複数の手法によるスギの樹液流速の通年計測と問題点
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.

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キーワード：スギ、飽差、樹液流検出の劣化
Keywords: Japanese cedar, vapor pressure deficit, deterioration of detecting sap flow

北海道のアカエゾマツにおけるモデルを用いた樹木年輪の生長フェノロジー解析

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.

森林生態系の水・二酸化炭素交換における下層植生の役割
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.

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キーワード：北方林、水・炭素循環、渦相関法
Keywords: boreal forest, water and carbon cycle, eddy covariance methods

全球土壌炭素の分布に影響を与えるファクターの探索
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.

キーワード：土壌炭素、データセット、地球システムモデル
Keywords: Soil carbon, Dataset, Earth system model

富士北麓カラマツ林における林床炭素収支の推定と変動要因
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 ×90 cm ×50 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 ×90 cm ×100 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.

キーワード：林床炭素収支、二酸化炭素、チャンバー、土壌呼吸、カラマツ林
Keywords: Understory carbon budget, CO2, Chamber, Soil respiration, Larch forest

マレーシアサラワク州の3つの熱帯泥炭地における土壌CO_2およびCH_4フラックス観測の初期結果
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.

キーワード：自動チャンバーシステム、泥炭林、オイルパーム
Keywords: Automated multi-chamber system, peat swamp forest, oil palm

大規模撹乱後の植生遷移初期におけるCO_2フラックスの変化
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.

キーワード：風倒害、渦相関法、植生回復
Keywords: Windthrow, Eddy covariance, Vegertation recovery

カラマツ林でのCO$_2$フラックス長期観測から見る撹乱影響

Influence of natural and human disturbances on long-term CO$_2$ exchange over larch forests

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カラマツ林は将来的に温暖化の影響を強く受けると予想される北東ユーラシア高緯度域の北方林を代表する植生であり、気候変動に対する陸域生態系の応答予測に関して重要度の高い調査対象である。また国内においては、戦後を中心として本州中北部から北海道にかけて広い範囲でカラマツが植林されてきたが、国産材の需要の低迷により多くのカラマツ人工林は管理が充分に行われていない現状にある。CO2吸収源として森林を考える場合、カラマツ林の管理が炭素収支に与える影響を評価することは重要である。

こうした背景から国立環境研究所ではカラマツ林の炭素収支に注目し、気候変動に対する応答や管理状況の違いによる影響を評価するために、北海道大学と共同で国内の３つのカラマツ林においてCO2フラックスの長期観測を行っている。山梨県の富士北麓フラックス観測サイトにおいては樹齢約50年のカラマツ人工林で2006年から観測を実施しており、2014年には30%の強度で間伐を実施した。北海道の苫小牧フラックスリサーチサイトにおいては2000年から樹齢約40年のカラマツ人工林で観測を行っていたが、2004年9月の台風による被災により90%以上のカラマツが倒れ、その後の回復過程を観察している。北海道北部の天塩CC-Lagサイトにおいては、2001年から針広混交林において観測を開始し、2003年に皆伐を行いカラマツを植林した。観測期間中に３つのサイトはそれぞれ異なる撹乱を受けており、微気象学的フラックス観測やバイオマス調査により得られた結果を比較し紹介する予定である。

キーワード：二酸化炭素、フラックス、撹乱、カラマツ、モニタリング
Keywords: CO2, flux, disturbance, larch, monitoring

衛星ライダーによるシベリアの森林資源変化の把握
Forest resources change observation using spaceborne LiDAR in Siberian

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シベリアを含む北半球高緯度地域では、地球温暖化による気温の上昇が最も急速に進行しており、こうした地域で植生の変化状況をモニタリングする技術を整備することは、極めて重要な課題となっている。継続的に広域を観測するためには衛星リモートセンシングを活用することが現実的だが、中でも、レーザ光を照射して地表面付近の鉛直構造を計測できる衛星ライダーが近年注目を集めている。これまでは、2003〜2009年にNASAが運用したICESat衛星が唯一のものであったが、数年以内に打ち上げ予定の衛星ライダーが複数機計画されており、森林観測への利用が見込まれている。そこで本研究では、既存の衛星ライダーICESat/GLASをシベリアの森林資源変化の観測に応用し、その能力を明らかにすることを目的とした。北緯40°以北かつ東経60°以東で西経170°までの範囲を観測したGLASデータを収集し、解析に適さないデータのスクリーニングをおこなった。具体的には、(1) 雲や非森林域を観測したデータ、(2) 波形にノイズが多いデータ、(3) 計測誤差が大きくなる傾斜地のデータなどである。その結果、解析に適した約300万点のデータセットを整備した。次に、GLAS波形の形状を解析することで、各観測地点における樹高と地上部バイオマスを推定した。樹高は、波形の開始位置と地盤からの反射ピークとの標高差であるRH100を計算した。地上部バイオマスは、シベリアを対象とした先行研究（Neigh et al., 2013）により構築された推定モデルにもとづいて計算した。その結果、対象地域全体での樹高と地上部バイオマスの平均は7.4mおよび23.0 Mg ha^{-1}であった。次に、森林資源の空間分布を把握するため、緯度経度ともに5°メッシュごとに樹高と地上部バイオマスのGLAS推定値の平均を計算した。樹高と地上部バイオマスの空間分布は類似しており、おおむね南では高く、北ほど低い値を示した。また、時間変化を把握するため、GLASの観測時期に応じて2つのグループ（2003〜2005年観測データ、2005〜2007年観測データ）に分割し、それぞれの平均値を計算してその変化傾向を確認した。その結果、樹高は全体にわずかに低下する傾向が見られた一方、地上部バイオマスは多くの地域で変化が見られないものの、西部など一部に増加傾向を示す地域が見られた（図を参照）。今後は、こうした変化傾向を示す原因について検討を進める予定である。このように、衛星ライダーを利用することで、広域の森林資源の変化状況を高精度にモニタリングできることが示された。

キーワード：森林資源、衛星ライダー、ICESat/GLAS、シベリア
Keywords: Forest biomass, Spaceborne LiDAR, ICESat/GLAS, Siberia
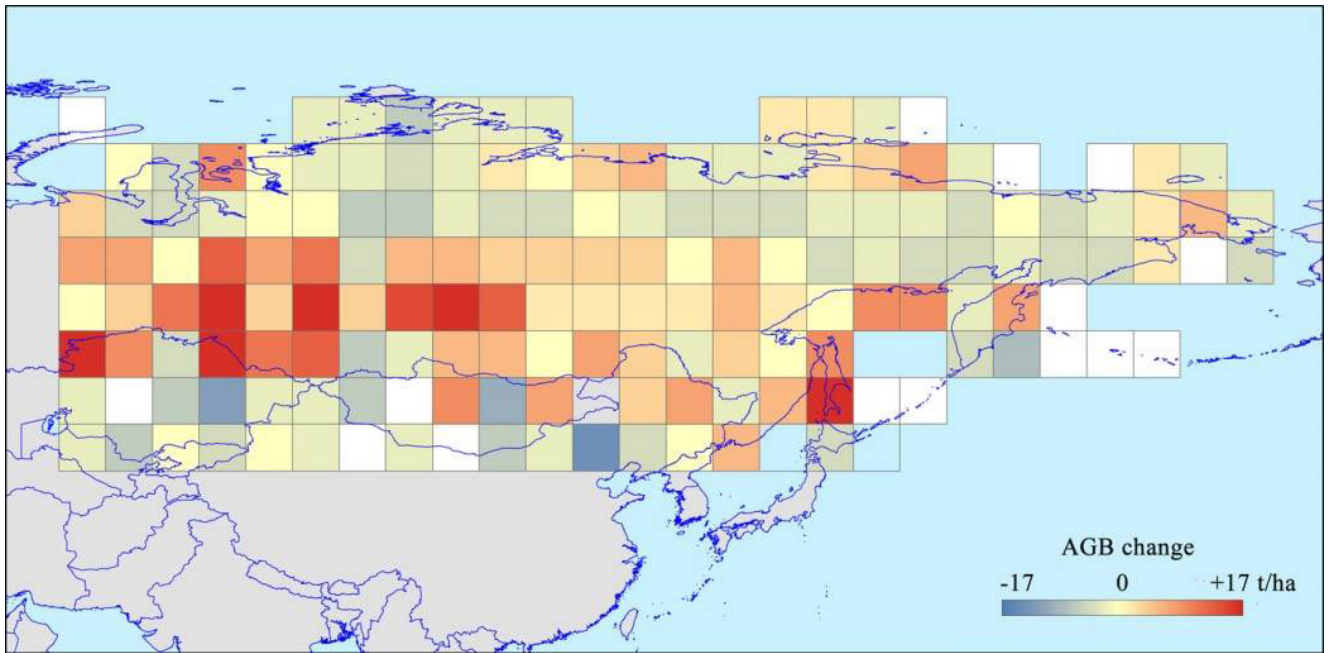
富士北麓カラマツ林における最近10年間のフェノロジーの変化と炭素収支量への影響
Phenological changes for 10 years and the influence on ecosystem productivity in a larch forest at the foot of Mt. Fuji

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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.

キーワード：フェノロジー、生育期間、気候変動、炭素循環、GPP
Keywords: Phenology, Growing season, Climate change, Carbon cycle, GPP

真瀬水田における太陽光誘発クロロフィル蛍光を利用した生態系光合成量の代表性
Sun-induced chlorophyll fluorescence reveals strong representativeness of ecosystem-level photosynthesis in rice paddy field in Mase Japan

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太陽光によって誘発されたクロロフィル蛍光は（Sun-Induced Fluorescence: SIF）生態系光合成量を代表し、衛星 [Frankenberg et al., 2011; Guanter et al., 2012; Joiner et al., 2013] や地上 [Daumard et al., 2010; Porcar-Castell, 2011]で観測できる指標として有望視されている。しかしながら、実際の陸域生態系での地上観測の例は未だ乏しく、SIFの利用可能性を妨げている。
我々は、アジア全域で育成されている水稲を対象としSIFと渦相関法に寄って観測された生態系光合成量GPPとの関係を検証した。データは、つくば市真瀬の水田(36°03'N, 140°01'E, 11 m a.s.l.)で、2006年から2012年まで30分間隔で取られた。イネ(Oriza sativa L.; cultivar Koshihikari)は、5月に移植され9月に収穫された。SIFは、水田に設置された渦相関法のための3mのマストに取り付けられた分光放射計(MS700, 英弘精機製；FWHM=10nm，測定インターバル=3.3nm)とローテーター(早坂理工製)から構成される半球分光放射計(HSSR)によって測定された太陽と生態系からの放射照度を利用して計算された。SIF（SIF_{760}）の計算は、760nm付近のO2-A吸収帯のスペクトルを利用し、Fraunhofer Line Depth 法[Maier et al., 2003]によって行われた。
2006年の生長期において、SIF_{760}とAPAR（吸収光合成有効放射）は、GPPと同様の日変化パターンを示したが、GPP-SIF_{760}の関係は月間の差がほとんどなかったが、GPP-APARの関係は月間で変化した。また、ほぼ直線的なGPP-SIF_{760} の関係は、すべての年において観測された。日SIF_{760} は日GPPと同様の季節変化を示した。一方で従来からの植生指標であるNDVIとEVIは、GPPよりも長い最盛期を示した。このように、SIFとGPPの間の強力な関係は、SIFは水田における生態系レベルの光合成の指標として非常に有効であることを証明している。

キーワード：分光放射測定、リモートセンシング、炭素循環
Keywords: spectroradiometry, remote sensing, carbon cycle