Sap flow measurement for Japanese cedar throughout the year with three techniques and related problem

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Forests cover about 66% of land area of Japan, and Japanese cedar (*Cryptomeria japonica*) occupies 18% of total forested area. In Kyushu Island, south-western part of Japan, the water balance of Japanese cedar stand has been made clear quantitatively by using eddy-covariance method and sap flow technique (Kumagai et al., 2014; Shimizu et al., 2015). Meanwhile, except these studies, very few measurements of sap flow have been carried out throughout the year, although Japanese cedar is the most representative planted species in the larger part of Japan. Recently, newly developed techniques, that is heat ratio method (HRM, Burgess et al., 2001) and heat field deformation method (HFD, Nadezhdina et al., 2012), have been available in Japan. Considering the background mentioned above, we preliminarily compared these new methods with traditional thermal dissipation method (TDM, Granier, 1985) for a mature Japanese cedar planted at the central part of Japan. (Iida et al., 2015a). In this study, we show the results of measurement with HRM, HFD and TDM throughout the year. And we point out the common problem of three techniques: calculated sap flow becomes smaller when a single sensor is used for relatively long period (i.e., more than 10 months).

We conducted measurements in a mature stand of Japanese cedar, whose age is 63, within Tsukuba Experimental Watershed located in southern part of Mt. Tsukuba, Japan. We picked up a tree of Japanese cedar whose height is 24.9 m and diameter at breast height is 40.4 cm, and installed sensors of TDP, HRM and HFD. We used handmade sensors for TDM (e.g., Iida et al., 2015b) and sensors for HRM and HFD manufactured by ICT international Pty Ltd (type SFM1 and HFD8, respectively). The length of TDM sensor was 20 mm, and the sap flux density was computed as mean value along the sensor length by the calibration equation proposed by Granier (1985). The width of sapwood was 44 mm, and additional TDM sensor was inserted into the sapwood at the depth from 20 to 40 mm. On the other hand, the length of HRM sensor was 35 mm, and the sap flow movement was detected at the depths of 12.5 and 27.5 mm. For HFD, the sensor length was 96 mm, and the depths of sap flow detected were 20, 30, 40, 50, 60, 70, 80 and 90 mm.

The values of sap flux density by HFD showed high correlation with vapor pressure deficit (VPD). Generally, conifer canopy has large aerodynamic conductance due to the needle leaf, and therefore has high coupling with the ambient air. Thus, the high correlation with VPD is reasonable. Similar trends were confirmed for TDP and HRM. However, the relationships changed with time, and sap flux densities had become gradually smaller since the sensor installation. The clear deterioration was found at 10-months after the installation, in common to TDP, HRM and HFD. This may be induced by wounding or air embolism, which cause disruption in water flow around the sensors (e.g., Moore et al., 2010). Therefore, to obtain the whole-year dataset of sap flow, attentions must be paid for any deteriorations by checking the relationships between sap flow and VPD.

Cited paper

Burgess, 2001. Tree Physiol., 21:589-598.
Granier, 1985. Ann. Sci. For., 42: 193-200. [English translation, in Evaporation, Benchmark Papers in Hydrology 2. Gash JHC, Shuttleworth, WJ (eds). IAHS Press: Oxfordshire; 61-63].
Iida et al., 2015a. Japan Geoscience Union Meeting 2015, ACG30-P05.
Iida et al., 2015b. Ecohydrology, DOI: 10.1002/eco.1650.
Kumagai et al., 2014. J. Hydrol., 508: 66-76.

Moore et al., 2010. Trees, 24:165-174.
Nadezhdina et al., 2012. Trees, 26:1439–1448.
Shimizu et al., 2015. J. Hydrol., 522: 250-264.

Keywords: Japanese cedar, vapor pressure deficit, deterioration of detecting sap flow

Model-based analysis of tree-ring growth phenology in *Picea glehnii* forests on Hokkaido Island, Japan

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Recent global change is predicted to broaden uncertainty of ecosystems especially in terrestrial area. To reduce such uncertainties, tree-ring data is recently paid attention. Tree-rings have high potential to examine terrestrial carbon fluxes since tree-rings intrinsically correlate with forest carbon gains and stocks. A long observation time-span (decades to centuries) of tree-rings also increases its potential, extending observation period beyond fundamental flux-tower carbon observation (two or three decades). However, annual tree-rings are not simply in proportion to the annual sum of forest production. Annual tree-rings are made in a short time-span (e.g. two to three months) and such growing season's production is important for tree-rings though such growing season is still not clearly determined in ecosystem models for many tree species. This insufficient tree-ring growth phenology scheme has prohibited ecosystem modelers to use tree-ring data for validation though it has high potential to reveal spatiotemporal carbon stocks. Therefore, this research aims at revealing tree-ring growth phenology in conifer-hardwood mixed forests on Hokkaido Island, Japan.

Seven tree-ring site data of Sakhalin spruce (*Picea glehnii*) on Hokkaido Island were obtained from the International Tree-Ring Data Bank. At each site, mean chronology was calculated in BAI (basal area increment). Long-term climate data were obtained from the ERA20C reanalysis data (1900-2010) with downscaling and bias correction using random forest modeling and Automated Meteorological Data Acquisition System (AMeDAS) data on Hokkaido Island. Eight climatic parameters were used to construct the Vegetation Integrated SImulator for Trace gasses (VISIT) model. Flux data in Teshio flux tower site was used to modify the VISIT model. Net primary production (NPP) in each tree-ring site was predicted using the modified VISIT model and the downscaled ERA20C data. Predicted daily NPP were summed up for various periods (from a month to seven months at two weeks intervals) and in various temporal timings (at two weeks intervals). To analyze the most effective NPP period for BAI explanation, correlations between BAIs and the sum of each NPP period were calculated with random factor of sites and years and the best generalized linear mixed model was selected using the Akaike's information criterion (AIC).

Model selection revealed that a model using the sum of NPP from day of year 43 to 183 was the best model. This period contains tree-ring growing season (June) for *Picea glehnii* and other top models whose AIC differences from the best model were less than two also contained this season, suggesting importance of production in the tree-ring growing season. However, onset of the effective NPP period varied from January to May among these top models.

This research revealed that NPP in the tree-ring growing season is an important factor for tree-ring width variations. Although this analysis aimed at clarifying mean growth phenology among seven sites, differences in growth phenology among sites is expected to be a potential source of wide variance in the timing of onset. Although tree-ring growth phenology is difficult to observe, this research suggests that the growth phenology can be estimated from statistical analysis between tree-ring and NPP, which connects to a next step toward tree-ring-based validation of ecosystem models to reduce terrestrial ecosystem uncertainties.

Keywords: Process-based ecosystem model, VISIT, Phenology, Conifer-hardwood mixed forest, Allocation

Role of understory vegetation on net ecosystem exchange of water and CO_2 at larch forest in eastern Siberia

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This study investigated evapotranspiration (ET) and CO_2 exchange over larch-dominated forests in the middle part of the Lena basin, eastern Siberia. Forest ecosystem in this region is characterized by low precipitation, a short growing season, and extensive permafrost. Seasonal thawing permafrost supplies soil water, which is prevented to infiltrating by an impermeable frozen layer, and supports forest development. Recently, expanding summer thawing depth and unusually wet soil layer maintained for a few years at larch forest observation sites caused decline of larch trees (Iijima et al, 2014) and would have affected the water and carbon flux of ecosystem scale (Ohta et al., 2014). To investigate vulnerability of the larch dominant forest faced to too wet condition, we analyzed water and CO_2 fluxes observed with eddy covariance methods inside and over the forest from 2004 to 2013.

The study site is the Spasskaya Pad station (62° 15′N, 129° 14′E) on alluvial terrace near Yakutsk. The mean annual air temperature and mean annual precipitation (1986–2004) at this site were −9 ºC and 256 mm, respectively. In tower site, soil water of active layer is high after unusually high precipitation (compared with the previous 20-year average) in two successive summers, and soil layer close to the ground surface was almost saturated around 2007-2009. The dominant species of the upper canopy is larch (Larix cajanderi), while development of birch (Betula platyphyila) and willow (Salix bebbiana) is remarkable during this decade. The understory was covered with dense cowberry (Vaccinium vitis-idaea). Through the wet period, 19 of 212 larch trees on 2500 m^2 area became dieback, and grasses and shrubs with a high water tolerance have invaded this site.

A decadal observation of hydro-meteorological variables shows inter-annual variability including extreme environmental conditions such as unusually wet active layer, which was maintained for a few years. Some mature larch trees locating poor drainage area suffered wet damage, while young birch and willow trees developed and herbs with water tolerance expanded. Compared to the fluxes of the whole ecosystem, those based on the understory layer changed through the study period due to increase biomass and change of inside canopy environments; plentiful light and soil water, and enhanced turbulent mixing. Evapotranspiration from the understory layer increased and contribution to the whole forest flux reached 60%. Although this layer always acts as CO_2 source in seasonal average through the study period, source strength weaken and changed to temporal sink in the early summer (June). On contrast, contribution of the larch layer, in spite of remaining uncertainty in quantity, decreased in both of evapotranspiration and CO_2 uptake. Interactions between larches and understory vegetation would support this forest ecosystem. Decline of larch contribution is made up by understory growing, resulting in relatively stable whole forest exchange rate at least until this wet event.

Acknowledgment:

Observation data used in this study was provided by Y. Iijima (Japan Agency for Marine-Earth Science and Technology) and T. C. Maximov (Institute for Biological Problems of Cryolithzone).

Reference:

Iijima et al., 2014. Sap flow changes in relation to permafrost degradation under increasing precipitation in an eastern Siberian larch forest. Ecohydrology 7, 177–187.

Ohta et al., 2014. Effects of waterlogging on water and carbon dioxide fluxes and environmental variables in a Siberian larch forest, 1998-2011. Agric. For. Meteorol. 188, 64-75.

Keywords: boreal forest, water and carbon cycle, eddy covariance methods

Factors affecting global distribution of soil carbon in observational datasets and Earth system models

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Soil is the largest carbon stock in the terrestrial ecosystem. Therefore, understanding soil carbon dynamics is essential to predict future climate change. In the last two decades, several global soil datasets have been developed, and some are under further improvement. These datasets contain the global distributions of soil physiochemical properties, which allow us to calculate the global distribution of the soil organic carbon (SOC) stock, and some datasets provide the SOC stock by default. These datasets are based on globally observed data points, although there are biases in spatial distribution and densities of some data points. Earth system models (ESMs) have been created to understand the current climate and project future climate conditions. These models incorporate the terrestrial carbon cycle including SOC. However, it was reported that ESM results agree moderately at the biome level but that the correlation between the distribution of the SOC stock simulated by the ESMs and that of observational datasets is poor when the two were compared at a fine scale (e.g., 1° scale). In this study, we identified key factors governing global SOC distribution in observational datasets and those simulated by ESMs. We applied a data mining scheme and boosted regression trees to identify influential factors and how these factors are related to the SOC stock (Elith et al., 2008). We revealed similarities and differences between the observational and ESM datasets after comparing their outputs. The results of this study will be useful to understand the nature of observational SOC datasets and ESM outputs to improve the terrestrial carbon dynamics model in ESMs.

Keywords: Soil carbon, Dataset, Earth system model

Estimation of understory carbon budget and environmental factors influencing on the processes in a larch forest on the northern foot of Mount Fuji

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Forest ecosystem is very important component of terrestrial ecosystems, and elucidating the carbon cycle mechanism in forest ecosystem is vital for understanding global carbon cycle and predicting future carbon budget along with global climate change. There are many studies reported carbon budget of specific forest ecosystem using eddy-covariance method, however, this technique cannot provide detailed information about each process of forest carbon cycle. Especially, information about understory carbon budget include understory vegetation is limited.

To understand the impact of forest understory carbon budget and environmental factors influencing on processes of understory carbon cycle, we set multi-channel automated chamber measurement system in larch forest on northern foot of Mt. Fuji in 2006. The control unit of chamber system mainly consisted of a data logger (CR1000, Campbell Scientific), an infrared gas analyzer (LI820, LI-COR) and an air compressor. We set soil chambers (90 cm x90 cm x50 cm) for soil CO_2 flux measurement. Surroundings of the half of those soil chambers were root cut with chainsaw until 25 cm depth for the measurement of heterotrophic respiration (Rh), and the remaining control chambers were used for soil respiration (Rs) measurement. We also set plant chambers (90 cm x90 cm x100 cm) which included understory vegetation to measure understory net CO_2 exchange (NUE), understory respiration (Ru) and understory gross primary production (GPP_u).

We got continuous data for 8 years from 2006 to 2013 with chamber measurement method. Comparison with eddy-covariance data showed that annual Ru accounted for 68.6% of annual ecosystem respiration, and annual GPP_u accounted for 16.3% of annual gross primary production of the larch forest. Primary factor for GPP_u was light intensity of forest understory, and positive correlation between annually estimated GPP_u and annual average of understory PPFD (R^2 = 0.64) was confirmed. Remarkable exponential correlations between soil temperature and Rs, Rh and Ru were observed, and total Q_{10} values for Rs, Rh and Ru were 2.49, 2.57 and 2.25, respectively. On the other hand, influence of soil moisture on those soil CO_2 fluxes were minor except summer season when soil moisture was notably decreased due to few rainfall.

Keywords: Understory carbon budget, CO2, Chamber, Soil respiration, Larch forest

Initial results of observations of soil CO_2 and CH_4 fluxes in three ecosystem types of tropical peatland in Sarawak, Malaysia

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Tropical peatlands in Southeast Asia store large carbon by accumulating peat and they are vulnerable to climate change and human disturbances.
Soil carbon dioxide (CO_2) and methane (CH_4) fluxes observations were started on September 2015 at three ecosystem types of tropical peatland in Sarawak, Malaysia. The sites were one tropical swamp forest with high ground water level and one with low ground water level, and an oil palm plantation on peat. In each site, we installed an automated multi-chamber system. We will present the initial results of the observations.

Keywords: Automated multi-chamber system, peat swamp forest, oil palm

Change of CO_2 flux during an early secondary succession after severe forest disturbance

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Forest ecosystems are expected as a major sink of atmospheric carbon dioxide (CO_2), whereas their ability to absorb CO_2 is severely perturbed by disturbances, such as deforestation, fires, windthrow etc. Many studies which adopted the chrono-sequence approach reported that such severe disturbances often changed forest to be a CO_2 source. However, there are few studies that directly measure CO_2 flux for a long term (more than 10 years) above a disturbed forest site during an early stage of secondary succession after severe disturbance.A flux site of a larch plantation in Tomakomai, Hokkaido, Japan was struck by a typhoon in September 2004. Because of wind storm, about 90% of trees fell down. The fallen trees were removed by heavy machinery from the site, through which the soil surface and understory species were also disturbed. After the operations of timber transport, secondary succession progressed naturally in the ex-forest site. We recommenced flux measurement in August 2005. CO_2 flux has been measured by the eddy covariance technique with an open-path CO_2 / H_2O analyzer (LI7500, Licor) during a snow-free period from mid-April to mid-November. Cumulative net ecosystem CO_2 exchange (NEE) during the snow-free period was positive every year until 2015, whereas it showed a negative relationship, which indicates that the CO_2 source strength of the ecosystem decreased. This negative relationship was caused by the increase of gross primary production (GPP) or ecosystem photosynthesis, which corresponded to vegetation recovery through secondary succession.

Keywords: Windthrow, Eddy covariance, Vegertation recovery

Influence of natural and human disturbances on long-term CO_2 exchange over larch forests

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Larch forest is an important research object for evaluating ecosystem response against future global warming because it is a representative vegetation type for high latitudinal northeast Eurasia where greater temperature rise due to climate change is anticipated. In Japan, Larch is a common tree type of plantation that has been planted widespread over northeastern Japan especially after World War II. However, many larch forests have been left unmanaged because of the sluggish lumber demand. Quantifying the influence of the forest management on carbon budget in larch forests has significance on the securement of forests as a source of CO2 absorption.
Thus, National Institute for Environmental Studies (NIES) has implemented long-term monitoring program of CO2 exchange over three domestic larch forests in association with Hokkaido University. We established the Fuji Hokuroku Flux Observation Site in the foothills of Mt. Fuji as an alternative base for monitoring, and began observations in January 2006. The site is dominated by larch trees of more than 50 year-old. 30% thinning was conducted at the site in spring of year 2014. Tomakomai Flux Research site was established in 1999 to carry out integrated monitoring on the carbon budget in a mature larch forest. However, the site was devastated by the typhoon in 2004. Flux observation at the site is ongoing after the typhoon disturbance.
We began observations of the effects of canopy opening on a larch forest ecosystem structure in 2001 at a mixed forest in Teshio experimental forest of Hokkaido University. The forest was clear-cut and planted with larch trees in 2003. We monitor and evaluate the changes in carbon budget and forest ecosystem structure. Those three observation sites were affected from different kinds of natural and human disturbance. We will introduce the comparison results of carbon fluxes and related parameters for the sites.

Keywords: CO2, flux, disturbance, larch, monitoring

Forest resources change observation using spaceborne LiDAR in Siberian

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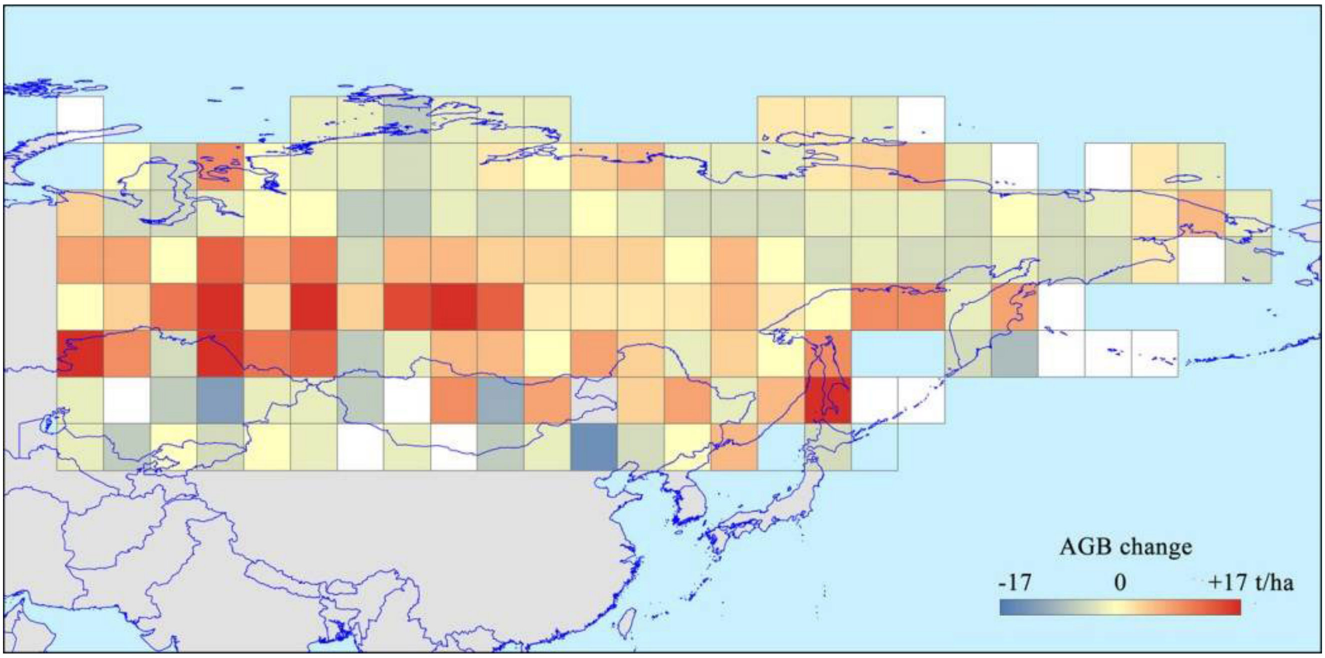
High-latitude area in the northern hemisphere, including Siberia, is the region most affected by climate change. A monitoring technology for vegetation change is very important for such region. Satellite remote sensing can provide the most practical mean for the large-scale and continuous observation, and spaceborne LiDAR is particularly expected. This sensor transmits a laser pulse to measure vertical structure near the Earth’s surface. ICESat/GLAS was the only spaceborne LiDAR so far, which was operated by NASA from 2003 to 2009. However, there are some future plans of spaceborne LiDAR, such as ICESat-2, GEDI, and MOLI, and they are expected to be used for forest monitoring. This study aims to clarify the potential of spaceborne LiDAR to quantitatively observe forest resources change in Siberia. We collected GLAS data acquired in 40°N-90°N and 60°E-170°W. Then, we excluded some GLAS data as follows: 1) the data in cloud covered area or non-forested area, 2) the data with large noise (SNR of GLAS waveform < 10), and 3) the data in steep sloped area (surface slope > 5°). As a result, we obtained about 3,000,000 points GLAS data suitable for the analysis. Next, we estimated canopy height and aboveground biomass from each of GLAS waveform data. We adopted RH100 (height from signal start to ground peak) for canopy height and an existing model (Neigh et al., 2013) for aboveground biomass. As a result, the average values were 7.4m of canopy height, and 23.0 Mg ha^{-1} of aboveground biomass in the whole study area. Next, we calculated the average of canopy height and aboveground biomass for every 5° longitude and latitude mesh, to understand the spatial distribution of forest resources. The spatial distributions of canopy height and aboveground biomass showed similar pattern, which was high in the south and low in the north in general. And, we separated the estimates data into the two period according to the GLAS observation (2003-2005 and 2005-2007), to understand the yearly change. As a result, canopy height showed a slightly decreasing trend, and aboveground biomass showed alomost no change, however, an increasing trend was seen in the western region (see figure). For the future, we will investigate the cause of this trend. This study showed that spaceborne LiDAR is suitable for monitoring the forest resources change accurately.

Keywords: Forest biomass, Spaceborne LiDAR, ICESat/GLAS, Siberia


AGB change
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+17 t/ha

Phenological changes for 10 years and the influence on ecosystem productivity in a larch forest at the foot of Mt. Fuji

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Phenological changes such as earlier budding or flowering and later leaf coloring and leaf fall have been reported around the world along with recent global warming. Phenology is an important index for climate change, and is also one of valuable factors to regulate the carbon cycle in terrestrial ecosystems. As the phenological responses to environment vary across species, assessment of long-term phenological trend for each species is required. In this study, we investigated the phenology of a Japanese larch forest by near-surface remote sensing, and analyzed the relationship between the phenology and climate change and also the influence of phenology on the forest ecosystem productivity derived from CO_2 flux observation.
Our study was conducted in a larch plantation at Fuji-hokuroku flux observation site (Fujiyoshida city, Yamanashi). About 87 % of the canopy is dominated by 60-year-old Japanese larch (*Larix kaempferi*) and the maximum LAI of the canopy was 3.2 m^2 m^{-2} in 2012. CO_2 flux and micro meteorological factors have been measured by eddy covariance method for ten years since 2006. For phenological observation, reflectance from the canopy has been continuously observed on the observation tower by using two spectral radiometers (upward and downward) and digital cameras. The vegetation index to detect seasonal changes of the canopy greenness was calculated as Green Ratio: GR=G/(R+G+B). The start and end dates of the growing season were determined from the days when the time series of GR indicated the maximum rate of increase and decrease. Then relationships of the yearly variations of phenology, temperature, net ecosystem exchange (NEE) and gross primary production (GPP) were analyzed.
As results, the mean dates of start and end of growing season were Apr. 23 and Nov. 8, with large amplitudes of 12 and 8 days respectively. Significant earlier or later phenological trend was not found across these ten years from 2006 to 2015. The mean annual growing season length was 198.5±4.1 days. The start and end dates were significantly related to the mean temperature respectively during Mar.-Apr. and during Sep.-Oct. The phenological responses to temperature were −4.5 day/ºC (R^2 = 0.88) in spring and 2.3 day/ºC (R^2 = 0.74) in autumn. In addition, the influences of phenology on GPP and NEE during spring (Apr. and May) and autumn (Oct. and Nov) were indicated. Meanwhile, yearly variations in annual GPP and NEE were more influenced by the decrease of summer productivities due to thinning and typhoon than phenological factors.

Keywords: Phenology, Growing season, Climate change, Carbon cycle, GPP

Sun-induced chlorophyll fluorescence reveals strong representativeness of ecosystem-level photosynthesis in rice paddy field in Mase Japan

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Chlorophyll fluorescence emission from ecosystem induced by sunlight (Sun-Induced Fluorescence: SIF) is now a key factor to accurately estimate the ecosystem-level photosynthesis activity as suggested by satellite studies, and has been recently detected by satellites [Frankenberg et al., 2011; Guanter et al., 2012; Joiner et al., 2013] and measured at field stations [Daumard et al., 2010; Porcar-Castell, 2011]. However, the few example of field-based assessment on the representation ability reduces its value for the availability to better understand the dynamics in CO_2 uptake by land ecosystem.
To elucidate the potential of SIF to estimate ecosystem GPP in typical Asian crop type, the canopy-top SIF was calculated from the spectrum data in Japanese rice paddy field in Mase in central Japan (36°03′N, 140°01′E, 11 m a.s.l.), and compared with eddy-tower measured GPP on half-hourly and daily bases during seven years from 2006 to 2012. The rice (Oriza sativa L.; cultivar Koshihikari) was transplanted in May and harvested in September normally. The SIF was estimated from the spectrums of downward Sun irradiance and upward canopy-reflected irradiance measured at the height of 3m above ground by HemiSpherical Spectro-Radiometer (HSSR), consisting of the spectroradiometer (MS-700, Eko inc., Tokyo, Japan) with the full-width at half maximum (FWHM) of 10 nm and wavelength interval of 3.3 nm. The SIF around 760nm (O2-A band: SIF_{760}) was calculated according to the Fraunhofer Line Depth principle [Maier et al., 2003] with several additional arrangements.
The GPP increased almost linearly as both SIF_{760} and APAR (Absorbed Photosyntethically Active Radiation) increased based on monthly-averaged diurnal courses during the growing season in 2006. The slopes of their regression lines differed much among the months in APAR, but in SIF_{760}. These nearly constant relationships among the months between GPP and SIF_{760} were kept for all the observation years. Daily averaged GPP and SIF_{760} indicated similar seasonality for multiple years although the conventional vegetation indices, NDVI and EVI, showed the smoothed temporal variations but with longer maximum period than GPP showed. Thus, those strong relationships of SIF to GPP confirmed that the SIF is a quite useful proxy of ecosystem-level photosynthesis in the rice paddy field.

Keywords: spectroradiometry, remote sensing, carbon cycle

