method", *Agricultural and Forest Meteorology,* 112, 203−215

8 Nobugo Saigusa, et al, 2005 "Inter annual variability of carbon budget components in an Asiaflux forest site estimated by long term flux measurements", *Agriculture and Forestry Meteorology,* 134, 4−16.

9 Hiroaki Kondo et al, 2001, "A numerical Simulation of Daily Variation of CO_2 in the Central Part of Japan", Journal of the Meteorological Society of Japan, Vol 79, No. 1, 11−21.

10 Yan Xiong, 2005 "A study on algorithm for estimation of global terrestrial net primary production using satellite sensor data, *Doctoral Thesis,* NWU.