Proportion of atmospheric methane to carbon dioxide observed by GOSAT over biomass burning regions in Africa

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Multi-species satellite measurements in important biomass burning regions are expected for better understanding the partitioning of reduced gas production (van der Werf, 2010). In this study, we utilized the data of atmospheric concentration of carbon dioxide (CO2) and methane (CH4) observed by Thermal And Near-infrared Sensor for carbon Observation (TANSO)-FTS onboard Greenhouse Gases Observing Satellite (GOSAT) to derive the ratios of the two species over the active biomass burning regions in Africa. Contribution of fire emission from Africa to the global carbon fire emissions is estimated as 52% by van der Werf (2010). It is well recognized that in Northern Hemisphere Africa (NHA), fires occur primarily in the Sahel between November and February. On the other hand, in Southern Hemisphere Africa (SHA), fires are prominent primarily between June and October (e.g., Roberts, et al. 2009). We investigated the proportions of CH4 to CO2 focusing on regions and seasonality and found the proportion of CH4 to CO2 during the burning season over NHA is higher than that in SHA. In addition to CH4 and CO2, we are going to show the results of combined analysis with carbon monoxide (CO) observed by Measurements Of Pollution In The Troposphere (MOPITT), and discuss potential of satellite sensors to characterize biomass burning.
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Keywords: carbon cycle, biomass burning, GOSAT

Relationships between CO_2 flux estimated by inverse analysis and land surface elements in South America and Africa

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Inverse analysis estimates the regional flux of greenhouse gases between the earth's surface and the atmosphere by using observed atmospheric concentration data that include satellite data. In particular, this method is effective in estimating the flux in regions where observational flux data are limited. However, inverse analysis is basically a mathematical optimization method. Therefore, confirmation of the causal validity of the spatial and temporal changes in the estimated flux is necessary. One confirmation method is validation of the relationship with physical and biological observation data (analysis data) of confirmed accuracy. In this study, the features and validity of changes in the CO_2 flux estimated by inverse analysis were verified by interrelation analysis with changes in precipitation, short-wave radiation, surface temperature, and Normalized Difference Vegetation Index (NDVI) in regions of South America and Africa where CO_2 flux observation data are limited. Sufficient accuracy of the land surface elements is required for the analysis results to confirm the CO_2 flux estimated by inverse analysis. An examination of the correlation of anomalies showed consistent relationships among the precipitation, short-wave radiation, surface temperature, and NDVI data used in this study, which were created independently. The relationships between change in the estimated CO_2 flux and characteristic changes of the land surface elements in South America and Africa were consistent in each region. This study confirmed the physical and biological validity of the changes in the CO_2 flux estimated by inverse analysis. During the period of this study, the NDVI anomaly was influential in South America, and the precipitation (soil wetness) anomaly was an essential factor in Africa for the CO_2 flux anomaly. The short-wave radiation anomaly was also influential in both South America and Africa. These relationships are detected more clearly in the results of inverse analysis using both ground-based CO_2 concentration data and GOSAT satellite data than in the results using only ground-based CO_2 concentration data. This demonstrates the usefulness of GOSAT data in regions with limited atmospheric CO_2 concentration data.

Keywords: inverse simulation analysis, CO2 flux, land surface element

Analysis of methane concentration variation observed by GOSAT in Sichuan Basin, China and its relationship with local sources

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Atmospheric Methane (CH_4) is one of the most important greenhouse gases, and the greenhouse effect generated by unit molecule of CH_4 is about 23 times higher than that of atmospheric Carbon Dioxide (CO_2). Therefore, it will be more effective to reduce the CH_4 emissions to mitigate the potential global warming than reducing CO_2 emissions. The increase of global atmospheric CH_4 concentration is mainly due to agricultural activities, in which irrigated rice paddy is one of the most important sources. China is the world's largest rice producer, accounting for about 22% of the rice planting area in the world and 37% of the global production. Therefore, studies of China's regional CH_4 emissions and its driving factors are of importance to understand the regional and global carbon cycle and the changing climate. In this study, XCH_4 observations from GOSAT, spanning from January 2010 to December 2013, are analyzed to study the spatio-temporal variation of XCH_4 in China and its relationship with regional surface emissions. In further, we investigate the driving mechanism of XCH_4 spatio-temporal variations, especially for high XCH4 values shown over Sichuan Basin in south-west China, by combining the emission mechanism of rice planting process, the meteorology data, the surface emission data and the regional atmosphere dynamic transportation.

The results indicate that spatially the Sichuan Basin presents a higher XCH4 concentration than other regions in China and is 17 ppb higher than the paddy area in the same latitude zone. Seasonally, XCH4 in Sichuan Basin during rice harvest season is generally higher than that in early cultivation period. However, comparing to paddy area in the same latitude zone, Sichuan Basin shows a relatively higher XCH4 value during the winter of noncultivation period when the emissions from rice paddies are weak and surface air temperature is low. To further investigate the high XCH4 concentration during this low-emission period, we use the HYSPLIT model to simulate the atmosphere dynamic transport process, and the result suggests that the typical closed topography of Sichuan Basin, which may lead to CH4 accumulation and keep it from diffusion, is one possible reason for the high XCH4 value in winter.

Our result from studying the CH_4 variations in Sichuan Basin, especially the abnormal higher value during winter, and their driving factors demonstrate a certain potential of using GOSAT-XCH_4 for investigating the regional CH_4 changes. This study presents preliminary results of CH_4 in China, and a further investigation of the CH_4 in the basin is still necessary as more satellite observations of CH_4 with improving accuracy are available in the coming future to further study the CH_4 variations and regional emissions.

[1]Xiuchun Qin, Liping Lei, Zhonghua He, Zhao-Cheng Zeng, Masahiro Kawasaki, Masafumi Ohashi, and Yutaka Matsumi, “Preliminary Assessment of Methane Concentration Variation Observed by GOSAT in China”, Advances in Meteorology,2015, DOI: 10.1155/2015/125059

Keywords: GOSAT, XCH4, paddy field emission, atmosphere transmission, topography

Development of Carbon cycle analysis system using satellite data and LETKF

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We have developed satellite data assimilation system using CO2 concentration data obtained from satellite measurements using an ensemble-based four-dimensional data assimilation system (LETKF). An online atmospheric transport model (MJ98-CDTM) is employed in the data assimilation system to optimize surface CO2 fluxes from satellite observations at spatial and temporal resolutions of 6 days and 2.8°, respectively. The features of GOSAT TIR L2 Ver. 1.0 data are their larger data number than that of SWIR L2 (about 10 times) and smaller standard deviation than their former version (TIR L2 Ver. 0.01). We have tested 4 types of satellite bias correction methods (w/o bias correction, monthly mean bias correction, all data bias correction and globally constant bias correction) using independent CO2 concentration analysis (JMA CO2 distribution) in our data assimilation system. Our results showed that estimated CO2 concentration and fluxes are significantly sensitive to bias correction method. This means that we should carefully choose satellite bias correction method. In addition, satellite data bias correction allows modifying surface CO2 flux almost entire earth surface. In the future, our satellite bias correction concept makes it possible to use multiple satellite observation data simultaneously in CO2 data assimilation.

Keywords: Carbon Cycle, Data Assimilation, Satellite Observation

Estimation of global surface fluxes of a greenhouse gas with LETKF data assimilation system

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We present global CO_2 flux estimations using the local ensemble transform Kalman filter (LETKF) system with the GOSAT obtained XCO_2 and the WDCGG compiled CO_2 concentration data. In the previous study [Miyazaki et. al., 2011], a performance of the LETKF system was evaluated using GOSAT column pseudo-data in reference and the other various types of CO_2 concentration data. Here, we use the GOSAT retrievals to estimate the flux with the 4-D data assimilation system.
The data assimilation system used in this study was developed by Miyazaki et al., 2011, on the basis of the LETKF scheme [Miyoshi et al.]. A basic methodology of the LETKF follows the original EnKF [Ott et al., 2004; Hunt et al., 2007].The covariance localization [Houtekamer and Mitchell, 2001] is used to remove long range spurious correlations. The state vector augmentation method [Anderson, 2001; Aksoy et al., 2006; Tong and Xue, 2008] has been applied to simultaneously estimate the atmospheric CO_2 concentration as model states together with the surface CO_2 flux as uncertain model parameters. The surface fluxes at every model grid points are analyzed with 4-daily assimilation window during 2012 year. The ensemble size is hundreds. The transport model is coupled with the Center for Climate System Research/National Institute for Environmental Studies/Frontier Research Center for Global Change (CCSR/NIES/FRCGC) atmospheric general circulation model (AGCM) version 5.7b [Numaguti et al., 1995]. The model spatial resolutions are horizontally T42 truncation (approximately 2.8 degree) and vertically 32 levels up to 7 hPa. The surface CO_2 concentrations used in this study are obtained with the flask sampling data observed at sites in the surface network, which is archived at the WDCGG, and the XCO_2 concentrations are retrieved from GOSAT soundings using the RemoTec algorithm [Butz et al., 2009]. These observational data assimilate into the transport model. The LETKF system performance is evaluated by error reduction ratio of the posterior to prior ensemble fluxes.
We show analysis results that are the error reduction ration depending on various types of the observational data and seasonal variability of the optimized fluxes over aggregated land scale.
Acknowledgements. The authors thank the RemoTeC Proxy products retrieved from GOSAT TANSO-FTS SWIR spectra using the RemoTeC algorithm that is being jointly developed at SRON Netherlands Institute for Space Research and the Karlsruhe Institute for Technology (KIT).

Keywords: Carbon cycling, Ggreenhouse gas, Data assimilation, LETKF

Application of Inversion Technique to Quick Update of Anthropogenic NO_x emission over East Asia with Satellite Observations and Chemical Transport Model

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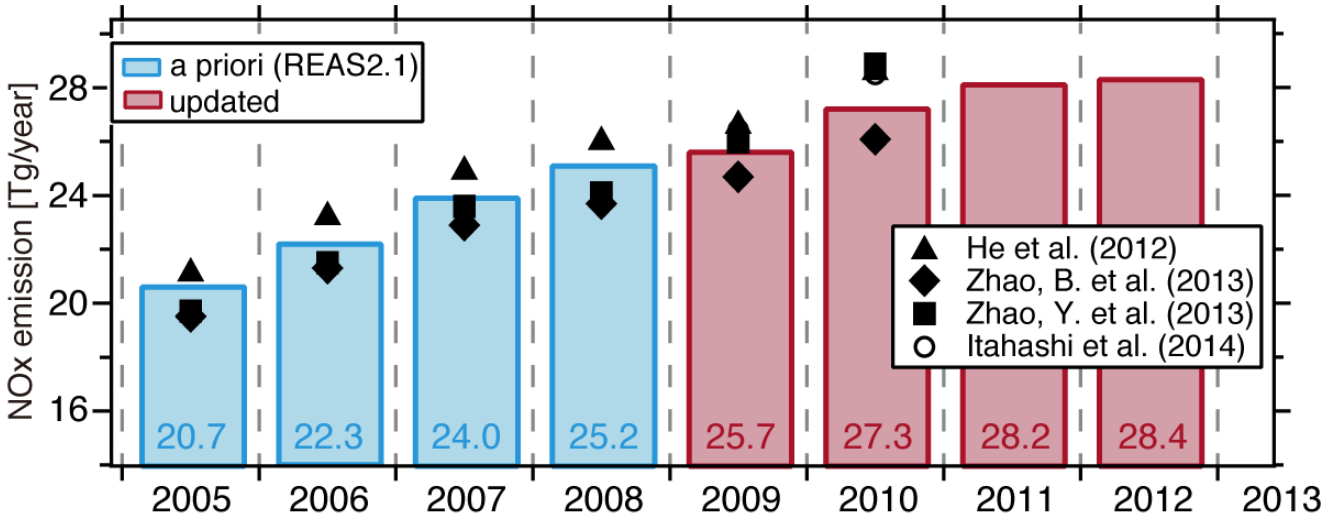
We developed a quick update system for an emission inventory with an inversion technique, and extended NO_x emission in Regional Emission inventory in the ASia version 2.1 (REAS 2.1) through 2009-May 2013 with satellite-observed tropospheric NO_2 vertical column densities (VCDs) and a chemical transport model. The observed NO_2 VCDs over the eastern Chinese region exhibited a drastic inter-annual variation over the eastern Chinese region due to the socioeconomic condition. During 2008-2009, the growing of the NO_2 VCD became sluggish because of pollutant controls by the 2008 Beijing Olympic game and the global depression, but revived in 2010 with a growth rate of 37.3%/year. The modeled NO_2 VCD with the updated emission successfully followed the inter-annual variation, and reproduced the observed seasonal cycle in which summer and winter have the seasonal bottom and peak, respectively. We estimated the updated Chinese anthropogenic NO_x emissions during 2009-2012 to be 25.7, 27.3, 28.2, 28.4 Tg/year; they fell within the range of the various estimates in the literatures. An annual growth rate during 2009-2012 and 2005-2012 was estimated to be 3.5%/year (0.9 Tg/year) and 5.3%/year (1.1 Tg/year), respectively. The system has the capability of updating NO_x emission in near real-time (NRT) for air qualtiy forecasting. Figure shows annual anthropogenic NO_x emission from China. Numbers in the panels represent annual Chinese anthropogenic NO_x emission. Other estimates of Chinese NO_x emission are also shown by symbols.

Keywords: Inversion, Emission inventory, Chemical transport model, Satellite observation, NOx emission



Characteristics of Version 1.0 CO_2 data retrieved from TIR band of GOSAT/TANSO-FTS

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Greenhouse Gases Observing Satellite (GOSAT) was launched on 23 January 2009, and has continued to make global observations of greenhouse gases, including both nadir and off-nadir measurements, for more than seven years since its launch. Carbon dioxide (CO_2) concentrations in several atmospheric layers can be retrieved from radiance spectra of the thermal infrared (TIR) band of Thermal and Near-infrared Sensor for Carbon Observation Fourier Transform Spectrometer (TANSO-FTS) on board the GOSAT. We have analyzed the latest released version of the TIR Level 2 (L2) CO_2 product (Version 1.0). We compared TANSO-FTS TIR V1.0 CO_2 data and CO_2 data obtained in the Comprehensive Observation Network for TRace gases by AIrLiner (CONTRAIL) project. The comparisons over several airports showed that the TIR V1.0 CO_2 data had a 1-2% negative bias in the middle troposphere; the magnitude of the bias varied seasonally and regionally. The comparisons in the upper troposphere and lower stratosphere (UTLS), where the TIR band of TANSO-FTS is most sensitive to CO_2 concentrations, showed that the averages of the TIR upper atmospheric CO_2 data agreed well with the averages of the data obtained by the CONTRAIL Continuous CO_2 Measuring Experiment (CME) within 0.1% and 0.5% for all of the seasons in the Southern and Northern Hemisphere, respectively. The magnitude of bias in the TIR upper atmospheric CO_2 data did not have a clear longitudinal dependence. The comparison results for flights in northern low and middle latitudes showed that the agreement between TIR and CONTRAIL CO_2 data in the upper troposphere was worse in the spring and summer than in the fall and winter. The negative bias in northern middle latitudes made the maximum of TIR CO_2 concentrations lower than that of CONTRAIL CO_2 concentrations, which leads to underestimate the amplitude of CO_2 seasonal variation. CO_2 growth rate estimated from the TIR UTLS CO_2 data from 2010 to 2012 was slightly lower (-0.6 ppm) than that from the CONTRAIL level flight data during the same period, which increases the differences between TIR and CONTRAIL CO_2 concentrations in UTLS.

Keywords: satellite remote sensing, retrieval algorithm, validation analysis, CO2

Validation of GOSAT SWIR XCO_2 and XCH_4 retrieved by PPDF-S method

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We focused on column averaged dry air mole fraction of atmospheric CO_2 and CH_4 (XCO_2 and XCH_4, respectively) retrievals from Greenhouse gases Observing Satellite (GOSAT) measurements through the photon path length probability density function (PPDF-S) based retrieval method that simultaneously retrieves target gas abundance and PPDF parameters. This method is used for an effective retrieval algorithm even under high concentration of clouds and aerosols. First, we validated PPDF-S XCO_2 and XCH_4 retrievals by comparing them with ground-based observations provided by the Total Carbon Column Observing Network (TCCON) from June 2009 to May 2014. For comparison, we also validate retrievals through another algorithm using full physics (FP)-based retrieval method. PPDF-S and FP retrieval methods are different in way to account for light scattering effect. All these XCO_2 and XCH_4 retrievals are provided by the National Institute for Environmental Studies (NIES). PPDF-S retrievals have positive biases (0.47 ±2.11 ppm for XCO_2 and 0.76 ±15.49 ppb for XCH_4), on the other hand, FP retrievals have negative biases (-0.28 ±2.34 ppm for XCO_2 and -2.16 ±13.26 ppb for XCH_4). Next, we compare global maps of XCO_2 and XCH_4 mean value, standard deviation and number of data between PPDF-S and FP retrievals. Over the ocean, PPDF-S method can retrieve large number of data whose standard deviation is larger than FP method. These PPDF-S retrievals over the ocean include data which are eliminated in post-screening process for FP method to exclude data that are strongly affected by clouds and aerosol.

Keywords: GOSAT, retrieval, carbon dioxide, methane

Global carbon budget estimation based on atmospheric oxygen and carbon dioxide observation during recent 15-year period

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Time series of atmospheric O_2/N_2 ratio and CO_2 mixing ratio of flask samples taken from NIES's flask sampling network are presented. The network includes ground sites, Hateruma Island (lat 24°03'N, long 123°48'E) and Cape Ochi-ishi (lat 43°10'N, long 145°30'E), and cargo ships regularly sailing in the Pacific region. The air samples collected in Pyrex glass flasks were sent back to our laboratory and the O_2/N_2 ratio and CO_2 mixing ratio were analyzed by using a GC/TCD and NDIR analyzers. Taking into account the global mass balances of atmospheric CO_2 and O_2, we estimate the global carbon sequestration rates of the ocean and land biosphere for the recent 15-year period. In this carbon budget calculation, we use the secular changes in the atmospheric O_2 and CO_2 burdens based on our flask observations and the fossil fuel-derived CO_2 emissions based on energy statistics. We also adopt the ocean O_2 outgassing fluxes (~0.5 PgC/yr), which is estimated from secular changes in the ocean heat content (0-2000m) and an estimated O_2-to-heat flux ratio. For example, the oceanic and land biotic carbon sequestration rates for the 15-year period (1999-2014) calculated from the observation at Hateruma Island are 2.4±0.7 Pg-C yr^{-1} and 1.5±0.8 Pg-C yr^{-1}, respectively. In the presentation, we also examine the temporal changes in the global carbon budgets and compare our estimations with the other reported carbon budget estimations.

Keywords: global carbon budget, oxygen, carbon dioxide

Achievements and Future Visions: Monitoring Carbon Cycle Change using an Integrated Observation, Modeling and Analysis System

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We are developing an integrated carbon observation and analysis system based on satellite, airborne and ground-based observations, and atmospheric and terrestrial carbon cycle models. Aircraft observations of atmospheric greenhouse gases (GHGs) are strengthened based on the “Comprehensive Observation Network for TRace gases by AIrLiner (CONTRAIL)” project. Atmospheric transport modeling, inverse modeling, and assimilation methods are being developed and improved for better utilization of observational data from the Asia-Pacific region. Global and regional surface fluxes are estimated by both "top-down” approach using inverse models and "bottom-up” approach using surface flux observation network data (e.g. AsiaFlux) and upscaling with terrestrial ecosystem models.
We will present current progress for better constraints of global, continental, and regional carbon budgets, and detection of carbon cycle change particularly in the Asia-Pacific. We also would like to raise following questions and discuss how to solve them in the next steps.
1) How can the current capabilities of top-down and bottom-up approaches contribute to reduce uncertainties in the estimates of large anthropogenic emissions? (e.g. fuel use, land use changes, and rapid urbanization)
2) What are the key target regions or events in the Asia-Pacific that we need to focus on? (e.g. El Niño-induced droughts, extreme forest fires in Southeast Asia, and peat degradations in tropical and boreal regions)
3) How should the current capabilities of observation, modeling and analysis systems be integrated into an operational system for long-term monitoring of changes in regional, continental, and global GHGs budgets?
4) What are the urgent requirements to realize such system? (e.g. strategies of more intensive observations in targeted area, and a platform for multi-model ensemble)
5) How can we provide scientific knowledge and data timely for evaluating mitigation and adaptation policies?

Keywords: Carbon Cycle, Integrated Observation and Analysis System, Asia-Pacific

Synthesis of top-down and bottom-up estimations of terrestrial CO_2 budget in Asia

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In the framework of Environment Research and Technology Development Funds (2-1401) from the Ministry of the Environment of Japan, we initiated synthesis analysis toward better estimations and understandings of terrestrial CO_2 budget in Asia. We used multiple different data products such as atmospheric inverse analysis (top-down estimation), terrestrial ecosystem models, remote sensing data, and data-driven models (bottom-up estimation). Our analysis focuses on (1) inter-decadal changes in terrestrial CO_2 fluxes at continental scales (Asia and Siberia), (2) testing consistency of terrestrial sink magnitude between top-down and bottom-up estimations in Asia, and (3) detection and analysis of 'hotspot' of terrestrial CO_2 budget changes in Siberia and tropical Asia. We will show these progresses, and discuss future direction of these studies.

Acknowledgement
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Keywords: Terrestrial, Synthesis, Carbon Dioxide

The potential of spaceborne LiDAR for precise forest resources observation

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Satellite remote-sensing is suitable for a large scale observation of forests, and spaceborne light detection and ranging (LiDAR) is a novel sensor that can be used for accurate measurement. Spaceborne LiDAR is an active sensor to transmit laser pulses, and it records the changes in return laser energy intensity as a waveform, and the waveform contained information on the vertical structure of forests. The only spaceborne LiDAR so far has been the Ice Cloud and land Elevation Satellite (ICESat)/ Geoscience Laser Altimeter System (GLAS), operated by NASA from 2003 to 2009. Many previous studies have applied GLAS data to forest observation, and they mostly estimated two essential parameters of forest resources: canopy height and aboveground biomass. We also applied ICESat/GLAS spaceborne LiDAR data to three forested areas: Hokkaido Island in Japan (cool-temperate forest), Borneo Island (tropical forest), and Siberia (boreal forest). As a result, we revealed the distribution of canopy height and aboveground biomass in the study areas. Furthermore, we implemented the following: (1) quantitative estimates of canopy height change according to typhoon disturbance in Hokkaido, (2) estimation of yearly forest loss rate in Borneo, and (3) hot spots detection of forest change in Siberia. In this way, spaceborne LiDAR enables us to observe forest resources accurately at each footprint point. However, an analysis combined with the other imagery data should be needed for entirely forest monioring, and the methodology has been studied in recent years. There are some plans of spaceborne LiDARs launched within a few years, and they will play an important role in global forest resources monitoring in the future.

Keywords: Canopy height, Forest biomass, Spaceborne LiDAR, ICESat/GLAS

Development of a low-cost in-situ methane observation system and results of field observation at a paddy field in India

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Methane (CH_4) is the second most prevalent greenhouse gas next to carbon dioxide (CO_2). The atmospheric concentration of methane tends to increase year by year, and it is important to obtain detail information on the source of methane and seasonal variation of its concentration. Since there are many unclear points about the regional differences and seasonal variations of the methane concentration, further ground-based observations are needed to investigate them in detail. Previous studies suggest that the emissions of methane from farmlands in Southeast and South Asia have significant contribution to the methane concentrations. But, there are many difficulties to conduct observations in such farmlands. At the paddy field in north India where we plan to observe methane, electric power are available for only 2-3 hours a day at night and the duration of power supply is not stable. In addition, the place where we can set the measurement instrument is nothing but a barn in the farmland, and we must manage to prevent bad influences on instruments by rain, dust, bugs, and rats. Thus, it is difficult to use existing commercial instruments, which are typically operated in a clean laboratory. Therefore, we developed a low-cost measurement system of methane to use at rural and remote area. Moreover, we have conducted the methane measurement using the developed system at the paddy field in India.

In this study, we used LaserMethane(ANRITSU Co. Ltd.) to measure the atmospheric concentrations of methane. LaserMethane is the portable instrument with low electricity consumption, which can measure methane concentrations in real time. LaserMethane is an open-path laser spectroscopic instrument which can measure methane selectively by tunable diode laser absorption spectroscopy. We developed a power supply, a data logging, and a remote control equipment for continuous operation of LaserMethane at remote area. We have conducted the methane observation at Sonipat, Haryana in India which is located at north of Delhi since the end of 2014 using the developed system. Along with LaserMethane, we have also obtained methane concentrations from the off-line analyses of ambient air, which have been sampled typically once a week, using gas chromatography. The concentration data of LaserMethane are calibrated by the air sampling data and meteorological data. In this presentation, we will present the introduction of the developed system and the measurement results which were obtained in 2015 at the paddy field in Sonipat, India. It showed that the concentrations of methane increased in monsoon season and winter. This characteristic enhancement of methane concentrations observed in monsoon season is considered to be due to the large methane emission from paddy field during rice cultivation. In addition, the real-time measurements indicated that the large variation of methane concentrations between day and night often appeared. We will also discuss the sources of the observed seasonal and diurnal variations.

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Keywords: in-situ methane measurement system, field observation in India, rice paddy field

Annual variaiton of soil respiriration in subtropical afforetation forest in Taiwan

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Global forests contain 69% of total carbon stored in forest soil and litter. But the carbon storage ability and release rate of warming gases of forest soil also affect global climate change. Soil carbon cycling processes are paid much attention by ecological scientists and policy makers because of the possibility of carbon being stored in soil via land use management. Soil respiration contributed large part of terrestrial carbon flux, but the relationship of soil respiration and climate change was still obscurity. Most of soil respiration researches focus on template and tropical area, little was known that in subtropical area. Afforestation is one of solutions to mitigate CO2 increase and to sequestrate CO2 in tree and soil. Therefore, the objective of this study is to clarify the relationship of tree species and soil respiration distribution in subtropical broad-leaves plantation in southern Taiwan. The research site located on southern Taiwan was sugarcane farm before 2002. The sugarcane was removed and fourteen broadleaved tree species were planted in 2002-2005. Sixteen plots (250m*250m) were set on 1 km2 area, each plot contained 4 subplots (170m2). The forest biomass (i.e. tree height, DBH) understory biomass, litter, and soil C were measured and analyzed at 2011 to 2015. Soil respiration measurement was sampled in each subplot in each month. The soil belongs to Entisol with over 60% of sandstone. The soil pH is 5.5 with low base cations because of high sand percentage. Soil carbon storage showed significantly negative relationship with soil bulk density ($p<0.001$) in research site. The differences of distribution of live tree C pool among 16 plots were affected by growth characteristic of tree species. Data showed that the accumulation amount of litterfall was highest in December to February and lowest in June. Different tree species planted in 16 plots, resulting in high spatial variation of litterfall amount. It also affected total amount of litterfall temporal variation. Soil respiration was related with season variation in research site. Soil temperature and soil respiration showed highly spatial variation in 16 plots. Soil temperature showed significantly exponential related with soil respiration in research site ($p<0.001$). Annual soil temperature was decrease with tree age increasing in this 5 years. Annual soil respiration was showed decrease with tree age increasing. However, soil respiration showed significantly negative relationship with total amount of litterfall ($p<0.001$), suggesting that the tree was still young and did not reach crown closure.

Keywords: Soil respiration, Plantation, Spatial Variation

Spatial and temporal seasonal variation of CO_2 efflux from the soil surface in the boreal forests in Central Siberia

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In boreal forest ecosystems, soil CO_2 flux may account for 40–80 % of the total CO_2 release in forest ecosystems [4], and it is the main pathway of transferring carbon from terrestrial ecosystems to the atmosphere. The amount of CO_2 released to the atmosphere through soil respiration is ten times greater than that resulting from the burning of fossil fuels [3]. Taking into account the considerable amounts of C stored in boreal soils [1] even small changes in soil respiration may cause great fluctuation in atmospheric CO_2 concentrations. Therefore, better understanding of soil respiration dynamics in diverse boreal forests is essential for understanding the global carbon balance [2].
The objectives of the present study are: (a) to study the dynamic changes in soil CO_2 efflux from the soil surface during frost-free season; (b) to identify the impact of meteorological variables (factors) on soil CO_2 efflux. The research was conducted in the boreal forests in Central Siberia (60°N, 90°E), Russia. Sample plots were represented by the lichen pine forest, moss pine forest, mixed forest and a plot with mineral sandy soil without a plant cover. We used the automated soil CO_2 flux system based on the infrared gas analyzer –LI-8100 (Li-cor Biogeosciences Inc., USA) for measuring the soil efflux. Soil temperature was measured next to each collar at the time of the CO2 efflux measurement with Soil Temperature Probe Type E (Omega, USA) in three depths –5, 10, 15 cm. Volumetric soil moisture was measured with Theta Probe Model ML2 (Delta T Devices Ltd., UK).
The presence and type of ground cover substantially affects the value of soil respiration fluxes. In 2015, the flow of carbon dioxide from the soil surface averaged 5.4 ±2.3 μmol CO_2 m^{-2} s^{-1}. The lowest soil respiration for forest areas was observed in the moss pine forest (1.14 μmol CO_2 m^{-2} s^{-1}). The lichen pine forest had the intermediate values (mean and SD) of soil respiration. A sandy soil plot without a plant cover demonstrated the lowest soil respiration (0.12 μmol CO_2 m^{-2} s^{-1}). The maximum soil respiration values and seasonal fluctuations were obtained in the mixed forest (29.62 μmol CO_2 m^{-2} s^{-1}).
The correlation analysis of dependence between soil temperature, soil moisture and soil CO_2 efflux showed that an increase of temperature and soil moisture at the beginning of the growing season (June) leads to inhibition of soil respiration processes. At the end of the growing season (September), we recorded a reduction in the impact of two climate factors (soil temperature and moisture) on soil respiration intensity. Nevertheless, the soil temperature appears to be the major driver controlling the soil CO_2 efflux during the frost-free season in analyzed Siberian boreal forests.
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